Healthy Housing 2016: Proceedings of the 7th International Conference on Energy and Environment of Residential Buildings

20-24 November 2016

Queensland University of Technology, Gardens Point Campus, Brisbane, Australia
Welcome from the Conference Chair - Dr Wendy Miller

If we view health and energy as integral parts of ‘sustainability’, then we could perhaps consider this definition of a sustainable house: an expression of personal, cultural and social identity that enables and supports its inhabitants to live a healthy and sustainable lifestyle.

In recognition of the importance of culture and context, I extend my warm welcome to you all for this conference. I acknowledge the Traditional Owners of the lands where QUT now stands - and recognise that these have always been places of teaching and learning. I pay respect to their Elders - past, present and emerging - and acknowledge the important role Aboriginal and Torres Strait Island people continue to play within the QUT community and Australia more broadly.

What is the context of our gathering this week? Just 2 weeks ago, on the 4th November, the Paris Agreement entered into force, signalling global collaboration on tackling climate change and its effects. It requires all Parties to “put forward their best efforts”, strengthen these efforts and report on their implementation (http://unfccc.int/paris_agreement/items/9485.php).

Our gathering here this week for the 7th International Conference on Energy and Environment of Residential Buildings is also an international collaboration and we welcome participants from Australia, China, Germany, Hong Kong, India, Indonesia, Japan, Malaysia, New Zealand, Portugal, Singapore, Thailand, United States and Vietnam. We are here to share and report on our best efforts in our specific fields of expertise and to discuss ways in which our efforts might be strengthened. Our work in residential buildings should be seen as part of the Paris Agreement efforts, as well as contributing to the broader sustainability agenda.

This conference was called HealthyHousing because I wanted to focus our attention on the reason why we research energy and environment quality issues: to ensure that residential buildings support and nurture the health and well-being of occupants and the broader environment.

For some, a dwelling is simply a shelter providing protection from the vagaries of the local climate. For others, one’s home may represent safety and security for our person and possessions; a private or quiet retreat; a place to nurture close relationships or raise a family; a representation of our personality and creativity; a display of our wealth or social status; a place over which we have some level of control.

In essence our home, regardless of the physical form it takes, is much more than its physical form: it is an integrated system that displays the success or otherwise of the interplay between occupants, specific building elements, the supply chain processes and practices that develop the built environment, and the social, cultural, regulatory, economic and environment context.

This integrated system approach to housing is demonstrated through the conference themes and the wide variety of papers shown in the program. I encourage you to read papers and attend sessions that may be outside of your usual focus. But more importantly, I encourage you to talk and socialise, to expand our cultural and disciplinary knowledge in order to develop relationships that can further enhance our collaborative efforts to deliver healthy, energy efficient and sustainable dwellings that meet the needs of humanity now and in a changing climate.

Finally I would like to sincerely thank and acknowledge our conference sponsors and energy efficiency seminar partner* who collectively demonstrate multidisciplinary fields and the collaborative spirit between academia, government and industry:

QUT School of Chemistry, Physics and Mechanical Engineering
QUT School of Civil Engineering and Built Environment
QUT Institute of Health and Biomedical Innovation
QUT Institute for Future Environments
Economic Development Queensland
PRD Nationwide

*German-Australian Chamber of Industry and Commerce.

Dr Wendy Miller
Senior Research Fellow (Sustainable Energy / Energy Efficiency)
School of Chemistry, Physics and Mechanical Engineering
Science and Engineering Faculty, Queensland University of Technology
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Thank you to our sponsors:

Economic Development Queensland

PRD

Institute of Health and Biomedical Innovation

ife Institute for Future Environments

School of Chemistry, Physics and Mechanical Engineering

School of Civil Engineering and Built Environment
Conference Committee

Chair

Dr Wendy Miller
(QUT, Chemistry Physics and Mechanical Engineering)

Deputy Chair

Dr Connie Susilawati
(QUT, Civil Engineering and the Built Environment)

Scientific Program

Associate Professor Karen Manley
(QUT, Construction and Project Management)

Program

Dr Stephen Berry
(University of South Australia, Low Carbon Living)

Dr Zakaria Amin
(QUT Visiting Fellow, Chemistry Physics and Mechanical Engineering)

Mr Aaron Lei Liu
(QUT PhD Candidate, Electrical Engineering and Computer Science)

Professor Hiroshi Yoshino
(Tohoku University Japan)
Welcome to QUT - a leading Australian university. We’re well known as ‘a university for the real world’ because of our close links with industry and our relevant teaching and applied research.

History

Over the years, QUT has grown and changed. From the establishment of the Brisbane School of Arts over 150 years ago, we have been at the forefront of innovation and progress in tertiary education. Although the name QUT has only been used for the last 26 years, the institutions that came before us made us the university that we are today.

Acknowledgement of Traditional Owners

We are committed to supporting reconciliation between Indigenous and non-Indigenous Australian people.

In keeping with the spirit of Reconciliation, we acknowledge the Turrbal, Jagera/Yuggera, Kabi Kabi and Jinibara Peoples as the Traditional Owners of the lands where QUT now stands - and recognise that these have always been places of teaching and learning.

We wish to pay respect to their Elders - past, present and emerging - and acknowledge the important role Aboriginal and Torres Strait Islander people continue to play within the QUT community.
Conference venue

Technical Tour meeting point

Tiny House display

Conference dinner meeting point
Conference Information

Registration Desk
The conference registration desk will be located on level 5 of P Block and open at the following times:

- Sunday 20 November: 2:30pm – 7:00pm
- Monday 21 November: 8:30am – 5:00pm
- Tuesday 22 November: 8:30am – 5:00pm
- Wednesday 23 November: 8:30am – 4:00pm

Social Functions

**Welcome Reception**
- **Date:** Sunday 20 November, 2016
- **Time:** 5:00pm – 7:00pm
- **Venue:** The Cube (P Block), Queensland University of Technology Gardens Point Campus
- **Dress:** Smart Casual

**Conference Dinner**
- **Date:** Tuesday 22 November, 2016
- **Time:** 6:30pm – 9:30pm
- **Venue:** South Bank Beer Garden, South Bank, Brisbane
- **Dress:** Smart Casual

If you would like to walk to dinner with the conference group, please meet at the start of the Goodwill Bridge (QUT side of the river) at 6.10pm. Alternatively, you can collect a walking map from the registration desk.

**Technical Tour**
- **Date:** Thursday 24 November, 2016
- **Time:** 8:30am – 4:30pm

Please meet the conference organiser at 8.15am on the grassed area behind P Block (near the Tiny House display site).

**GoAccess Public Transport Card**
Full conference registrations (Monday-Wednesday) include a 5-day public transport GoAccess Card (valid on any 5 days during 20-26 November)

Your GoAccess card entitles you to unlimited travel on all TransLink bus, train, tram and ferry services in South East Queensland. So if you are planning on touring after the conference you may wish to use your GoAccess card to visit Noosa on the Sunshine Coast (Cooroy train station) or head south to the beautiful Gold Coast (Robina train station).

To plan your journey please visit the Translink website https://translink.com.au

**Mobile Phones**
As a courtesy to fellow delegates and speakers, please ensure your phone is switched off or is on silent during all conference sessions.

**Name Badges**
It is requested all delegates wear their name tags at the conference. This will help other attendees identify who you are, and also provide a visual security check for the venue.

Catering may be refused if you are not wearing your name tag.

**Internet Access**
You will be allocated a username and password, located on your name badge, to access the QUT network. This username and password will give you access to any of the computers on campus, as well as the wireless network, if you have a laptop. For information on accessing the wireless network on your laptop, please see staff at the registration desk.

**ATMs (Cash points)**
- Commonwealth Bank – Level 3, P Block (Food Court)
- RediATM – Level 3, P Block (Food Court)
- Westpac – Level 3, P Block (Food Court)
- Suncorp - Machines may be found at V Block, Vending Podium (near M Block)

**On-campus attractions**
- QUT Art Museum – is located in U Block and is open Monday- Friday from 10am – 5pm and on Saturday and Sunday from 12pm-4pm. Admission is free.
- Old Government House – is recognised as one of Queensland’s most important heritage sites. It is open to the public 7 days a week and entry is free.

**Lost Property**
All lost property can be handed in/collected from the registration desk.

**Electricity**
Mains supply in Australia is 220/240V-AC, 50Hz with three pin plugs used across the country. You can buy adaptors for any electrical equipment you bring with you from good travel stores, chemists, department stores and the Visitor Information Centre in Queen Street Mall.
Getting Around Brisbane

Bus Services
A number of buses stop near QUT Gardens Point in Alice Street. Translink (http://translink.com.au/) will also provide information of the nearest bus stop for the route number that you are seeking. The bus route numbers and destinations are also included on signage at each of the city bus stops.

CityCats
The closest CityCat stop is the ‘QUT’ stop. Arriving at QUT on the CityCat, please walk along the River path until you reach the Goodwill Bridge and you will see P block directly in front of you on your left.

There is also a pathway through the middle of the under freeway carpark that leads into the QUT campus. Take the lift just across the pedestrian crossings to ‘Level 4’ and then follow paths and the signs to Z block and then further on to Science and Engineering Centre (SEC; P Block).

CityCats operate daily from 5.50am to 10.30pm.

Trains
The closest station to QUT is the South Bank Railway Station, you will need to walk across the Goodwill Bridge to reach QUT. P Block is directly in front of you once you exit the bridge. To find bus, CityCat and train timetables, please visit www.translink.com.au

Taxi
A taxi rank is located at the George Street Entry and at various locations throughout Brisbane City. To order a taxi, call 131 008.

Walking
QUT is an easy walk from anywhere in the CBD. It’s advised to use the George Street entry.

City Centre Free Loop Buses Schedule
Clockwise Loop – service departs QUT every 15 minutes between 7:00am and 6:00pm
Anticlockwise Loop - service departs QUT every 15 minutes between 7:05am and 6:05pm

FREE CityHopper Ferry
The CityHopper service allows you to rediscover Brisbane for free with ferries running every 30 minutes between 6am and midnight, seven days a week.

The CityHopper travels along the Brisbane River, stopping at North Quay, South Bank 3, Maritime Museum, Thornton Street, Eagle Street Pier, Holman Street, Dockside and Sydney Street terminals.

As the CityHopper is free, all you need to do is hop on and hop off and enjoy taking in the Brisbane River and city sights.

For up-to-date timetable information, visit TransLink’s website - www.translink.com.au
Brisbane Dining Precincts

Brisbane City

There are many exciting eating establishments, which are scattered across the CBD. For easy reference the two main areas are:

Queen Street Mall - Offers numerous food courts for quick, casual meals, open air cafes for those who prefer to take their time or a number of different restaurant & bars spread from one end of the mall to the other

Riverside/Eagle Street Pier - Is the heartland of the city’s dining precinct. In this prime riverfront location, there are literally dozens of places to eat with many of the restaurants making the most of the stunning river views for alfresco, relaxed dining.

Fortitude Valley

‘The Valley’, as it is known by the locals, is full of an energy and individualism that makes it one of the most exciting dining areas in Brisbane. This vibrant dining locale offers everything from quality Asian to distinctive European and Middle Eastern cuisine. The main dining precincts are the Brunswick Street precinct (Brunswick Street, the Brunswick Street Mall, Central Brunswick and Chinatown), the James Street precinct and the Emporium precinct.

South Bank

Eating out at Brisbane’s South Bank gives diners so many options. There are restaurants and cafes in South Bank Parklands but the precinct also extends to nearby Little Stanley Street and Grey Street. This is a heartland of Brisbane’s dining scene, offering cuisines from around the world and for all budgets. It’s also a dynamic place, with new places opening regularly.

West End

West End has so many eating options on Boundary Street from Vulture Street to Melbourne Street. You’ll also find other dining areas on Hardgrave Road and a small selection further down Vulture Street or on Melbourne Street, towards South Brisbane.

West End is known as the place to cruise the cafes, rather than dine in formal restaurants. There are always footpaths overflowing with patrons. There are all-night places to buy pizza or kebabs and early morning joints for strong coffee interspersed amongst the real and living village.
### Program

**Sunday 20 November**

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<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>2:30pm - 7:00pm</td>
<td><strong>Registration</strong>&lt;br&gt;Level 5, Science and Engineering Centre (P Block), QUT Gardens Point</td>
</tr>
<tr>
<td>5:00pm - 7:00pm</td>
<td><strong>Welcome Reception</strong>&lt;br&gt;The Cube, Science and Engineering Centre (P Block), QUT Gardens Point</td>
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**Monday 21 November: Conference Day 1**

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<tr>
<th>Time</th>
<th>Event</th>
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<tr>
<td>8:30am</td>
<td><strong>Registration</strong>&lt;br&gt;Level 5, Science and Engineering Centre (P Block), QUT Gardens Point</td>
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<tr>
<td>9:00am</td>
<td><strong>Plenary 1</strong>&lt;br&gt;Room: P514 Chair: Wendy Miller</td>
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<tr>
<td>9:00am</td>
<td><strong>Conference Opening</strong>&lt;br&gt;Stephen Kajewski, Head of School of Civil Engineering and Built Environment, Queensland University of Technology, Australia</td>
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<tr>
<td>9:30am</td>
<td><strong>Keynote Address</strong>&lt;br&gt;Tackling health inequalities through action on housing&lt;br&gt;Nathalie Röbbel, World Health Organisation, Switzerland</td>
</tr>
<tr>
<td>10:00am</td>
<td><strong>Keynote Address</strong>&lt;br&gt;Housing and Health: Lessons from New Zealand&lt;br&gt;Dr Nevil Pierse, University of Otago, New Zealand</td>
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<tr>
<td>10:30am</td>
<td><strong>Morning Tea</strong></td>
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<th>Time</th>
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<tbody>
<tr>
<td>11:00am</td>
<td><strong>Session 1.1 - Indoor Environment Quality</strong>&lt;br&gt;Room: P514 Chair: Nevil Pierse</td>
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<tr>
<td></td>
<td>1.1A - Effectiveness and Impact of the National Healthy Homes Partnership on Occupant Health&lt;br&gt;Michael Goldschmidt, University of Missouri, and Pamela Turner, University of Georgia, USA</td>
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<td>1.1B - Happy homes – the relationship between homes and mental wellbeing: a review of the literature&lt;br&gt;Mike Burbridge, Curtin University, Australia</td>
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<td>1.1C - Methamphetamine Contamination in Homes - Contamination and Risk Levels&lt;br&gt;John Edwards, Flinders University, Australia</td>
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<td></td>
<td>1.1D - Effect of Indoor Thermal Environment on Children's Physical Activity and Body Temperature&lt;br&gt;Moeka Ubukata, Keio University, Japan</td>
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<td>1.1E - A study on development of a new-type air cleaner for creating healthy indoor environments&lt;br&gt;Atsuo Nozaki, Tohoku Bunka Gakuen University, Japan</td>
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<td>1.1F - Prevention strategy against fungal attack using selected fungi as biologic sensors&lt;br&gt;Keiko Abe, Institute of Environmental Biology, Japan</td>
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<tr>
<td>11:45am</td>
<td>1.1G - Low cost sensor network for indoor air quality monitoring in residential houses: Lab and indoor tests of two PM sensors&lt;br&gt;Xiaoting Liu, Queensland University of Technology, Australia</td>
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<tr>
<td></td>
<td>1.2A - Effect of phase change materials on indoor thermal comfort of a multistory building located in different climate regions of China&lt;br&gt;Hongzhi Cui, Shenzhen University, China</td>
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<td></td>
<td>1.2B - Environmental sustainability of prefabricated modular residential buildings compared to traditional equivalent: Two case studies in Perth, Australia&lt;br&gt;Lio Hebert, Curtin University, Australia</td>
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<td></td>
<td>1.2C - Thermal performance of passive techniques for roofs in tropical climate&lt;br&gt;Xingguo Yang, Nanyang Technological University, Singapore</td>
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<td></td>
<td>1.2D - Design Decision-making towards Energy-efficiency Upgrades of Residential Building Façade Refurbishment&lt;br&gt;Guopeng Li, Dalian University of Technology, China</td>
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<td></td>
<td>1.2E - Effects of UV on radiation properties of cool coating&lt;br&gt;Xingguo Yang, Nanyang Technological University, Singapore</td>
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<td>1.2F - Research on rural heating design temperature based on residential behavior pattern&lt;br&gt;Nina Shao, Dalian University of Technology, China</td>
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<td></td>
<td>1.2G - Design issues in expansion and modification process of detached houses in Bangkok&lt;br&gt;Pachara Chantanayingyong, Chulalongkorn University, Thailand</td>
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<tbody>
<tr>
<td>12:00pm</td>
<td><strong>Session 1.2 - Sustainable Design &amp; Construction</strong>&lt;br&gt;Room: P512 Chair: Hiroshi Yoshino</td>
</tr>
<tr>
<td>12:15pm</td>
<td>1.2A - Effect of phase change materials on indoor thermal comfort of a multistory building located in different climate regions of China&lt;br&gt;Hongzhi Cui, Shenzhen University, China</td>
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<tr>
<td>12:30pm</td>
<td>1.2B - Environmental sustainability of prefabricated modular residential buildings compared to traditional equivalent: Two case studies in Perth, Australia&lt;br&gt;Lio Hebert, Curtin University, Australia</td>
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<td>12:45pm</td>
<td>1.2C - Thermal performance of passive techniques for roofs in tropical climate&lt;br&gt;Xingguo Yang, Nanyang Technological University, Singapore</td>
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<tr>
<td>1:00pm</td>
<td>1.2D - Design Decision-making towards Energy-efficiency Upgrades of Residential Building Façade Refurbishment&lt;br&gt;Guopeng Li, Dalian University of Technology, China</td>
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<tr>
<td>Time</td>
<td>Session 2.1 - Indoor Environment Quality</td>
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<tr>
<td>12:45pm</td>
<td>Lunch</td>
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<tr>
<td>2:00pm</td>
<td>2.1A - A methodology for predicting PM2.5 penetration and deposition based on the air infiltration through the window gaps Chao Chen, Beijing University of Technology, China</td>
</tr>
<tr>
<td>2:15pm</td>
<td>2.1B - Decrease in the number of bacteria for nucleic acid extraction and sampling of microbiome from the environment Yudai Takahashi, The University of Tokyo, Japan</td>
</tr>
<tr>
<td>2:30pm</td>
<td>2.1C - What can we learn if we measure the indoor and outdoor concentration of PM2.5 at the same time? Yangyang Xie, Tsinghua University, China</td>
</tr>
<tr>
<td>2:45pm</td>
<td>2.1D - Pilot Monitoring of Ultratine Particle Number Concentrations in some Households in Hanoi Phong Thai, National University of Civil Engineering, Vietnam</td>
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<tr>
<td>3:00pm</td>
<td>2.1E - Field measurements of PM2.5 and ultratine particles in residential houses Naoki Kagi, Tokyo Institute of Technology, Japan</td>
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<tr>
<td>3:15pm</td>
<td>2.1F - The relationship between indoor and outdoor PM2.5 concentrations in the severe cold region of China: based on a long-term field measurement Ye Xiao, Harbin Institute of Technology, China</td>
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<tr>
<td>3:30pm</td>
<td>Afternoon Tea</td>
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<tr>
<td>4:00pm</td>
<td>Electronic Poster Presentations</td>
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<tr>
<td>4:00pm</td>
<td>The Cube, Science and Engineering Centre (P Block), QUT Gardens Point Chair: Aaron Liu</td>
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<tr>
<td>5:00pm</td>
<td>CIB Task Group 86 (Healthy Cities) Workshop: Housing in the context of precincts and cities. Includes teleconferencing options</td>
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<td>5:00pm</td>
<td>Room P512 Chair: Lidia Morawska</td>
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<tr>
<td>Time</td>
<td>Session 3.1 - Indoor Environment Quality</td>
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<tr>
<td>11:00am</td>
<td>3.1A - Thermal environment and thermal adaptation in residential buildings</td>
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<tr>
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<td>Zhaojun Wang, Harbin Institute of Technology, China</td>
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<tr>
<td>11:15am</td>
<td>3.1B - Pilot study on relationship between indoor and outdoor temperature in Brisbane’s households</td>
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<td>Akwasi Bonsu Asumadu-Sakyi, Queensland University of Technology, Australia</td>
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<tr>
<td>11:30am</td>
<td>3.1C - Field studies to investigate impact of increasing R-value of building envelope on winter indoor relative humidity of Auckland houses</td>
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<td>Bin Su, Unitec Institute of Technology, New Zealand</td>
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<tr>
<td>11:45am</td>
<td>3.1D - Indoor air condition in narrow living spaces</td>
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<td>Masatoshi Tanaka, Fukushima Medical University, Japan</td>
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<tr>
<td>12:00pm</td>
<td>3.1E - Effects of Nighttime Bedroom Temperature on Morning Blood Pressure during Winter: A Multilevel Analysis</td>
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<td>Yusuke Nakajima, Keio University, Japan</td>
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<tr>
<td>12:15pm</td>
<td>3.1F - Long-term Thermal Performance Evaluation of Green Roof System in Shanghai District Based on a New Model</td>
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<td>Yang He, Tongji University, China</td>
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<td>12:30pm</td>
<td>3.1G - Investigation and improvement of indoor air quality in office buildings</td>
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<td>Xu Liu, Chongqing University, China</td>
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<tr>
<td>12:45pm</td>
<td>Lunch</td>
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<tr>
<td>Time</td>
<td>Session 4.1 - Energy and Environment and Health</td>
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<tr>
<td>2:00pm</td>
<td>4.1A - Field Measurements of Indoor Temperatures and Blood Pressure of Elderly Person Kenichi Hasegawa, Akita Prefectural University, Japan</td>
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<td>4.1B - The role of simulation in improving the thermal comfort and energy performance of existing aged care facilities Zakaria Amin, Queensland University of Technology, Australia</td>
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<tr>
<td>2:30pm</td>
<td>4.1C - Study on Association Between Indoor Thermal Environment of Residential Buildings and Cerebrovascular Disease in a Cold Climatic Region of Japan Hiroshi Yoshino, Tohoku University, Japan</td>
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<tr>
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<td>4.1D - Effects of Indoor Air Temperature on Blood Pressure among Nursing Home Residents in Japan Yukie Hayashi, Keio University, Japan</td>
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<td>3:00pm</td>
<td>4.1E - Domestic Energy Use by Australians with Multiple Sclerosis Frank Bruno, University of South Australia, Australia</td>
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<td>4.1F - Impact of Regional Differences in Residential Environment on Healthy Life Expectancy in 1,300 Japanese Municipalities Kentaro Suzuki, Keio University, Japan</td>
</tr>
<tr>
<td>3:30pm</td>
<td>Afternoon Tea</td>
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<tr>
<td>4:00pm</td>
<td>Session 5.1 - Indoor Environment Quality Room: P514 Chair: Lidia Morawska</td>
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<td>5.1A - Physical Characteristics of Residential Sprinklers Water Spray Wilson Y. K. Woo, Hong Kong Polytechnic University, Hong Kong</td>
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<td>5.1B - Thermal environment and thermal comfort in a passive residential building in the severe cold area of China Zhaojun Wang, Harbin Institute of Technology, China</td>
</tr>
<tr>
<td>4:30pm</td>
<td>5.1C - Sanitation infrastructure and their impacts on groundwater: A case study of 3 villages in Semarang City Sudarno Sudarno, Diponegoro University, Indonesia</td>
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<td>5.1D - The regulating effect of S.trifasciatavar. laurentii on indoor environment Na Li, Beijing University of Technology, China</td>
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<td>6:30pm - 9:30pm</td>
<td>Conference Dinner South Bank Beer Garden</td>
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# Energy, Indoor Environment, Health and Seniors: Industry and Research Collaboration Day

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<tr>
<th>Time</th>
<th>Session 6.1 - Understanding the Links between Housing and Health for Seniors</th>
<th>Session 6.2 - Building the business case for sustainability in housing</th>
</tr>
</thead>
</table>
| 9:00am | **Collateral Health Benefits of a Green Retrofit of Housing for Low-Income Seniors: Lessons from a Case Study and Future Research Directions**  
Room: P514 Chair: Laurie Buys | **6.2A - Background and context - the EU RenoValue project**  
Wendy Miller, Queensland University of Technology, Australia |
| 9:30am | Professor Sherry Ahrentzen, University of Florida, USA  
(Virtual presentation and Q&A) | **6.2B - International and national trends relating to housing and energy efficiency / sustainability regulations and market directions**  
Stephen Berry, University of South Australia, Australia |
| 9:45am | | **6.2C - Energy and sustainability features of housing and key information sources**  
Wendy Miller, Queensland University of Technology, Australia |
| 10:00am | **Discussion Forum:**  
Laurie Buys, Institute for Future Environments, Queensland University of Technology, Australia  
Rosemary Kennedy, Design Studio, Queensland | **6.2D - Risks, opportunities and integration into practice**  
Connie Susilawati, Queensland University of Technology, Australia |
| 10:15am | **University of Technology, Australia**  
Hiroshi Yoshino, Tohoku University, Japan  
Kenichi Hasagawa, Akita Prefectural University, Japan  
Lidia Morawska, International Laboratory of Air Quality and Health, Queensland University of Technology, Australia | **Discussion** |

## Energy Innovation in the Built Environment: Knowledge Transfer from Germany

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<th>Time</th>
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| 11:00am | **Welcome**  
Michael Rosemann, Honorary German Consul for South Queensland, Australia  
Moderator: Stephen Berry, University of South Australia, Australia | **Discussion** |
| 11:10am | **Energy efficiency case studies from Germany**  
Jonas Maasmann, Technical University of Dortmund, Germany | **Discussion** |
| 11:35am | **Healthy homes and passive house construction**  
Thomas van Raamsdonk, General Manager of Pro Clima Australia, Australia | **Discussion** |
| 12:00pm | **Beyond efficiency: sensors and data enabling human centric smart buildings**  
Jerry Arguriou, Steinel Australia | **Discussion** |
| 12:25pm | **German-Australian research collaborations in housing and energy: Data Analysis and Building Passports**  
Wendy Miller, Queensland University of Technology, Australia | **Discussion** |
| 12:40pm | **Q & A Panel** | **Discussion** |

## Conference Closing Remarks

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| 2:00pm | **Senior Living Innovation Design Challenge**  
Room: P506 & P506A Chair: Rosemary Kennedy | **Discussion** |
| 4:00pm | **Conference Closing Remarks**  
Panel Discussion (Conference Organising Committee) & Q&A  
Future directions for enhancing energy and environment performance of residential buildings: research, policy, practice  
Room P514 Chairs: Wendy Miller & Connie Susilawati | **Discussion** |
Thursday 24 November - Technical Tour

8:30am - 4:30pm

Technical Tour
Meeting point: grassed area behind P Block (near the Tiny House display site) at 8:15am
Whole day tour to a sustainable residential development on the Gold Coast.
Bus departs Brisbane 8.30am and returns approximately 4:30pm.
(If you have not registered for the Technical Tour but would like to attend, please visit the registration desk)
The International Council for Research and Innovation in Building and Construction (CIB) is an international network of experts who cooperate and exchange information in the fields of building and construction related research and innovation. Task Group TG86 - Building Healthy Cities - addresses the planning, design, construction, management and maintenance, and deconstruction of all components of the built environment.

Professor Lidia Morawska, Chair of TG86, warmly invites you to join the TG86 workshop which will be held in association with the 7th International Conference on Energy and Environment of Residential Buildings (Healthy Housing) that is taking place 20-24 November 2016 in Brisbane, Queensland, Australia. You do not need to be a member of CIB in order to participate in this workshop.

Date: Monday November 21, 2016
Venue: Room P512, P Block, Queensland University of Technology Gardens Point campus, Brisbane, Australia
Time: 17:00 - 19:00 (UTC+10)

Participate in this TG86 workshop to learn more about cutting-edge ideas and research industry movement of visionary academic researchers, whose solutions get to the street as fast as possible. Contribute your knowledge and expertise to discussions on the links between healthy housing and healthy cities.

Chairperson: Professor Lidia Morawska

Workshop Agenda:
1. Overview of the purpose and goals of TG86 – Professor Lidia Morawska (QUT), TG86 Coordinator
2. Background research: definitions and indicators for different city typologies (Healthy Cities QUT Student Project Team: Xin Wang, Asad Amir, Marc Milliner, Jasem Alostath, Tim Henry)
   - Sustainable
   - Smart
   - Energy Efficient
   - Liveable
   - Healthy
3. Comments from the invited Panelists
   - Dr Nathalie Röbbel (WHO, Geneva)
   - Professor Yinping Zhang (Tsinghua University, China)
   - Associate Professor Michael Goldschmidt (US National Healthy Homes Partnership)
   - Professor Nevil Pierce (He Kainga Oranga/Housing and Health Research Programme, New Zealand)
   - Professor Hiroshi Yoshino (Tohoku University, Japan)
4. General Discussion of all participant and formulation of Next Steps
   - Selection of performance indicators
   - Quantitative measures for indicators
   - Ranking and weighting of indicators
   - Normalisation
Healthy Housing Industry Day

Energy, Indoor Environment, Health and Seniors: Industry and Research Collaboration Day

**Date:** Wednesday 23 November, 2016

**Time:** 9.00am – 4.00pm

**Venue:** P Block, Queensland University of Technology Gardens Point campus, Brisbane

**Agenda:**

1. **Concurrent Seminars**
   1. Understanding the Links between Housing and Health for Seniors
      - Collateral Health Benefits of a Green Retrofit of Housing for Low-Income Seniors: Lessons from a Case Study and Future Research Directions
      - Professor Sherry Ahrentzen, University of Florida, USA (Virtual presentation and Q&A)
      - Discussion Forum
   2. Building the business case for sustainability in housing
      - EU RenoValue project
      - International and national trends relating to housing and energy efficiency / sustainability regulations and market directions
      - Energy and sustainability features of housing and key information sources
      - Risks, opportunities and integration into practice

2. **Energy Innovation in the Built Environment: Knowledge Transfer from Germany**
   - Energy efficiency case studies from Germany
   - Healthy homes and passive house construction
   - Beyond efficiency: sensors and data enabling human centric smart buildings
   - German-Australian research collaborations in housing and energy: Data Analysis and Building Passports

3. **Senior Living Innovation Design Challenge**
Big World Home: A flat-pack DIY Tiny House

Date: 21 & 22 November, 2016
Time: 7.30am - 6.00pm
Location: QUT - Green lawn between P Block and the Goodwill Bridge

As part of the conference QUT has organized a display of a new innovation in Tiny Houses.

A Big World Home is a portable, completely off-grid house that can be built by two unskilled people in just a few days using only a hammer and a drill. It is a revolutionary form of affordable transitional housing that aims to bridge the gap between renting and owning.

At 13.75m² this tiny home comes completely fitted out with a living room, bed, running water and a plumbed bathroom. The entire structure itself is self-sufficient with solar panels and inbuilt rainwater tanks.

This world-first patented technology integrates insulation, waterproofing and structural integrity within 39 panels that are modular, adaptive, cheap, durable and easy to install.

Affordable Housing

Australia’s five major metropolitan cities have been classified as ‘severely unaffordable’ for the past 11 years. The generational gap is widening, wages are declining, relative prices increasing, and most mortgages continue to go to existing home owners. Big World Homes is challenging the notions of house ownership being intrinsically linked to the huge costs of land ownership by negotiating with developers, councils and individual landowners for eligible, off-grid home owners (or tenants) to come together to create pop-up communities on unused development sites or vacant land. Can houses be affordable, healthy and sustainable?
**Nathalie Röbbel**

Technical Officer, Public Health, Environmental and Social Determinants of Health, World Health Organization, Geneva

Nathalie Röbbel is a technical officer in the Department of Public Health, Environmental, and Social Determinants of Health (SDH) at WHO in Geneva and is currently leading the department’s work on developing WHO Housing and Health Guidelines. Her main tasks are to provide technical support for streamlining social determinants of health within environmental health programs. Before joining WHO HQ, she worked as a technical officer at the WHO Regional Office for Europe, in Bonn and Copenhagen, where she was responsible for environmental health performance reviews and involved in several housing and health related projects. Ms Röbbel holds a Ph.D. in sociology from the Rheinische-Friedrich-Wilhelms University in Bonn, Germany.

**Dr Nevil Pierse, University of Otago, New Zealand**

Dr. Nevil Pierse is Deputy Director of He Kainga Oranga/Housing and Health Research Programme. Originally a statistician by training, his current work is done in partnership with a wide variety of stakeholders including government and community organisations, and is focused on the design and implementation of randomised trials in the home and community.

His previous studies have shown the benefits of efficient home heating and insulation, which was instrumental in the $300 Million EECA, Warm Up New Zealand, Heat Smart programme. This programme has delivered over $1 Billion in saving for New Zealand. Nevil’s other work includes the HRC funded Home Injury Prevention Intervention, which showed that simple home repairs and modification reduced the number of falls in homes by 27%. He was part of the group awarded the 2014 NZ Prime Ministers prize for Science. He is currently working on the SHELTER study which looks at home interventions to prevent rehospitalisation of children with respiratory disease.

**Professor Yinping Zhang, Tsinghua University, Beijing**

Yinping Zhang, Ph.D, is professor of Dept. of Building Science, Dean of Beijing Key Laboratory of Indoor Air Quality, Head of Building Environment Test Center, Tsinghua University.

Zhang got his Bachelor degree (1985), Master degree (1988) and Ph.D degree (1991) in University of Science and Technology of China (USTC). He was a visiting scholar or professor in Stuttgart University, Germany (1994.5-95.5), Tokyo University, Japan (1996.10-12), and Technique University of Denmark (DTU) (2004.10-12) and the Otto Monsted visiting professor of DTU, Denmark (2007/2008, 3 months).

His research interests are indoor air quality and building energy efficiency. He has published over 160 inter. journal papers (H index=36 on Web of Science Core Collection). He is member of editorial boards of over 10 Chinese IAQ related standards. He has given 15 keynote speeches in Inter. Conf. including the 11th and 13th Inter. Conf. of Indoor Air (Copenhagen, 2008; Hong Kong, 2014).

He is a deputy-chairman and the secretary-in-chief of Chinese Association of Indoor Environment and Health, fellow of Inter. Academy of Indoor Air Science, Chair of Scientific and Technological Committee (STC) 22-Air Cleaning of Inter. Society of Indoor Air Quality (ISIAQ). Zhang is serving as associate editor of Energy and Buildings, member on editorial boards of other 6 inter. journals including Indoor Air, Building and Environment and PLoS ONE. He has received a series of awards such as Outstanding Young Researcher Award of NSFC (2007), the 1st Prize of Natural Science of Ministry of Education of China (2010) and the 2nd Prize of Ministry of Education of China (2005).
Dr Iain MacGill is an Associate Professor in the School of Electrical Engineering and Telecommunications at UNSW Australia, and Joint Director (Engineering) for the University’s Centre for Energy and Environmental Markets (CEEM).

Iain’s teaching and research interests at UNSW include electricity industry restructuring and the Australian National Electricity Market, sustainable energy generation technologies, distributed energy resources, energy efficiency options, and energy and climate regulation, market design and policy. CEEM itself undertakes interdisciplinary research in the monitoring, analysis and design of energy and environmental markets and their associated policy frameworks. It brings together UNSW researchers from the Faculties of Engineering, Business, Science, Law and Arts and Social Sciences, with project funding from partners including the Australian Federal Government, CSIRO, State Governments and industry. Iain leads work in two of CEEM’s three research areas, Sustainable Energy Transformation, including energy technology assessment and renewable energy integration; and Distributed Energy Systems including distributed generation and demand-side participation. To learn more about CEEM visit the Centre website – www.ceem.unsw.edu.au.

Professor Sherry Ahrentzen, University of Florida, USA

Sherry Ahrentzen, PhD, is Shimberg Professor of Housing Studies at the University of Florida. Her research focusing on housing and community design that fosters the physical, social and economic health of households has been published extensively in journals and books, and presented at national and international conferences. She has over 75 published articles, chapters, and reports, and has received more than 30 research and instructional grants from various agencies and organizations.

Her recently completed research involved leading a multidisciplinary team to examine the impacts of a green building retrofit on resident health and indoor environmental quality in the housing of low-income seniors in Phoenix, Arizona. She has also co-authored a book with Kim Steele on designing and developing housing for adults with autism and other neurodevelopmental conditions, At Home with Autism: Designing for the Spectrum. She currently co-leads a multidisciplinary team of faculty and graduate students examining building/infrastructure performance for occupant health, focusing on older adults in residential settings. This team is one of the initial cohorts of the AIA Consortium of Health and Design Research.

In 2003 she received the Distinguished Professor Award from the Association of Collegiate Schools of Architecture; in 2009 she received the Career Award from the Environmental Design Research Association; and in 2014, she was the recipient of the ARCC James Haecker Award for Distinguished Leadership in Architectural Research.
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Field measurements of PM2.5 and ultrafine particles in residential houses

Field studies to investigate impact of increasing R-value of building envelope on winter indoor relative humidity of Auckland houses

Happy homes - the relationship between homes and mental wellbeing: a review of the literature

Housing design for temperate climates: the priority to energy sufficiency

Impact assessment of inhabitants on the economic potential of energy efficient refurbishment by means of a novel socio-technical multi-agent simulation

Impact of regional differences in residential environment on healthy life expectancy in 1,300 Japanese municipalities

Incongruence of superior goals and energy efficiency funding programs

Indoor air condition in narrow living spaces

Investigation and improvement of indoor air quality in office buildings

Investigation of energy performance of a rammed earth built residential house in sub-tropical, tropical and temperate climates of Australia

Long-term thermal performance evaluation of green roof system in Shanghai District based on a new model

Low cost sensor network for indoor air quality monitoring in residential houses: Lab and indoor tests of two PM sensors

Methamphetamine contamination in homes - contamination and risk levels

Occupancy inefficiency of larger detached houses

Physical characteristics of residential sprinklers water spray

Pilot monitoring of ultrafine particle number concentrations in some households in Hanoi

Pilot study on relationship between indoor and outdoor temperatures in Brisbane households

Prevention strategy against fungal attack using selected fungi as biologic sensors

Rational or emotional? Failing to attract home owners in Germany to conduct energy-efficient renovation measures from a marketing perspective

Regenerative sustainability and geodesign in Byron Shire

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Statistical analysis of residential energy consumption except heating in Beijing of China

Study on association between indoor thermal environment of residential buildings and cerebrovascular disease in a cold climatic region of Japan

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The relationship between indoor and outdoor PM2.5 concentrations in the severe cold region of China: based on a long-term field measurement.

The role of simulation in improving the thermal comfort and energy performance of existing aged care facilities

Thermal environment and thermal adaptation in residential buildings

Thermal environment and thermal comfort in a passive residential building in the severe cold area of China

Thermal performance of passive techniques for roofs in tropical climate

This subtropical life: are new apartment buildings providing locally-appropriate outcomes for apartment living in Brisbane?

Tools Developed in CSIRO for Building Design and Thermal Performance Evaluation

Understanding Australian real estate agent perspectives in promoting sustainability features in the residential property market

What can we learn if we measure the indoor and outdoor number concentration of PM2.5 at the same time?

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Papers
Prevention Strategy against Fungal Attack Using Selected Fungi as Biologic Sensors

Keiko Abe
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Dr. Eng. Tomomi Murata, The University of Kitakyushu, Japan. t-murata@fb3.so-net.ne.jp

Abstract

Purpose / Context - The purpose of this study was to develop a prevention strategy against fungal attack in any residential building, which had been previously proposed and applied to conserve cultural assets using a fungal index. The strategy consisted of four stages: current status assessment, diagnosis, preventive measures, and finally confirmation of the preventive measure. In the current status assessment, the microclimates in a target room are to be evaluated firstly using the fungal index, which assesses the environmental conditions critical for fungal growth. The microclimates are diagnosed and categorized into the following three levels: A (free of contamination), B (probable contamination), or C (unavoidable contamination), depending on the index values <1.8, 1.8-18, and >18, respectively. Suitable preventive measures are to be adopted at the sites with level B or C. After implementing the preventive measures, the fungal indices ought to be measured again for the evaluation of the employed preventive measure as well as the confirmation of level A.

Methodology / Approach - One storeroom was selected as a target room to apply the approach, as a case study of the prevention strategy against fungal attack, including the diagnosis using fungal index values at the sites of interest, selection of a preventive measure, and the subsequent confirmation of the preventive measure.

Results – Fungal index measurements throughout a period of one year as a current status assessment revealed that the microclimates in the target room were level B only in winter. As a preventive measure, a commercially available dehumidifying system was selected and installed in the target room. Fungal-index measurements confirmed that the room conditions had changed from level B to level A.

Key Findings / Implications – The cause of level B in the target room was moisture invasion from the neighboring storeroom which had been air-conditioned at 20°C and 55% RH year-round, warmed and humidified in winter. The preventive measure implemented has completely suppressed fungal growth in the target room. This practical application of the strategy was successful.
Originality - The phenomenon of moisture moving from warm and humidified rooms to cold and non-humidified ones will occur in any residential building in winter, resulting in mold contamination of cold wall surfaces. However, the systematic use of a fungal detector and fungal index will make a quantitative diagnosis of dampness possible, followed by the selection of a suitable preventive measure.

Keywords - Fungi, Fungal index, Fungal detector, Microclimate, Mold contamination

1. Introduction

Microclimates at fungal growth sites on construction materials always tend to be equilibrated with the prevailing environmental conditions of the materials' surfaces where fungi are growing. If a microclimate suitable for fungal growth is identified, a preventive measure can be reasonably taken. One of the authors proposed a fungal detector and fungal index (Abe, 1993a), taking into account the observation that the potential of a microclimate to grow fungi in a given environment could be accurately predictable by observing the fungal growth itself. The index quantifies the potential for fungal growth in the microclimate at examination sites. Upon measuring the index, a fungal detector, in which carefully selected sensor fungi are encapsulated, is exposed at each survey site. The spores in the detector will grow if the microclimate is suitable for such growth. The index is assessed based on the hyphal extension (a response) of the sensor fungi during the exposure period of the detector.

Eurotium herbariorum J-183 was initially selected as the sensor fungus in the fungal detector (Abe, 1993a). This fungus showed the greatest response among numerous test-fungi under the various climates surveyed (Abe, 1993b), but did not respond below 70% relative humidity (RH). Furthermore, in climates with nearly 100% RH, hyphal extension of this fungus ceased at a relatively earlier growth stage (at the stage with short hyphae less than 500 µm), and the index value could not be estimated. Thus, in order to compensate for the weak sensitivity of E. herbariorum J-183, additional sensor fungi in the detector were incorporated: Aspergillus penicillioides K-712 for less humid environments (Abe, 2010), and Alternaria alternata S-78 for extremely humid environments (Abe, 2012). The detector, encapsulating the above three sensor fungi, was reported in a previous paper (Abe, 2012).

The prevention of fungal (mold) contamination is necessary for our healthy living. Spores of fungi are always floating in the air, infiltrating buildings and attaching to walls, ceilings, floors, or items in rooms. In the case of a microclimate that has the potential to support fungal growth, fungal spores will germinate, extend hyphae, produce new spores, and finally scatter the spores, resulting a cycle of fungal contamination. Under such conditions, not only the contamination of construction materials and various items in the room, but also negative effects on our health, such as fungi-induced allergy, might develop. In our previous study, children in all homes with a fungal index >18 in their living rooms (10 out of 100 investigated homes) in summer were found to have allergies (Abe, 2012). To avoid fungal contamination and their negative effects on our health, we need to detect the microclimates that facilitate the growth of fungi and adopt suitable preventive measures before detrimental effects develop.

A prevention strategy against fungal attack for the conservation of cultural assets at a minimal cost and in a sustainable way was proposed previously (Abe and Murata, 2014), where microclimates were monitored using the fungal index, and three climatic levels influencing mold contamination were proposed to take suitable measures and prevent fungal (mold) contamination before suffering from damage caused by fungi (mold). This strategy must be applicable in our living environments.

In this report, the authors introduce the fungal index, fungal detector, and prevention strategy, and also a case study applying this strategy. The study will provide useful information on how to resolve mold contamination in our living environments, especially in cold seasons.

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2. Methods

2.1 A fungal index and fungal detector

A fungal index was determined biologically using a fungal detector (Figure 1). The index was measured using the fungus that showed the greatest response among the three sensor-fungi in the detector exposed to a test environment. The three sensor-fungi were the moderately xerophilic *E. herbariorum* J-183, strongly xerophilic *A. penicillioides* K-712, and hydrophilic *A. alternata* S-78. Using the longest hyphal length among the three sensor-fungi, the number of response units, ru, was obtained by applying a standard curve. The standard curve, which shows the relationship between the hyphal length (µm) and response units (ru), was reported previously (Abe, 2010). The value of the index was defined as the response units (ru) per exposure period (weeks).

![Figure 1 A fungal detector encapsulating three sensor-fungi.](image1)

![Figure 2 Typical growth responses to the environment.](image2)

Figure 2 shows examples of the responses of the sensor fungus Eurotium herbariorum J-183: A being “below the measurable lower limit” with no germination, B being “in a measurable range” as the case when hyphal length is ca. 500 µm, and C being “above the measurable upper limit” with a hyphal length >2,600 µm. The responses shown in Fig. 2A, 2B, and 2C, which are visible as
hyphal lengths, correspond to the growth responses of <7, 24, and >72 ru, respectively, expressed as response units. When the exposure period of fungal detectors was 4 weeks, the values of the fungal index (response units divided by exposure weeks, 4) were calculated as <1.8, 6.0, and >18.0, respectively. If the exposure periods were different, the values of the fungal index would be different. For example, if the exposure period was 8 weeks, the values of the index would be <0.9, 3.0, and >9.0, respectively.

2.2 Prevention strategy against fungal attack using a fungal index

Figure 3 shows a prevention strategy against fungal attack, which was originally proposed for the conservation of cultural assets in storerooms (Abe and Murata, 2014). The strategy consists of four stages: 1) investigation for current status assessment, 2) diagnosis, 3) taking preventive measures, and 4) investigation for Level-A confirmation. On the current status assessment, microclimates in a target room are evaluated using the fungal index. In the diagnosis, investigated environments are categorized into three levels, A, B, or C, depending on the index values, <1.8, 1.8-18, or >18, respectively. If an investigated room maintains level A continuously, the room is considered free of contamination. If the room maintains level B, fungal contamination might occur and preventive measures are necessary. If the room maintains level C, fungal contamination is unavoidable, and preventive measures should be taken promptly. After implementing the preventive measures, fungal indices are measured again for the evaluation of the employed preventive measure and confirmation of level A.
2.3 Application of the prevention strategy

A certain building for storage and exhibitions of cultural assets was selected for the application of the prevention strategy shown in Figure 3. Mold contamination was already visible and identified in a storeroom (Storeroom-I) and north stair-hall (1st and 2nd floors) of the building. Two storerooms (Storerooms-II and -III) were air-conditioned at 20 to 21°C and 55% RH throughout the year. Storeroom-I, the north stair-hall, and south entrance hall were not air-conditioned, while all of the exhibition rooms were air-conditioned during the exhibition periods in spring and autumn. Each exhibition period was ca. two months.

The current status assessment commenced on Sep. 12, 2013. The number of survey sites in the building was ten. Fungal index measurements using fungal detectors were conducted in autumn, winter, and summer. Temperatures and RH were measured and recorded at each survey site. One storeroom diagnosed as level B on the current status assessment was selected as the target room. A preventive measure was implemented in the target room at the end of 2015. After taking the preventive measure, the fungal index was measured again for its evaluation and level-A confirmation. The measurements of the temperatures and RH have been continued until the present.

3. Results and Discussion

3.1 Current status assessment and diagnosis

Table 1 shows fungal index values and the microclimate levels in the investigated building in winter and summer from 2013 to 2014. There was marked variation in the indoor environments of the building. The fungal index values differed as expected by site, and by season at the same site.

Table 1: Fungal indices in the investigated building on the current status assessment

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fungal index</td>
<td>Level</td>
</tr>
<tr>
<td>Exhibition room-I</td>
<td>&lt;1.8</td>
<td>A</td>
</tr>
<tr>
<td>Exhibition room-II</td>
<td>&lt;1.8</td>
<td>A</td>
</tr>
<tr>
<td>Exhibition room-III</td>
<td>&lt;1.8</td>
<td>A</td>
</tr>
<tr>
<td>Storeroom-I, Northeast</td>
<td>13.0</td>
<td>B</td>
</tr>
<tr>
<td>Storeroom-II, Center</td>
<td>&lt;1.8</td>
<td>A</td>
</tr>
<tr>
<td>Storeroom-III, North</td>
<td>&lt;1.8</td>
<td>A</td>
</tr>
<tr>
<td>Storeroom-III, South</td>
<td>&lt;1.8</td>
<td>A</td>
</tr>
<tr>
<td>Stair hall, 1st floor</td>
<td>11.9</td>
<td>B</td>
</tr>
<tr>
<td>Stair hall, 2nd floor</td>
<td>15.5</td>
<td>B</td>
</tr>
<tr>
<td>Outdoors, northeast of the building</td>
<td>&lt;1.8</td>
<td>A</td>
</tr>
</tbody>
</table>

In winter, a fungal index of 13.0 was recorded in storeroom-I, and the index values 11.9 and 15.5 were recorded on the 1st and 2nd floors within the north stair-hall, respectively. The microclimates at these three survey sites were found to be level B. Mold contamination was already visible at all of the three survey sites. Fungal indices at other survey sites were below the measurable lower limit (<1.8), and microclimates at these survey sites were level A without any mold contamination.

In summer, all of the fungal indices were below the measurable lower limit in the examined building. All microclimates were level A, suggesting that fungi will not grow in the building during summer. All of the fungal indices in the building were also below the measurable lower limit in autumn (fungal index: <1.4 from Sep. 12 to Oct. 24, 2013).

In contrast to the indoor cases, the outdoor climates were level A (fungal index: <1.8) in winter, and level B in summer (fungal index: 16.6) and autumn (fungal index: 3.0).
Around the area of the examined building, the outdoor climate was dry in winter and humid in summer as the typical climates of Honshu Island in Japan. In storerooms with no air-conditioners, the outdoor climates affected their microclimates. In summer, when both the outdoor temperature and RH were high, the fungal index levels in many storerooms on Honshu Island became detectable and the microclimates in these rooms were diagnosed as level-B or -C different from the target storeroom reported in this investigation (Abe, 2014).

3.2 Explanation for the fungal contamination

Table 2 shows each fungal index and room climates, temperature, RH, and humidity ratio in each room at the current status assessment in winter. The values of climatic factors were the average of those during the exposure period of the fungal detectors.

Storeroom-II, Storeroom-I, and the north stair-hall were actually built in a line from south to north on the east side of the building, that is, the entrance door of Storeroom-II was on the wall of Storeroom-I, the entrance door of Storeroom-I was on the wall of the stair hall, and the north entrance door of the building was on the north wall of the stair hall.

<table>
<thead>
<tr>
<th>Survey site</th>
<th>Fungal index (%)</th>
<th>Temperature (°C)</th>
<th>RH (%)</th>
<th>Humidity ratio (g/kg dry air)</th>
<th>Movement of moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storeroom-II</td>
<td>&lt;1.8</td>
<td>20.0</td>
<td>55.0</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Storeroom-I</td>
<td>13.0</td>
<td>10.7</td>
<td>90.7</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Stair hall, 2nd floor</td>
<td>15.8</td>
<td>9.3</td>
<td>92.7</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>Outdoors</td>
<td>&lt;1.8</td>
<td>7.0</td>
<td>62.9</td>
<td>3.9</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Room climates from Dec. 25, 2013 to Jan. 22, 2014, on the current status assessment

- a) Fungal index values were measured using fungal detectors.
- b) Humidity ratio was calculated from the average values of the measured temperature and RH during the exposure period of fungal detectors.

The climate of Storeroom-II was 20℃ and 55% RH with air-conditioning, but the temperatures of Storeroom-I and the stair hall with no air-conditioning were affected by the outdoor temperature (7℃). Eventually, the temperatures of these rooms were much lower than Storeroom-II: 10.7 ℃ in Storeroom-I and 9.3 ℃ in the stair hall.

The humidity ratio of 8.0 g/kg in Storeroom-II was the highest among these rooms. The humidity ratios of neighboring Storeroom-I, the stair hall, and outdoors were 7.2, 6.7, and 3.9 g/kg, respectively.

RH of the air differs depending on the temperature and humidity ratio. Under the condition of moisture supplied from the air-conditioner in Storeroom-II, humidity ratios of both Storeroom-I and the stair hall were not as low as outdoors. RH of these rooms changed to higher levels of more than 90%. The high RH in these rooms, as a consequence, induced the high fungal indices.

The climatic phenomena observed in these rooms indicated that the outdoor temperature certainly affected the room temperatures, while the outdoor RH did not affect the room RH so much. Moisture moves from a space with a higher humidity ratio to that with a lower humidity ratio. When there are rooms with different humidity ratios, water vapor (moisture) moves between the rooms if the doors separating the two rooms are not airtight, or wall structures between the rooms are moisture-permeable. To keep Storeroom-II at 20℃ and 55% RH with a cold and dry outdoor climate in winter, heating and humidification were inevitable. The moisture being supplied from the air-conditioner in Storeroom-II automatically increased the humidity ratio in the room. Thus, the moisture diffused from Storeroom-II to Storeroom-I, then, to the stair hall, and finally to the outdoors.

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3.3 Preventive measure

The preventive measure introduced for Storeroom-II was as follows: A dehumidification system (Amenity Technology Co., LTD, Tokyo, Japan) was installed. In this system, a dehumidifier was placed outside Storeroom-I, the target room, and connected to the room with air-ducts. The air in the room was drawn into the dehumidifier through a duct, and the dried air in the dehumidifier was returned to the room through another duct. The room, ducts, and dehumidifier were connected in a closed system. The operation of the dehumidifier was controlled based on fungal indices theoretically computed from the on-site temperature and RH measured in the target room (near the air-duct drawing the room air into the dehumidifier). The dehumidifier was operated only when the computed fungal index changed from a negative (zero) to positive value. For the computation of the index values using the on-site temperatures and RH, the computation software Eur.v2 (Institute of Environmental Biology) (Abe, 2006a, b) was used.

3.4 Investigation for level-A confirmation

Table 3 shows fungal indices in the investigated building in winter after taking the preventive measure.

All fungal-index values at survey sites in the building were below the detectable lower limit (<1.4). Also, 10 additional survey sites in the target room (Storeroom-I) were below the detectable lower limit. All rooms in the building were concluded to be Level A. Fungal index values indicated that the installed preventive measure operated sufficiently to inhibit fungal growth.

It was expected that all microclimates not only in Storeroom-I but also in the stair hall would change to level A. This proved that the cause of the high fungal indices in the building on the current status assessment was due to the movement of moisture from Storeroom-II to Storeroom-I and from Storeroom-I to the stair hall.

Table 3: Fungal indices in the investigated building after taking the preventive measure

<table>
<thead>
<tr>
<th>Location of each survey site</th>
<th>Fungal index</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhibition room-I</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Exhibition room-II</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Exhibition room-III</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Storeroom-I, Northeast</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Storeroom-II, Center</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Storeroom-III, North</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Storeroom-III, South</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Stair hall, 1st floor</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Stair hall, 2nd floor</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
<tr>
<td>Outdoors, northeast of the building</td>
<td>&lt;1.4</td>
<td>A</td>
</tr>
</tbody>
</table>

Table 4 shows the temperature, RH, and humidity ratio of each room in winter after adopting the preventive measure. Both humidity ratios in Storeroom-I and the stair hall were 5.5 g/kg. The estimated fungal indices from temperatures and RH were 0.0 in Storeroom-I and 0.2 on the 2nd floor of the stair hall.
Table 4: Room climates from Jan. 16 to Feb. 19, 2016, after taking the preventive measure

<table>
<thead>
<tr>
<th>Survey site</th>
<th>Temperature (ºC)</th>
<th>RH (%)</th>
<th>Humidity ratio (g/kg dry air)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storeroom-II</td>
<td>20.7</td>
<td>56.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Storeroom-I</td>
<td>13.6</td>
<td>57.4</td>
<td>5.5</td>
</tr>
<tr>
<td>Stair hall, 2nd floor</td>
<td>10.3</td>
<td>71.1</td>
<td>5.5</td>
</tr>
<tr>
<td>Outdoors (pilot)</td>
<td>7.4</td>
<td>57.3</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Humidity ratio was calculated from the measured temperature and RH during the exposure period of fungal detectors.

The dehumidification in Storeroom-I in winter avoided an increase in the amount of water vapor not only in Storeroom-I but also in the stair hall. RH and the humidity ratios in these rooms were lower than those on the current status assessment, and, thus, fungal growth in these rooms could be prevented.

Room conditions with additional sources of moisture like Storeroom-I are typical cases in usual buildings in winter. The use of unflued gas heaters and heat pump heaters were compared with those in New Zealand in a cold season, revealing that the use of unflued gas heaters, which was an additional source of moisture, markedly increased the capacity to grow fungi on wall surfaces (Boulic et al., 2015).

Dampness, which is the traditional term in the field of construction and has the same meaning as moist conditions in buildings, is associated with adverse health effects (WHO, 2009). Dampness accelerates fungal growth and causes visible mold growth. Mold is harmful to the health of people. Fungi (mold) are known to have the potential to cause allergies, including sneezing, a running nose, red eyes and skin rashes, and asthma. Fungal index values reflected the conditions of dampness in buildings. Thus, the systematic use of the index will provide practically useful information to avoid ill-effects caused by dampness. The prevention strategy (Figure 3) is applicable to any building including residential homes. The measurement of the fungal indices using fungal detectors directly leads to the identification and prediction of sites where fungi will grow and mold contamination will appear. Also, the device to estimate the fungal index using the on-site temperature and RH, the details of which are described below, provides quick and useful information on our living spaces, especially to detect seasons when fungi will grow and visible mold will appear.

Recently, devices, which can measure the temperature and RH at a survey site for quick estimation of the fungal index, were developed and became available on a commercial basis. Those are Wireless Fungal Logger LR8520 (Hioki E. E. Corporation, Nagano, Japan) and Kabi-toronics (Amenity-technology Co., Ltd, Tokyo, Japan). They might be helpful to identify the sites and seasons where mold contamination is unavoidable, and helpful to evaluate preventive measures.

Figure 4 shows the computed fungal index in Storeroom-I. A and B indicate the index in the current status assessment from 2013 to 2014, and that before and after implementing the preventive measure from 2015 to 2016.

On the current status assessment, the computed fungal index based on the measured temperatures and RH became positive and increased from the middle of November (Figure 4A).

During the period before implementing the preventive measure in 2015, the computed fungal index varied, just as that in 2013. After adopting the preventive measure on Dec. 26, 2015, the computed fungal index dropped almost immediately.

The seasonal change of the computed fungal index supported the measurements of fungal index using fungal detectors. Both fungal indices showed that the season experiencing mold contamina-
tion in the room was winter, and that the dehumidification system used as the preventive measure was effective.

Figure 4 Seasonal changes of computed fungal index in Storeroom-I. A: on the current status assessment. B: before and after implementing the preventive measure

4. Conclusions

This case study applied a prevention strategy against fungal attack, in which a fungal index that assesses the conditions critical for fungal growth was used for evaluation of the microclimate, suggested that this strategy would be applicable to any building of concern.

The effectiveness of the dehumidification system, in which the computed fungal index based on the on-site temperature and RH was used for the operation, was verified through fungal index measurements using fungal detectors.

Room condition with an additional source of moisture like the target room are typical cases in usual buildings; some rooms in a building were warmed and humidified but other rooms were not, and moisture in warm and humidified spaces moved to cold and non-humidified spaces, resulting in mold contamination of cold wall surfaces in winter.

The approach to inhibit fungal contamination described in this paper could be applicable in general buildings. The fungal index measured using the fungal detector will be helpful in the assessment, and the fungal index based on the on-site temperature and RH will be helpful in the control of indoor environments. Such fungal indices should be available to evaluate remediation in homes, schools, hospitals, storerooms, and other buildings.

5. Acknowledgement

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6. References


Development and assessment of representative building performance simulation models for Australian residential dwellings

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Abstract

Purpose / Context - The characterisation of the residential building stock existing in Australia in terms of attributes relevant to energy performance is increasingly an important task for planning and policy purposes. There is a lack of information and documentation on the energy performance characteristics of the existing residential stock in Australia, particularly those constructed prior to the introduction of building efficiency regulations; approximately 85% of the 9 million dwellings in Australia (ABS, 2001, 2011). This lack of information creates a significant barrier for studies which have attempted to develop representative energy simulation models for existing buildings.

Methodology / Approach - Statistical review was undertaken on the Australian residential sector, focussed on buildings constructed between 1970 to 2011, for the purpose of developing representative building simulation models to aid in the quantification of the potential for energy efficiency upgrades. Taguchi and ANOVA methods were used to produce a reduced number of models that incorporated significant parameters for the determination of the energy performance. Differential Sensitivity Analysis (DSA) was then undertaken on a single model to quantify the effect of design parameters on the amount of energy needed for maintaining indoor conditions within a comfortable range.

Results – The Taguchi and ANOVA analysis identified floor types, floor area, climate, level of ceiling insulation and wall materials as the most important attributes to be considered in the development of representative simulation models. DSA of design parameters on an example representative model developed in this study showed how the parameters with the greatest influence on building energy consumption were airtightness, air conditioning system coefficient of performance, window-to-wall ratio, level of ceiling insulation and glazing SHGC and type.

Key Findings / Implications – This study showed the typical Australian residential stock characteristics and potential energy efficacy upgrade strategies. This work has implications of defining the representative dwelling types for current stock, as well as performance assessment of sample dwelling model with investigation of potential energy retrofitting parameters to address the climate change challenge.

Originality - The paper provides rather informative overview of Australian residential building stock, structured new contribution in order to defining the referenced building and assessing the effectiveness of specific design parameters towards energy demand loads in dwellings.

Keywords Representative dwelling model, Energy Efficiency, Differential sensitivity analysis

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1. Introduction

Numerous previous studies have shown the necessity of making improvements to the energy efficiency of the existing building stock in order to rapidly reduce greenhouse gas emissions (IPCC, 2014; Stern, 2006). However, the selection of the optimal retrofitting strategy for dwellings is a complex task that involves significant knowledge and expertise (Ma et al., 2012). Each dwelling in an existing stock will have a unique combination of form, fabric and operation which will influence the energy performance and optimal upgrade strategies. Individual assessment of a dwellings performance is a time-consuming and costly exercise. Many studies (e.g. Chidiac et al., 2011; Sehar et al., 2012) have employed various stock aggregation techniques to simplify the assessment process. ‘Reference’ or ‘archetypal’ buildings have been employed previously as a tool to provide generic energy efficiency assessments of existing building stocks. The purpose of a reference building is to represent the energy performance of a typical building in a segment of the building stock (Theodoridou et al., 2011; Korolija et al., 2013). Whilst there is significant variation in the approaches taken by international studies to define representative residential building models (Filogamo et al., 2014; Famuyibo et al., 2012), some consistent frameworks do exist; for example, the TABULA project in Europe (Oroulta et al., 2014). A discussion of the process and criteria used to segment the building stock into representative typologies for the studies reviewed above, and others, can be found in (Daly et al., 2016).

The aim of the research presented in this paper was to develop a set of representative dwellings for residential buildings constructed between 1970 and 2011 in Australia, for use in building performance simulation. The research further aimed to identify significant parameters which impact heating and cooling energy requirements to aid energy retrofitting decision-making. Significantly less research has been undertaken in characterising the Australian housing stock than in other regions globally. There are several factors that make residential building stock studies in Australia particularly difficult, related to both to the stock characteristics, and the accessibility of data regarding the building stock. Age, which has often been used as a primary segmentation criterion for building stocks in other nations, does not have a strong relationship to building construction techniques and thermal performance in Australia, mostly because the National Construction Code in Australia has only mandated minimum thermal performance since 2003.

2. Methodology

This paper first provides a statistical review on the characteristics of the dwellings under consideration. Simple building simulation models developed on the basis of this review were then analysed using the Taguchi method and an Analysis of Variance (ANOVA) process, in order to identify the key building attributes that influence heating and cooling requirements. The key attributes were then used for defining a reduced number of representative building models for a substantial sub-set of the existing building stock. Finally, one example representative model was analysed using Differential Sensitivity Analysis to quantify the effect of design parameters on the amount of energy needed to maintain indoor comfort conditions within an acceptable range.

2.1 Review of Australian Bureau of Statistics (ABS) Housing Data

In this study, available data from the ABS datasets, in conjunction with other relevant resources, were collected and analysed to determine the most common characteristics of the Australian building stock from 1970 to 2011. Previous studies (Wong, 2013; Ren et al., 2012; Warren-Myers et al., 2012) have used ABS data to understand the relationships between building typology and sustainable renovation outcomes in Australia. A major barrier in the use of ABS data is the inability to access data at the property address level, due to privacy concerns. This prevents the consideration of cross-correlation and clusters of multiple attributes for particular buildings. Therefore, for the purposes of stock level performance modelling based on ABS data, a model which represents each unique set of potential building configurations should be created to
represent the full range of construction types. However, this process would result in a large number of building models. By recognizing that certain characteristics will have less significant effects on performance, the total number of representative simulation models can be reduced. In order to reduce the total number of simulation models and to prioritise the attributes for representative models, principles from the Taguchi and ANOVA methods have been used.

The process of converting ABS data into the selected construction types required several assumptions:

- A basic three bedroom, timber frame detached house plan from NSW government housing provider, was assumed for all building configurations (Thomas, 2011).
- The floor plan was adjusted to give a window-to-wall ratio (WWR) of 15%, and then perturbed to create three floor areas (78 m², 122 m² and 156 m²).
- The generic plan was modified to reflect the full range of characteristics shown in Table 1: Residential building characteristics and assumptions used for baseline representative models and sensitivity analysis. Material thermal properties are from (AIRAH, 2013).

- , and modelled in three climates of New South Wales in Australia (Climate zone 5, 6 & 7).
- The NatHERS indoor comfort conditions, which vary according to climate zone, time of day, and indoor space type, were utilised for this study (NatHERS, 2012). The total heating and cooling demand to keep the internal spaces within the comfortable range for all hours was the output measure considered for this work. This was calculated using the EnergyPlus simulation software.

<table>
<thead>
<tr>
<th>Model input factor</th>
<th>Model variable input levels</th>
<th>Model constant input levels</th>
<th>R-Value (m²K/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Detached</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>External wall</td>
<td>Brick veneer</td>
<td>-</td>
<td>0.534</td>
</tr>
<tr>
<td></td>
<td>Double brick</td>
<td>-</td>
<td>0.679</td>
</tr>
<tr>
<td></td>
<td>Fibro</td>
<td>-</td>
<td>0.437</td>
</tr>
<tr>
<td>Internal wall</td>
<td>Gypsum board</td>
<td>-</td>
<td>0.538</td>
</tr>
<tr>
<td>Floor</td>
<td>Slab on Ground</td>
<td>-</td>
<td>0.287</td>
</tr>
<tr>
<td></td>
<td>Suspended Timber</td>
<td>-</td>
<td>0.439</td>
</tr>
<tr>
<td>Roof</td>
<td>Steel sheet</td>
<td>-</td>
<td>0.206</td>
</tr>
<tr>
<td></td>
<td>Clay Tile</td>
<td>-</td>
<td>0.370</td>
</tr>
<tr>
<td>Ceiling</td>
<td>Gypsum board no insulation</td>
<td>-</td>
<td>0.347</td>
</tr>
<tr>
<td></td>
<td>Gypsum board With poor insulation</td>
<td>-</td>
<td>1.34</td>
</tr>
<tr>
<td>Floor area</td>
<td>78 m²-122 m²-156m²</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bedrooms</td>
<td>Two-Three</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Airtightness¹</td>
<td>Poor-Medium</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Orientation</td>
<td>North-East-South West</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Window to Wall ratio</td>
<td>-</td>
<td>15%</td>
<td>-</td>
</tr>
<tr>
<td>Glazing</td>
<td>-</td>
<td>Single glazed</td>
<td>-</td>
</tr>
<tr>
<td>NatHERS Climates</td>
<td>5/6/7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Thermostat setting</td>
<td>-</td>
<td>Winter 20°C- summer 24.5°C</td>
<td>-</td>
</tr>
<tr>
<td>COP</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Occupants</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Energy supply</td>
<td>-</td>
<td>Electricity</td>
<td>-</td>
</tr>
</tbody>
</table>

1: Airtightness is defined by settings correspond to the crack templates as Poor and Medium. In this case every surface in the model has a crack and its size (characterised by flow coefficient and exponent) specified by Designbuilder cracks database (DesignBuilder, 2015).
2.2 Taguchi design of the simulation models

DesignBuilder, a graphical user interface for the EnergyPlus simulation engine, was employed for the simulations in this paper. The Taguchi mix-mode design method was used to reduce the required model runs. This method uses a fractional factorial test design, termed Orthogonal Arrays (OA) (Yang and Tarng, 1998), to reduce the number of simulations required for exploring the influence of building model attributes in the representative models. The selection of a suitable OA depends on the number of attributes and their levels, i.e. the number of building parameters and their possible values. To test the sensitivity of the nine variable design parameters of Table 1, with 3 and 2 levels of possible values, a traditional full factorial design would require 2592 model runs, while with the Taguchi mix-mode design the required numbers of model runs was only 36. The variable attributes and levels considered for this study are given in Table 1.

Using the Taguchi method allowed factors to be weighted equally and assessed independently of all other factors (Minitab Statistical Software Support, 2016). The Taguchi method applies the signal-to-noise ratio (S/N), a measure of robustness, to minimize the effect of noise and optimize the process performance (Zahraee et al., 2015). In this study the delta S/N ratio; that is the difference between the maximum and minimum average signal-to-noise ratios for the attributes level, was used to determine the relative similarity of the building attribute levels. ANOVA was also performed in order to determine the contribution of each attribute to the total model energy demand. Decision about the significance of attributes or their effect was taken based on the p-value (p-value>0.05) and the variance of effect for parameters of every attributes based on delta S/N ratio (delta S/N<2).

2.3 Differential sensitivity analysis

To understand the influence of different design parameters on dwelling energy load demands, it is also useful to consider the relative influence of these input parameters. In this study differential sensitivity analysis was undertaken, and the non-dimensional influence coefficient was calculated as a comparison index. Previous studies identified non-dimensional influence coefficients as a useful index for building sensitivity studies (Thomas, 2011; Bertagnolio S, 2012; Daly et al., 2014).

The base-case and parametric ranges considered in this analysis are shown in Table 2. The base-case design parameters and the range of variation were determined with reference to: Section J of the Building Code of Australia (ABCBS, 2015); the default values included in AIRAH guides (AIRAH, 2013); market products (knauf insulation, 2016); and previously published input values from Australian studies (BRANZ Ltd, 2014; Tony Isaacs Consulting, 2009; Belusko and Timothy, 2011; Department of Industry, 2013). The model was first simulated using the base-case inputs, and then the parameters of interest were varied one at a time, while holding all the other parameters constant, for three climate zones in NSW. The predicted total building energy demand load for each case, and the average influence coefficient across each parameter range were calculated.
Table 2: Representative model inputs and parametric range for sensitivity analysis

<table>
<thead>
<tr>
<th>Parameters of interest</th>
<th>Representative model inputs</th>
<th>Sensitivity analysis ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall R-value (m²K/W)</td>
<td>0.5</td>
<td>0.5 - 6.5</td>
</tr>
<tr>
<td>Floor R-value (m²K/W)</td>
<td>0.4</td>
<td>0.4 - 4.4</td>
</tr>
<tr>
<td>Roof R-value (m²K/W)</td>
<td>0.4</td>
<td>0.4 - 4.4</td>
</tr>
<tr>
<td>Ceiling R-value (m²K/W)</td>
<td>1.3</td>
<td>0.3 - 6.3</td>
</tr>
<tr>
<td>Internal wall R-value (m²K/W)</td>
<td>0.5</td>
<td>0.5 - 3.5</td>
</tr>
<tr>
<td>Glazing types U-value (W/m²K)</td>
<td>5.8</td>
<td>1.7 – 5.8</td>
</tr>
<tr>
<td>Glazing SHGC</td>
<td>0.8</td>
<td>0.2 - 0.8</td>
</tr>
<tr>
<td>Window frame U-value (W/m²K)</td>
<td>3.6</td>
<td>3.5 - 5.9</td>
</tr>
<tr>
<td>Airtightness</td>
<td>Poor</td>
<td>Very Poor- Excellent</td>
</tr>
<tr>
<td>Occupant number</td>
<td>1</td>
<td>0 - 4</td>
</tr>
<tr>
<td>Openable window area (%)</td>
<td>50</td>
<td>25 - 75</td>
</tr>
<tr>
<td>South eaves (m)</td>
<td>0.4</td>
<td>0 - 4.5</td>
</tr>
<tr>
<td>East-west eaves (m)</td>
<td>0.1</td>
<td>0.1 - 1</td>
</tr>
<tr>
<td>Window awning (m)</td>
<td>0.1</td>
<td>0.1 - 1</td>
</tr>
<tr>
<td>WWR (%)</td>
<td>15</td>
<td>15 - 75</td>
</tr>
<tr>
<td>COP</td>
<td>1</td>
<td>1 - 5</td>
</tr>
</tbody>
</table>

3. Results and Discussion

3.1 Statistical Review of ABS Housing characteristics

Data from the Australian Bureau of Statistics was used to consider the stock characteristics for buildings constructed from 1976 to 2011. In order to leverage the limited data available, the results from numerous ABS surveys and census, which collected different information, were collated and analysed.

Figure presents summary data from a range of ABS surveys undertaken between 1976 and 2011; the table shows the average value where data is taken from more than one survey. Data for dwelling structure, number of bedrooms, and wall materials were taken from the 1976 and 1986 Census of Population and Housing (ABS, 1976,1986), the 1994 and 1999 Australian Housing Survey (ABS, 1999) and the 2011 Environmental Issues: Energy Use and Conservation survey (ABS, 2011). Data for roof materials is gathered from 1994 and 1999 Australian Housing Survey (ABS, 1999), for Insulation from the 1994,1999 and 2011 Environmental Issues: Energy Use and Conservation surveys (ABS, 2008; ABS, 2011).

On average, 70% of the housing stock in both Australia and NSW are occupied detached houses or detached bungalows, with two and three bedrooms, as shown in Figure 1. (ABS (2005)) reported that the average floor area of new residential buildings in Australia has increased by 37.4% (from 149.7 m² to 205.7 m²) between 1984-95 and 2002-03.

In Australia, dwellings are made from a variety of materials, brick veneer (22%) and double brick (38%) are the most common wall materials. Tiles (62%) and steel (33%) are the most typical roofing materials. The vast majority of the insulated buildings have the insulation placed in ceiling (98%) and the type of insulation is usually batts or fibreglass (62%). The minimum height of ceilings is 2.4m for habitable areas (ABCB,1996) and single glazed windows are the most common window types (ABS, 2008). Whilst there are significant shortcoming in the available data, the airtightness of Australian homes has been shown to be below the expected standard (Biggs et al., 1986) and may be two to four times as draughty as North American or European Buildings (ZCA, 2013). Whilst the ABS provided no survey data in relation to floor types, (DEHWA, 2008) stated that a significant number of Australian dwellings used concrete slabs and suspended timber for flooring.
3.2 Design of Experiment (Taguchi) and ANOVA methods analysis

For the purposes of developing representative simulation models based on the ABS data review, the sets of the most common attribute combinations, as shown in Table 1, (see variable parameters), are selected to represent the majority of available construction types. To ensure accurate analysis (Sadeghifam et al., 2015), important variables such as size, orientation and climatic data had been considered in design attributes.

In order to reduce the total number of required simulation models and cover at the same time most possible combinations of building stock characteristics, the DOE (Taguchi) method experimental plan was used to prioritise the variable building attributes of Table 1 for representative models. Simulation models were created for the different combinations of the properties that are shown in Table 3. This table displays the summary results of the first iteration of Taguchi mix-mode method with five attributes with 2 levels of variation and four attributes with 3 levels of variation. Each model run had a different combination of design attributes level; the predicted total heating and cooling energy requirements for each configuration in Table 3 is shown in “Total energy” column.

The results of the ANOVA from the Taguchi orders analysis with the delta S/N ratio for the first trial are presented in Table 4. The attributes that most influence the total heating and cooling demand on the modelled dwellings are shown in order of relative contribution. Approximately 90% of the thermal energy demand of the typical building model is directly associated with the floor types, building size, climate, level of ceiling insulation and wall materials attributes. The delta S/N ratio indicates very low variance in the influence of the roof type, number of bedrooms, orientation and airtightness factors levels. This suggests that variables of these attributes have similar effects on response and could potentially be accumulated into a single variable for future works.

To test the effect of ignoring low impact attributes (i.e. when p-value > 0.05) with low variance (delta S/N<2) and rating them as constant for future representative models, four trials for the factors that had the lowest impact (roof types, number of bedrooms, orientation and airtightness) had been simulated with the removal of one of the insignificant factors in each trial. This strategy allowed any errors to be observed. The percentage contribution of attributes remaining after the elimination of insignificant factors showed that the removal of insignificant factors has a small impact on the remaining factors, in all cases less than 2% difference when comparing with the results of Table 4.
This process effectively reduced the number of attributes requiring further investigation, and allowed the creation of twelve representative simulation models for the retrofit analysis stage which should be modelled by taking into account the building size and the local climate, namely:

- Type A. Brick veneer wall with suspended timber floor with and without ceiling insulation.
- Type B. Brick veneer wall with slab on ground floor with and without ceiling insulation.
- Type C. Double brick wall with suspended timber floor with and without ceiling insulation.
- Type D. Double brick wall with slab on ground floor with and without ceiling insulation.
- Type E. Lightweight wall with suspended timber floor with and without ceiling insulation.
- Type F. Lightweight wall with slab on ground floor with and without ceiling insulation.

3.3 Differential sensitivity analysis of example reference building model

The type A of representative building model with insulation defined in the previous section was then analysed to investigate the relative impact of different energy efficient design parameters on predicted energy consumption. To evaluate the relative influence of each parameter under consideration, the absolute influence coefficient was calculated, as described in 2.3. The calculated influence coefficients are given in Table 5. For all locations, the four most influential parameters were found to be: airtightness, COP of air conditioning system (modelled as an ideal system), WWR and level of ceiling insulation. Airtightness and COP are the two most influential for all locations, but the rank of all other parameters varied depending on location.

When combining the parameters that result to the highest thermal energy needs, we could notice that the thermal energy requirements are more than double of those calculated when combining the parameters that result to the lowest calculated thermal needs (Figure 2). It should be noted the COP was assumed as 1 to have better comparison scale between all scenarios.
Figure 1: Range of predicted thermal energy use intensity of representative dwellings, type A model, using the simulated range of inputs from Table 2.

Table 5: Influence coefficients of input parameters for type A representative dwelling simulation models

<table>
<thead>
<tr>
<th>Parameters of interest</th>
<th>Climate 5 Rank</th>
<th>Climate 6 Rank</th>
<th>Climate 7 Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airtightness</td>
<td>0.4006</td>
<td>0.3577</td>
<td>0.4382</td>
</tr>
<tr>
<td>COP</td>
<td>0.2667</td>
<td>0.2667</td>
<td>0.2667</td>
</tr>
<tr>
<td>WWR</td>
<td>0.1498</td>
<td>0.1443</td>
<td>0.1095</td>
</tr>
<tr>
<td>Ceiling insulation</td>
<td>0.116</td>
<td>0.1321</td>
<td>0.1213</td>
</tr>
<tr>
<td>Glazing (SHGC)</td>
<td>0.0869</td>
<td>0.0634</td>
<td>0.0332</td>
</tr>
<tr>
<td>Glazing types</td>
<td>0.0622</td>
<td>0.065</td>
<td>0.0619</td>
</tr>
<tr>
<td>Floor insulation</td>
<td>0.0437</td>
<td>0.0472</td>
<td>0.0445</td>
</tr>
<tr>
<td>Openable Window</td>
<td>0.0202</td>
<td>0.01</td>
<td>0.0044</td>
</tr>
<tr>
<td>Wall insulation</td>
<td>0.0108</td>
<td>0.011</td>
<td>0.0149</td>
</tr>
<tr>
<td>Number of Occupants</td>
<td>0.0074</td>
<td>0.0085</td>
<td>0.0097</td>
</tr>
<tr>
<td>Roof insulation</td>
<td>0.007</td>
<td>0.0077</td>
<td>0.0066</td>
</tr>
<tr>
<td>Window Frame</td>
<td>0.0055</td>
<td>0.0045</td>
<td>0.0036</td>
</tr>
<tr>
<td>East-west Awning</td>
<td>0.0034</td>
<td>0.0028</td>
<td>0.0019</td>
</tr>
<tr>
<td>South Eaves</td>
<td>0.0033</td>
<td>0.0024</td>
<td>0.0047</td>
</tr>
<tr>
<td>Internal partition</td>
<td>0.0018</td>
<td>0.0022</td>
<td>0.0024</td>
</tr>
<tr>
<td>East-west Eaves</td>
<td>0.0004</td>
<td>0.0004</td>
<td>0.0009</td>
</tr>
<tr>
<td>North-South Awning</td>
<td>0.0002</td>
<td>0.0002</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

4. Discussion and limitations

The use of statistical data to define dwelling models that can represent a significant proportion of buildings in a stock can be a relatively fast and simple method to quantify the energy savings when upgrading the existing housing stock. However, this approach may not offer precise results or insights into the particular challenges and possibilities for individual buildings. The accuracy of the method depends firstly on the existence of a significant data resource to ensure the defined models are representative of the different construction configurations likely to occur in a stock. In this work, there was important limitation in the data available through the Australian Bureau of Statistics. Therefore, the influence of the main construction characteristics on predicted energy consumption were explored, in order to develop representative models which cover a large proportion of the detached houses within the stock and have substantially different energy performance characteristics. However, the distribution of the representative homes within the considered stock was not able to be determined with the currently available ABS data. Further, the role of occupant behaviour was not considered in this study. Occupancy was represented as a single occupant constantly, and internal gains, for instance the use of domestic equipment, water heating, and lighting were not considered in this study. In actual buildings these patterns can vary, and can often affect whether the benefits from building upgrades are realised fully.

In using Taguchi and ANOVA methods, there is an “Error”, which refers to errors caused by uncontrollable factors (noise) that are not included in the experiment, and the experimental error. Shahavi et al. (2015) advises the value should be less than 50% to be reliable. The errors of all trials in this paper were less than 10%, which suggests that nearly all important and effective factors have been considered, and that errors in developing the Taguchi experiments are not significant. Confirmation test, which is the optimal combination of process parameters and their levels, also were run in order to verify the result of minimum thermal energy case expectation. Taguchi design was used primarily to study the main effect of building attributes on the value of
the annual thermal energy requirements, and possible interactions between attributes were neglected.

The use of non-dimensional influence coefficient from DSA will need to be further investigated in future work. DSA provides information about the sensitivity of a parameter at a single point in the parametric space, and does not provide insight into areas outside the parametric range of a given set of simulations, unless the data can be linearly extrapolated. In this study, a linear relationship between the range of the parameters and the outputs of DSA has been assumed, however the effect of this assumption should also be tested while extending this study in the future. DSA also does not allow the interaction between parameters to be assessed. However, despite the potential for misinterpretation, review of previous literature indicates that influence coefficients is the useful measure available for use in building energy sensitivity analysis comparisons (Daly et al., 2014; Simm et al., 2011).

5. Conclusion

A methodology for developing typical representative dwelling models of the Australian building stock, with a particular focus on the State of NSW was presented. The most prevalent building envelope design parameters for retrofitting were identified after reviewing ABS data. Building simulation, Taguchi and ANOVA methods were applied for evaluating the influence of typical characteristics on dwelling heating and cooling loads, and to filter out those characteristics that have an insignificant effect on the calculated annual thermal energy requirement. This process led to the development of a series of representative simulation models for a large part of the housing stock in NSW. Building simulation was also combined with the DSA method for one of the representative building models in order to demonstrate a method for identifying how sensitive the predictions of thermal loads are on a number of building parameters. The result showed that floor type, building size, climate, level of ceiling insulation and wall materials have a substantial contribution to dwelling performance, and should be explicitly specified in models that represent the stock of existing buildings in Australia. Having fixed the previous parameters for representative models (floor type, building size, etc.) and based on the sensitivity analysis with DSA from the range of values described in Table 2, the most influential parameters on the annual thermal energy requirements were airtightness, COP of the heating/cooling system, WWR, level of ceiling insulation, and SHGC.

6. References

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The role of simulation in improving the thermal comfort and energy performance of existing aged care facilities

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Abstract

Context - Minimum thermal performance standards for residential building envelopes have been increasing in many countries for several decades, addressing concerns about occupant comfort, operational costs and greenhouse gas emissions. Simulation tools play a role in assessing the space heating/cooling load of new buildings and for evaluating options for systematic retrofitting of existing dwellings. The purpose of this study was to examine the role and limitations of simulation in informing potential retrofit activities for an aged care facility.

Methodology - The study utilised a 110 apartment Aged Care facility as a case study. Two typical apartments from this case study were selected for indepth study. A simulation tool (BersPro 4.1) utilised for regulatory purposes in Australia for new construction, was utilised to simulate existing building thermal performance and expected performance of three retrofit actions.

Results – The thermal performance of the existing buildings meet regulatory requirements at the time of construction (pre 2006) but are 70% higher than current regulations. Enhanced air movement, through the installation of ceiling fans, showed the largest reduction in space heating/cooling load (52.5%), followed by ceiling insulation (22.6%) and double glazing (4.3%).

Key Findings – The simulations identified differences in the heating/cooling loads of sleeping and living spaces within the apartments. The benefits of the proposed retrofit options, however, are questionable because of practical limitations of the existing building and the mismatch between these occupants and occupancy assumptions made in the simulation tool.

Originality - This paper applies a simulation tool to an examination of retrofit options for existing senior housing. It reveals limitations in relying on simulation tools for this purpose unless other issues, such as the uniqueness of this particular demographic, are equally considered.

Keywords - aged care, building envelope, retrofit, senior housing, simulation tools, thermal comfort
1. Introduction

The building sector is a significant contributor to greenhouse gas emissions and the increasing stringency of energy performance requirements for new construction has been a policy focus of many countries for decades. Improving the energy performance of existing buildings has been a more recent focus, as a climate change mitigation and adaptation strategy. Retrofitting is clearly in the regulatory agenda of some regions, as exemplified in the European Energy Performance of Buildings Directive (EPBD2012) that sets clear guidelines and goals for retrofitting of the existing building stock. Australia, however, has not set energy efficiency goals for existing building stock.

Recent research underscores the importance that simulation software plays in informed decision making, evaluating options for new build or refurbishment of existing buildings from both technical and economic perspectives (Leinartas & Stephens, 2015; Ramirez-Villegas, Eriksson, & Olofsson, 2016; Suarez & Fernandez-Aguera, 2015). Some research has highlighted limitations of using simulation, such as whether occupant behaviour should be / is included in the model (Wei, Hassan, Firth, & Fouchal, 2016) and the inability of existing tools to evaluate multiple criteria beyond purely functional aspects (Chantrelle, Lahmidi, Keilholz, El Mankibi, & Pierre, 2011). Other research suggests that energy policies may fall short of their expected outcomes because of the complex and dynamic relationships between energy efficiency and “the myriad of thermal experiences and preferences” of occupants and their socio-cultural and individual contexts (Tweed, Humes, & Zapara-Lancaster, 2015). In particular these authors highlight the tendency for energy policy to assume a uniform thermal environment and to overlook the specific requirements of different demographics, such as the elderly.

It is well known that older people are more prone to temperature related illness due to reduced physiological capacity to manage temperatures changes as we age (Roelofsen, 2015), as evidenced by numerous studies on issues such as the mortality and morbidity rates associated with extreme weather events and/or fuel poverty (Aström, Forsberg, & Rocklov, 2011; Dalip, Phillips, Jelinek, & Welland, 2015; Howden-Chapman et al., 2012; Roelofsen, 2015; Vandentorren et al., 2006). Cognitive decline and loss of mobility can also impact on adaptive responses as can income, environmental concerns (e.g. acoustics, security), personal motivations (e.g. frugality, pride, independence) and life experiences (e.g. of rich and varied thermal environments) (Tweed et al., 2015). Very little research examines the links between health, indoor environments and energy efficient housing for the aged, despite the higher exposure rate elderly people have to the indoor environment of their residence (Ahrentzen, Erikson, & Fonseca, 2015; Mendes et al., 2013).

Affordable and appropriate housing plays a fundamental role in assuring quality of life and active and independent living, which can result in a lessening of demand on health and aged care systems (Oswald et al., 2007; World Health Organisation, 2002). The increasing evidence linking older people’s resilience to temperature extremes and the characteristics of buildings they occupy (Loughnan, Carroll, & Tapper, 2015; Vandentorren et al., 2006) would indicate the importance of considering these aspects in any refurbishment activities relating to this demographic. The purpose of this study was to examine the role and limitations of simulation in informing potential retrofit activities for an aged care facility.

2. Background

2.1 Thermal performance requirements of Australian housing

The thermal performance standards for Australian housing are communicated in the National Construction Code (NCC) published by the Australian Building Codes Board (ABCB), an advisory board to the federal and state governments. The regulations are adopted by, and administered at, a State level, and compliance with regulations can be demonstrated through the use of computer based simulation tools approved and accredited through the Nationwide House Energy Rating Scheme.
The NatHERS tool ranks the thermal envelope of a building by the sum of the heating and cooling energy loads to maintain conditioned areas (bedrooms and main living rooms) to predetermined comfort level protocols and occupant behaviour protocols incorporated in the software. The generated ‘star rating’ is correlated to megajoules of energy required for space heating or cooling per square meter of conditioned floor area per year, and minimum performance standards have increased over time (Table 1) (Nationwide House Energy Rating Scheme, 2014).

### Table 1: Energy rating (space heating/cooling loads) for housing in Brisbane over time

<table>
<thead>
<tr>
<th>Star rating</th>
<th>1</th>
<th>3.5</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>MJ/m²·yr</td>
<td>203</td>
<td>83-72</td>
<td>71-56</td>
<td>55-44</td>
<td>43-35</td>
<td>34-26</td>
<td>25-18</td>
<td>17-11</td>
<td>10</td>
</tr>
</tbody>
</table>

| Regulation standard | (nil) | 2003 | 2006 | 2010 |

### 2.2 The case study context

The Aged Care Community is located in Brisbane’s southern suburbs (Lat. 27.6°S; Long. 153°E) and is in Australia’s east-coast sub-tropical climate zone (Australian Building Codes Board). This climate is characterized by warm, humid summers and mild winters (Table 2).

### Table 2: Key climatic parameters for Brisbane (derived from www.bom.gov.au)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Winter (Jun, Jul, Aug)</th>
<th>Spring (Sep, Oct, Nov)</th>
<th>Summer (Dec, Jan, Feb)</th>
<th>Autumn (Mar, Apr, May)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{max-mean}}$</td>
<td>21.3°C</td>
<td>25.5°C</td>
<td>28.7°C</td>
<td>25.8°C</td>
</tr>
<tr>
<td>$T_{\text{min-mean}}$</td>
<td>9.8°C</td>
<td>15.6°C</td>
<td>20.9°C</td>
<td>19.6°C</td>
</tr>
<tr>
<td>RH_{9am}</td>
<td>65%</td>
<td>60%</td>
<td>66%</td>
<td>67.7%</td>
</tr>
<tr>
<td>RH_{3pm}</td>
<td>51.7%</td>
<td>58%</td>
<td>62.7%</td>
<td>58.3%</td>
</tr>
<tr>
<td>Solar radiation mean/daily</td>
<td>13.6 MJ/m²</td>
<td>21.6 MJ/m²</td>
<td>22.9 MJ/m²</td>
<td>16.3 MJ/m²</td>
</tr>
<tr>
<td>Sunshine Hours mean/daily</td>
<td>7.6</td>
<td>9.0</td>
<td>8.2</td>
<td>7.7</td>
</tr>
</tbody>
</table>

The facility consists of 110 one and two bedroom apartments within a community setting that also includes a heated swimming pool, community centre, dining room, library and gardens. Onsite nursing care is provided 24 hours/day and a full range of nursing and home help services, from low to high care to palliative care, is available to residents in their own unit within this estate. The average age of residents is reported by management to be about 80 years and most residents live alone. The single and two storey apartment blocks were constructed in four stages over a period of approximately 3 years (2005 - 2007). Units range in size from 36m² to 74m², with the typical internal floor area 55-60m². This study focuses on the single storey units constructed prior to 2006 (units 1-46 shown in Figure 1) with an in-depth study of two units (highlighted in Figure 1). Mean monthly electricity consumption per unit was 122 kWh/month (range 64.5 - 410 kWh/month).

### 3. Methodology

#### 3.1 Physical characteristics of units under study

The two units selected for study are examples of the Type A and Type B apartments that dominate in the early development of the site: single storey dwellings with shared walls (party walls); floor area 55m² and 56m² respectively. Construction properties are shown in Table 3 and floor plans in Figure 2. The interior space of both units consists of two bedrooms, a bathroom and an open plan kitchen/dining/lounge room.
3.2 Occupancy and operation of case study units

Each unit is occupied by one elderly person. The second bedroom of each unit is utilised as a ‘spare’ room for guests and/or an office/hobby/reading room. The average monthly electricity consumption for these two units was 83.4kWh and 118kWh for Case A and Case B respectively.

Table 3: Building properties

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>DETAIL</th>
<th>U-value</th>
<th>R-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>External walls</td>
<td>150 mm concrete, plasterboard internal lining. Height 2550mm. No insulation. Medium colour (absorptance 0.5)</td>
<td>2.07</td>
<td>0.32</td>
</tr>
<tr>
<td>Internal walls</td>
<td>90mm timber frame with plasterboard sheeting. No insulation.</td>
<td>3.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Windows (and other glazed elements)</td>
<td>Aluminium framed, single glazed clear. Solar heat gain coefficient 0.74.</td>
<td>6.57</td>
<td>0.48</td>
</tr>
<tr>
<td>Skylights</td>
<td>500 mm x 500 mm skylights in bathrooms</td>
<td>4.48</td>
<td>0.2</td>
</tr>
<tr>
<td>Roof</td>
<td>20° pitch roof with corrugated iron; dark colour (absorbance 0.85); anticon foil blanket under roof R1.2.</td>
<td>4.57</td>
<td>0.06</td>
</tr>
<tr>
<td>Ceilings</td>
<td>10mm plasterboard ceilings. No insulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>Ceramic tiles 8mm in bathrooms and kitchen 10 mm carpet in all other areas Uninsulated concrete slab (100mm) on ground.</td>
<td>4.57</td>
<td>0.06</td>
</tr>
</tbody>
</table>
3.3 Simulation

After physical inspection of the buildings, three potential retrofit options were selected for simulation, two involving improving the thermal performance of the building envelope (R2 bulk insulation for the ceiling; replacement of single glazing with double glazing (clear glass, air filled; the most common double glazing option in Australia)) and one involving improving air movement for enhancing the thermal experience of occupants without cooling the space (i.e. the installation of ceiling fans). These options were selected based on ease of material availability in the Australian market and recent literature: a study on Australian housing reports that ceiling insulation is the most common practise among occupants undertaking renovations (Ambrose, James, Law, Osman, & White, 2013); improved glazing is known for its energy efficiency benefits (Hee et al., 2015); and ceiling fans have been reported as common inexpensive solutions for improving comfort and energy efficiency in warm and humid climates (Aynsley, 2007; Zhai, Zhang, Pasut, Arens, & Meng, 2015).

BersPro 4.2 was utilised as the simulation tool. It is one of three simulation tools accredited by NatHERS for use for regulatory compliance purposes in Australia. Using Reference Meteorological Year (RMY) climate files, the software calculates heat flows into and out of the building envelope on an hourly basis to determine the space heating and cooling loads. Protocols for occupancy patterns, sensible and latent heat leads and heating and cooling schedules are pre-set by the regulator, to enable comparison between designs within each climate zone. For this climate zone cooling thermostats are set at 25.5°C while heating thermostats are set at 18°C, (dropping down to 15°C between midnight and 7am). Thermal comfort conditions are maintained in the living room from 7am to midnight and in bedrooms from 4pm to 9am.

4. Results

4.1 Base Run

Simulation of the two units as constructed yielded star ratings of 4 and 4.5 respectively, confirming compliance with the regulations at the time of construction. The results (Table 5) show that both units have a high cooling demand and negligible heating load. Closer inspection of the results, room by room, shows that the main bedrooms perform much better than the other rooms. In particular the open plan kitchen/lounge room of both units require relatively high cooling energy to meet the temperature protocols established by the regulator.

The temperature data from this ‘as constructed’ simulation was analysed to show the percentage of time each monitored zone would be within different temperature bands (Figure 3). In the legend, the acceptable summer ‘comfort band’ of 20-26°C assumed by NatHERS (rounding up 25.5 to 26°C) for this climate is shown in green, with temperature bands beneath this represented in blue, and temperature bands higher than this in pink/red. These graphs clearly show that for both units the bedrooms had a higher proportion of time in the comfort band than the open plan kitchen/living area. For regulatory purposes, bathrooms are usually treated as un-conditioned spaces, but for this study they were considered as conditioned spaces similar to ensuites because of the single occupancy.

![Figure 3: Temperature Distribution in Case A and Case B](image-url)
4.2 Simulation of proposed retrofits

The three different retrofit actions explained in 3.3 were modelled for each apartment. Seasonal comparisons of the impact of each retrofit action are shown for each unit in Figures 4 and 5. A summary of the impacts, in relation to absolute and percentage change in total energy load due to each action, is shown in Table 6.

The addition of R2 bulk insulation to the ceiling increased the star rating in both cases by 1, reducing the total cooling energy by approximately 20 and 15 MJ/m² for Case A and Case B respectively (more than 20%). The second retrofit option, utilising double glazing, showed only a minor improvement in overall energy load (4-6%) and hence no change to the star rating. This result was not unexpected as previous simulation studies for sub-tropical climate zones have shown that advanced glazing is required to significantly reduce summer cooling loads. This previous simulation study showed that single glazing could reduce cooling loads if it was low e and/or tinted, and that double glazing options would need to use advanced glazing as well (an external tint and internal low e coating)(Bell & Miller, 2008).

To specifically address summer conditions, the third option - adding ceiling fans - was considered in 2 stages. First, 2 ceiling fans were added to the open plan kitchen/living area only. When simulated, this resulted in significant reduction (about 41%) in annual energy consumption, allowing both apartments to meet current regulations regarding the thermal performance of residential buildings. The second step, adding a ceiling fan to the second bedroom as well, resulted in a further reduction (total reduction 50% compared with base case). Whilst ceiling fans do not reduce the temperature, the NatHERS protocols assume that the increased air movement will give a cooling effect to occupants and hence a mechanical cooling device (e.g. air conditioner) will not be used unless the temperature exceeds 25.5°C.

The simulation results show that theoretically at least, the installation of ceiling fans would have the greatest impact on reducing summer cooling load (about 50%), followed by ceiling insulation (about 20%). However, simulations do not account for all real world conditions so cannot be relied on solely to inform retrofit actions. Some of the real world conditions that apply in this case are discussed in the following section.

<table>
<thead>
<tr>
<th>Case A</th>
<th>All Zones (MJ/m²)</th>
<th>Bedroom 1 (MJ/m²)</th>
<th>Bedroom 2 (MJ/m²)</th>
<th>Lounge/Kitchen (MJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>80.8</td>
<td>10.8</td>
<td>38.5</td>
<td>89.5</td>
</tr>
<tr>
<td>Heating</td>
<td>8.2</td>
<td>7.7</td>
<td>0.6</td>
<td>7.1</td>
</tr>
<tr>
<td>Total</td>
<td>89</td>
<td>18.5</td>
<td>39.1</td>
<td>96.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case B</th>
<th>All Zones (MJ/m²)</th>
<th>Bedroom 1 (MJ/m²)</th>
<th>Bedroom 2 (MJ/m²)</th>
<th>Lounge/Kitchen (MJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>64.5</td>
<td>5.2</td>
<td>28.1</td>
<td>86</td>
</tr>
<tr>
<td>Heating</td>
<td>13.1</td>
<td>5</td>
<td>7.9</td>
<td>14.2</td>
</tr>
<tr>
<td>Total</td>
<td>77.6</td>
<td>10.2</td>
<td>36.1</td>
<td>100.1</td>
</tr>
</tbody>
</table>
Table 6: Summary of Simulation Results

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Case A</th>
<th>Case B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rating</td>
<td>Total Actual Energy (MJ/m²)</td>
</tr>
<tr>
<td>As constructed</td>
<td>4</td>
<td>89</td>
</tr>
<tr>
<td>R2 bulk insulation added to ceiling</td>
<td>5</td>
<td>68.9</td>
</tr>
<tr>
<td>Single glazing replaced with double glazings</td>
<td>4</td>
<td>85.2</td>
</tr>
<tr>
<td>2 ceiling fans added to Lounge/Kitchen</td>
<td>6</td>
<td>52</td>
</tr>
<tr>
<td>2 ceiling fans added to lounge/kitchen and 1 fan added to bedroom 2</td>
<td>7</td>
<td>42.3</td>
</tr>
</tbody>
</table>

Figure 4: Case A simulation comparison

Figure 5: Case B simulation comparison
5. Discussion

5.1 Ceiling Fans and Insulation

Whilst ceiling fans are shown by the simulation to be the retrofit option with the highest benefit, there are practical realities that make this unfeasible. The first limitation is that the National Construction Code requires a ceiling height of at least 2700mm for the safe operation of ceiling fans (in new dwellings). The existing buildings have ceiling heights of 2550mm and therefore the installation of ceiling fans would add a safety risk that would need to be mitigated (e.g. through the selection of fans that with a short rod; fans with blade designs and materials that present a lower risk, etc). Installing fans in low ceilings (under 2700mm) on shorter rods decreases their efficiency by as much as 40% (Aynsley, 2007). The simulation tools also don’t differentiate between fan types (e.g. their blade design and hence throw and efficiency), so provide no assistance in the selection of the most appropriate fan for the purpose. Wall mounted fans may be an alternative solution, however the simulation tools don’t model the effect that such fans would have. The cooling effect of air movement, i.e. the calculation of Standard Effective Temperature (SET) for climates with high humidity, depends on skin temperature and wettedness, metabolic rate, and clothing insulation. The authors of this paper are not aware of any studies specifically examining the effect of air movement from fans on the thermal experience of elderly occupants (e.g. what are the range of clo levels and metabolic rates), and whether air movement in itself would be acceptable to this demographic.

Thirdly, ceiling fans typically require the active engagement of occupants to switch them on / off / change the fan speed. Some senior citizens may be unable to sense changes to their thermal environment, hence triggering the operation of fans; and other occupants may not be mobile (Walker & Paliadelis, 2016), so would require remote fan controllers within their reach.

While the addition of bulk insulation to the ceiling did not generate the same extent of energy reduction, this refurbishment action is a passive strategy that does not require the involvement of occupants to manage. This is also the cheapest of the refurbishment strategies selected as the materials are easily available and the roof cavity is accessible, minimising installation costs. The total cost for installing R2 insulation is less than AUD$500 per unit. Assuming a fixed electricity price of AUD $0.25 kWh, the simple pay back period for the installation of the ceiling insulation would be 6.4 and 8.3 years for Case A and B respectively. A higher R rated product would cost slightly more (in materials, not in installation) but would result in greater energy savings.

This simple comparison highlights the complex nature of the interplay between energy efficiency, thermal comfort, occupants and costs. This need to evaluate building options by two or more parameters simultaneously has led to the development and testing of an optimisation tool - MultiOpt (Chantrelle et al., 2011). The criteria utilised in testing this tool however were limited to quantifiable aspects such as energy consumption, environmental impact, cost and thermal discomfort (measured by percentage persons dissatisfied (PPD)). There is a need for further research to identify socio-cultural criteria that could be utilised in a multi-criteria optimisation tool.

5.2 Occupancy protocols in simulation tools

Because this simulation tool is used for regulatory purposes, to enable comparison between properties within the same climate zone, a set of occupancy assumption are incorporated. This includes assumptions of dwelling occupancy of 2 adults and 2 children; assumptions of sensible and latent heat loads associated with that occupancy rate; and room occupancy as mentioned in 3.1. This demographic, however, appear to spend most of their time in their residence (Walker & Paliadelis, 2016) and there is some evidence to suggest that bedrooms are utilised frequently during daytime hours. The simulation analysis was helpful in identifying thermal conditions of spaces within the dwelling, information that could assist in developing strategies that improve thermal experiences in specific rooms as well as for the dwelling as a whole entity. A more thorough understanding of how seniors like to utilise their spaces would be beneficial.
5.3 Limits to adaptive comfort and the ‘senior’ demographic

The adaptive comfort principle assumes that people will undertake actions to create / maintain their comfort (Nicol & Roaf, 2007), with three categories of adaptation: physiological, psychological and behavioural. Physiological studies have shown that older people can experience diminished capability in maintaining a stable core temperature (Lewis, 2015), possibly contributing to their higher vulnerability to heat waves as experienced in the UK (Brown & Walker, 2008). Other physiological changes include reductions in muscle strength, work capacity, sweating capacity, ability to transport heat from the body core to the skin, hydration levels, vascular reactivity and cardiovascular stability (Van Hoof, Kort, Hensen, Duifnstee, & Rutten, 2010). Their study suggests that older people may in fact perceive thermal comfort differently.

An increasing number of studies are pointing to the need to consider not only energy efficiency but also, simultaneously, improvements in indoor environment conditions other than thermal conditions (e.g. low VOC) (Ahrentzen et al., 2015), other qualities of the spaces (e.g. acoustic) and occupants preferences for how they wish to use the spaces and what value they place in the home environment (Tweed et al., 2015; Van Hoof et al., 2010). In addition to calculating energy cost savings, more efforts need to be made to quantify health benefits of retrofit actions (Ahrentzen et al., 2015), requiring collaboration between built environment and health professionals.

6. Conclusion

This study has shown that this regulated simulation tool can provide useful insight into the thermal conditions of specific spaces within buildings and the impact of specific retrofit activities can have on those spaces. Such a tool, however, does not incorporate additional criteria that should be included in retrofit decisions, such as the needs and preferences of the specific occupants, and benefits other than energy reductions. There is a strong need for the development of multicriteria optimisation tools that can be used by facilities owners/operators to evaluate refurbishment options that provide multiple benefits: reduced greenhouse gas emissions and operating costs, enhanced indoor environment quality and improved health and wellbeing of the occupants.

7. References


Australian Building Codes Board. Climate Zone Map: Australia Wide. from www.abcb.gov.au


Investigation of energy performance of a rammed earth built residential house in sub-tropical, tropical and temperate climates of Australia

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Australia  
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Mr M Mahmudul Hasan, Anderson Energy Efficiency, Australia, hasan@andersonenergy.com.au

Abstract

Purpose / Context - This paper will examine the predicted energy consumption (MJ/m²) of a residential house made of rammed earth in sub-tropical, tropical and temperate climates of Australia using design data of the building fabric and glazing.

Methodology - To improve energy performance of this building project, thermal simulation and comprehensive simulated data analysis were conducted, using BERSPro and according to the NatHERS Technical Note. This includes detailed analysis of heating and cooling energy (MJ/m²). Different constructions, including rammed earth wall, lightweight wall and heavy weight wall were used as building fabrics to achieve a cost effective, energy efficient and sustainable solution

Results - Thermal performance of rammed earth is similar to other constructions in sub-tropical and tropical climate. No insulation is required for a rammed earth built house in tropical climate for the proposed floor plan. However, it requires more insulation with rammed earth in external walls to achieve NCC-compliant 6 star rating in temperate climate.

Key Findings / Implications – The research highlighted that the rammed earth in external walls of the proposed house achieved minimum 5 stars in sub-tropical climate and minimum 6 stars in tropical climate without any changes of other building elements i.e. insulation, glazing, awning. On the other hand, rammed earth house in temperate climate didn’t achieve 6 stars without changing other building elements.

Originality - Two research questions are highlighted in this study (a) What would be the thermal performance of the rammed earth compared to other constructions in these three climate zones (b) What are the changes required to any building element for energy performance improvement of this building project? A comparative study for a rammed earth house has not being conducted before this research in climate zones 1, 2 and 6 using the NatHERS Technical Note and BERSPro software.

Keywords - Energy, Rammed earth, house, climate, Star rating
1. Introduction

Buildings worldwide account for a surprisingly high 40% of global energy consumption (Energy Efficiency in Buildings, 2009). Both residential and commercial buildings account for approximately 23% of Australia’s greenhouse gas emissions (Building and Construction, 2011). In 2014, Space conditioning accounted for 40% of residential energy use in Australia (Energy Rating, 2015). Building fabric, specially type of building construction and glazing play a key role to reduce the energy consumption of the building. Ciancio and Beckett (2009) highlighted the use of sustainable building material such as rammed earth wall to reduce the use of HVAC and to achieve a comfortable living space. Rammed earth walls have low thermal resistance but high thermal mass compared to light weight construction. However, thermal resistance is not only responsible for comfortable living (Allinson & Hall, 2007; Faure & Le Roux, 2012). Studies in NSW, Australia and in West Argentina, Galcia and Spain (Page et al. 2011; Larsen et al. 2002; Orosa & Oliveira 2012) indicated that the high thermal mass but low thermal resistance provides better thermal performance and lower heating and cooling demand than high thermal resistance material.

Energy consumption of a rammed earth built office building was studied in Churles Sturt University in NSW, Australia using questionnaire survey and simulation (Taylor et al. 2008). A case study of rammed earth built small commercial office was investigated in climate zones 1, 2 and 6 of Australia using Energyplus thermal simulation which demonstrated that rammed earth was a better performer than some wall types in sub-tropical, tropical and temperate climates (Hasan & Dutta, 2015). A hypothetical un-insulated rammed earth built house was investigated by AccuRate software in climate zone 3, 5 and 7 of Australia. (Dong et al. 2014). However, a comprehensive study on rammed earth built house and its energy consumption scenario and compliance with building code was not investigated in subtropical, tropical and temperate climate using NatHERS Technote and BERSPro.

In this study, energy performance in terms of heating and cooling energy total (MJ/m²) of a rammed earth (R value 0.32 m².K/W and thermal mass 1285 KJ/m³K) built house was examined using design data of the building fabric and BERSPro simulation. As per Queensland development code (QDC MP4.1) and as per Part 3.12 of the National Construction Code, NCC 2016, a new built house building must achieve 6 Stars. To serve this purpose, design compliance for energy efficiency of a single storey residential house was examined in BERSPro v4.2 thermal simulation with different construction details in external walls including lightweight, heavy weight and rammed earth construction. The energy performance of the rammed earth built house was also compared with light weight and heavy weight constructions in sub-tropical (climate zone 2), tropical (climate zone 1) and temperate climate (climate zone 6) of Australia.

2. Methodology

NatHERS-accredited software calculates the energy required for artificial heating and cooling, based on standardized assumptions of occupancy, internal heat loads and thermostats (NatHERS, 2016). This allows relative comparisons between buildings with 6 Stars (out of 10) representing a house that will be uncomfortable less than a house that scores 4.5 Stars. BERSPro Version 4.2 that uses Chenath V2.13 and simulation engine 2.2, has been used in this study to investigate the energy performance of a rammed earth built house.

First, all architectural design data including floor plan, elevations, sections, site plan, wall and roof constructions, glazing (all external glass doors and windows) and finishes were collected. The floor plan of the house is shown in Figure 1.

For the house in a sub-tropical climate, the location selected was Brisbane (-27°S 153°E), the tropical climate location was Cairns (-17°S 146°E) and the temperate climate location was Melbourne (-38°S 145°E). The initial assumptions for the house are listed in Table 1. Regulatory credits of 1.5
Stars apply for a complying outdoor living area with minimum R1.5 insulated roof and 1 kW PV panel as per QDC MP4.1. All glazing were sliding windows and doors. Using construction details as per Table 2, 2D modelling and zoning of the designed building in BERSPro V4.2 software was conducted (Figure 2). The zoning procedure followed the NathERS Technical Note 1.2.

![Floor plan of the house](image)

**Figure 1: Floor plan of the house**

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area</td>
<td>House 116 m², Veranda 32 m², Garage 24 m², Deck 9 m²</td>
</tr>
<tr>
<td>Complying outdoor living area</td>
<td>+ 1kW solar panel = 1.5 Star credit</td>
</tr>
<tr>
<td>Roof</td>
<td>Metal, R1.0 insulation with foil-backed, including verandah</td>
</tr>
<tr>
<td>Glazing</td>
<td>Low e medium tint glass in aluminium frame (Uw 4.66, SHGCw 0.44)</td>
</tr>
<tr>
<td>Windows and doors</td>
<td>All sliding, 45% opening</td>
</tr>
<tr>
<td>Ceiling fans</td>
<td>No ceiling fans</td>
</tr>
<tr>
<td>External colours</td>
<td>Medium colour external walls and roof (solar absorptance 0.5)</td>
</tr>
</tbody>
</table>

The star credits were not required for climate zone 1, tropical Queensland.
Five different types of wall constructions as shown in Table 2 were used in this study.

Table 2: Base case constructions for external walls used for climate zones 1, 2 and 6

<table>
<thead>
<tr>
<th>External wall construction type</th>
<th>Added insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 mm Rammed earth</td>
<td>no insulation</td>
</tr>
<tr>
<td>190 mm concrete</td>
<td>no insulation and no lining</td>
</tr>
<tr>
<td>Cavity panel metal cladding</td>
<td>no insulation</td>
</tr>
<tr>
<td>200 mm Straw Board</td>
<td>no insulation</td>
</tr>
<tr>
<td>Brick veneer wall</td>
<td>no insulation</td>
</tr>
</tbody>
</table>

The building orientation was rotated at 0, 45, 90, 180, 225, 270 and 315 deg. In each case, the energy number (MJ/m²) was examined and the rammed earth house was compared with other constructions. A minimum of 4.5 Stars in climate zone 2 (sub-tropical) was obtained for each construction in the worst orientation. This allowed the maximum regulatory star credit of 1.5 Stars. This insulation was then the base design for further orientation analysis and comparison. In climate zone 1 (tropical) the added insulation for worst orientation for any construction was determined to achieve 6 Stars. No wall insulation was added to the external walls if it was not required.

The initial design for the climate zone 6 (temperate) was as per Table 3. The design was allowing more sunlight by removing the veranda from the north side and using low e clear glass instead of using low e tint glass. The house was simulated using the various wall construction types shown in Table 2 to achieve 6 Stars requirement as per NCC. If any construction type didn’t achieve 6 Stars without insulation, then insulation was added for the worst orientation to reach 6 Stars. The results of the rammed earth-built house were compared with other constructions. The process described is outlined in Figure 3.
Table 3: Initial assumptions for the house (climate zone 6, Victoria)

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor area</td>
<td>House 116 m², Garage 24 m², Deck 9 m²</td>
</tr>
<tr>
<td>Complying outdoor living area</td>
<td>Verandah removed to allow more sunlight for the house</td>
</tr>
<tr>
<td>Roof</td>
<td>Metal, R1.0 insulation with foil-backed</td>
</tr>
<tr>
<td>Glazing</td>
<td>Low e clear glass in aluminium frame (Uw 4.7, SHGCw 0.63)</td>
</tr>
<tr>
<td>Windows and doors</td>
<td>All sliding, 45% opening</td>
</tr>
<tr>
<td>Ceiling Fans</td>
<td>No fans</td>
</tr>
<tr>
<td>External Colours</td>
<td>Medium colour to external walls and roof (solar absorptance 0.5)</td>
</tr>
</tbody>
</table>

Figure 3: Methodology for obtaining a NCC/QDC-compliant solution

3. Results and discussion

3.1 Rammed Earth built house in Sub-tropical climate

From Figure 4, it was observed that rammed earth walls in the proposed house demonstrated energy numbers between 47 MJ/m² and 54 MJ/m² in all orientations. The performance numbers were equivalent to 5.5 Stars (48 MJ/m²) and 5 Stars (55 MJ/m²) energy rating. The changes of building elements from the base case were shown in Table 4. Rammed earth walls which didn’t require any insulation to achieve minimum 5 stars had the better energy performance than the concrete wall and brick veneer wall.

Brick veneer wall with no insulation showed the worst energy performance of all wall types. Cavity walls and straw board both required minimum R2.0 insulation to achieve minimum 5 Stars (55 MJ/m²) to maximum 6 Stars (43 MJ/m²) requirement, which demonstrated better energy perfor-
mance than any other wall types. Insulation in these walls enhanced the energy efficiency star rating (e.g. from 4 Stars to 6 Stars).

Table 4: Changes of building elements from the base case for sub-tropical climate

<table>
<thead>
<tr>
<th>External wall construction type</th>
<th>Changes from base case of Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 mm rammed earth</td>
<td>No changes</td>
</tr>
<tr>
<td>190 mm concrete</td>
<td>No changes</td>
</tr>
<tr>
<td>Cavity panel metal cladding</td>
<td>+ R2.0 wall insulation</td>
</tr>
<tr>
<td>200 mm straw board</td>
<td>+ R2.0 wall insulation</td>
</tr>
<tr>
<td>Brick veneer wall</td>
<td>No changes</td>
</tr>
</tbody>
</table>

The difference between rammed earth and cavity walls with insulation R2.0 was around 10MJ/m². If insulation is added to rammed earth walls, then it can provide similar energy numbers to the insulated cavity walls. From the base case (Table 1 for climate zone 2 and Table 2) and Figure 4, it was obvious that rammed earth walls without any insulation was an alternative option to obtain energy efficient building fabric in sub-tropical climate compared to other constructions types.

Figure 4: Energy performance of the house for different constructions in external walls in sub-tropical climate

3.2 Rammed Earth built house in tropical climate

From Figure 5, it was observed that rammed earth walls demonstrated better energy performance than the concrete walls, cavity walls with insulation, and brick veneer walls. The proposed house with the rammed earth walls demonstrated energy numbers between 106 MJ/m² and 118 MJ/m² in all orientations. The performance numbers were equivalent to 6.5 Stars (117 MJ/m²) and 6 Stars (128 MJ/m²) energy rating. Rammed earth walls achieved minimum 6 stars and maximum 6.5 stars without any added insulation. The changes of building elements from the base case are listed in Table 5. These changes include lowest additional cost options for the worst orientation. Unlike the sub-tropical climate, the building with cavity panel walls (in Table 5) did not need added wall insulation; but the roof required additional R1.0 insulation (total R2.1 insulation) and the glazing needed changing to low e heavy tint glass with aluminium frames (Uw 4.8, SHGCw 0.36).
Table 5: Changed building elements from the base case for tropical climate

<table>
<thead>
<tr>
<th>External wall construction type</th>
<th>Changes from base case of Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 mm rammed earth</td>
<td>No changes</td>
</tr>
<tr>
<td>190 mm concrete</td>
<td>No changes</td>
</tr>
<tr>
<td>Cavity panel metal cladding</td>
<td>R1.0 insulation + low e heavy tint glass + R2.0 wall insulation</td>
</tr>
<tr>
<td>200 mm straw board</td>
<td></td>
</tr>
<tr>
<td>Brick veneer wall</td>
<td>No changes</td>
</tr>
</tbody>
</table>

Figure 5 shows that rammed earth walls in a tropical climate without any insulation, was an efficient alternative building fabric compared to other construction types. Insulated straw board walls showed the best energy performance of any other wall types. However, the straw board with no insulation demonstrated less than 5 Stars energy rating similar to sub-tropical climate. The difference between rammed earth and straw board walls with R2.0 insulation was around 8MJ/m². The minimum star rating observed in the tropical climate was 6 Stars, whereas 5 Stars energy rating was observed in the sub-tropical climate.

Figure 5: Energy performance of the house for different constructions in tropical climate

3.3 Rammed earth built house in temperate climate

In temperate climate (e.g. Melbourne), the minimum requirement for a new house is 6 Stars. The star credits are not applicable for climate zone 6. Table 6 lists the added insulation required in the temperate climate. The rammed earth wall thickness was reduced 100mm to compensate for the thickness of the added insulation. Without extra insulation in external walls and additional insulation to roof, no constructions achieved minimum 6 stars energy rating (130 MJ/m²) for the temperate climate. The added insulation are examples including lowest cost options. Different combinations of R-value to walls and ceiling/roof may have given similar results.
### Table 6: Changed building elements from the base case for temperate climate

<table>
<thead>
<tr>
<th>External walls type</th>
<th>Changes from base case (Table 4) to external walls</th>
<th>Changes from base case (Table 4) to other elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 mm rammed earth</td>
<td>200 mm rammed earth</td>
<td>R2.0 insulation to roof or ceiling</td>
</tr>
<tr>
<td>190 mm concrete</td>
<td>+R3.0 insulation</td>
<td>R2.0 insulation to roof or ceiling</td>
</tr>
<tr>
<td>Cavity panel metal cladding</td>
<td>R3.0 insulation</td>
<td>R3.5 insulation to roof or ceiling</td>
</tr>
<tr>
<td>200 mm straw board</td>
<td>R2.0 insulation</td>
<td>+R1.0 to garage partition</td>
</tr>
<tr>
<td>Brick veneer wall</td>
<td>R2.0 insulation</td>
<td>R3.0 insulation to roof or ceiling</td>
</tr>
</tbody>
</table>

The energy numbers for the changes of building elements of the proposed house were illustrated in Figure 6. The rammed earth built house with insulation demonstrated the lowest energy numbers in 90 deg orientation compared to other construction types. The second lowest number for the rammed earth was observed in 315 degree rotation, highlighting the benefit of passive solar design.

From 135 to 270 degree orientation, the energy numbers of all constructions were observed more than 110MJ/m². Brick veneer walls demonstrated better energy performance in 0 and 45 degree orientation. Straw board walls showed better energy performance in 0 and 45 degree orientation compared to other constructions. However, more insulation in roof and garage partition walls were required to achieve 6 stars requirement for the house as shown in Table 6.

Overall, external insulation in rammed earth walls depicted the similar energy performance nature compared to other constructions. Though the insulation was required for the rammed earth built house, the insulation requirement for the roof/ceiling in the cavity panel, straw board and brick veneer built house was higher than rammed earth built house as shown in Table 6.

### 4. Conclusions

For this case-study building, to comply with the Code a number of changes in building elements were required in a temperate climate. Apart from designs with lightweight external wall construction, no changes of other building elements were required for sub-tropical and tropical climates. The building orientation, glazing, insulation in roof and ceiling and overall shading have a significant effect in achieving the desired energy rating and thermal comfort in any climate. The difference
between optimum and worst orientation was 0.5 to 1.0 Stars. From the results of different construction types, it can be concluded that no added wall insulation for rammed earth built house provided better energy performance in tropical and sub-tropical climates than in a temperate climate.

The level of added insulation listed was the minimum necessary to comply with the Code requirements. More wall insulation can improve the energy efficiency, but it may be more cost effective to add ceiling insulation or tint glazing depending on orientation and climate.

The 6 Stars for the tropical climate and 5 Stars in the sub-tropical climate can be achieved for a rammed earth built house with no added external wall insulation. Without additional insulation in external walls and roof, a rammed earth built house didn’t achieve 6 Stars in a temperate climate. Rammed earth walls were confirmed as an effective, energy efficient construction in sub-tropical and tropical climates because of the diurnal temperature range. In cool temperate climate, rammed earth external walls with external insulation acted as thermal energy storage for passive heating.

Overall, rammed earth demonstrated its thermal potential for use in external walls as an alternative to lightweight and heavy weight constructions. If rammed earth is used correctly in the right climate, thermal mass can delay the heat flow through building envelope, which is effective to reduce cooling demand in tropical and sub-tropical climates, and heating demand for temperate climates. Though the energy performance of rammed earth is better in a tropical climate than a temperate climate, higher thermal discomfort may occur in a tropical climate.

To minimise thermal discomfort, proper use of cross flow ventilation and controlled air movement by ceiling fans are important consideration for the new house design in tropical and sub-tropical climates. No ceiling fans were used in these thermal performance simulations. Use of ceiling fans in combination with a rammed earth built house can compensate for some thermal discomfort in tropical and sub-tropical climates.

A more comprehensive case study on rammed earth is required regarding buildability, availability, cost and thermal comfort in all climate zones of Australia. In terms of environmental impact, rammed earth is a low greenhouse gas emission product. Australian builders, house owners, architects, technologists and governments can work together and establish a sustainable technology plan to encourage people to use this environmentally-friendly construction in newly built houses.

5. References


Pilot Study on Relationship between Indoor and Outdoor Temperatures in Brisbane Households

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Abstract

Purpose / Context – Temperature is known to have impact on human health. In estimating such health effects outdoor temperature data are usually used as proxy for temperature exposure due to scarcity of indoor temperature data though humans spend most of their time indoor. Thus there is a need to investigate how outdoor temperature relates to indoor temperature especially in residential settings.

Methodology / Approach – Field measurements were conducted in 15 residential houses in different suburb of Brisbane to identify the relationship between indoor and outdoor temperature during the winter season of 2016.

Results – In the month of June the minimum indoor temperature ranged from 9.56 – 16.25 °C, whiles the maximum was between 22.19 – 26.50 °C. Also for the month of July minimum temperature ranged between 11.75 – 16.69 °C and the maximum temperature was between 24.75 – 28.31 °C. In the month of August, for indoor temperature minimum temperature was between 12.31 – 17.75 °C and a maximum of 22.69 – 26.31 °C. Outdoor temperature recorded in the month of June varied between 2.95 – 7.80 °C for minimum range and 24.00 – 32.44 °C for maximum range. July minimum temperature ranged from 6.25 – 17.75 °C between 9.31 °C as maximum temperature was between 28.50 – 34.38 °C. Minimum outdoor temperature for the month of August was also between 5.69 – 17.75 °C as the maximum temperature ranged between 24.44 – 35.00 °C. Pearson correlation coefficient calculated between mean hourly indoor and outdoor temperatures ranged from 0.25 – 0.85.

Key Findings / Implications – The results obtained indicated that indoor and outdoor temperatures relationship in residential settings may vary depending on factors including type of ventilation, insulation, type of building and behaviour of occupants.
Asumadu-Sakyi, A  Pilot Study on Relationship between Indoor and Outdoor Temperatures in Brisbane Households

Originality – The findings attained will contribute to precise estimation of temperature exposure at a personal level especially in residential settings and empirical data will contribute to filling the gap of limited indoor temperature data.

Keywords - indoor temperature, outdoor temperature, residential houses, temperature sensors

1. Introduction

The impact of outdoor temperature (cold and hot) on human health has been well documented by studies in the field of epidemiology and environmental science (Basu, 2009; Seposo, Dang, & Honda, 2015; Wang, Chen, Kuang, Duan, & Kan, 2014) . The relationship between temperature and health effects is non-linear with U or V or J shape with increased risks for both hot and cold temperature (Breitner et al., 2014; Ebi, Mills, Smith, & Grambsch, 2006). Outdoor temperature induced health effects identified are respiratory, cardiovascular, cerebrovascular and cardiopulmonary (Baccini et al., 2008; Basu & Ostro, 2008; Ishigami et al., 2008). These health risks are currently estimated using daily outdoor temperature data from either single or network monitoring stations since they are readily available. This approach does not account for temperature variations in microenvironment thereby resulting in discrepancy in estimating temperature exposure to humans (Zhang et al., 2011). However, the daily activities of humans require them to spend most of their time indoors especially the vulnerable group of population. The lack of indoor temperature data for epidemiological studies has been highlighted by the World Health Organization (WHO) and other studies. This has been attributed to the challenge of attaining significant sample size that make such studies statistically meaningful (Ormandy & Ezratty, 2012). Further, studies on indoor air have also reported much on indoor temperature conditions on household thermal comfort (de Dear et al., 2013) though but little is known about how the immediate outdoor temperature conditions relates to indoor temperature conditions especially in microenvironments such as residential settings.

This study seeks to identify the relationship between outdoor (immediate surroundings) and indoor temperature in urban residential settings of Brisbane. The findings attained will contribute to precise estimation of temperature exposure at a personal level and also aid regulatory studies and policy makers such as the WHO in amending and developing guidelines to curtail the menace of temperature exposure in these times of climate change.

2. Methodology

Fifteen houses participated in this study, their locations spread across the city of Brisbane, Queensland, Australia. These were houses of colleague students, staff, friends from the International Laboratory for Air quality and Health (ILAQH), Queensland University of Technology (QUT) upon given their consent about the project. To the date of this report, six of them have returned the measurement data with their locations shown in Figure 1.

The houses were selected when residents will occupy it for the next six months. Validated questionnaire were adapted, modified and given to occupants to acquire information on the houses such as types, location, high sets or low set and type of ventilation. Also occupants were directed on placing and downloading of data unto their computer. Indoor and outdoor temperatures (°C) were simultaneously and continuously measured at an interval of 30 min through the winter season for a period of three months (June – August, 2016) using Labjack-Digit temperature sensors (data loggers). Each house was given two labelled (I &O) temperature sensors which were hung in the living room and immediate surroundings (outdoor). For indoor measurements occupants were instructed to place the sensor on an inner wall; at a breathing height; and away from any source of heat and where it will not be moved regularly. Outdoor measurements were carried out as sensors were hung in a safe place to shield it from sunlight and south of the house. Residents were guided on how to download data from sensors unto their
computers. This enabled them to send logged data through emails every two weeks till completion of the study.

Figure 1 Map of Brisbane residential suburbs with location of six houses highlighted in blue and red spots (adapted from the State of Queensland (Department of Natural Resources and Mines, 2013)

3. Results and discussion

The summary of statistics of temperature readings recorded and calculated Pearson correlation coefficient between mean hourly indoor (I) and outdoor (O) temperatures presented in Table 1 and Table 2 are temperature readings obtained in 6 out of the 15 residential houses. These include Coopers Plains, Durack, High Gate Hill, Indooroopilly, Milton, North Lake. Summary of statistics contains calculated mean, standard deviation of the mean, 95% Confidence Interval (C.I) of I/O temperatures recorded. Pearson correlation coefficient (r) calculated between mean hourly I/O temperatures was to find the correlation between I/O temperatures in residential houses differing in locations. The shape of the relationship I/O temperature was examined using simple line graph as shown in Figure 1, 2, 3. Similar shape was observed in I/O temperatures obtained other 5 houses. The outdoor temperatures for all the houses corresponded with June (10 – 21 °C), July (8 – 21 °C) and August (9 – 22 °C) average temperature of Brisbane. Also indoor temperature obtained for all the houses in the various suburbs were between the recommended perceived comfort temperature range of (20.8 to 23.6 °C) by ASHARE standard 55. All statistical analysis was done with R statistical software (R version 3.3.1, 2016).

Outdoor temperature may influence the temperature in indoor environments. A review into this relationship identified 32 articles which reported indoor temperature during summer together with their corresponding outdoor temperature. A positive correlation between outdoor and indoor temperature was noted in the higher temperature range (> 20 °C) unlike the cold temperature
range where heating activities alter the relationship to a point that there is no correlation. Thus, indicating the relationship in the warm/hot or cold temperature may vary depending on factors including air conditioning, ventilation, insulation, building direction, socioeconomic factors and behaviour of occupants. (Nguyen, Schwartz, & Dockery, 2014) also identified unique correlation curves in Boston and observed that at warmer outdoor temperatures, there is a strong correlation between indoor and outdoor temperature ($r = 0.91$, slope $\beta = 0.41$). In this study which was carried out in winter season, indoor temperatures significantly correlated with outdoor temperatures in some type of buildings such as Queenslander throughout the month of measurement (0.82, 0.83, 0.84 and 0.73, 0.75, 0.74). Whiles in other buildings there was no significant correlation (0.33, 0.28, 0.28).
Table 1: Summary of statistics of the field measurements in residential settings in six suburbs of Brisbane

<table>
<thead>
<tr>
<th>ID</th>
<th>Type of Residence</th>
<th>Month of Measurement</th>
<th>Number of Measure (N)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean (s.d)</th>
<th>95% C.I</th>
<th>Mean</th>
<th>Median</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>Multi story</td>
<td>Indoor</td>
<td>June</td>
<td>1440</td>
<td>9.56</td>
<td>26.31</td>
<td>17.16</td>
<td>10.00</td>
<td>14.40</td>
<td>17.00</td>
</tr>
<tr>
<td></td>
<td>Outdoor</td>
<td>June</td>
<td>1440</td>
<td>7.19</td>
<td>16.88</td>
<td>17.01</td>
<td>16.80</td>
<td>17.21</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Queenlander</td>
<td>Indoor</td>
<td>July</td>
<td>1488</td>
<td>6.13</td>
<td>23.58</td>
<td>16.26</td>
<td>15.75</td>
<td>16.25</td>
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</tr>
<tr>
<td></td>
<td>Outdoor</td>
<td>July</td>
<td>1488</td>
<td>6.81</td>
<td>16.50</td>
<td>17.25</td>
<td>16.99</td>
<td>17.50</td>
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</tr>
<tr>
<td></td>
<td>Single Storey</td>
<td>Indoor</td>
<td>August</td>
<td>1488</td>
<td>6.29</td>
<td>25.81</td>
<td>17.75</td>
<td>17.39</td>
<td>17.80</td>
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<td></td>
<td>Outdoor</td>
<td>August</td>
<td>1488</td>
<td>8.56</td>
<td>17.25</td>
<td>18.05</td>
<td>17.52</td>
<td>18.05</td>
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<td>25.81</td>
<td>17.75</td>
<td>17.39</td>
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<td>August</td>
<td>1488</td>
<td>8.56</td>
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<td>18.05</td>
<td>17.52</td>
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</tr>
</tbody>
</table>

*Note: The table provides a summary of the field measurements of indoor and outdoor temperatures in six suburbs of Brisbane, with statistics including minimum, maximum, mean, median, and 95% confidence intervals.*
<table>
<thead>
<tr>
<th></th>
<th>Single story</th>
<th>Indoor</th>
<th>Outdoor</th>
<th>Indoor</th>
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</table>

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HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.
Table 2: Summary of Pearson correlation coefficient between mean hourly indoor and outdoor temperatures

<table>
<thead>
<tr>
<th>ID</th>
<th>Type of Residence</th>
<th>Month of Measurement</th>
<th>Pearson correlation (r) between Mean hourly Indoor and outdoor temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>Single Storey</td>
<td>June</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>July</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>August</td>
<td>0.69</td>
</tr>
<tr>
<td>DR</td>
<td>Single storey</td>
<td>June</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>July</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>August</td>
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</tr>
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<td>HG</td>
<td>Queenslander</td>
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<td></td>
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<td>July</td>
<td>0.83</td>
</tr>
<tr>
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<td>0.39</td>
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</tbody>
</table>

All p-values <0.0001

Figure 2 Plot of Mean hourly indoor and outdoor temperature at Coopers Plains in the month of June where red line represents indoor temperature and green is outdoor temperature.
4. Conclusion

The results obtained indicated that indoor and outdoor temperatures relationship in residential settings may vary depending on factors including type of ventilation, weather season, insulation, type of building and behaviour of occupants. These results will be confirmed by collating responses obtained from the questionnaire survey to the results of field measurements which are yet to be done.
5. References


Domestic Energy Use by Australians with Multiple Sclerosis

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Abstract

Heat intolerance is a major medical problem affecting people with multiple sclerosis (MS). When their core body temperatures increase people with MS experience significantly increased symptoms which greatly reduces their capacity to participate in social, household and work activities, as well as increasing their need for pharmaceuticals and medical services. For people with MS, using air conditioners is a medical necessity.

This work was carried out in partnership between the University of South Australia and MS Australia to develop an accurate understanding of electricity consumption patterns in MS households, particularly in relation to their need to keep cool to avoid increasing their MS symptoms.

This research involved surveys and examining energy bills in 38 households of people with MS. Participant households used, on average, about 16.8% more electricity in summer and 10.5% more electricity in winter than the average for the area. This increased to 32.2% more in summer when the 24% of homes with solar PV were removed.

Examining non-solar homes more closely, summer electricity use showed those using more than the average (60% of sample) used about 80% more electricity while the rest used 18% less. The latter were predominantly found to have introduced energy savings initiatives and were careful about energy use.

The research provided evidence that people with MS require more air conditioning to keep cool as a result of their medical condition. The work provides vital material for future policy in relation to supporting vulnerable and often low income households with high energy use due to medical need.

Keywords - multiple sclerosis, air conditioning, cooling, domestic energy use
1. Introduction

People with MS identify high temperatures as one of the top three factors adversely affecting them (Simmons et al., 2004), and this in turn is known to have a significant impact on their quality of life and economic situation (De Judicibus & McCabe, 2007). Hot weather can become a significant problem for people with MS if they are unable to stay cool, with as little as 0.2–0.5°C increase in core body temperature resulting in increased MS symptoms (Guthrie & Nelson, 1995).

Previous Australian research has found that 90% of people with MS are heat intolerant, and all but the 10% who do not have or cannot afford an air conditioner, rely on air conditioners extensively on hot days and nights as a medical necessity (Summers et al, 2012). In 2011 there were approximately 21,000 people with MS in Australia (Covance & Menzies Research Institute Tasmania, 2011). MS is a chronic, progressive and incurable disease that attacks the central nervous system (brain and spinal cord). Most people with MS are of working age and three-quarters are women (Covance & Menzies Research Institute Tasmania, 2011).

People with MS face significant disease-related expenses that must generally be met from lower than average incomes as a consequence of their MS (Covance & Menzies Research Institute Tasmania, 2011). Additionally, the rapidly rising costs of electricity they require to keep cool, along with the growing number of hot days and nights due to climate change (BOM & CSIRO, 2007) create an increasingly difficult financial burden for many people with MS.

Given this situation, a clearer understanding of energy use in households of people with MS is vital. This paper presents the results and analysis of energy use in 38 households in four capital cities in Australia. This work builds directly on the Keeping Cool Survey (Summers & Simmons, 2012) conducted in 2008-09 which provided a strong overview of the impact of heat intolerance on air conditioner use by people with MS. This new research adds depth and detail regarding total energy use in these households with a particular focus on keeping cool, and utilises actual energy billing data as the central parameter for analysis.

It is also important to note that heat (and/or cold) intolerance are also common to many other people with a wide range of conditions including Parkinson’s disease, motor neuron disease, lymphoedema, amputees, spinal cord and brain injury, post-polio syndrome and fibromyalgia. Consequently the medical need and costs of keeping cool are not unique to people with MS, and this research is also likely to be indicative of issues facing many people who are heat and/or cold intolerant.

2. Methodology

The objective of this research was to determine air conditioner use within the broader context of household energy consumption by Australians with MS. It builds on the Keeping Cool Survey: Air Conditioner Use by Australians with MS (Summers & Simmons 2012), which found that 90% of people with MS in Australia were heat intolerant, and operated their air conditioners more frequently and for longer periods than most Australians out of medical necessity. That work also noted that high levels of electricity use by this group along with their low income made them especially vulnerable to increases in electricity costs.

Since that time not only have electricity costs increased significantly but gas prices have also increased. As gas penetration is quite substantial in some states of Australia – particularly Victoria, where about 81% of Victorian households and 92% in Melbourne are connected to mains gas – both gas and electricity billing data was collected. This was important given that some people with MS also report sensitivity to the cold and are therefore likely to require more heating than average in the winter. Also, overall the economic burden of energy use in MS households is of interest given that the rising energy costs must be met from often quite limited incomes already stretched due to other MS disease-related costs.
In this research, energy audits were conducted in 38 households of people with MS across Australia. Accompanying these audits was an air conditioning survey very similar to that conducted in the earlier study of Summers et al. (2012). The air conditioning survey was completed by 36 of the 38 households. In addition, data loggers were installed in 9 homes for monitoring temperature to determine thermal temperature levels and the patterns of use for cooling systems. The data from these households was compared to other ‘average efficiency’ and state of the art ‘high efficiency’ households which were previously monitored by the University of South Australia (UniSA) (Saman et al, 2012 & 2013).

The location and number of the participating homes was; Adelaide (16), Brisbane (5), Sydney (2) and Melbourne (15). These cities have been selected based on the fact that these climates have the largest number of people with MS. An energy audit was conducted in the 38 homes and included a short survey questionnaire completed by 36 homes that detailed major energy consuming appliances, such as those for heating and cooling, as well as registering any energy efficiency measures put in place such as insulation, and the impact of hot weather on the person with MS. The questionnaire was used to determine the type, size and efficiency of existing air conditioning system, pattern of use of air conditioning, and energy consumption associated with any other major energy consuming equipment.

In addition to the surveys, electricity and gas bills were sought from the 38 households. The household energy bills along with the information from the energy audits were analysed to determine summer electricity use. Due to the significance of air conditioning on summer bills a comparison was made between the home owners’ usage in summer with that of the state average or post code region – whichever was available - on the Energy Made Easy web site (Energy Made Easy, 2014). If the energy usage is greater than the average it is a reasonable assumption that costs will be higher than the average.

A summary of the samples used in this research is summarized in Table 1.

### Table 1: Summary of samples used

<table>
<thead>
<tr>
<th></th>
<th>Total Number of Households with Audits</th>
<th>Temperature Data Loggers</th>
<th>Electricity Bill Data</th>
<th>Gas Bill Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>16</td>
<td>3</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Brisbane</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Melbourne</td>
<td>15</td>
<td>4</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Sydney</td>
<td>2</td>
<td></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>38</td>
<td>9</td>
<td>25</td>
<td>15</td>
</tr>
</tbody>
</table>

#### 2.1 Data collected from Energy Bills

The 38 households involved in the project were asked to provide a signed release form to enable collection of electricity and gas bills for a period of 2 - 3 years, if available. Of these, 25 homes provided useable billing data – a few had less than a year of data that did not include summer, others provided just gas and no electricity bills. Although this represents just 66% of homes, some homes provided over 20 electricity and 20 gas bills, which was very useful for identifying trends.

Data collated over the billing periods (90 days for electricity and 60 or 90 days for gas, depending on the retailer) included energy use, energy cost, concession credits, whether the home had solar or not, postcodes and comparison data from the Energy Made Easy web site. When data from the energy bills was collated the pensioner all year round electricity concession, the gas winter heating and medical electricity cooling concessions paid by retailers were all noted. The analysis was aided by incorporating the number of household members – taken from the survey. This seasonal energy use data was then plotted together with the postcode and state average data taken from the Energy Made Easy web site.
2.2 Using Energy Bills

Electricity and gas bills are generally the most inexpensive and readily available way to measure household energy consumption, which is why they were used for this research. They are not however a simple way of determining exactly what the energy was used for. Consequently, there are some significant limitations to this method. The strengths of using energy bills include:

(a) data is available over longer periods of time
(b) often more affordable than using direct monitoring
(c) data readily available for all households
(d) they are generally very accurate
(e) they are a source of not only energy data but, costs, tariffs, concessions and emissions
(f) in some cases provide a year of quarterly historical bar graph energy use data.

The best way to get an accurate picture of energy use for cooling (and heating) is to install data logging equipment to monitor the energy directly at end-use. Monitoring equipment is usually located in the electricity or gas meter box and data collected at 15 minute or 30 minute intervals. Total household energy use is generally collected as well. Logging equipment is left in place, ideally over a one year period, and the percentage of total home energy use for heating and cooling can then be accurately determined. However, though this is the ideal procedure it is expensive and time consuming.

The next best option for data collection is to use homes with ‘interval’ or ‘smart’ meters that provide the retailer with ½ hourly electricity usage data. Unfortunately most homes in Australia are not yet equipped with these meters, although they are being rolled out gradually in many locations.

3. Results and Discussion

This section presents the results from the survey questionnaire, energy audits, billing data and temperature loggers.

3.1 Air conditioning Survey Summary

The energy audit carried out during this project included a detailed air conditioning survey. The average results are given in Table 2. The number of contributors to the survey was 36. In relation to wall insulation, the fact that 100% of homeowners said there was ‘none’ could indicate that some may not have known whether there was any or not but answered in the negative anyway.

As expected it can be seen that a majority of participants in this research with MS do in fact experience a number of adverse symptoms during hot weather. Many of the questions used in this survey mirror questions that were asked in the previous Keeping Cool Survey (Summers & Simmons 2012), and some comparisons are useful for considering the group participating in this survey relative to the previous extensive national survey of 2,384 respondents. The average temperatures at which people turn on their air conditioners to get cool were essentially identical in both surveys: 29°C in this survey compared to 29.2°C previously. Efforts to improve thermal efficiency are slightly higher for this group than in the previous survey, for instance external window coverings at 63.9% compared to 40% previously.

Comparison of the results in relation to what happens to the person with MS when they get too hot, respondents in this current survey generally identified higher incidences of problems occurring. For instance, 94.4% reported reduced energy and needing more rest, compared to 82% previously, and 75% reported being unable to participate in their usual social activities compared to about 46% previously. A much larger proportion reported having been hospitalized because of heat – 13.9% compared to about 3% previously. Data from the earlier Keeping Cool Survey is a valid and robust description of the national MS population given the quality of the sampling frame used and that well over 10% of the total estimated number of people with MS in Australia were surveyed.
Not surprisingly, given the smaller sample here there is some variation from national averages and it would appear that in comparison nationally, this survey sample is impacted somewhat more by heat than the national average would indicate.

Table 2: Summary of results from air conditioner survey

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Yes</th>
<th>No</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>How hot is it outside when you usually turn your air conditioner on?</td>
<td>29 C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How old is your air conditioner?</td>
<td>7.3 yrs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer thermostat</td>
<td>23.1 C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter thermostat</td>
<td>22.5 C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How many hrs would air con be used on HOT summer day when temp &gt; 30C</td>
<td>10.4 hrs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hrs air con on an AVERAGE hot summer day when temperature 25 to 30 C?</td>
<td>3.4 hrs</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In addition to an air conditioner, do you have any other home modifications that help you keep cool? Please note any that apply

- External window blinds, awnings, or other coverings 63.9% 36.1%
- Internal window blinds, awnings, or other coverings 63.9% 36.1%
- Roof insulation 63.9% 36.1%
- Roof Vents 11.1% 88.9%
- Wall insulation 100.0%

As a person with MS, what happens to you when you get too hot? (Tick all that apply):

- Nothing I cope just fine
- I lack energy and require more rest 94.4% 5.6%
- Apart from fatigue, my other symptoms of MS become worse 72.2% 27.8%
- I am unable to participate in normal social activities (time with family or friends) 75.0% 25.0%
- I am unable to do my normal household duties (eg cleaning, cooking, etc.) 69.4% 2.8% 27.8%
- I am unable to work effectively 63.9% 36.1%
- I am unable to look after myself in the usual manner 27.8% 2.8 %* 69.4%
- I need more medication to cope 8.3% 8.3% 83.3%
- I have felt sufficiently unwell to require a doctor or other health professional 8.3% 2.8% 88.9%
- I have been hospitalised because of heat 13.9% 2.8% 83.3%
- Seizures 2.8% 2.8% 94.4%
- Physical collapse 33.3% 66.6%
- Loss of motor function 52.8% 47.2%

* sometimes

3.2 Electricity and Gas Bills

The data from the air conditioning survey was combined with data from energy bills, and the following information extracted for use in analysis;

- Household occupancy
- Gas and/or electricity use per season
- Gas and/or electricity costs per season
- Whether home has solar PV or a solar water heater
- Whether energy concessions were in place
- Air conditioner type plus any other air conditioner information from the survey
- Energy efficiency initiatives noted

Additionally, using the Energy Made Easy web site a comparison was made of summer and winter household electricity use with the state or post code average – whichever was applicable.

A summary of results are presented in Table 3. The Table of results is divided into three parts:

- All available data
- Homes that do not have solar
- Homes with solar (photovoltaics and/or solar hot water)
Table 3: Summary of air conditioner and billing data surveys

<table>
<thead>
<tr>
<th>Air conditioning and Billing Data</th>
<th>Ave All Homes with Billing Data</th>
<th>Ave Homes with No Solar</th>
<th>Ave of Homes With Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>How hot is it outside when you usually turn your air conditioner on?</td>
<td>29.0 C</td>
<td>29.2 C</td>
<td>28.3 C</td>
</tr>
<tr>
<td>How old is your air conditioner?</td>
<td>7.3 yrs</td>
<td>8.3 yrs</td>
<td>5.9 yrs</td>
</tr>
<tr>
<td>Summer thermostat</td>
<td>23.1 C</td>
<td>23.2 C</td>
<td>23.0 C</td>
</tr>
<tr>
<td>Winter thermostat</td>
<td>22.5 C</td>
<td>22.7 C</td>
<td>19.5 C</td>
</tr>
<tr>
<td>How many hrs would A/C be used on HOT summer day when temp &gt; 30C</td>
<td>10.4 hrs</td>
<td>11.2 hrs</td>
<td>9.3 hrs</td>
</tr>
<tr>
<td>Hrs A/C on an AVERAGE hot summer day when temperature 25 to 30 C?</td>
<td>3.4 hrs</td>
<td>4.1 hrs</td>
<td>1.5 hrs</td>
</tr>
<tr>
<td>Number of Persons in Home</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Annual Energy Bill (Electricity + Gas) $/y</td>
<td>$2,068</td>
<td>$2,350</td>
<td>$1,174</td>
</tr>
<tr>
<td>Summer Electricity Use &gt; or &lt; State Ave (%)</td>
<td>16.8%</td>
<td>32.2%</td>
<td>-32.0%</td>
</tr>
<tr>
<td>Winter Electricity Use &gt; or &lt; State Ave (%)</td>
<td>10.5%</td>
<td>13.0%</td>
<td>2.8%</td>
</tr>
</tbody>
</table>

The results showed that participant households used, on average, about 16.8% more electricity in summer and 10.5% more electricity in winter than the state or post code average. This increased to 32.2% more in summer when the 24% of homes with solar PV are removed. Not only do solar PV systems have maximum impact on peak loads in summer but the Energy Made Easy web site data was developed using historical data taken at a time when the percentage penetration of solar PV would have been less than 5%, so impact of solar on the resulting average electricity use would have been small. In 2014 the penetration of PV on South Australian households was 24% - the highest penetration in Australia.

Table 3 shows that the homes that had solar installed tended to have newer air conditioners, set their thermostats lower than average in winter but not in summer and used their air conditioners less in both summer and winter. Their average energy bills ($1174/y) were approximately 50% less than the non-solar households, and they used about 32.0% less electricity than the state averages in summer.

Table 4 shows the household summer electricity and gas use greater than or less than the state averages for non-solar homes for summer and winter, along with energy cost from energy bills. The average number of people in each household (for both above and below average energy use) was 2.5. The non-solar homes tended to have higher annual energy bills compared with the overall average, $2350/y compared to $2068/y. When the data of the non-solar group was analysed more closely it was found that:

- about 60% of homes used more electricity than average in summer, and on average they used ~80% more.
- the remainder of homes that used less, ~18% less than the state averages were predominantly found to have introduced energy savings initiatives and were careful about energy use. None had ducted refrigerative air conditioners – 12.5% had window/wall, 25% evaporative and 67.5% split system air conditioners.
Table 4: Summary of summer and winter electricity use compared to state averages for non-solar homes

<table>
<thead>
<tr>
<th></th>
<th>Summer electricity use</th>
<th>Winter electricity use</th>
<th>Total Cost (electricity + gas bills)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of homes &gt; state average</td>
<td>80%</td>
<td>52%</td>
<td>$3,115</td>
</tr>
<tr>
<td>Average of homes &lt; state average</td>
<td>-18%</td>
<td>-30%</td>
<td>$1,564</td>
</tr>
<tr>
<td>TOTAL relative to state average</td>
<td>32.2%</td>
<td>13.0%</td>
<td>$2,350</td>
</tr>
</tbody>
</table>

A number of graphs were plotted using available data to see whether any correlations could be found between occupancy, costs, usage hours on hot days etc. Little correlation was found, however, a selection of the graphs is shown below to illustrate common usage patterns and other details.

Figure 1 shows the annual energy bill taking into account number of persons in the home. The households with solar have been included in this figure, which clearly shows that the solar homes have cheaper bills. Figure 2 shows the summer electricity use greater than each state’s average taking into account number of persons in the home. The high outlying points on both graphs are from two homes with underfloor heating which is expensive to operate.

Two reasonably strong data correlations found in the analyses that were not particularly surprising: as both summer and winter energy use increases, so do the costs for those households. And the converse is equally true.
3.3 Data from Temperature Loggers

From the sample of 38 homes of people with MS (PwMS), 9 were selected to have monitoring equipment installed (3 in Adelaide, 4 in Melbourne and 2 in Sydney), so that the temperature in the bedroom and/or the living area of the home of the person with MS could be monitored. This enabled the temperature levels and the pattern of air conditioning use in these homes to be determined.

Data logger material was also available for households in Adelaide and Sydney. In Adelaide comparison data was available from December 2012 to February 2013, and averages from 9:30am to 8:30pm were used. The average temperature in the 2 homes with PwMS was 1.5°C cooler than the 9 homes without PwMS. Furthermore, the temperature in the households without PwMS was on average at 27°C or greater for 150 hours (i.e. 52%) more than the households with PwMS. The data for the households without PwMS was taken from Lochiel Park, an energy efficient housing development (Saman et al, 2012 & 2013).

A comparison was also made for 2 homes with PwMS to 7 homes without PwMS for Sydney. Table 5 shows average temperature data for the 2 households with PwMS and 7 households without PwMS. Since Sydney has a milder weather, only days with a maximum temperature above 35°C were analysed. The data is taken from 9:30am to 8:30pm. Table 5 shows that the average temperature in the homes with PwMS was 0.8°C lower than the homes without PwMS.

Table 5: Indoor temperature in Sydney households with and without PwMS on days over 35°C

<table>
<thead>
<tr>
<th>Day</th>
<th>Max outdoor temperature</th>
<th>Indoor temp of homes with PwMS</th>
<th>Indoor temp of homes without PwMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/12/2012</td>
<td>36.6</td>
<td>26.1</td>
<td>27.1</td>
</tr>
<tr>
<td>24/12/2012</td>
<td>37.6</td>
<td>26.5</td>
<td>27.2</td>
</tr>
<tr>
<td>5/01/2013</td>
<td>37</td>
<td>25.7</td>
<td>26.6</td>
</tr>
<tr>
<td>8/01/2013</td>
<td>41.1</td>
<td>25.8</td>
<td>27.4</td>
</tr>
<tr>
<td>8/02/2013</td>
<td>35.4</td>
<td>25.4</td>
<td>26.1</td>
</tr>
<tr>
<td>9/02/2013</td>
<td>35.7</td>
<td>26.7</td>
<td>26.5</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>26.0</td>
<td>26.8</td>
</tr>
</tbody>
</table>

4. Conclusion and Policy Recommendations

This study examined energy use and costs, with a particular focus on medically-required cooling on hot days and nights in 38 homes of people with MS compared to average residential energy use patterns. The Australian states targeted were Queensland, New South Wales, Victoria and South Australia and the people with MS were asked to participate in a survey, energy audit and electricity plus gas bill analysis. Gas was included as in Victoria and SA gas forms quite a high proportion of energy use in many homes and during the energy audit it was found that some people found cold as well as hot weather particularly problematic as a consequence of their MS. A detailed examination of the findings can be found in the project report (Bruno et al, 2014).

The main findings from this study regarding households that include people with MS are:

- Participant households used, on average, about 16.8% more electricity in summer and 10.5% more electricity in winter than the state or post code average. This increased to 32.2% more in summer when the 24% of homes with solar PV were removed.
- Looking more closely at non-solar homes, summer electricity use showed that those using more than the state or post code average, 60% of sample, used about 80% more while the rest used about 18% less. The latter were predominantly found to have introduced energy savings initiatives and were careful about energy use.
• In addition, 52.6% of non-solar homes had annual energy costs (electricity plus gas) of $2000 - $5950, putting them in the medium to high cost range. The remainder had an average bill of $1540/y.

• Homes with either solar PV or a solar hot water tended to have newer air conditioners, set their thermostats lower than average in winter but not in summer and used their air conditioners less in both summer and winter. Their average energy bills ($1174/y) were approximately 50% less than the non-solar households, and they used about 32.0% less electricity than the state averages in summer.

• Frequently gas bills are of the same order and sometimes higher than electricity bills.

• Homes with ducted refrigerative air conditioners were associated with the highest energy use and electricity bills and those with window/wall air conditioners with the lowest bills. However, the latter were most likely to be smaller and the air conditioning confined to single rooms. Ducted evaporative air conditioners used the least electricity but as they are frequently associated with gas heating the annual energy bills for homes with this form of cooling were virtually the same as those that use split system air conditioners for both heating and cooling.

Recommendations include:

• Existing and new energy efficiency schemes regarding existing and future housing stock should ensure that specific targeting of these high energy use/low income households are targeted as part of their overall strategy.

• Examining the potential of developing a single national medical energy concession, ideally based on a percentage of the overall energy bill to ensure equity, reduce administrative costs and provide incentives for concession funders to promote energy conservation measures (including solar PV installations) for these households.

• Future research should include a more detailed study of energy use in MS households, as well as in other households such as those with Parkinson’s disease, spinal cord injury, etc that are known to have a medical need to keep warm and/or cool.

5. References


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Happy Homes – the Relationship between Homes and Mental Wellbeing: a Review of the Literature

Professor Gregory Morrison, Curtin University Sustainability Policy Institute, Australia, greg.morrison@curtin.edu.au

Abstract

Purpose: This paper set out to uncover the advice available to help people take effective action within our home to improve mental health. The literature and professions are virtually silent on the issue. The professional advice is often the opposite suggesting we should get out of our homes - go for a walk, exercise, play sport, go to the cinema, meet friends, socialise and don’t isolate yourself. There is nary any advice about what we can do to our homes to help maintain our mental health. Our home - the physical space where we spend large amounts of energy and time is largely an empty shell for the mental health industry. The message currently presented appears to be “remember to close the door as you leave … to get better”. Safe and secure housing is a fundamental pillar of an inclusive and productive society. Yet we don’t know for sure what safe, secure, or good housing looks like.

Approach: This paper will begin that dialogue with a comprehensive literature review. The approach adopted to investigate this literature focussed on thinking about what a policy official might experience if they were tasked to develop guidance on steps to improve housing’s impact on mental health. Such an individual would not necessarily be aware of the extent of the literature, or of academic disciplines. This approach both made the literature review problematic, but also in some ways also produces a useful insight.

Key findings: The paper concludes that there are three issues that should shape future research: first is the need for transdisciplinary translational research; second is to focus initially on the needs of the resident before the bricks and mortar; third is to endeavour to include the social pillar of sustainable development alongside the economic and environmental.

Originality: This paper is original as it seeks to start a conversation about what self-help measures people can adopt within their homes to protect or enhance their mental wellbeing

Keywords: mental wellbeing, mental health, housing, homes, transdisciplinary research, translational research
1. Introduction

The prevalence of mental health issues in the community is a concern. Australia suffers from 8 suicides per day with a disproportionate representation in the Aboriginal community. Society’s response has been evolving. Mental health is now a topic for public debate. However, the role of the space where people live - the home - has received relatively little attention. The self-help advice that is available routinely refers to the importance of socialising, taking up a hobby and generally getting outside (e.g., BeyondBlue, 2014, or Better Health Victoria, 2016). Unlike the environmental and economic pillars of sustainable development, and unless you are in the care of the state, there is little to help builders, renovators, landlords, tenants, carers or home owners to take actions to improve the potential for their living space to either prevent a slide down the mental health continuum or just to enjoy better mental well-being.

Table 1: Mental health continuum (developed from Bridging the Distance (2016) and Mental Health Commission of Canada (2016)).

<table>
<thead>
<tr>
<th>Self-care and social support</th>
<th>Intervention by health care sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy</td>
<td>Reacting</td>
</tr>
<tr>
<td>Normal functioning</td>
<td>Common and reversible</td>
</tr>
<tr>
<td>Normal mood fluctuations.</td>
<td>Irritable/Impatient</td>
</tr>
<tr>
<td>Usual self-confidence</td>
<td>Trouble falling asleep</td>
</tr>
<tr>
<td>Comfortable with others</td>
<td>Lowered energy</td>
</tr>
<tr>
<td></td>
<td>Difficulty in relaxing.</td>
</tr>
<tr>
<td></td>
<td>Intrusive thoughts.</td>
</tr>
<tr>
<td></td>
<td>Decreased social activity</td>
</tr>
</tbody>
</table>
2. Background

There is longstanding acknowledgement that a person’s physical and mental health can be impacted by the place where they live (Chapin, 1951; Novick, 1971). Since human’s earliest history those who developed good interventions to keep the unwanted out (hungry animals, weather, enemies) and the wanted in (warmth, family, food, community) survived. Without good housing people have little chance of maintaining meaningful activities and supportive relationships (Browne & Hemsley, 2010). Housing gives people a physical and cultural space in society and can influence how, and what, they contribute to society (Bendiner-Viani & Saegert, 2007).

3. Methodology

The approach adopted to conduct this literature focussed on providing support for a policy official if they had been tasked to develop guidance on possible steps to improve the houses’ impact on the occupants’ mental health. Such an individual would not necessarily be aware of the extent of the literature, or the academic disciplines. This approach both made the literature review problematic, and in some ways also produces a useful insight.

Papers were selected through a search of the literature using Web of Science with the terms “housing” and “mental health” (and variants) searching both paper title and content. Not surprisingly this produced a large number of papers. Only those papers that illuminated the relationship between housing and mental wellbeing were selected for deeper analysis.

‘Relevant papers’ were defined as those that demonstrated an evidenced link between action by a party (e.g. decision maker, policy maker, designer, carer, home owner, or occupier) and the impact on the person living in the house’s mental wellbeing. This meant that the issues defined as ‘self-care’ and ‘social support’ could be interrogated as well as ‘intervention by health care sector’ (see Table 1).

These papers came from a range of disciplines largely within the health, planning and built environment sectors. For the purposes of this paper ‘housing’ was broadly defined so as not to limit by physical structure or tenure and refers to a physical built space designed for human habitation.
'Mental health' has been similarly broadly defined to capture the impacts of interventions across the mental health continuum (see Table 1) that help people move away from treatment and intervention with a particular focus on the self-care and social support end of the spectrum. A total of 96 papers were analysed in detail with findings listed and analysed. Three categories of findings emerged from the analysis relating to the impact of housing on an occupant's mental health. The categories were: scope of influence over own life; quality of the home (both build and use) and quality of the neighbourhood.

Topics such as homelessness, alcohol, drugs and their impact on housing and mental health were not included in this review (despite the volume in the literature). Interestingly the large corpus of work on biophilics was only covered tangentially by this literature review in spite of the long established and positive link between impacts of nature on mental health (Sodelund & Newman, 2015).

4. Discussion

There is little in the literature about what healthy people can do within their homes to protect and improve their mental wellbeing (either in new, or existing homes). The main focus of the literature with regard to housing and mental health was:

1. Focus on those marginalised in society (be they at the ‘intervention’ end of the mental health continuum or in need of housing assistance);
2. The issues that can trigger a decline in physical and/or mental health of home dwellers; and
3. Descriptive research (i.e. we did this and that happened) rather than translational research (i.e. translating the evidence into policy advice).

There is a pervading tendency in the literature of viewing the house as primarily a tool for delivering policy (e.g. meeting carbon targets for the benefit of society). As such much of the discourse is about how to use the home to deliver benefits to a non-static combination of the individual, community and wider society.

In many ways this is what joined-up, or co-ordinated, Government is about – using the most effective tools to deliver policy outcomes. However it also means that the interests of the individual are not subjugated to the interest of the community or wider society. Somehow all interest need to be met – this is why policy making is not simple.

There was no unity in the review about the definition of what a quality house or local neighbourhood looked like, with the majority of the papers focussing on ‘poor quality’. However, there are issues identified that are associated with a positive impact on mental health which should therefore be embraced by society. There are also issues identified that negatively impact mental health (which should therefore be avoided in future). There was a final set of issues identified that were currently too complex to be set into a binary function of embrace/avoid and require further work. Under each section we have included a table with a very brief summary of each paper which have been accordingly categorised as ‘embrace’, ‘avoid’ or ‘complexity’.

This review revealed that there is not a single ‘thing’ that can be defined as good housing in terms of promoting mental health. Rather it is the result of three interconnected evidenced categories where intervention could be effective in helping to improve an individual's mental health.

These go wider than the simple fabric of the house and the categories are:

- the extent of an individual’s influence over their own lives;
the quality of the individual’s housing (which subdivides into both quality of build and of use); and
the quality of the local neighbourhood.

This is illustrated in Figure 1 which suggests that from the perspective of the individual ‘good’ housing does not exist in isolation, but is probably better described as a combination of influence, location and quality. Categories may be mutually compensatory (i.e. a good neighbourhood may mask a poor dwelling). However, importantly the extent of this compensation is unclear. Policy makers might not have a similar view of good housing – and therein lies the heart of problem. A Commonwealth policy maker with responsibilities for delivering climate change outcomes may view ‘good’ differently from a care worker at shire level.

Figure 1: Categories influencing a person’s mental health

Category 1: Influence over decisions
Several studies pointed towards the importance of helping people take control over their lives. This was as true for those suffering from drug and alcohol dependence (Allen, 2003) as to the management and maintenance of a residential complex (Mridha, 2015). Control over one’s destiny is one of the key’s to self-actualisation (Henwood et al., 2015) and papers that focussed on the issue pointed towards the importance of involving residents in the decision making process. However, this is not just about residents and includes involvement of a wider network of stakeholders (Connellan et al., 2013), and further the process of involvement should not be seen as a tick box exercise but rather a continuous endeavour as its impact is additive (Shenassa, 2007). In the leadership literature this is typically referred to as empowerment, but empowerment means that someone still has the power to withdraw authority; Marquet (2012) speaks of emancipation – that is the freedom to make a decision, be it good or bad.

Influence and control comes in many forms ranging from controlling the temperature of the house to decisions about where or how to live. It can mean the development of participatory systems so that a community can have some form of control over its destiny (Shrubsole et al, 2014). The key appears to be the balance between doing something to people and doing something with people, as coercive action is unlikely to be generally successful (Allen, 2003); whereas involvement seems to be helpful (see Table 3 below). Therefore, the development of capacity to deliver individual, designer, carer, health professional and community leadership and dialogue could be an important lever to help maintain mental health across the piece. It is the lack of influence over one’s future that can be counter-productive.
Table 3 provides a summary of the literature relating to an individual’s influence over decisions that will impact upon them (see methodology for explanation of table headings). It shows that there was general consensus that involvement in decisions is something to be embraced because of the link to a person’s mental wellbeing and that it should become pervasive as the issue is not just about ‘big’ decisions, but also minor irritations (such as setting the temperature of the dwelling (Walker, 2013)).

Table 3: Theme: Influence over decision – summary of the literature

<table>
<thead>
<tr>
<th>Embrace</th>
<th>Avoid</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respect and status of residents (Bond et al., 2012)</td>
<td>Designs to avoid (Connellan et al., 2013)</td>
<td>Multiple uses and end users to consider (Keams et al., 2015)</td>
</tr>
<tr>
<td>Inclusive design and self-actualisation (Henwood et al., 2015)</td>
<td>Impact of preset thermostats (Walker, 2015)</td>
<td>Issues around citizenship contribution to society (Sylvestre et al., 2007)</td>
</tr>
<tr>
<td>Include carers in decision making (Browne &amp; Hemsley, 2010)</td>
<td>Avoid coercion (Allen, 2003)</td>
<td></td>
</tr>
<tr>
<td>Management and maintenance (Mridha, 2015)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control is additive (Shenassa et al., 2007)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participatory systems (Shrubsole et al., 2014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration of stakeholders in the design process (Connellan et al., 2013)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empowerment – community integration (Nelson et al., 1998)</td>
<td></td>
<td></td>
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<tr>
<td>Seeing from the residents perspective (Smith et al., 2015)</td>
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</table>

Category 2: Quality of the neighbourhood

The quality of the local neighbourhood was specified by several authors for its impact on people’s mental health and wellbeing. The causation ranged from the socio-economic status of the neighbourhood (Fitzpatrick, 2007) through to the impact of new front doors (Curl et al., 2015) to design of new neighbourhoods (Jones-Rounds et al., 2014). The issue of design of something new compared to improving something old was not explicitly covered together in the papers reviewed. However, it was dealt with in separate papers (eg Galea et al., (2007), Fitzpatrick (2007), Jones-Rounds et al., (2014)). That said the provision of quality outdoor space, regardless of the local neighbourhood can have a positive impact – which Gidløf-Gunnarsson and Ohrstrom (2007) demonstrated through the provision of noise ‘free’ areas, and others (Bendiner-Viani and Saegert, 2007) demonstrated in terms of ‘good quality’ public space. Understanding the causal pathways will be important in helping to design effective interventions with only intended consequences (Dunstan et al., 2013).

Table 4 summarises the literature on the quality of the community. This is a complex area where there is much descriptive work, but – in this review – less translational work. The dynamics between local community and quality of housing emerges with Jones-Rounds et al., (2014) arguing that a quality exterior environment can offset poor interior environment.
Table 4: Quality of the community – summary of the literature

<table>
<thead>
<tr>
<th>Embrace</th>
<th>Avoid</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community safety (Blackman &amp; Harvey, 2001)</td>
<td>Poor quality neighbourhood (Galea et al., 2007)</td>
<td>Quality of interactions with neighbours and quality of neighbourhood (Dunstan et al., 2013)</td>
</tr>
<tr>
<td>Thermal comfort and new front doors (Curl et al., 2015)</td>
<td>Lack of green space (Bertram &amp; Rehdanz, 2015)</td>
<td>Planning/health linkages (Wells et al., 2010)</td>
</tr>
<tr>
<td>Sounds (Andringa &amp; Lanser, 2013)</td>
<td>Loneliness resulting from residential structures (Kearns et al., 2015)</td>
<td>Recovery from stress following viewing green spaces (van den Berg et al., 2015)</td>
</tr>
<tr>
<td>Noise free areas (Gidlof-Gunnarsson &amp; Ohrstrom, 2007)</td>
<td></td>
<td>SES of neighbourhood ( Fitzpatrick, 2007)</td>
</tr>
<tr>
<td>Green space (Bertram &amp; Rehdanz, 2015)</td>
<td></td>
<td>Impact on TV watching (MacLeod et al., 2008)</td>
</tr>
<tr>
<td>Location important rather than dwelling type (McCarthy, 1985)</td>
<td></td>
<td>Quality of neighbourhoods is important but so too is respect and status (Bond et al., 2012)</td>
</tr>
</tbody>
</table>

Category 3: Quality of the home

The literature revealed much in terms of the link between mental health and housing and develops two sub-themes relating to how the house is designed and how the house is used.

Poor design impacts mental health (Guite et al., 2006); poor housing can also have intergenerational impacts as children’s emotional functioning can be impacted (Coley et al., 2013). It also helpfully identified issues that were applicable to only some sections of society – for example for people on low-moderate income ‘unaffordable’ housing has a negative impact on their mental health (Bentley et al., 2011); or age related mental health impacts and housing (Howden-Chapman et al., 2011).

This literature review did not find what a good or “normal” (Hogan and Carling, 1992) house was in terms of helping people attain or retain a healthy mental state. This is consistent with Bonnefoy (2007) and Evans et al., (2003). However there is some discussion about the development of a housing quality assessment tool (Keall et al., 2010). Although there is not agreement on whether housing quality is more important than housing type (Kearns et al., 2012).

Table 5 summarises the literature relating to the quality of the home. There is a wealth of research on the relationship between the home and mental wellbeing, but there is little that an individual might be able to adopt to enhance their mental wellbeing.

Table 5: Quality of the home – summary of the literature
<table>
<thead>
<tr>
<th>Embrace</th>
<th>Avoid</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating and new front doors (Curl et al., 2015)</td>
<td>Unaffordable housing (Bentley et al., 2011)</td>
<td>Influence of sleep quality, indoor air quality, accessibility, obesity, mould, hygrothermal conditions and energy consumption on mental health (Bonnefoy, 2007)</td>
</tr>
<tr>
<td>Lack of draughts (Blackman &amp; Harvey, 2001)</td>
<td>Poor design and social features (Guite et al., 2006)</td>
<td>Clustering of ailments in deprived areas (Adamkiewicz et al., 2014)</td>
</tr>
<tr>
<td>Engage with nature (Maller et al., 2009)</td>
<td>Dampness (Hopton &amp; Hunt, 1996)</td>
<td>Indoor conditions affect physical health (Veitch, 2008)</td>
</tr>
<tr>
<td></td>
<td>Affordability issue as get older (Howden-Chapman et al., 2011)</td>
<td>Housing tenure (Baker et al, 2013)</td>
</tr>
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<td></td>
<td>Crowded homes (Solari &amp; Mare, 2012)</td>
<td>Healing environment MOBE (Hoisington et al., 2015)</td>
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<tr>
<td></td>
<td>Overcrowding (Shenassa et al., 2007)</td>
<td>Home repossession (Pevalin et al., 2009)</td>
</tr>
<tr>
<td></td>
<td>Violence, housing disarray and childhood asthma (Suglia et al., 2010)</td>
<td>Quality of interactions with neighbours and quality of neighbourhood (Dunstan et al., 2013)</td>
</tr>
<tr>
<td></td>
<td>Crowding (Wells &amp; Harris, 2007)</td>
<td>Step down community housing for people coming out of care (Barr et al., 2013)</td>
</tr>
<tr>
<td></td>
<td>Heat stress (Maller &amp; Strengers, 2011)</td>
<td>Homes and mental health making the policy links (Johnson, 2005)</td>
</tr>
<tr>
<td></td>
<td>Poor quality housing has higher impact on mental wellbeing than housing type (Grigg et al., 2008)</td>
<td>Affordability and homelessness (Martin, 2015)</td>
</tr>
<tr>
<td></td>
<td>Influence of sleep quality, indoor air quality, accessibility, obesity, mould, hygrothermal conditions and energy consumption on mental health (Bonnefoy, 2007)</td>
<td></td>
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<tr>
<td></td>
<td>Clustering of ailments in deprived areas (Adamkiewicz et al., 2014)</td>
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<td>Housing tenure (Baker et al, 2013)</td>
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</tr>
<tr>
<td></td>
<td>Home repossession (Pevalin et al., 2009)</td>
<td>Quality of interactions with neighbours and quality of neighbourhood (Dunstan et al., 2013)</td>
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<td></td>
<td>Step down community housing for people coming out of care (Barr et al., 2013)</td>
<td>Homes and mental health making the policy links (Johnson, 2005)</td>
</tr>
<tr>
<td></td>
<td>Affordability and homelessness (Martin, 2015)</td>
<td>Health implications of multiple environmental risk exposure (Evans et al., 2003)</td>
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<tr>
<td></td>
<td>Health implications of multiple environmental risk exposure (Evans et al., 2003)</td>
<td>Patient physical environment (van der Schaaf et al., 2013)</td>
</tr>
<tr>
<td></td>
<td>Patient physical environment (van der Schaaf et al., 2013)</td>
<td>Pleasurable and annoying sounds (Andringa &amp; Lanser, 2013)</td>
</tr>
<tr>
<td></td>
<td>Little research on the positive health effects of exposure to areas of good sound quality (van Kempen et al., 2014)</td>
<td>Improvements produce health benefits (Pevalin, 2009)</td>
</tr>
<tr>
<td></td>
<td>Improvements produce health benefits (Pevalin, 2009)</td>
<td>Poor housing &amp; children’s emotional functioning (Coley et al., 2013)</td>
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<td></td>
<td>Unexpected consequences (MacLeod et al., 2008)</td>
<td>Unexpected consequences (MacLeod et al., 2008)</td>
</tr>
<tr>
<td></td>
<td>Community, family and individual influencers (Curtis et al., 2013)</td>
<td>Community, family and individual influencers (Curtis et al., 2013)</td>
</tr>
<tr>
<td></td>
<td>Global south might need different research methodologies (Ferguson et al., 2013)</td>
<td>Global south might need different research methodologies (Ferguson et al., 2013)</td>
</tr>
<tr>
<td></td>
<td>House design big impact on use of environment (Marcheschi et al., 2016)</td>
<td>House design big impact on use of environment (Marcheschi et al., 2016)</td>
</tr>
<tr>
<td></td>
<td>Permanent housing has a positive impact (Smith, 2005)</td>
<td>Permanent housing has a positive impact (Smith, 2005)</td>
</tr>
</tbody>
</table>
Sub-category – how the house is designed

Housing design quality was shown to be key – good design has a big impact on how people use the house and development (Marcheschi et al., 2016), and the opposite (Guite et al., 2006). Simple things like daylight, view of nature (Maller et al., 2009) and noise (Andringa & Lanser, 2013), being damp free (Hopton & Hunt, 1996) are all important but so too are other variables (such as the interesting emerging work on microbiomes (Hoisington et al., 2015)). Whilst all are part of good design: all can be devalued through occupation. Designing a house to drive behaviours that promote mental health (Marcheschi et al., 2016) or how people use the house (Brunsgaard & Fich, 2016) are clearly important and bring us back to the issues of values raised by Sylvestre et al., (2007).

However new build whilst important will always be less in quantity than the number of existing homes. Housing improvements also deliver benefits (Pevalin et al., 2008) – such as reducing drafts (Blackman & Harvey, 2001), removing dampness (Hopton & Hunt, 1996), renovating bathrooms and kitchens (Curl et al., 2015) as well as providing heating (ibid). Issues such as preset thermostats (Walker, 2015) can have the opposite impact and could result in heat stress which itself has a negative impact on mental health (Maller & Strengers, 2011). Interestingly Curl et al., (2015) showed that the provision of heating can also negatively impact occupants’ physical activity which in turn can impact on mental health.

Sub-category - how the house is used

Not being able to afford housing or not able to afford to run the house as designed are both stress inducers and can negatively impact a person’s mental wellbeing. Such impacts are clearly delineated according to the ability to pay. Unaffordable housing is seen to be a key issue relating to mental wellbeing for those who are in the low-to-moderate income bracket (Bentley et al., 2011) as is the ability to pay bills (the impact of which changes with age (Howden-Chapman et al., 2011)). Although not directly related to cost, but linked, the link between housing tenure and mental well-being is unclear with studies demonstrating both sides of a different coin. Pevalin (2009) demonstrated that the mental health impact of home repossession is greater if it is owned rather than rented. Whereas Baker et al., (2013) found “little evidence of an intrinsic relationship between tenure and mental health”. However, Smith (2005) found a strong link between secure, permanent accommodation and improving mental health.

How occupants use a house can impact on mental wellbeing. Overcrowding (Solari & Mare, 2012) is one such example of how occupants’ use of their house can devalue good design and lead to a negative impact on mental health (Shenassa et al., 2007). Reducing overcrowding will improve mental health (Wells & Harris, 2007). Curtis et al. (2013) similarly identifies community, family and individual behaviours as being important influencers. For example production of ‘annoying’ noise (Andringa & Lanser, 2013) can mitigate design and lead to stress of inhabitants or neighbours.

The behaviour of housing occupants – violence or just disarray - can also have a negative impact on health (Suglia et al., 2015). The issue of how a house is used also links to the earlier discussion over control. Lack of control, or influence over the behaviour of inhabitants or neighbours can lead to negative mental health impacts.

5. Limitations of this work

As the literature is limited about the modifications that can be made to people’s homes to improve their mental well-being (or help to protect them from a decline) it is not possible to say with confidence that all such literature has been captured. However the lack of evidence in the literature is a theme that has been present – and commented upon – since the research of Evans et al. (2003).
The approach of this literature review however, did mean that much literature on the role of intervention in prisons, police stations and similar institutions were not included. Similarly, there is much in the literature about ‘green offices’ and how green office space may or may not help to improve the productivity of, and environment for office workers (e.g. Thatcher and Milner (2012)). This paper has not sought to identify the research in the green office space and apply it to private housing but there are very likely to be transferable lessons.

Similarly this review did not pick up the body of work on biophilics. This is a rich stream of work that could well inform translational research to deliver benefits along the mental health spectrum as well as cover new and existing homes.

The vast majority of the papers reviewed were based in a western context with Marais and Cloete (2014), Marais et al., (2013) and Mridha (2015) being the exceptions. It is important to recognise that the research methodologies used in western cultures are not necessarily directly transferrable to other regions of the world (Ferguson et al., 2013; Marais et al., 2013).

6. Conclusion

There are three over-arching observations from this literature review.

Firstly is the need for transdisciplinary (Jantsch, 1972) and translational research (Nelson et al., (1998), Osypuk (2014) and Veitch (2008)). Transdisciplinary because the literature review revealed the difficulty faced in capturing all the relevant disciplines; and translational because there is a continued and evidenced need to start developing interventions that can help people in the self-help/social support end of the continuum. Such translational research needs to focus on as a minimum the individual and their social support as delivery pathways. Ideally such studies should be longitudinal (Pevalin et al., 2008). Either way, it cannot be acceptable from a policy perspective to leave those issues largely uncovered.

Secondly, Novick (1971) spoke about the need to focus on the person. This still applies today, but we should be focussing first on the individual and their needs. In the UK Government there is a discourse of ‘policy making as if people matter’. This needs to be the case for work on housing. A focus on the person first and then the bricks and mortar is essential. If policy makers do not do this then we will continue to deliver the sorts of social unintended consequences identified by Shrubsole et al. (2014).

Thirdly – linking both the above points – housing and mental health policy development, and particularly housing building codes and guidelines seem to focus predominantly on the economic and environmental pillars of sustainable development. Inclusion of the environmental pillar over the last couple of decades represents real and genuine progress; the next step needs to more explicitly include the social pillar.

7. Recommendation for future work

With so many interdependencies between the three themes of influence, design and community it is difficult to identify a way to break down the vectors of causation. However, a productive transdisciplinary route is available to the innovative university. A living lab – perhaps based in either new and/or existing student accommodation could help to understand the interdependencies within and between the themes. Such a project could start the process of developing translational research to help update building codes and design guidelines with those actions that can be undertaken, particularly at the self-help social care end of the continuum, to promote mental well-being.

8. Declaration

This work has been supported by a PhD scholarship from the Low Carbon Living CRC.
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Better Health Victoria (2016) 10 tips to stay mentally healthy.

BeyondBlue (2014) Staying Well. BeyondBlue, Melbourne, Australia


Design Issues in Expansion and Modification Process of Detached Houses in Bangkok

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Abstract

Purpose / Context - This research was conducted to find better solutions of expansion and modification process of detached houses in Bangkok, alongside with the improvement of existing structures, in order to provide design possibilities which can accommodate future modifications.

Methodology / Approach - This paper categorised existing detached house structures into 3 different categories: 1. Interlocking and joint; 2. Masonry and concrete casting; and 3. Prefabricated load bearing wall and modular unit. This paper analysed 30 randomly selected expansion projects to detached house units in Bangkok. It used questionnaire surveys involving parties in the expansion process in order to investigated pros and cons of existing structure toward expansion projects.

Results – The study reveals the prefabrication system has the most difficulties with the future modification due to the fact that there is inflexibility of the structure itself. On the other hand conventional systems such as 1. interlocking and joint and 2. Masonry and concrete, provide more flexibility in modification. However, house owners still need to consult with engineers because the quality of long-term expansive construction requires expertise.

Key Findings / Implications – The research focuses on the advantages and disadvantages of various existing structures of detached houses towards modification processes.

Originality - The research contributes to improve current expansion and modification of detached houses in Bangkok. This study also states the potential status of structure, expanding material and modification construction process.

Keywords - house expansion, modification, prefabrication, customisation
1. Introduction

Bangkok is the capital city of Thailand. There are 5,692,284 city occupants and 2,746,944 housing units (Bangkok Official Statistics Registration Systems, 2015) with incessantly residential growth rate. Rural citizen from other provinces and foreigners moved here for better life opportunities and better living condition, this phenomenon affects density of Bangkok. It testifies by elevating of land price around 3 - 4% for 2 consecutive years in 2013 to 2014 (Pornchokchai, 2014) with supplemented by excessive condominium, apartment, town home and developed housing projects that emerged around mass transit stations (BTS and MRT) and suburban areas. Limiting space and expansive habitants forced expansion and modification to the detached house.

Another factor derived from customisation of tenants that intended to redesign the space from existing developed housing project and modified a house to conform user’s lifestyle and satisfaction. To understand the diversity of house structures, this research conducts an analysis of existing detached house structure into 3 different categories. Under the aspect of construction methods, Figure 1 shows various materials and technique of construction.

1.1 Interlocking and Joint

The origin of detached house in Bangkok using natural wood as main materials that can harvest around site area as local material, surprisingly semi-prefabricating system have been used extensively by applied to house’s structure and wood panels (Translated in Thai as ฝา or Fa eg. Fa Pakon, Fa Saibua) using interlocking and joint to form a house which can disassemble for purpose of relocation.

Figure 1 Various materials and techniques of construction

Figure 2 Traditional Thai house - terrace expansion (original 3D model by John)
The traditional Thai house is normally built with three notable characteristics: 1. Elevated floor; 2. Steep pinch roof with long overhangs; and 3. Large open terrace (Chalermwat, 2001). The characteristic and materials of traditional Thai house benefits the modification process with flexibility in expanding function and utilise space. For example, Figure 2 shows a terrace to connect house units together. However traditional Thai house is not the only significant example of interlock and joint category but it shows clear evidences of combination between materials and construction technique that support further modification.

1.2 Masonry and Concrete casting

With development of construction materials, masonry and concrete casting have been broadly used to construct every scale of architecture projects including house and housing projects in Bangkok. The masonry technique uses bricks or stone units laid and bound together by mortar: it is generally a highly durable form of construction (Almansa, 2010). On the other hand, the casting technique is performed by pouring concrete into formwork which is reinforced with steel bars to strengthen a structure.

In terms of modification, this category is still questionable on adaptive ability and flexibility for modification process, due to materials and structural aspects.

1.3 Prefabricated (Load bearing wall) and modular unit

Prefabrication has been around in architectural industry for a long period of time. This system has been used by Great Britain’s colonisation in India, Middle East, Africa, Australia, New Zealand, Canada, and America. Since the British were not familiar with local materials, components were manufactured in England and shipped to the various locations worldwide (Smith, 2009). Manning cottage in 1624 was one of the earliest evidence of prefabricated housing, sent to a fishing village of Cape Anne (Massachusetts) (Areiff, 2002), shown in Figure 3.

Figure 3 Portable Colonial Cottage (Manning) manufactured in Great Britain and shipped to colonies throughout the world. Credit: Ryan E. Smith
On the other hand, prefabrication in the east was adopted by post-war era especially in Japan to compensate for devastated housing in World War 2 (Oshima, 2008). In Thailand, the prefabricated system has been selected prominently by housing development due to advantages of the system: save construction time, maximise profit, minimum construction waste, and for safety procedure. A majority of prefab systems for housing units are pre-cast load bearing walls and pre-stressed concrete slab. This type of system does not require a beam to support vertical load but on the other hand pre-cast units face some difficulties, from tailor-made design and flexibility to adaptability for any future development.

Sustainable development and sustainable construction have been increasingly concern throughout the world (Kibert, 1994). Prefabricated systems can minimise time and materials for construction process by using off site factory but in contrast the system seems to be inflexible usability in terms of adaptation and modification.

The following section evaluated satisfaction and opinions of involving parties in modification process with expectation to develop sustainable and optimise house modification technique along with improve existed structural system adaptive ability to support future expansion and modification.

2. Research method

This paper categorised existing detached house structures into 3 different categories: 1. Interlocking and joint; 2. Masonry and concrete casting; and 3. Prefabricated load bearing wall and modular unit. The purpose is to contemplate future development with suitable construction techniques. Data was collected from 30 house expansion projects from detached house units in Bangkok. These study subjects are selected alongside with the questionnaire survey from people who are involved with the construction process. The questionnaire surveys are administered with 1. Detached house owners; 2. Architects/Engineers; and 3. Contractors, in order to figure out the pros and cons of the existing structure toward the expansion process. Empirical evidence has been gathered to support this argument, by giving advantages and disadvantages of existing structures toward expansion process. Figure 4 shows the overall research method in diagrammatic form.
The main topics of questionnaire survey focused on function of expansion area, construction material of expansion area, cost, timing, and opinion on existing structure toward expansion process (limitation, difficulty, advantages, and disadvantages). The subjects of investigation have been selected randomly from Jatujak district and Bang-kane district which considers as periphery areas of Bangkok that develop through suburbanisation, these locations consist copiously with detached house and housing units that developed by private owners and developers.

Basically, the 3 type of structures have been categorised by specified criteria of characteristic, material and technique of construction. However, the study methodology was changed a little due to the absence of interlocking and joint subject these days. This survey will focus on Masonry /concrete casting (Conventional) and Prefabricated load bearing wall /modular unit (Prefabricated) only. Most of the prefabricated sites were designed and constructed by a developer company by using a load bearing wall system that has been custom-made according to architectural designs, prefabricated from the factory and assembled on the site. Some subjects were built from steel modular structure. Refer to the appendix for site locations.

3. Data Analysis

The analysis section will have dedicated on 5 main categories: 1. functions of expansion area; 2. construction material of expansion area; 3. Cost; 4. Timing; and 5. Opinion on existing structure toward expansion process (limitation, difficulty, advantages, and disadvantages). A data in each category will divide into 2 groups; existing conventional and prefabricated structure systems to demonstrate similarity and dissimilarity by converting raw data into numerical (percentage) with supportive arguments and empirical evidences to compare and magnify an outcome.

3.1 Function of expansion of area

Table 1 shows majority in trend of expansion for conventional construction which owners tend to expanded storage space (30%) far beyond other functions. On the other hand, house owners who chose to use prefabricated construction, expanded living room area (40%) following by storage space (33.3%). Due to the fact that developer and architect provided inadequate space for following function to reach owners’ satisfaction level but the outcome cannot be summarised as a whole, for future trend of future expansion projects. With the needs of the owner were diverse and dissimilar from each other. This show some significant problems from and early stage of design in prefabricated category that architect cannot provide enough living room and storage spaces for the users.

<table>
<thead>
<tr>
<th>Functions</th>
<th>Conventional Structure</th>
<th>%</th>
<th>Prefabricated Structure</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garage</td>
<td>3</td>
<td>15%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Storage</td>
<td>6</td>
<td>30%</td>
<td>5</td>
<td>33.3%</td>
</tr>
<tr>
<td>Kitchen</td>
<td>3</td>
<td>15%</td>
<td>2</td>
<td>13.3%</td>
</tr>
<tr>
<td>Maid Room</td>
<td>2</td>
<td>10%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Bedroom</td>
<td>2</td>
<td>10%</td>
<td>2</td>
<td>13.3%</td>
</tr>
<tr>
<td>Living room</td>
<td>3</td>
<td>15%</td>
<td>5</td>
<td>40%</td>
</tr>
<tr>
<td>Wash area</td>
<td>1</td>
<td>5%</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>

3.2 Construction material of expansion area

From Table 2, steel played a dominant role for expansion material in conventional category since it’s required less time to construct compare to reinforce-concrete that required setting period (28 days), good quality of wood become expensive due to abbreviated and insufficient
supply. Most of the time expansion process with existing conventional structure allows new expansion part to attach directly on existing structure and form simultaneously effect to the houses.

On the other side, majority of expansion process on prefabricated structure used load barring wall to construct expansion area along with project construction period (construction by developer) due to limitation of load barring wall structure which cannot be penetrate and demolish selected area because all of above process will decrease structure performance. Another technique that been used by house owners was to build detached expansion steel structure (33.3%) from existing to avoid association with load barring wall

Table 2: Construction materials of expansion area

<table>
<thead>
<tr>
<th>Materials</th>
<th>Conventional Structure</th>
<th>%</th>
<th>Prefabricated Structure</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced Concrete</td>
<td>4</td>
<td>26.6%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Brick &amp; Mortar</td>
<td>3</td>
<td>20%</td>
<td>3</td>
<td>20%</td>
</tr>
<tr>
<td>Wood</td>
<td>2</td>
<td>13.3%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Steel</td>
<td>6</td>
<td>40%</td>
<td>5</td>
<td>33.3%</td>
</tr>
<tr>
<td>Concrete (LBW)</td>
<td>0</td>
<td>0%</td>
<td>7</td>
<td>46.6%</td>
</tr>
</tbody>
</table>

3.3 Cost

Table 3 shows average cost of expansion process. Conventional and prefabricated categories cost average around 200,000 - 300,000 THB, however there are 5 cases in prefabricated category that cost less than 100,000 THB. It indicated the adaptability of existing prefabricated structure in term of scale and adaptive ability compare to expansion on conventional structure.

Table 3: Cost for expansion process

<table>
<thead>
<tr>
<th>Budget</th>
<th>Conventional Structure</th>
<th>%</th>
<th>Prefabricated Structure</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>500,000 THB</td>
<td>2</td>
<td>13.3%</td>
<td>1</td>
<td>6.6%</td>
</tr>
<tr>
<td>400,000 THB</td>
<td>2</td>
<td>13.3%</td>
<td>1</td>
<td>6.6%</td>
</tr>
<tr>
<td>300,000 THB</td>
<td>2</td>
<td>13.3%</td>
<td>4</td>
<td>26.6%</td>
</tr>
<tr>
<td>200,000 THB</td>
<td>5</td>
<td>33.3%</td>
<td>4</td>
<td>6.6%</td>
</tr>
<tr>
<td>100,000 THB</td>
<td>4</td>
<td>26.6%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>90,000 THB</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>13.3%</td>
</tr>
<tr>
<td>60,000 THB</td>
<td>0</td>
<td>0%</td>
<td>2</td>
<td>13.3%</td>
</tr>
<tr>
<td>40,000 THB</td>
<td>0</td>
<td>0%</td>
<td>1</td>
<td>6.6%</td>
</tr>
</tbody>
</table>

3.4 Timing

Time is one of the most crucial factors for expansion process because delay construction period can affect addition cost for owners and contractors. From the Table 4, average timing for conventional category used 3 months (33.3%) for expansion process and maximum period was 6 months (6.6%). In contrast, prefabricated house owners tend to expand their space along with developer (53.3%) to avoid and minimise chances of future expansion due to limitation of load barring wall. Average of detached structure on prefabricated category used 2 months (33.3%) for expansion process.
### Table 4: Construction period of expansion process

<table>
<thead>
<tr>
<th>Month(s)</th>
<th>Conventional Structure</th>
<th>%</th>
<th>Prefabricated Structure</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1</td>
<td>6.6%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>13.3%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>13.3%</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>33.3%</td>
<td>1</td>
<td>6.6%</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>20%</td>
<td>5</td>
<td>33.3%</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>13.3%</td>
<td>1</td>
<td>6.6%</td>
</tr>
<tr>
<td>During Construction</td>
<td>0</td>
<td>0%</td>
<td>8</td>
<td>53.3%</td>
</tr>
</tbody>
</table>

### 3.5 Opinions on existing structure toward expansion process (limitation, difficulty, advantages and disadvantages)

One of the significant factors that affect expansion process was characteristics of existing prefabricated load barring wall. It refuses any expansion structure to attach on. Even more, redesign and relocation of windows and doors cannot be done, there is lack of modification flexibility. Conversely, detached expansion structure avoid occurrence of fracture and crack on joint location between existing and expansion structure, on the other hand, expansion on conventional houses facing fracture and cracks on a joint due to unequally used of shorter piles system from existing piles to reduce cost and time but it resulted incongruous sunken rate between existing and expansion structure.

### Table 5: Advantage and disadvantage of 2 construction methods

<table>
<thead>
<tr>
<th>Structure</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Conventional Structure   | • Flexibility of existing structure support attach expansion  
                          | • Acquainted system (do not require expert)              | • Attached expansion structure may cause crack between joint |
| Prefabricated Structure  | • Detached expansion structure                  | • Incongruity design                                           | • Redesign and relocation of windows and doors cannot be done due to limitation of load barring wall system |

Following are some comments from owners, architects, and contractors to demonstrate disadvantages from prefabricated system toward modification process.

**Difficulty from existed modular structure and load barring wall systems:**

> [T]his house use SCG HEIM modular housing system with expansion process; it faced some difficulty due to limitation of existing structure. Expansion unit have to detach from existing structure. - Owner of P01

> [W]e cannot relocate existed door and window location due to load barring wall system which we consider this problem as adaptive ability of the house. - Owner of P05

> [I]f our customers want to redesign their property it will be much easier and convenient for owner, architect, engineer and contractor if they redesign before construction stage. It will be risky to damage existing structure for later expansion process. - Architect of P15
It was very difficult when we have to dealing with prefabricated house because it has so many limitations to existing structure. On the other hand, detached system is the most suitable for this kind of expansion. - Contractor of P08

Some project facing some difficulty on timing and budget:

Limited time and budget also become significant problem for this project. – Contractor of P05

Law and regulation of expansion process is also one of crucial factors to avoid illegally action because it can cause demolition after project completions, which simply waste time and money. Figure 5 shows piles selection for expansion process.

Figure 5 Piles selection for expansion process

Another factor that effect quality of expansion works come from insufficient professional knowledge on expansion process, as resulted that majority of house owners often hired only contractor to complete the job who cannot compute structure loads and stability of expansion structure which normally causing cracks between old and new structure shows in Figure 6, the worst case can affect failure collapse of a structure.

Figure 6 Empirical evidence of structure failure
4. Suggestions

There are 3 main suggestions from data analysis to improve the expansion process.

1. Develop a prefabricated system to support future expansion but allow changeable and renovation of wall panels without affecting the building structure. Figure 7 shows the potential of the redesign prefabrication system that allows some modified area on the panels.

2. Consult with experts and professionals such as architects and/or engineers not just in term of design and structure but to be legitimate to law and regulation.

3. Make sure to use appropriate piling system for expansion process to avoid imperfection incident in the future.

5. Conclusion

Structural expansion seems common for detached house to maximise habitat space to owners satisfy level. In contrast, the process requires profound attention in order to create long-term practical design and ability in modification. It needs cooperation and interaction among 3 parties; house owners, architects or engineers and contractors to maximise work performance and capability outcome.

There are some flaws to improve on existing structure methods especially prefabricated system, it can be revise in term of design stage which allow users to adapt and provide more flexibility to structure. By fixing the problem from its origin, prefabricated system can perform perfectly from construction period. While most of the previous researches have tried to indicated only advantages of prefab system. With sustainable system thinking as its priorities were to reduce cost, time and control construction quality but at the end, house owner/builder can consider dynamic matter that have to adapt and changes according to users’ needs and requirements.

6. References

7. Appendix

Figures 10 and 11 show the site locations for this research. Most of the prefabricated sites were designed and constructed by a Developer Company by using a load bearing wall system that have been custom-made according to architectural designs, prefabricated from the factory and assembled on the site. Conventional structure sites are indicated by red and coded with ‘C’ follow by cardinal numbers. Prefabricated existing structures are indicated by yellow and coded with ‘P’.

Figure 10 Site location 1

Figure 11 Site location 2
A methodology for predicting $PM_{2.5}$ penetration and deposition based on the air infiltration through the window gaps

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Abstract

**Purpose / Context** - During the process of ventilation, outdoor fine particulate matter enters indoor space through gaps in the external window of building and pollutes the indoor environment. Penetration factor ($P$), deposition loss rate ($k$), and air exchange rate ($a$) are important parameters to evaluate the number of outdoor fine particles infiltrate into indoor space and the exposed quantity of indoor personal fine particulate matter. At present, these parameters are mainly obtained through the methods of laboratory actual measurement or theoretical derivation.

**Methodology / Approach** - In this study, according to the law of indoor-outdoor particle mass balance and statistical theory, a novel method for estimating the above three parameters was developed, which dependent on a large number of indoor and outdoor $PM_{2.5}$ mass concentrations field monitored data.

**Results** – The results of the method application in three typical office buildings showed that the value of penetration factor ($P$) was influenced by the external window air-tightness level obviously, it was about 0.965 when external window air-tightness in level-4 and it was 0.920 when external window air-tightness The influence factors of penetration factor ($P$) and deposition loss rate ($k$) are different by analyzing in the last section

**Key Findings / Implications** – The value of $P$, $k$ can be treated as be as a fixed value. The window with different structure has different value of $P$.

**Originality** - A new method of Reference can be provided to study the windows crack permeability, predict the impact outdoor $PM_{2.5}$ on indoor environmental and analyze the $PM_{2.5}$ exposure of indoor.

**Keywords** - Airborne fine particulate matter ($PM_{2.5}$) pollution; Infiltration characteristic; Penetration factor; Deposition rate; evaluation model
1. Introduction

Epidemiological studies have shown that many serious human diseases, such as cardiovascular disease and lung function impairment, can be caused by long-time exposure to fine particulate matter (PM$_{2.5}$). A large number of experiment has also proven that when the external windows are closed, outdoor PM$_{2.5}$ can also go into the indoor environment through the cracks around external windows, mainly through infiltration (Chan, 2002; Chen et al., 2016; Massey et al., 2012; Massey et al., 2009). Actually, the process of PM$_{2.5}$ going into indoors through infiltration is very complicated. In this research area, researchers preferably focus on two important parameters, i.e. penetration factor ($P$) and deposition rate ($k$), due to their direct reflection of the characteristic of outdoor particles going into indoors, as well as their attenuation characteristic.

Many researchers have adopted mathematical approaches to determine the two parameters: Liu and Nazaroff (2001) investigated the influence of pressure difference and crack size on particle penetration characteristic using a theory model that calculates the penetration factor using the crack size and the pressure difference between the two sides of the crack. Based on this study, Tian et al. (2009) established a penetration factor mathematical model with crack roughness correction, and Chen et al. (2012) proposed a method calculating the penetration factor based on real window structure. Bennett and Koutrakis (2006) tried to use dynamic indoor-outdoor PM$_{2.5}$ mass concentration balance equations to compute the values of both $P$ and $k$ for various air exchange rate, but the result showed that it was really hard to reach a solution because there were more than one values of $P$ and $k$ obtained from this method. The infiltration factor ($F_{in} = aP/(a+K)$) can then be obtained with the minimum error as the constraint. Based on the study carried out by Bennett and Koutrakis, Mleczkowska et al. (2016) took less than 5% of the minimum error to calculate the mean penetration factor and deposition rate. However, the air exchange rate in the sampling sites also need to be measured, and it can only give the mean air exchange rate during the measurement period but cannot provide dynamic values. To solve this problem, this paper introduces a novel method that can calculate penetration factor, deposition rate and dynamic air exchange rate based on field measured indoor-outdoor PM$_{2.5}$ mass concentrations. The method is very useful when analyzing outdoor particle penetration characteristic, indoor particle deposition characteristic and building infiltration performance.

2. Materials and methods

2.1 Model development

Under the condition of infiltration, indoor PM$_{2.5}$ mass concentration is dependent on the rate of outdoor PM$_{2.5}$ going into indoors and then some other processes happening indoors such as coagulation, chemical reaction and resuspension. However, researchers (Branis et al., 2005; Hahn et al., 2009; Lopez-Aparicio et al., 2011) have proven that the impact of indoor coagulation, chemical reaction and resuspension on indoor PM$_{2.5}$ mass concentration is ignorable. Therefore, the indoor-outdoor PM$_{2.5}$ mass concentration dynamic equation can be expressed as (Li and Chen, 2003)

$$V \frac{dC_{in,t}}{dt} = aP C_{out,t} + \sum v_{sources} + R L_f A_f - aC_{in,t} - kC_{in,t}$$  \hspace{1cm} (1)

where $V$ is the room volume, (in m$^3$); $C_{in,t}$, $C_{out,t}$ are indoor and outdoor PM$_{2.5}$ mass concentrations at time $t$, respectively, (in μg/m$^3$); $a$ is air exchange rate, (in h$^{-1}$); $P$ is penetration factor, (dimensionless); $v_{sources}$ is hourly indoor PM$_{2.5}$ pollutant source (in μg/h); $k$ is deposition rate, (in h$^{-1}$); $R$ is indoor PM$_{2.5}$ resuspension rate, (in h$^{-1}$); $L_f$ is PM$_{2.5}$ mass per unit area, (in μg/m$^2$); $A_f$ is inner surface area of room, (in m$^2$).
When there is no indoor PM$_{2.5}$ pollutant source and also ignoring any coagulation and phase change process, Equation (1) can be simplified as Equation (2).

$$\frac{dC_{in}}{dt} = aPC_{out, t} - (k + a)C_{in, t}$$  (2)

Equation (2) can be solved when using discreet time steps, expressed as Equation (3) (Bennett and Koutrakis, 2006),

$$C_{in, t} = \frac{a_P C_{out, t} \Delta t}{(k + a)} \left(1 - e^{-\left(\frac{t}{\Delta t}\right)\Delta t}\right) + C_{in, t-1} \cdot e^{-\left(\frac{t}{\Delta t}\right)\Delta t}$$  (3)

where $\Delta t$ is time step, in this study $\Delta t = 1h$; $a_i$, $P_i$, $k_i$ are hourly air exchange rate, penetration factor and deposition rate, respectively. Therefore, Equation (4) can be obtained when $C_{in,i}$, $C_{out,i}$ (i=1, 2,……n) are known for a period of time:

$$\begin{align*}
C_{in,1} &= \frac{a_1 P_1 C_{out,1}}{(k_1 + a_1)} \left(1 - e^{-\left(\frac{t}{\Delta t}\right)\Delta t}\right) + C_{in,1} \cdot e^{-\left(\frac{t}{\Delta t}\right)\Delta t}, \\
C_{in,2} &= \frac{a_2 P_2 C_{out,2}}{(k_2 + a_2)} \left(1 - e^{-\left(\frac{t}{\Delta t}\right)\Delta t}\right) + C_{in,2} \cdot e^{-\left(\frac{t}{\Delta t}\right)\Delta t}, \\
&\vdots \\
C_{in,n} &= \frac{a_n P_n C_{out,n}}{(k_n + a_n)} \left(1 - e^{-\left(\frac{t}{\Delta t}\right)\Delta t}\right) + C_{in,n-1} \cdot e^{-\left(\frac{t}{\Delta t}\right)\Delta t}
\end{align*}$$  (4)

where hourly indoor and outdoor PM$_{2.5}$ mass concentrations could be determined by field measured data, so the unknowns are air exchange rate ($a_i$), penetration factor ($P_i$) and deposition rate ($k_i$). Since the number of equations is ($n$-1) and the unknowns were 3($n$-1) in equation (4) (there were $n$-1 $a_i$, $P_i$, $k_i$).

### 2.2 Model solution

There are two main factors influencing penetration factor; one is window crack structure, including the crack width, length, depth and the number of the right-angle bends, and another is the airflow characteristic in the window crack. However, relevant studies have confirmed an insignificant influence of air exchange rate on penetration factor (Chen et al., 2012; Liu and Nazaroff, 2001; Tian et al., 2009), so the penetration factor can be regarded as constant for a certain building, namely $P \approx P$ ($P$ is mainly ranging from 0.8 to 1.0 under normal conditions according to Benett and Koutrakis (2006) and Mleczkowska et al. (2016)). On the other hand, the deposition rate is mainly dependent on particle size, internal surface roughness and indoor airflow velocity near the wall. With a certain room structure and closed doors and windows, the indoor airflow is nearly to zero, so the deposition rate can also be considered to be a constant, with a $k$ mainly ranging between 0 and 0.4.

Based on the above analysis, $P$ and $k$ can both be considered as a constant for a certain building, so Equation (4) can be transferred into Equation (5), which has ($n$-1) equations and ($n$+1) unknowns (there were $n$-1 $a_i$, and only one $P_i$, $k_i$).
Chen, C

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\[
\begin{align*}
C_{in2} &= \frac{a_1PC_{out}}{(k + a_1)} (1 - e^{-(k + a_1)}) + C_{in2} \cdot e^{-(k + a_1)} \\
C_{in3} &= \frac{a_1PC_{out}}{(k + a_2)} (1 - e^{-(k + a_2)}) + C_{in2} \cdot e^{-(k + a_2)} \\
&\quad \vdots \\
C_{in_i} &= \frac{a_1PC_{out_i}}{(k + a_{i-1})} (1 - e^{-(k + a_{i-1})}) + C_{in_{i-1}} \cdot e^{-(k + a_{i-1})} \\
&\quad \vdots \\
C_{in_n} &= \frac{a_1PC_{out_{n-1}}}{(k + a_{n-1})} (1 - e^{-(k + a_{n-1})}) + C_{in_{n-1}} \cdot e^{-(k + a_{n-1})}
\end{align*}
\]

(5)

In this study, the penetration factor was assumed to be ranging from 0.8 to 1.0 and the deposition rate was from 0 to 0.4, and the change of step size was 0.01. So combinations between \(P_i\) and \(k_j\) (referred as \([P_i, k_j]\)) could be established. Among them, \(P_i+1=P_i+\Delta (P_i=0.8, i=1-20); k_j+1=k_j+\Delta, (k_i=0.01, j=1-40)\), so the total number of matrix \([P_i, k_j]\) was 840, as expressed in Equation (6):

\[
\begin{pmatrix}
(0.80, 0.01) & (0.80, 0.02) & \cdots & (0.80, k_j) & \cdots & (0.80, 0.4) \\
(0.81, 0.01) & (0.81, 0.02) & \cdots & (0.81, k_j) & \cdots & (0.81, 0.4) \\
\vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\
(P_i, 0.01) & (P_i, 0.02) & \cdots & (P_i, k_j) & \cdots & (P_i, 0.4) \\
\vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\
(1, 0.01) & (1, 0.02) & \cdots & (1, k_j) & \cdots & (1, 0.4)
\end{pmatrix}
\]

(6)

To selected out the reasonable values \([P_i, k_j, a_{ij1}, a_{ij2}, \ldots, a_{ij_n}]\) from the eight hundred forty numbers of ventilators, the air exchanges rate almost stable when outdoor meteorological parameters in a steady state. Therefore, standard deviation (\(\delta_{ij}\)) was adopted to evaluating the stability of air exchange rate (\(a_{ij}^{n-1}\)). All values of \(\delta_{ij}\) were sorted from lowest to highest (the values within 1<\(a_{ij}<0\) were removed) and the former 5% were the solutions of Equation (5), and also regarded the mean value of corresponding penetration factor and deposition rate were the solutions

\[
\delta_{ij} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n-1} (a_{ij} - \bar{u})^2}
\]

(7)

where \(\bar{u}\) is the arithmetic mean value of \(a_{ij}^{n-1}\).
3. Case study

In order to evaluate the reasonable of the proposed method, which depends on a large number of indoor-outdoor PM2.5 mass concentrations monitoring data, three typical office buildings have been monitored for a long-term. Among them, sampling site 1 located in Dongcheng District, of Dongzhimen Avenue, adjacent to the East Second Ring Road, and sampling site 2 located in Peace West Bridge of Chaoyang District, adjacent to North Third Ring Road, sampling site 1 and 2 were both in Beijing.

![Fig. 1 Location of the monitored office in Beijing](image1)

![Figure 2 Floor plans of the monitored office in SP1 (a) and SP2 (b)](image2)

Indoor and outdoor $PM_{2.5}$ mass concentrations were monitored using LD-5C(R) line laser particle monitors. The monitor sensitivity was 1μg/m3. The counting interval was 5 minutes, and the monitoring data was uploaded to the server through a wireless network. Indoor temperature and humidity were automatically collected using the Testo 175-H2 temperature and humidity logger. Meteorological parameters were obtained from the local meteorological observatory (update hourly), which was located approximately 2km east from the monitoring office. The parameters included real-time data of outdoor dry bulb temperature, relative humidity, atmospheric pressure, wind speed and direction. The exterior windows of the office building were closed during the measurement time.

Air-exchange is mainly determined by the grade of window air tightness. Table 1 shows the tightness scale of the window under internal-external pressure difference of 10 Pa referred to the classified standard of Graduations and test methods of air permeability, water tightness, wind load resistance performance for building external windows and doors(GB/T 7106-2008). Obviously, the higher grade of window, the more it can prevent.
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Table 1: Air permeability performance level of window.

<table>
<thead>
<tr>
<th>level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_i$</td>
<td>3.5~4.0</td>
<td>3.0~3.5</td>
<td>2.5~3.0</td>
<td>2.0~2.5</td>
<td>1.5~2.0</td>
<td>1.0~1.5</td>
<td>0.5~1.0</td>
<td>≤0.5</td>
</tr>
</tbody>
</table>

$q_i$ is volume of air flow through per length of crack, m³/(m·h)

Table 2: Basic condition of the sampling site.

<table>
<thead>
<tr>
<th>sampling point</th>
<th>Room size (D×W×H, m³)</th>
<th>airtightness</th>
<th>Window size (H × D, m)</th>
<th>crack width (m)</th>
<th>crack depth (mm)</th>
<th>crack height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.8×4.5×4.4</td>
<td>4</td>
<td>1.15×0.7</td>
<td>3.7</td>
<td>50</td>
<td>0.82</td>
</tr>
<tr>
<td>2</td>
<td>3×6×4</td>
<td>8</td>
<td>1.2×0.9</td>
<td>8.4</td>
<td>70</td>
<td>0.56</td>
</tr>
</tbody>
</table>

The method of estimate the height of window crack base on the airtightness of external windows (Chen et al. under reviewing).

3.1 Analysis of measured buildings in site 1

3.1.1 Data collection

Data for six consecutive hours during stable meteorological parameters is chosen to compute $P$ and $K$. Time interval is 1 hour and the measured data is divided into a set of 6 hours. So we could get a pair of the $[P,k]$ value by using the method in Model Solution. At last, 43 sets of date respective in winter and spring are selected to compute the $[P,k]$.

3.1.2 Values of the $P$ and $k$

![Figure 3 The $P$ and $k$ calculated by 2x43 groups measured data](image)

Fig.3 shows the calculated value of $P$ and $k$ in winter and spring by using the method in Model Solution. As is shown here, the value of $P$ in winter and spring are nearly equal, and the value is 0.965±0.022and 0.965 ± 0.024 respectively. The value of $k$ in winter approximately is same as the spring, and the figure is 0.123±0.046 and 0.131±0.041 separately. The result shows the values of $P$ and $k$ are stable. It also proved that the values of $P$ and $k$ have little relationship with the air change rate, and the major factors are structural characteristics of the building.
3.1.3 Model validation

In order to validate the rationality of AER, this study used drikold as the tracer gas (CO₂) source to measure the air exchange rate. Drikold releases CO₂ until the concentration becomes stable. Then the indoor CO₂ concentration would gradually decrease to the original level because of existence of air infiltration, and based on this process the corresponding air exchange rate could be calculated. In this study, Lutron MCH-383SD was used for measuring both indoor and outdoor CO₂ concentrations, with a monitoring range between 0 and 4000ppm; an error of ±40ppm when CO₂ concentration is less than 1000ppm, an error of ± 5% rdg (rdg means tester reading) when the CO₂ concentration exceeds 1000ppm, and an error of ± 250ppm when the CO₂ concentration rises beyond 3000ppm.

The monitored curves of both outdoor and indoor CO₂ concentrations are shown in Figure 4. Drikold released CO₂ until the concentration rose to about 3800ppm when both doors and windows were closed. Then the Drikold was stopped and the indoor CO₂ concentration gradually decreased to the original level.

![Figure 4](image)

According to Equation (9)(You et al., 2012), the calculated air exchange rate was 0.24 h⁻¹ during the monitoring period. It showed a good agreement with the model calculation result (0.22 h⁻¹). Therefore, there is confidence to the proposed model about its prediction accuracy.

\[ AER = \frac{\ln C_0 - \ln C_t}{\Delta T} \]  

(9)

where the AER is the air exchange rate, (in h⁻¹); \( C_0 \) and \( C_t \) are the initial concentration and the concentration in \( t \) time, (in ppm), \( \Delta T \) is the monitoring time, (in s).

3.2 Analysis of measured buildings in site 2

3.2.1 Data collection

Data for six consecutive hours during table meteorological parameters is chosen to compute \( P \) and \( k \). Time interval is 1 hour and the measured data is divided into a set of 6 hours. So we could get a pair of the \([P, k]\) value by using the method in Model Solution. At last, 48 sets of date are selected to compute the \([P, k]\).
3.2.2 Values of the $P$ and $k$

Fig. 5 shows the calculated value of $P$ and $k$ by using the method in Model Solution. The value of $P$ is 0.92 ± 0.11. The value of $k$ is 0.12 ± 0.076. Trapping efficiency of the window in site 2 is 1 times higher than site 1. The value of $k$ is the same in the two sites.

![Figure 5 The $P$ and $k$ calculated by 48 groups measured data](image)

3.3 Analysis of the differences $P$ and $K$

The value of $P$ in sampling site 1 and sampling site 2 are 0.96 and 0.92 respectively. The major factor that influences the $P$ is the structural characteristics window, including crack height, crack depth, and crack width. There has been a positive correlation between crack depth and the value of $P$, and the crack height is negatively correlated with the value of $P$. Crack depth of site 1 and 2 is 0.05m and 0.07m respectively. The value of $P$ in site 1 is 40 percent higher than site 2. Crack height of site 1 and 2 are 0.82mm and 0.56mm respectively. So, the value of $P$ in site 2 is smaller. The wall roughness, the ratio of volume to room surfaces ($V/S$) can influence the deposition loss rate ($k$), $k$ is positively correlated with roughness and $V/S$. The figure in site 1 and 2 are both 0.12. The differences of roughness need to be further studied.

4. Conclusion

Based on field measured indoor-outdoor PM$_{2.5}$ mass concentrations, a novel method that can be used to calculate penetration factor, deposition rate and dynamic air exchange rate has been proposed and validated. It is very useful when analyzing outdoor particle penetration characteristic, indoor particle deposition characteristic and building infiltration performance. Main conclusions that could be obtained from this study include:

1) The penetration factor and deposition rate were nearly constant for a given building structure;
2) The Penetration factor decreases when the window air-tightness level is promoted;
3) There was no conspicuous evidence for that the deposition rate is influenced by room dimension and internal surface roughness.
4) The indoor PM$_{2.5}$ mass concentration could be reduced when replacing low air-tightness windows by high ones.
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Incongruence of superior goals and energy efficiency funding programs

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Abstract

Purpose / Context – Political topics like energy efficiency and climate protection are en vogue. There are manifold funding programmes, but since these are bound to the goals of the respective programmes, the implemented projects do not adequately consider integrative aspects. It is necessary to analyse the purpose of those funding programs and to bring them in correlation with higher goals of urban development.

Methodology / Approach – In the case of ‘Bottrop Innovation City’, 5 depth-interviews were conducted to provide initial impressions of the modernization of municipal structures

Results – Some of the assessed municipalities show elaborative strategies to develop promising energy efficiency projects, all of which with a grand amount of funding resources.

Key Findings / Implications – Political top topics have influence on the urban development for centuries.

Originality – Germany as a model for energy efficiency strategies has a vast funding scheme which does not exist in other countries. Therefore, it is necessary to analyse the organisation and to develop guidelines for an even better and more sustainable funding scheme. Funding schemes affect city development and have impacts on the housing and the neighbourhood. It is necessary to understand which impacts a funding scheme has, to review the aims of programs with the superior goals and to give guidance for a better use of the respective funding scheme. Other countries could learn from those strategies and could adapt to certain degree to establish a similar funding scheme. Additionally, municipalities could be supported in their strategies for sustainable city development, be it with or without funding resources.

Keywords - Energy efficiency- funding scheme- Incongruence
1. Introduction

1.1 Literature Review

In the last decades, changes in climate have caused impacts on natural and human systems all over the world. ‘Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate’ (IPCC, 2015). In the future, there must be effective measures and strategies to reduce climate change (Federal Government, 2008).

One of the big strategies and a shared policy goal of many governments around the world is to increase energy efficiency. The advantages of efficient use of energy are well known and flatten investments in energy infrastructure and lower fossil fuel dependency (IEA, 2008). In former times, there were different strategies to reduce the impacts of climate change and to increase energy efficiency. One of the most popular agreement was initiated by the UN is the conference, the ‘Agenda 21’ held in Rio in 1992. 179 governments agreed to limit their emissions of greenhouse gases. The following years have seen far reaching changes and response to climate change (Green Alliance, 2014). One important agreement is the Kyoto Protocol from 1997 (UNFCCC, 2011). In the year 2015, there was the United Nation Conference on Climate Change in Paris where 196 countries confirmed to devote themselves to more sustainability and to work on the energy efficiency goals and to reduce their greenhouse gas emissions (Green Alliance, 2014). All governments agreed on the long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels. The aim was to limit the increase to 1.5°C; since this would significantly reduce risks and the impacts of climate change (UN, 2015).

There are many holistic strategies like the C40 Cities Climate Leadership Group who aim to reduce greenhouse gas emissions in the world’s megacities. The group consists of 83 members around the world (C40, 2015). To date, there are many studies and documents which deal with climate change and city development. One example is the study ‘City of tomorrow’ which deals with the challenges and visions on how cities should look like in future (EU, 2011). Furthermore, there is the Intergovernmental Panel on Climate Change, which published its Fifth Assessment Report in 2014, summarising the work of thousands of scientists across the world. The 2013 report the IPCC was the first to put the total amount of carbon in numbers that could be emitted while simultaneously keeping the 2°C target (IPCC, 2015). Today, city development cannot be planned without considering climate change and its impacts. Even on the big conferences like the United Nations Conference on Housing and Sustainable Urban Development Habitat III in Quito, Ecuador 10/2016 the New Urban Agenda (NUA) document is going to be resolved, which will provide guidelines and recommendations for sustainable urban development within the next two decades (Cities Alliance, 2015). Up to today, many cities have become members of national and transnational city networks, like the C40 Cities as mentioned before (Kern, 2008).

In fact, global climate change affects local governments in three different ways. First, a high portion of greenhouse gas (GHG) emissions is generated in cities. Second, the effects of global climate change have a direct impact on cities, which need to adapt to the changing situation. Third, linkages and synergies between sustainable development and climate policy become most obvious at the local level.

Especially the building sector contributes to up to 30% to the global annual greenhouse gas emissions and consumes up to 40% of all energy. In total, the building sector has the most potential for delivering significant and cost-effective GHG emission reductions (UNEP SBCI: 2009). All in all, it is important that all climate protection and energy efficiency measures have to be implemented on the local level in a way that has long lasting effects on the development, particularly with regard to the high potential of the building sector.
1.1.1 German Energy Transition

An important step towards meeting these prior mentioned climate goals is the ‘Energiewende, Germany’s energy transition policy, which was launched to support the objectives set out in the Energy Concept in 2010 (BMUB, 2014).

According to the German Federal Government, CO₂-emissions are to be reduced by 40% until the year 2020 (Federal Government 2008). Furthermore, the electricity supply is to consist to at least an 80% share of renewable energies by 2050. Another goal is to reduce energy consumption by 10% till 2020 and by 25% till 2050 compared to the 2008 baseline (Umweltbundesamt, 2010). Especially the present building stock shows significant potentials for actions as these have high energy consumption rates, which make up to about 40 % of the total energy consumption in Germany (Federal Government, 2008). However, the remediation rate of buildings stagnates at approximately 1 % per year. Because of this, the potential in the building sector should be activated more strongly in the future (BMWI, 2014).

1.1.2 German Funding Scheme

Funding problems can in general be regarded as one of the most serious barriers impending the efforts to implement energy transition policies on local level. In most OECD countries, climate change policy remains a voluntary task of local governments that have limited mandatory responsibilities in this regard. A major issue for implementing related policies is lack of funding, since these compete with other demands that often appear to be more important from the perspective of policy makers and citizens.

Furthermore, cities normally only have limited opportunities to generate funding for climate protection measures (Kern, 2008). To put efficiency saving measures into practice nonetheless, the (German) government developed financial funding programs. The aim of this support is twofold. First, municipalities are supposed to have a better chance to increase the amount of energy efficiency projects on local level as they get significant financial support from the government. Second, this approach contributes to the implementation of energy-efficient measures on the local level more easily and with a longer lasting effect. Of course these aims are regulated in different laws like in the town and country planning code (BauGB, 2015) and for the Energy Saving Directive in the EnEV (Energieeinsparverordnung) which sets out building standards, and by state laws.

The German administration system is divided in three levels: federal government, state government and the local municipalities. The state authority is not exercised directly by the people; they delegate it to elected, representative or parliamentary bodies (Katz, 2002). In comparison to other countries the municipalities in Germany have the local self-government (GG § 28). The municipalities have the right to manage all affairs on local levels within the limits set by law. However, certain functions are executed by the municipalities on behalf of the federal state governments (Badura, 2003). Nonetheless, the municipal authoritative power can be used in very creative ways, even to generate funding for the implementation of their climate protection policy (Kern, 2008).

For example, there are different programs from the EU to the state government which are offered the municipality to implement certain measures at the local level and it is a grand effort for them to apply for a suitable program. This is the reason why energy efficiency and climate change projects and their measures in Germany are highly promoted. Not only projects with concepts and the implementation is promoted but also the position of a reconstruction manager who has the task to implement the measures (BMUB, 2015). With a successful application for a funding program every municipality has to pay a certain amount to the funding organisation. This contribution depends on the funding program and is often between 5-10 % of the total funding amount. However, some of the municipalities in the western part of Germany, like in the Ruhr Area, have a precarious budgetary (Bertelsmann Stiftung, 2007). Because of this reason the funding organisations have
special conditions for municipalities with a precarious budgetary, which for instance are not obliged to contribute with their otherwise compulsory financial share of the total funding sum.

1.1.3 Planning Australia:
In comparison to the German planning system, the Australian federal system is organized differently. The Australian Federal Government has considerably more financial power than the states. On the local level however, municipal governments have by far less financial resources than in Germany (Ahuri 2015: 12). But in both countries it is the consensus that all local government planning schemes and policies are required to be consistent with State Government planning objectives and requirements (State of Western Australia 2014: 4).

Australia’s federal system of governance is different to the German, since only one governmental planning law exists. The Australian government structure consists of the nationwide Australian Government, the six states and two territories, all of which have own urban planning laws and procedures, resulting in separate systems of planning and land use management. Consequently, there is no single urban planning system for Australia – rather, there are a number of planning systems that operate largely independently of each other along state based lines (Williams 2007).

2. Research Problem
Germany and its municipalities meet the requirements to realize projects on local levels, which could serve as a pilot worldwide. But this support system has the disadvantage that the municipalities are dependent on public funding. For the implementation of large projects municipalities try to access different forms of funding, for instance funding provided by the EU, which is also a common approach for institutions on state level.

In the past years and even today there are many projects related to the topics of energy efficiency and climate protection. For municipalities with precarious budgetary it is difficult to implement projects which push the city development forward or which solve essential problems of the city without any funding money. Because of this reason they develop a holistic strategy which fits to many funding programs. These days there a lot of programs which deals with energy efficiency or climate protections and because of this the municipality develops strategies which match to these ‘en vogue’ topics. These projects will ultimately be congruent with the goals of support programs, but do not solve the original problems of the city, like ‘goal-30-ha’ of the Federal government. This goal is a political intention and should lead to a reduction of the daily growth of area for settlement and transport from 100 ha today to 30 ha by 2020 (Malburg-Graf et al, 2007).

To sum it up, the intention of the developed strategy to acquire the highest funding possible to enable the solution of a city’s initial issue within one major project. Therefore, superior goals like sustainability, quality of life and climate adaptation are not considered in the specific project as it should be. First, the projects fulfil the aims of the support programs but it is not confirmed that they have to fulfil the goals of the superior goals. Last, there are funded projects which are internally consistent, concerning the city development however these are not the best solution in terms of sustainability.

Because of the precarious budgetary situation of the cities in the Ruhr-Area in Germany, it is difficult to create projects that contribute to urban development relevant projects. Through the funding scheme however, it is possible to develop projects with a specific aim orientation like energy efficiency or climate protection.

Current topics like energy efficiency or climate protection are promoted through different political levels. These topics are in the foreground of the political agenda and because of this, there are manifold funding programs related to these topics. It is moot point whether or not projects imple-
mented through these funding schemes are the best sustainable solution for urban planning. Normally, large-scale projects could only be realized given sufficient funding. It seems as if the content of projects is mainly determined by the aims of the funding program. Other important topics like goal-30-ha are not promoted in the same way as climate protection or energy efficiency. Hence, it could be more difficult to develop projects which solve these problems.

The aim of this study is to highlight the importance of municipalities for the building sector and to underline the influence of both on the energy transition debate. Therefore, the planning process and the decision-making process of the case study Bottrop will be analysed. Problems, obstacles, and impulses will be identified. In this way dependencies of municipalities on funding programs and their limited capacities to implement urban development projects without funding will be clarified. Through the case study, analysis incongruences between city development goals and the implemented projects will be analysed.

3. The case

One of the major energy efficiency projects in Germany is ‘Innovation City’ in Bottrop, which was created due to a call launched by the industry association Initiativkreis Ruhr (IR). This pilot-project tries to implement several energy efficiency subprojects since 2010. The transformation through active public-private partnerships and an engaged citizenry into a living laboratory can be observed (ICLEI 2014).

The main aim is to reduce the CO₂ emission by 50 % until 2020 and to create a sustainable, low-carbon city by reshaping existing housing, transport and energy ‘regimes’. For this purpose, numerous individual projects together with practice partners and industry covering the sectors of urban planning, housing, industry, tertiary buildings and transport were implemented in the last years (Huber 2013). Furthermore, the transition process in Bottrop is an effort of steered transformation between public and private institutions, an unprecedented experiment in Germany and maybe even worldwide (Huber 2013).

The beginning of Bottrop’s transition started in 1990s when the city administration adopted its first energy conversation measures. Some involved city departments continuously developed competences for energy efficiency, which cumulated in the application process for the Innovation City project in 2010. At the same time private actors started pioneering renewable energy projects (Huber 2013).

The Innovation City Ruhr has become a model for the renewal of the entire Ruhr Area, but also to other industrial cities worldwide. The main idea of the project was to transform seven districts in the heart of the city with more than 14,000 buildings and 70,000 inhabitants into a role model of energy efficiency. The city became a living laboratory for urban redevelopment, sustainable energy and climate change mitigation. Under the slogan ‘Innovation City Ruhr’, the Initiative Group launched a campaign to find a pilot city to conduct comprehensive urban development, with the final objective of replicating the pilot’s successful projects across the Ruhr region (ICLEI 2014). After the successful application as Innovation City Ruhr, the organisation IC Management GmbH was founded. This organisation takes care about the aims of the innovation system and develops new ideas for the implementation (Huber 2013).

The energetic restructuring of existing buildings is one of the most important measures to reduce CO₂-emissions. The city has a modernization rate of 3 % pa over the last years, which is, in comparison to the German average with 0,9 %, very high (DV 2016: 6). From a scientific point of view, the Bottrop Model City is also a unique testing ground for the exploration of possible pathways to a climate-friendly and energy efficiency urban redevelopment (ICLEI 2014).
For implementation, each program requires an individual funding constellation. Some of the activities are funded within the framework of public research or urban development programs, supported by the EU commission, national, or Land ministries. Others rely on financial means brought in by industrial companies or other external partners (e.g. banks like KfW-Bank) (Huber 2013). In fact, Bottrop had a very successful strategy to use the funding scheme from EU to state government level effectively, because over the last years manifold projects about energy efficiency were implemented. The city administrative of Bottrop successful applied to funding programs of the EU – federal state level and with the slogan ‘Blue sky – green city’ they found a holistic strategy which fitted to various funding programs.

4. Methodology

In-depth interviews will serve as a qualitative-explorative research approach, since its objectives is to understand the correlation between the support program scheme and superior goals. Furthermore, impulses will be identified. So will be problems and obstacles during the process to get a better understanding of the entire process flow and to get first results about guiding the project in a specific direction (Marxwell, 2005). In detail 5 stakeholders from the city administration will be interviewed. Most were main stakeholders who played an important role during the planning process. For every interview guideline were employed to ensure comparability. All interview partners were selected by purposeful sampling (Patton, 2009). In average the interviews took between 50 and 120 minutes.

All interviews were recorded and transcribed. For the evaluation qualitative content analysis were used (Mayring, 2005) with the software MAXQDA to sort the important statements and to enable ranking regarding respective importance. Because of the semi-standardized guideline, it was possible for all interview partner to explain important aspects in detail. In the end the material was reviewed, analyzed and interpreted to the research context.

5. Result and Discussion

5.1 Overall Results

So far, the interviews revealed that the project Innovation City can be described as an extensive energy efficiency project which raised a grand funding amount through well elaborated strategies. Over 100 projects were implemented on local level. The conjecture is that the energy efficiency projects are congruent with the funding programs but may however not be the most sustainable solution for the entire city development. To evaluate the impact of the project, it is necessary to analyse the funding constellation in context of the project in detail.

The result of the interviews is, that there are different impulses which pushed the project forward. The first impulse is the funding constellation. Without the considerably high funding amount, it would not have been possible to implement so many projects. This includes the possibility to found the Innovation GmbH. Though this company it was easier to use the network to local companies and to take responsibility over factors like marketing, developing strategies etc. Next to the financial support, there were a lot of entrepreneurial partners who supported the project. During the project process there were different jour-fix events in various constellations with experts, scientists or local companies, which helped to bring to project forward.

Also important is the size of the city of Bottrop, because with 117.000 inhabitants the city administration is manageable and the distance to the public administration is short. There is a close cooperation between public offices and between the public administration and Innovation City GmbH. Another important point is the low fluctuation of staff which is the basis for trustful working atmosphere.
Positive secondary effects are the synergies related to the funding scheme because the ministries request the city of Bottrop to apply for particular funding programs. Bottrop has the chance to formulate its special needs concerning city development and the energy transition debate. The city administration founded a guideline ‘11.1 Promotion of energetic renovation’ which is addressed to people who own real estate property in the pilot area (Bottrop, 2014). This guideline was supported by the Federal Land Ministry Of The Land Of North Rhine-Westphalia and will be disseminated to other municipalities. In this case Bottrop was again pilot and could profit from the synergies to the ministry level.

6. Conclusion

In summary, we found evidence for the importance of the funding scheme and the dominance of topics like energy efficiency, which are set on the top of the political agenda. Without those programs it is difficult to implement projects. Particularly the implementation of other city development relevant projects in the city is difficult.

City development is dominated by these themes and the manifold funding programs show which projects can be implemented. Because of the budgetary situation, the Ruhr Cities often do not have a chance to plan something different. In fact, the cities are dependent on financial support, but it is arguable if the projects mentioned above are the most sustainable solution. This paper shows the necessity for a guideline for municipalities to strengthen awareness regarding funding schemes and their impacts on city development.

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Field Measurements of Indoor Temperatures and Blood Pressure of Elderly Persons

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Abstract

Purpose / Context – To clarify the association between the indoor environment of residential buildings and cerebrovascular disease, an epidemiological survey of elderly persons living in three areas of Japan that have different rates of death due to cerebrovascular disease was conducted.

Methodology / Approach – This paper describes field measurements of indoor temperatures and blood pressure of 30 elderly persons during one year.

Results – In almost all houses in Japan, indoor temperature differences between a living room and non-heated spaces, such as the bedroom, corridors and lavatory, during heating times are large, and the indoor temperature at daybreak can be as low as the outdoor temperature.

Key Findings / Implications – The systolic blood pressure of elderly persons is positively associated with exposure to temperatures lower than 15°C.

Originality – The findings of this study will contribute to the knowledge regarding the association between the indoor thermal environment and health.

Keywords – Cerebrovascular disease, Indoor thermal environment, Blood pressure of elderly persons, Field measurement
1. Introduction

The major causes of death for Japanese people are cancer, heart disease and cerebrovascular disease. The incidence rate of cerebrovascular disease in particular is higher during winter than summer. One possible reason for this seasonal difference is that exposure to cold temperatures can cause fluctuations in blood pressure. In houses with poor thermal insulation, indoor temperature differences between heated and non-heated spaces, such as the bedroom, corridors, and lavatory, can be large during winter. Many houses in the Tohoku region have a poor thermal environment during winter, and the incidence rate of cerebrovascular disease in this area is the highest compared to other areas in Japan.

To clarify the association between the indoor environment of residential buildings and cerebrovascular disease, an epidemiological survey of approximately 200 elderly persons living in Yamagata Prefecture in the Tohoku region of Japan was conducted. The specific areas investigated included three rural towns (Towns A, B and C). The demographics of these towns are shown in Table 1. The survey was divided into three phases. The first phase (Phase 1) was a cross-sectional questionnaire on housing characteristics related to the indoor thermal environment and occupants’ lifestyle habits among 188 elderly persons. The second and final phases (Phase 2 and Phase 3) comprised field measurements of the indoor thermal environment and blood pressure of selected subjects from Phase 1. This paper describes the results obtained from indoor temperature and blood pressure measurements of 30 elderly persons during one year. An association between blood pressure and exposure to indoor temperatures in elderly persons in particular is analyzed statistically.

Table 1: Demographics of the towns in Yamagata Prefecture surveyed in the present study

<table>
<thead>
<tr>
<th>Items</th>
<th>Town A</th>
<th>Town B</th>
<th>Town C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population^1 (persons)</td>
<td>6,519</td>
<td>9,059</td>
<td>8,770</td>
</tr>
<tr>
<td>Number of households^1 (N)</td>
<td>1,904</td>
<td>2,330</td>
<td>2,311</td>
</tr>
<tr>
<td>Population density^1 (persons/km²)</td>
<td>31.9</td>
<td>83.7</td>
<td>44.6</td>
</tr>
<tr>
<td>Number of elderly persons^1 (persons)</td>
<td>2,148</td>
<td>2,687</td>
<td>2,798</td>
</tr>
<tr>
<td>Rate of aging^1 (%)</td>
<td>32.9</td>
<td>29.6</td>
<td>31.9</td>
</tr>
<tr>
<td>Standardized mortality ratio^2 (%)</td>
<td>164.2</td>
<td>50.6</td>
<td>61.6</td>
</tr>
</tbody>
</table>


2. Materials and Methods

2.1 Study design

This survey was divided into three phases, as shown in Figure 1. A preliminary survey was conducted before these phases to ask elderly residents if they would be willing to participate in subsequent surveys. Phase 1 was a cross-sectional questionnaire on housing characteristics related to the indoor thermal environment and occupants’ lifestyle habits among 188 elderly persons. The second phase (Phase 2) was conducted over a week during winter, and included field measurements, measurements of indoor temperatures in a living room, bedroom, lavatory and other rooms, and home blood pressure measurements of 55 elderly persons. The final phase (Phase 3) included long-term field measurements of indoor and outdoor temperatures and home blood pressure measurements of 30 elderly persons. This paper presents the results from field measurements during the final phase and a statistical analysis of the results through Phase 3.
2.2 Outline of field measurements in final phase

The final phase (Phase 3) included measurements of temperature and home blood pressure. A data logger with temperature and humidity sensors was used for the measurements of the indoor environment. At the beginning of long-term measurements, a data logger was placed near the center of the living room (1.1 m above the floor) in each house. Outdoor temperature and humidity were measured at one house in each area (i.e., Town A, Town B and Town C). The temperature and humidity were measured from October 2014 to January 2016 every 20 min during the measurement period. The subjects participating in the final phase measured blood pressure on their own using a blood pressure manometer. Participants recorded systolic blood pressure, diastolic blood pressure and pulse count every week during the measurement period. According to the guidelines for self-monitoring of blood pressure at home (The Japanese Society of Hypertension, 2011), the subjects measured their blood pressure within one hour after waking up and before going to bed every week.

2.3 Description of measured houses and subjects

Measurements were conducted in the houses of those who agreed to participate after the questionnaire survey in the first phase (n = 232). The measurements were conducted in 30 houses in three areas for at least one year. These 30 houses were detached houses with wood construction, and were inhabited by elderly person(s) more than 65 years old. Most of the houses lacked sufficient thermal insulation on the building envelopes. During winter, the heating equipment was operated intermittently, and the heating space was limited to just the living room.

Table 2 shows a description of the subjects that participated in the field measurement. Ten subjects from each area were included. There were more male than female subjects, and all subjects in Town B were male. The age of subjects ranged from 66 to 87 years; the median age was 71.5 years. Approximately one-third of the subjects were taking antihypertensive medication daily. These subjects had been diagnosed with hypertension by a medical doctor.
3. Results and Discussion

3.1 Indoor temperature profile during heating season

An example (house of subject No.3 in Town A) of room temperature profiles during winter are presented in Figure 2. An unvented kerosene heater was used in the living room of this house. The room temperatures over a week during the heating season were averaged. The living room temperature at a point 1.1 m above the floor was maintained at approximately 18°C during the evening after supper. However, after the heater was turned off, the room temperature decreased rapidly, and was 5°C by daybreak. The living room temperature at a point 10 cm above the floor was approximately 6°C lower than the temperature at 1.1 m. The global temperature (i.e., radiant temperature) was approximately 1°C lower than the room temperature during the heating time. The temperatures of a bedroom, washroom and corridor remained between 2°C and 5°C throughout the day. The temperature differences between a living room and unheated spaces, such as the washroom during the evening after supper was approximately 20°C. The occupants living in this house were exposed to large temperature differences when moving to unheated spaces from the living room during the heating time.

3.2 Indoor temperature and blood pressure

Figure 3 presents the relationship between the systolic blood pressure of a subject (No. 5 in Town B) and the indoor temperature over the course of blood pressure measurements. These data were measured during the measurement period over one year. The systolic blood pressures within one hour after waking up and before going to bed are presented in this figure. The blood pressure within one hour after waking up ranged from 110 to 170 mmHg, and the blood pressure before going to bed was lower than 150 mmHg. These data indicate a morning surge in blood pressure. The systolic blood pressure tended to depend on the room temperature, even if it was in the morning. Furthermore, blood pressure greater than 160 mmHg was measured when subjects were exposed to temperatures less than 10°C.

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Figure 2 Indoor temperature profile of house of subject No. 3 in Town A

Figure 3 Indoor temperature and systolic blood pressure

3.3 Monthly profiles of systolic blood pressure

Figure 4 presents monthly profiles of systolic blood pressure in each town. The monthly data represent the median blood pressure for subjects in each town and all subjects for each month during the measurement period. A total of 30 values each month were used to calculate the median. There were seasonal changes in the median blood pressure of subjects from the three towns. The blood pressure tended to be higher during the heating season (i.e., from October to March) and lower during summer. The increased blood pressure during the heating season could be one of the risks for elderly persons to develop cerebrovascular disease. In general, the incidence rate of cerebrovascular disease was higher during winter than summer. In houses with poor thermal insulation, indoor temperature differences between heated and non-heated spaces are larger during winter, and occupants could be exposed to colder temperatures often even in indoor spaces.
3.4 Association between indoor temperature and blood pressure

Figures 5(a) and (b) present the statistical values of systolic blood pressure for outdoor and indoor temperature ranges, respectively. Both outdoor and indoor temperatures were classified into four ranges from below 5°C to more than 15°C, at intervals of 5°C. The values in every temperature range include the median systolic blood pressure from 14 subjects who were not taking antihypertensive medication.

For the outdoor temperatures, the median blood pressure was higher at lower temperature ranges. This tendency was not statistically significant, but supports the results of the monthly blood pressure profiles, as presented in Figure 4. On the other hand, for the indoor temperatures, the median blood pressure at indoor temperatures below 15°C was significantly higher than that at indoor temperatures over 15°C (p<0.05, Kruskal–Wallis test). The difference in systolic blood pressure between indoor temperatures below 10°C and over 15°C was 10 mmHg. Furthermore, median blood pressure increased to approximately 140 mmHg when elderly persons were exposed to indoor temperatures below 15°C. These results indicate that the systolic blood pressure of elderly persons is positively associated with exposure to temperatures lower than 15°C.
4. Conclusions

To clarify the association between the indoor environment of residential buildings and cerebrovascular disease, an epidemiological survey of elderly persons living in three areas of Japan that have different rates of death due to cerebrovascular disease was conducted. The survey was divided into three phases. This paper describes the results obtained from the final phase, which included field measurements of indoor temperatures and blood pressure of 30 elderly persons during one year. Results indicate that in most houses, indoor temperature differences between a living room and non-heated rooms, such as a bedroom, corridor and lavatory, during heating times are large, and that the indoor temperature at daybreak can be as low as the outdoor temperature. The systolic blood pressure of elderly persons was shown to be positively associated with exposure to temperatures lower than 15°C.

5. Acknowledgments

The authors would like to thank the residents who were involved in this study for their cooperation. This survey was supported partly by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology in Japan.
6. References


Estimation on Humidification and Ventilation for Infection Control in Residence for the Elderly

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Abstract

Purpose / Context - The aim of this study is to clarify an estimation method of humidification for infection control in residences. In Japan indoor humidity is very low in winter especially in recent insulated houses without unvented stoves. Dwellers know that it is necessary to keep humidity adequate for infection control, but most of them don’t know the moderate humidity or the effect of ventilation for infection control. In this study, the state of influenza infection control was evaluated using the measurement results on indoor air in the rooms of six Japanese facilities for the elderly. The temperature is kept better in these residences than that in common Japanese houses. But the humidity is quite very low in winter. The energy saving is thought to be one of the causes of this state.

Methodology / Approach - Under the assumption that influenza virus generate at a constant rate, the concentrations of survived influenza viruses in indoor air were calculated using an equation, which is given on the basis of the survival tests on influenza virus by G.J.Harper. The equation gives the concentration of influenza viruses using the ventilation rates and absolute humidity. Then an index on virus reduction which integrates ventilation effect and humidity effect was proposed.

Results - The energy consumption of ventilation and humidification for infection control is calculated using this index. The results show that it is effective to control ventilation rate for both of infection control and saving energy in many rooms in these facilities.

Key Findings / Implications - Effective strategies for infection control in residences are discussed using the index of influenza infection control.

Originality - The index of influenza infection control is proposed in this study. This index is useful to estimate indoor air quality. The index is expected to be used for the design of building performances and air conditioning systems.

Keywords - influenza, infection, humidity, ventilation, energy saving

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1. Introduction

In Japan, indoor humidity is very low in winter especially in most of the recent insulated houses without unvented stoves. The influenza infection is one of the high risk factors for dwellers’ health. This prevention is very important especially for the elderly. Dwellers know that it is necessary to keep humidity moderate for infection control and they use portable humidifiers. Though they have to supply water frequently and keep them clean, these maintenance is not easy especially for the elderly. Most of them don’t know the moderate humidity, the effect of ventilation or the energy consumption for ventilation and humidification.

In former studies, it was made clear that though the portable humidifiers are used in most facilities for infection control, indoor humidity is very low. The average humidity was lower than 40RH% (the standard value in AMAB1970 / the act on the maintenance of sanitation in buildings established in 1970) in most of the rooms in the facilities. Indoor humidity is thought to be very low in most new residences in winter in Japan. The control of humidity will be more necessary in Japan, because the population of the elderly is rapidly increasing.

2. Methods of estimating influenza infection control

2.1 Index for influenza infection control

Influenza infection through the air depends on ventilation rate and indoor humidity as shown figure1. J.Harper showed the influence of temperature and relative humidity upon the survival rate of virus in chambers. Jeffry Sharman et al. showed that the survival rate of influenza in the air depends on absolute humidity. Kurabuchi et al. showed simulation results on the movements of influenza viruses considering the influence of absolute humidity.

Figure 2 shows the data by G.J.Harper on the decrease of the survival rate of influenza viruses. The survival rates decrease first in the case of high absolute humidity. Approximation lines using the survival rates when the value is above 10% are shown in this figure. These correlation coefficients are high ($R^2 = 0.49 - 0.94$).
Figure 2 Exponential approximations of Influenza virus survival ratios in the tests by G.J.Harper

Figure 3 shows the relationship between the humidity and the exponents of these approximate equations $\beta$. This left figure shows that the exponent $\beta$ depends on relative humidity. However the exponent is different by temperature. The right figure shows that the exponent $\beta$ depends on absolute humidity. However the approximate equation of $\beta$ when temperatures are 7.0-8.0 deg-C is not similar to that of 20.5-24 deg-C.

Therefore, the flowing equation of $\beta$ (20.5-24 deg-C) is thought to be suitable for the estimation of the heating spaces.

$$\beta = 0.0142 \cdot e^{0.4011 \cdot x_i}$$  \hspace{1cm} (1)$$

where, $x_i$: indoor absolute humidity (g/kg')

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When the generation rate of influenza viruses is 0, the indoor concentration of influenza viruses $C_{inf}$ ($n/m^3$) is shown as the next equation (2). $C_{inf}$ ($n/m^3$) is the number of influenza viruses in the air at 1m$^3$.

$$C_{inf} (t) = C_{inf} (0) e^{-\beta t}$$  \hspace{1cm} (2)

This equation shows that the exponent $\beta$ is correspond to ventilation time. Therefore, the concentration of influenza virus is calculated using the next equation (3) considering the effect of ventilation and absolute humidity.

$$C_{net} = M_{inf} / (N+\beta)$$  \hspace{1cm} (3)

Where, $M_{inf}$: generation rate of influenza viruses in the air of 1 m$^3$ (n/(m$^3$h))

$N$: ventilation time (1/h)

When the generation rate of influenza viruses from a person $M_{inf_p}$ is used, the next equation is given.

$$C_{net} = M_{inf_p} / (Q_p + \beta V_p)$$  \hspace{1cm} (4)

Where, $Q_p$: ventilation rate a person(m$^3$/hp)

$V_p$: space volume a person(m$^3$/p)

The ratio of the concentration of influenza viruses to the generation rate of influenza viruses from a person $\Gamma$ is shown as the next equation. The ratio is thought to be an index of influenza infection control.

$$\Gamma = C_{net} / M_{inf_p} = 1 / (Q_p + \beta V_p)$$  \hspace{1cm} (5)

The index of influenza infection control $\Gamma$ is 0.027 when the indoor temperature is 24 deg-C and the indoor relative humidity is 40 RH%. The index of influenza infection control $\Gamma$ is 0.031 when the indoor temperature is 17 deg-C (AMAB1970) and the indoor relative humidity is 40 RH% (AMAB1970).

The ventilation rate a person $Q_p$ is calculated using the next equation.

$$Q_p = M_{CO2_p} / D_{CO2}$$  \hspace{1cm} (6)

Where, $D_{CO2}$: the difference of the indoor concentration and the outdoor concentrations of CO$_2$

$M_{CO2_p}$: the generation rate of CO$_2$ from a person

The energy loads for ventilation and humidification $L_{vh}$ are calculated using the next equation.

$$L_{vh} = k_v \times D_v + k_x \times D_x$$  \hspace{1cm} (7)

Where, $k_v$: coefficient of ventilation (=0.34)

$k_x$: coefficient of humidification (=0.834)

$D_v$: the difference of the indoor temperature and the outdoor temperature

$D_x$: the difference of the indoor absolute humidity and the outdoor absolute humidity.
2.2 Characteristics of the index of influenza infection control \( \Gamma \) and the energy load \( L_{vh} \)

Figure 4 shows the characteristics of the index of influenza control \( \Gamma \). The left figure shows a contour graph of \( \Gamma \) with indoor absolute humidity \( X_i \) and ventilation rate a person \( Q_p \). The ventilation rate a person \( Q_p \) decreases with indoor absolute humidity \( X_i \). This shows that when humidity is higher, the required ventilation rate tends to be lower.

The right figure shows the contour with indoor absolute humidity \( X_i \) and the energy load of ventilation and humidification \( L_{vh} \). The contour was calculated under the following conditions. The outdoor absolute humidity was 3.0 g/kg'. The outdoor air temperature was 0 deg-C. The energy load \( L_{vh} \) increases with absolute humidity \( X_i \) and decreases when the absolute humidity \( X_i \) reaches a critical point. The tendency shows that if absolute humidity is higher than a critical point, the energy consumption will be saved.

![Figure 4 Relationships between absolute humidity and Ventilation rates a person \( Q_p \) / energy loads of ventilation and humidification \( L_{vh} \)](image)

3. Estimation of influenza infection control in facilities for the elderly

The state of influenza infection control was investigated using the measured temperatures, humidity and concentrations of carbon dioxide in the facilities for the elderly as shown in table 1. The facilities were built in 1970s to 2010s in northern areas of Japan (Hokkaido and Miyagi). Indoor spaces are heated with floor heating systems with the exception of a facility (MB) in Miyagi Prefecture. Their rooms and common spaces are humidified using portable humidifiers. Humidification units which are included in air conditioning systems are also used in HB and MB.

![Table 1 Summary of investigated facilities](image)

Figure 5 shows the change of daily average of indoor temperatures and absolute humidity in HA and MA. The temperatures are controlled to 22-26 deg-C in HA and to 20-24 deg-C in MA. The indoor temperatures are well controlled in most facilities. The indoor absolute humidity changes from 4.5 to 6.5 g/kg' in HA and form 3.5 to 8.0 g/kg' in MA. The indoor absolute humidity is low in all the facilities.

Figure 6 shows the daily average ventilation rate a person $Q_p$. The ventilation rate gradually increased in this term. This increase of the difference between outdoor and indoor temperature is thought to be a factor of this tendency. The ventilation rate $Q_p$ is influenced by the mechanical ventilation and opening windows by nursing care staffs and/or dwellers. The staffs often open windows to exhaust the smell while and after disposing of excretion in the facilities for the elderly. Therefore the ventilation rate is thought to change significantly.

Figure 7 shows the index of influenza infection control $\Gamma$. The index of influenza infection control $\Gamma$ also changes significantly. The index decreased gradually in this term. One of the factors of the decrease is thought to be the increase of ventilation rate a person $Q_p$.

Figure 8 shows the energy load $L_{vh}$. The energy load changes significantly. The energy load $L_{vh}$ increased gradually in this term. One of the factors of this increase is thought to be the increase of ventilation rate a person $Q_p$. 

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Figure 7 Change of Influenza-infection-control-index $\Gamma$ in HA and MA

Figure 8 Change of energy load of ventilation and humidification $L_{vh}$ in HA and MA

Figure 9 shows the relationships between indoor absolute humidity $X_i$ and the ventilation rate a person $Q_p$ and the relationship between indoor absolute humidity $X_i$ and index of influenza infection control $\Gamma$. The index $\Gamma$ is lower than 0.031 ($\text{(AMAB1970)}$) in the most facilities. The index $\Gamma$ is higher than 0.031 in MA-R1,MA-R3 and MA-CS where the ventilation rates a person $Q_p$ are low. There are not any significant relationships in these figures.

Figure 10 shows the relationship between the ventilation rate a person $Q_p$ and the index $\Gamma$ and the relationship between the index $\Gamma$ and the energy load $L_{vh}$. The left figure shows that the index $\Gamma$ depends on the ventilation rate a person $Q_p$. The right figure shows that the energy load $L_{vh}$ depends on the index $\Gamma$.

The main factor of the index $\Gamma$ and the energy load $L_{vh}$ are thought to be the ventilation rate a person $Q_p$, because absolute humidity is very low in all the facilities.
The index $\Gamma$ made it possible to estimate the state of infection control in indoor spaces using the measured temperatures, humidity and concentrations of carbon dioxide. The index $\Gamma$ and the energy consumption for ventilation and humidification $L_{vh}$ varied from space to space. These results showed that it is necessary to control both of ventilation rates and humidification rates on the basis of the estimation using $\Gamma$ and $L_{vh}$.

4. Acknowledgements

This study is a part of “a study on the state of indoor air quality and the maintenance in facilities for the elderly”. The study was carried out under the ethical reviews of National Institute of Public Health (NIPHBIRA#12100). The authors express their gratitude to Prof. Hirofumi Hayama and Assistant Prof. Koki Kikuta Hokkaido University, Prof. Yoshinori Honma and Prof. Shuang Yan Miyagi ca Women’s University, all the staffs and residents of the facilities for the elderly.

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Effects of Indoor Air Temperature on Blood Pressure among Nursing Home Residents in Japan

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Abstract

Purpose / Context – To quantify the relationship between indoor temperature and blood pressure in Japanese nursing home residents.

Methodology / Approach – A field study of 27 nursing homes in Japan was conducted. We measured the indoor temperature of nursing homes and collected data on resident’s blood pressure via a standardised questionnaire. Facilities were classified into two groups based on measured indoor temperature. Blood pressure rise in winter was defined as the difference in blood pressure between January and August to minimise individual variation.

Results – Daytime and night-time indoor temperatures were significantly associated with blood pressure rise in winter, even after adjusting for the effects of potential confounders such as age, gender, body mass index, residential period, care level, systolic blood pressure in August, and medication in January. A 1°C decrease in the indoor room temperature was significantly associated with a 0.74 mmHg increase in the blood pressure rise in winter for daytime temperature (p < 0.01) and a 0.72 mmHg increase for night-time temperature (p < 0.01).

Key Findings / Implications – The association between indoor temperature and blood pressure that we found could contribute to controlling the blood pressure of residents by improving indoor thermal environments in nursing homes.

Originality – Our findings from this field study on residents in nursing homes expand the applicability of previous studies on the general population in real life situations and clarify the generalisability of experimental evidence about thermoregulation and blood pressure in controlled settings.

Keywords – Indoor Thermal Environment, Blood Pressure, Aged Care, Field Survey, Senior Living
1. Introduction

The ageing Japanese population has the world’s highest proportion of elderly people, and the number of residents in nursing homes is increasing. High blood pressure is a risk factor in longer periods of care (Gohgi, 2005), and controlling the blood pressure of residents in nursing homes is important for care prevention. The effects of indoor thermal environment on blood pressure have been reported in previous studies. A large-scale field study on general dwelling house residents suggested that increases in blood pressure can be controlled with a warm indoor temperature in winter (Saeki, 2015 and 2014). Because the effects of temperature on blood pressure are greater in older people (Umishio, 2015 and 2014; Lanzinger, 2014), conducting a survey for elderly nursing home residents is important. To quantify the association between indoor temperature and nursing home residents’ blood pressure, we conducted a field study among 27 nursing homes in Japan. We measured the indoor temperature of nursing homes and collected data on residents’ blood pressure through a standardised questionnaire.

2. Methodology

2.1 Participants

In winter and summer of 2015, field studies on the indoor thermal environment of nursing homes and resident’s blood pressure were conducted. The study included 1100 residents in 27 facilities located in Yamanashi, Nagano, Osaka, Nara, Hyogo, and Kyoto prefectures. The facilities were special nursing homes for the elderly, geriatric health service facilities, or pay nursing home.

2.2 Study protocol

The indoor temperatures in facilities were measured for approximately 4 weeks in January to February. Three facilities in Yamanashi prefecture also participated in measuring indoor temperatures from August to September. Information about residents’ was recorded by care staff using a standardised questionnaire. The buildings’ characteristics, including building age, structure, insulation performance, and number of residents and staff, were recorded at the same time.

2.3 Indoor air temperature

Temperatures and relative humidity were measured at 20 min intervals 0.1 m and 1.1 m above the floor in private rooms, dining halls, corridors, and dressing rooms. These temperatures and relative humidity were measured by using Thermochron (KN laboratories) data loggers in Yamanashi prefecture and AD-5696 (A&D company) data loggers in other prefectures. The local meteorological office in each study area provided outdoor temperature data recorded at 10 min intervals.

2.4 Blood pressure and individual attributes

Because of the difficulties in presenting questionnaires to residents in nursing homes, standardised questionnaires were completed by care staff. The medical charts, average blood pressure, and use of antihypertensive drugs in January, March, August, and November were recorded for each resident. Individual attributes, including age, gender, height, weight, duration at current residence, care requirements, seasonal blood pressure, and medication were recorded at the same time.
2.5 Statistical analysis

The 27 facilities were classified into two groups based on the room temperature recommended in Cold Weather Plan for England 2013 (Figure 1). The recommendation is as follows: “heat your home to the right temperature: your living room should be 21 °C (70 °F), and your bedroom and the rest of the house heated to 18 °C (65 °F)” (PHE, 2013). In this study, daytime was defined as 06:00 to 17:59, and night-time was defined as 18:00 to 05:59 the following day, based on the forecast phrasing of the Japan Meteorological Agency. In this report, the temperatures measured 1.1 m above the floor were used for analysis. For continuous variables with a normal distribution, mean ± standard deviation (SD) was reported. For variables with a skewed distribution, medians and interquartile ranges were reported. Mean and median values were compared by using a t-test. The proportions of both groups were compared by using the chi-squared test. Relationships between the indoor temperature and residents’ blood pressure were assessed by using multilevel analysis and multiple regression analysis. The applicability of multilevel analysis was verified by the intraclass correlation coefficient (ICC) and the design effect (DE) of the null model. If the ICC was over 0.10 and DE was over 2.0, the data were considered in its configuration. All p-values were two-sided, and p < 0.05 was considered statistically significant. All statistical analyses were performed with SPSS ver. 22.0 software.

Figure 1 Grouping rule based on Cold Weather Plan for England 2013 (PHE, 2013)

3. Results

3.1 Characteristic and indoor air temperature of facilities

For the 27 facilities, the building age was 5.1 ± 5.2 (mean ± SD) years. There were seven facilities (25.9%) with double glazing and 11 facilities (40.7%) with insulated walls (Table 1). Facilities 1 and 2 in Yamanashi prefecture were located at the same site. Temperatures in most of the facilities were stable and had only had small differences between daytime and night-time. However, the relative humidity was around 20% indicating that the air was dry (Table 2). Eighteen facilities were classified into the cold group according to the recommended temperatures (Table 2). In analysing the indoor temperature, the outdoor thermal environment should be considered. Facilities 1 and 2 at the same site were extracted to compare the indoor temperatures of warm and cold groups. To remove the effects of sunlight, temperature data for private rooms on the north side of the building were used. Seasonal comparison of indoor temperature and outdoor temperature showed that indoor temperature differed regardless of the outdoor temperature in winter, though indoor temperature in summer did not differ greatly (Figure 2).
Table 1: Characteristics of facilities

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<td>Unknown</td>
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</tbody>
</table>

LTCHF, long-term care health facility; N, no; PNH, pay nursing home; RC, reinforced concrete; S, steel; SENH, special elderly nursing home; W, wooden; Y, yes.

3.2 Characteristics and blood pressure of residents

Of the 1100 residents, (mean age ± SD, 86.5 ± 6.9 years), 250 (22.7%) were male. In the t-test of seasonal blood pressure, there were significant differences in January and November, although the systolic blood pressure in March and August did not differ (Table 3). According to the results in Figure 2, the indoor temperature in August did not differ greatly between the warm group and cold group, whereas it did differ in January. These results indicate that systolic blood pressure was affected by the indoor temperature in winter.
Table 2: Indoor temperatures and relative humidities of facilities

<table>
<thead>
<tr>
<th>ID</th>
<th>Survey season</th>
<th>Daytime temperature [°C]</th>
<th>Night-time temperature [°C]</th>
<th>Daytime humidity [%]</th>
<th>Night-time humidity [%]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>outdoor private dining</td>
<td>outdoor private dining</td>
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<tr>
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<td></td>
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<td>20.8 33.5</td>
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<td>18.4 28.1</td>
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</tr>
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<td>22.4</td>
<td>68.8 22.9</td>
<td>77.7 22.6</td>
</tr>
<tr>
<td>11</td>
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<td>21.9</td>
<td>60.2 26.6</td>
<td>65.1 26.0</td>
</tr>
<tr>
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<td>28.4 23.8</td>
<td>28.4</td>
</tr>
<tr>
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<td>Winter</td>
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<td>21.5</td>
<td>66.9 30.2</td>
<td>75.1 30.8</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>6.2 19.9 4.0</td>
<td>19.4</td>
<td>22.2 25.7</td>
<td>22.6</td>
</tr>
<tr>
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<td></td>
<td>6.7 18.4 4.0</td>
<td>21.6</td>
<td>66.9 30.1</td>
<td>75.1 27.6</td>
</tr>
<tr>
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<td>20.8</td>
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<td>66.9 29.4</td>
<td>75.1 29.1</td>
</tr>
<tr>
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<td>19.8</td>
<td>23.2 25.6</td>
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<tr>
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<td>77.7 15.1</td>
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<td>18.6</td>
<td>20.4 21.3</td>
<td>19.7</td>
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<tr>
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<td>20.5</td>
<td>60.2 26.3</td>
<td>65.1 20.5</td>
</tr>
<tr>
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<td>6.2 22.0 4.0</td>
<td>21.8</td>
<td>21.5 24.3</td>
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<td>21.0</td>
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<td>65.1 21.1</td>
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<td>19.3</td>
<td>66.9 19.4</td>
<td>75.1 22.8</td>
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<td>65.1 24.1</td>
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<td>75.1 27.9</td>
</tr>
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<td>71.2 66.1</td>
<td>69.1</td>
</tr>
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<td>61.7 62.9</td>
<td>61.4</td>
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<tr>
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<td>25.7 25.7 24.8</td>
<td>24.8</td>
<td>60.6 68.7</td>
<td>62.5</td>
</tr>
</tbody>
</table>

Highlights indicate temperatures below the recommended values.

Figure 2: Indoor and outdoor temperature in facilities 1 and 2.
The broken line shows where the indoor temperature equals the outdoor temperature.
Table 3: Characteristics and blood pressure of residents

<table>
<thead>
<tr>
<th>Basic characteristics</th>
<th>Cold group (n=755)</th>
<th>Warm group (n=345)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years, mean (SD)</td>
<td>86.4 (6.8)</td>
<td>86.7 (7.3)</td>
<td>0.49</td>
</tr>
<tr>
<td>BMI, kg/m², mean (SD)</td>
<td>20.4 (3.5)</td>
<td>20.2 (3.5)</td>
<td>0.53</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>577 (76.7)</td>
<td>269 (78.2)</td>
<td>0.59</td>
</tr>
<tr>
<td>Duration at current residence, years, median [IQR]</td>
<td>1 [1 - 2]</td>
<td>2 [1 - 3]</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Current care level, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support level 1</td>
<td>36 (5.2)</td>
<td>14 (4.2)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2</td>
<td>30 (4.3)</td>
<td>8 (2.4)</td>
<td></td>
</tr>
<tr>
<td>Care level 1</td>
<td>147 (21.1)</td>
<td>48 (14.5)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>145 (20.8)</td>
<td>51 (15.5)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>135 (19.3)</td>
<td>69 (20.9)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>131 (18.8)</td>
<td>68 (20.6)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>74 (10.6)</td>
<td>72 (21.8)</td>
<td></td>
</tr>
<tr>
<td>Average systolic blood pressure, mmHg, mean (SD)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>128.8 (15.3)</td>
<td>126.4 (16.4)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>March</td>
<td>129.0 (15.7)</td>
<td>127.0 (16.3)</td>
<td>0.51</td>
</tr>
<tr>
<td>August</td>
<td>127.0 (15.5)</td>
<td>126.5 (16.2)</td>
<td>0.57</td>
</tr>
<tr>
<td>November</td>
<td>129.0 (15.7)</td>
<td>127.0 (16.3)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Antihypertensive drugs, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>292 (45.8)</td>
<td>119 (44.6)</td>
<td>0.74</td>
</tr>
<tr>
<td>March</td>
<td>291 (54.8)</td>
<td>126 (54.1)</td>
<td>0.85</td>
</tr>
<tr>
<td>August</td>
<td>343 (54.1)</td>
<td>138 (53.9)</td>
<td>0.96</td>
</tr>
<tr>
<td>November</td>
<td>347 (54.7)</td>
<td>142 (54.0)</td>
<td>0.84</td>
</tr>
</tbody>
</table>

BMI, body mass index; IQR, interquartile range; SD, standard deviation.

3.3 Effects of indoor air temperature on blood pressure

Because there are wide variations in absolute blood pressure among individuals, blood pressure rise in winter was defined as the difference in blood pressure between January and August to minimise individual variation. The warm group had a lower blood pressure rise in winter than did the cold group (Figure 3). The t-test showed that the effect of indoor temperature on blood pressure was not ambiguous, and other factors which could affect blood pressure were not considered. Therefore, multilevel analysis was used to clarify the association between indoor temperature and blood pressure rise considering configurative effects of individual differences. In the null model with blood pressure rise in winter as the objective variable, ICC was 0.02, and DE was 1.81, which shows that there were no configurative effects for blood pressure rise in winter in this study subject (Table 4). Because multilevel analysis was not suitable for this subject, multiple linear regression analysis was used. In the multiple linear regression model, the indoor temperature of north-facing private rooms showed a significant inverse association with blood pressure rise in winter, even after adjusting for potential confounders such as age, gender, body mass index (BMI), residential period, care level, systolic blood pressure in August, and medication in January (Table 5).
Effects of indoor air temperature on blood pressure among nursing home residents in Japan

Figure 3 Comparison of blood pressure rise in winter between the cold group and warm group

<table>
<thead>
<tr>
<th>Table 4: ICC and DE of the null model</th>
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</thead>
<tbody>
<tr>
<td><strong>Fixed components</strong></td>
</tr>
<tr>
<td>Intercept</td>
</tr>
<tr>
<td><strong>Random components</strong></td>
</tr>
<tr>
<td>Variance of residual</td>
</tr>
<tr>
<td>Variance of intercept</td>
</tr>
<tr>
<td>Akaike's information criterion</td>
</tr>
<tr>
<td>Intraclass correlation coefficient</td>
</tr>
<tr>
<td>Design effect</td>
</tr>
<tr>
<td>n</td>
</tr>
</tbody>
</table>

*p < 0.05, **p < 0.01

Table 5: Multiple regression model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unstandardised coefficients</th>
<th>Standardised coefficients</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>71.83</td>
<td>-0.49</td>
<td>9.47</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Systolic blood pressure in August</td>
<td>-0.45</td>
<td>-0.40</td>
<td>-12.34</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Antihypertensive drugs in January</td>
<td>3.09</td>
<td>0.11</td>
<td>2.73</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Daytime mean room temperature in north private room</td>
<td>-0.74</td>
<td>-0.10</td>
<td>-2.62</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Model 2: $R^2 = 0.25$, $F = 54.87$, $p < 0.001$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unstandardised coefficients</th>
<th>Standardised coefficients</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>71.16</td>
<td>-0.48</td>
<td>10.39</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Systolic blood pressure in August</td>
<td>-0.44</td>
<td>-0.48</td>
<td>-12.21</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Antihypertensive drugs in January</td>
<td>2.90</td>
<td>0.10</td>
<td>2.57</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Night-time mean room temperature in north private room</td>
<td>-0.72</td>
<td>-0.12</td>
<td>-2.97</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
4. Discussion

In this field study of 1100 residents in 27 nursing homes, indoor temperature and seasonal mean blood pressure data were collected. To the best of our knowledge, this is the first study to evaluate the association between indoor temperature and blood pressure of residents in nursing homes. Our findings from this field study on these residents expand the applicability of previous studies on the general population in real life situations and clarify the generalisability of experimental evidence on thermoregulation and blood pressure in controlled settings. The difference in indoor thermal environment between the warm group and cold group was significantly associated with blood pressure. Moreover, daytime and night-time indoor temperatures were significantly associated with an increase in blood pressure rise in winter, even after adjusting for the effects of potential confounders such as age, gender, body mass index, residential period, care level, systolic blood pressure in August, and medication in January. Antihypertensive drugs in January showed an association with an increase of blood pressure. Residents who use antihypertensive drugs tend to have a higher risk of hypertension and may have affected this result. In the multiple regression model, a 1 °C decrease in indoor room temperature was significantly associated with a 0.74 mmHg increase in the blood pressure in winter for daytime temperature ($p < 0.01$) and a 0.72 mmHg increase for night-time temperature ($p < 0.01$). The significant association between lower indoor temperatures and higher blood pressure is important because it suggests that controlling indoor temperatures could prevent lengthening the period of care need and could decrease disease. Japan’s Healthy Japan 21 government policy claimed that a 2 mmHg decrease in blood pressure could prevent 10,000 cases of stroke and 3500 age-related decline crises (MHLW, 2000). Our results show that a 3 °C increase in indoor room temperature may decrease blood pressure by 2.22–2.16 mmHg, which meets the requirements of Healthy Japan 21.

The decreased correlation between outdoor and indoor temperatures during winter observed in our study (Figure 2) suggests that the variability in building quality can mitigate exposure to cold. The effect of indoor temperature on residents in nursing homes may be much larger than the effect of outdoor temperature, because residents are likely to have disabilities and spend most of their time indoors.

This study had some limitations. First, we recruited facilities using non-random sampling, so the generalisability of the study may be limited. The indoor temperature in the nursing homes was higher than in previous studies of individual housing. To clarify the effect of cold indoor temperature, we should include participants living in colder indoor temperatures and vary the indoor thermal climate. Second, the blood pressure data were limited to seasonal average values. Because indoor temperature changes every day, blood pressure also changes. Furthermore, we assumed that biological mechanisms for acute increases in blood pressure and seasonal variations in blood pressure are similar. However, changes in factors such as diet may also play a role in the seasonal effects of temperature on blood pressure (Brook, 2011). Examining daily blood pressure would allow us to use multilevel analysis and consider absolute blood pressure, which varies between individual residents, and daily blood pressure, which is affected by daily indoor temperature. This would allow us to discuss absolute blood pressure, which is an important factor in disease (Wu, 2015). Furthermore, although we could obtain daily blood pressure, we did not measure the indoor room temperature when the blood pressure was taken. These data may be more strongly associated, but we could not examine them using our method. To obtain this information, we require the time and room in which blood pressure was measured, which would increase the burden on the care staff. Because our research was based on the normal operation of nursing homes, it was not possible to use this method.
5. Conclusion

A field study was conducted to quantify the association between indoor temperature and resident’s blood pressure in Japanese nursing homes. Our conclusions are as follows.

- The facilities in this study had stable room temperature, but were dry with a relative humidity of around 20.0%.
- Comparing two facilities that were located at the same site showed that the facility in the warm group had a higher indoor temperature in winter. The difference in temperature at 1.1 m were significant in only the cold group. Both facilities had similar indoor temperatures in summer.
- Comparison of seasonal blood pressure between the warm group and cold group showed a significant difference in January and November ($p < 0.05$). In addition, the blood pressure rise in winter was significantly lower in the warm group ($p < 0.05$).
- In the multiple regression model, a 1 °C decrease in the indoor room temperature was significantly associated with a 0.74 mmHg increase in the blood pressure rise in winter for daytime temperature ($p < 0.01$) and a 0.72 mmHg increase for night-time temperature ($p < 0.01$).

6. Acknowledgements

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7. References

Long-term Thermal Performance Evaluation of Green Roof System in Shanghai District Based on a New Model

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Abstract

In recent years, most studies of green roof system are focused on short period measurement or modelling without considering long-term performance, however, the latter is concerned by many architects and engineers. And this paper is aimed to evaluate green roof's long-term thermal performance in Shanghai district based on a new model and analyze various factors' effect on thermal index. Green roof is usually divided into three big layers, namely plant layer, substrate layer and structure layer. The model developed in this paper not only considers the effect of wind velocity's vertical distribution on coupled hygrothermal transfer, but also involves multiple reflection of solar radiation between different layers. Based on the field measurement from July, 2014 to June, 2015, the model has a good agreement in most cases. And simulation results indicate that green roof has a better insulation effect than corresponding common roof both in summer and winter, and its equivalent thermal resistance is not a fixed value. Many factors show significant effect on green roof's long term thermal performance, such as LAI, soil's thermal conductivity, indoor temperature etc. According to the method in this paper, it is possible to have a quick comparison of thermal performance between green roof and common roof, and judge whether green roof system meets the insulation rule of local energy conservation.

Keywords: Long-term thermal performance, Green roof system, Coupled hygrothermal modelling, Equivalent thermal resistance.
1. Introduction

As a kind of building component with long history, green roof has received much attention for its multiple benefits in recent years. According to the thickness of substrate, green roofs are typically divided into two categories: including intensive green roof and extensive green roof. Although better in some benefits, intensive green roof is less commonly used than extensive green roof for extra structural reinforcement and expensive maintenance. Thermal and energy performance is one of the most concerned topics of green roof system nowadays, some researchers conducted field or laboratory measurement in various areas (Saadatian, et al., 2013), and some others analyze thermal performance of green roof system by developing various models based on heat and mass balance (Djedjig, et al., 2012). However, most studies are focused on instantaneous or just short period's performance without considering its long-term seasonal effect. In addition, research based on field measurement, although of great interest for understanding the behavior of the type of roof analyzed, are difficult to extrapolate for other conditions. What's more, there is lack of thermal performance evaluation index of green roof system, and it is difficult to carry out a quick and accurate comparison between green roof and other type of roof. In the past decade, Shanghai's government has released various rules to promote city vertical greening, one of which is related to green roof whose area mush reach more than 30% of total roof area. And this paper is focused on long term thermal performance of extensive green roof system by simulation based on a new model which is validated by data of field measurement in typical seasons, and sensitive analysis is carried out to obatain the parameters that has significant effect.

2. Methodology

2.1 Field experiment of green roof and common roof

As is illustrated in Fig.1, there were two test rooms using the same building materials located at Jiading Campus of Tongji University, the dimensions were both 3m*3m*2.7m. The left roof was extensive green roof, and the right one was just common roof that was made of foam sandwich panel (75mm thick). Extensive green roof was made up of foam sandwich panel and 36 prefabricated greenery modules which was connected by buckles, and the size of every module was 50cm*50cm*7cm (not including the canopy layer). The greenery module was well designed, which combined plant layer, substrate layer, filtering membrane and drainage layer together (Fig.2). The plant was sedum linear, a type of succulent vegetation, which is very common in Shanghai district. The substrate was about 4cm thick and was comprised of peat soil, powdered perlite, vermiculite aggregate and organic fertilizer. During the experiment, the windows and door were locked, and indoor temperature was controlled by air conditioner at 26 ℃ in summer and 24 ℃ in winter. A weather station was installed near the roof to record the local meteorological data, including air temperature, relative humidity, solar radiation, wind speed and precipitation. Type-T thermocouples were set at different heights along the vertical direction of green roof and common roof, measuring temperatures of different layers. For green roof, 28 thermocouples measured temperature of seven positions, including indoor air, inner and outer surface of sandwich panel layer, drainage layer, substrate layer, canopy layer and local air temperature 15cm above vegetation. And for common roof, 16 thermocouples measured temperatures of four positions, including indoor air, inner and outer surface of sandwich panel, air temperature 15cm above the panel. All the thermocouple were set at data acquisitions system which scanned all sensors every one minute and stored the data in a local computer. Four TDR (Time Domain Reflectometry) sensors were used to measure volumetric water content of substrate layer, and four humidity sensors were set above the roofs to record local relative humidity. Furthermore, six heat flux sensors were installed at the inner surface of sandwich panel to measure heat flux through both roofs. And these sensors were put near the center of the roof to avoid edge effect.
2.2 Numerical model of green roof

Adopting various simplifications, researchers proposed different models of green roof system. From the simpliest thermal resistance model to heat and moisture balance model, more and more physical phenomena were considered. And this paper takes another three factors into green roof model based on SVAT1 theory proposed by Shuttleworth (Shuttleworth, et al., 1990): (1) Multiple solar reflection was considered between different layers of plant; (2) the effect of wind profile on turbulent transfer coefficients below and above canopy surface was considered; (3) Coupled heat and moisture transfer was applied in substrage layer based on the theory of Philip & de Vries (Philip and De Vries, 1957). As is illustrated in Fig.3, the following assumptions are used based on previous study (D.J. Sailor, 2008; E.P.D. Barrio, 1998): (1) Green roof is divided into three big layers, including plant layer, substrate layer and structure layer, and its area is large enough to be assumed horizontally homogeneous. (2) The biochemical reactions and heat conduction through plants are ignored. (3) The change of substrate water content equals to the water loss through evapotranspiration, and plant's water loss is not considered. (4) The canopy is considered as a semi-transparent medium, in which radiation obeys Beer’s law. (5) The structure layer is waterproof, where moisture transfer is not involved.

2.2.1 Longwave radiation distribution

In longwave range, transmittance and reflectance of the leaf tissue are negligible. The canopy will transmit only the radiation which is not even once intercepted by a leaf. In this paper, plant layer of green roof system is divided into n parts, and the longwave transmittance of plant layer can be calculated by the following equation:

1 SVAT: Soil-Vegetation-Atmosphere Transfer
\[ \tau_{LR,C} = \exp(-k_{LR} \cdot LAI) \]  

(1)

Where, \( k_{LR} \) is the extinction coefficient for longwave radiation, some values of it are supplied in literatures. LAI is leaf area index of plant layer.

And longwave radiation that each part receives can be derived as follows:

\[ R_{l,f,i} = F_{ij} \cdot \varepsilon_i \varepsilon_j \sigma(T_{4,p,j}^4 - T_{4,p,i}^4) + F_{ig} \cdot \varepsilon_i \varepsilon_g \sigma(T_{4,g}^4 - T_{4,p,i}^4) + F_{isky} \cdot \varepsilon_i (I_{sky} - \sigma T_{4,p,i}^4) \]  

(2)

where, \( R_{l,f,i} \) is longwave radiation of each part of plant layer, \( F_{ij} \) is radiation view factor, \( \varepsilon \) is longwave radiation absorption coefficient, \( T_g \) and \( T_p \) are ground surface temperature and leaf temperature of each layer.

When \( j<i \),

\[ F_{ij} = (1 - \tau_{LR,C,i-1} \cdot \tau_{LR,C,i-2} \cdots \tau_{LR,C,i+1} \cdot (1 - \tau_{LR,C,j})) \]  

(3)

When \( j>i \),

\[ F_{ij} = (1 - \tau_{LR,C,i+1} \cdot \tau_{LR,C,i+2} \cdots \tau_{LR,C,n-1} \cdot (1 - \tau_{LR,C,j})) \]  

(4)

\[ F_{ij} = (1 - \tau_{LR,C,i-1} \cdot \tau_{LR,C,i-2} \cdots \tau_{LR,C,n} \cdot (1 - \tau_{LR,C,1})) \]  

(5)

\[ F_{isky} = (1 - \tau_{LR,C,i} \cdot \tau_{LR,C,i-1} \cdot \tau_{LR,C,i-2} \cdots \tau_{LR,C,2} \cdot (1 - \tau_{LR,C,1})) \]  

(6)

2.2.2 Solar radiation distribution

Absorptivity, reflectivity and transmissivity of each part of plant layer is defined as following equations:

\[ \alpha_{SR,C} = 1 - \rho_{SR,C} - \tau_{SR,C} \]  

(7)

\[ \rho_{SR,C} = (1 - \tau_{SR,C}) \cdot \rho_{SR,P} \]  

(8)

\[ \tau_{SR,C} = \exp(-k_{SR} \cdot Lc\eta_{LAI}) \]  

(9)

\[ k_{SR} = [(1 - \rho_{SR,P})^2 - \rho_{SR,P}]^{1/2} \cdot k_{LR} \]  

(10)

Where, \( k_{SR} \) is the extinction coefficient for solar radiation, \( \tau_{SR,P} \) and \( \rho_{SR,P} \) are transmittance and reflectance of the leaf tissue respectively.

After multiple reflection, absorption and transmittance, the total absorptivity can be derived as follows:

\[ \alpha_{12 \cdots n} = \alpha_1 (1 + \frac{\tau_{12 \cdots n}}{1 - \rho_{12 \cdots n}}) \]  

(11)

\[ \alpha_{12 \cdots i-j} = \alpha_1 (\frac{\tau_{12 \cdots i-j}}{1 - \rho_{12 \cdots i-j}} - \frac{\alpha_{12 \cdots i-j}}{1 - \rho_{12 \cdots i-j}}) \]  

(12)

\[ \alpha_{12 \cdots j} = \frac{\tau_{12 \cdots j-1} \alpha_j}{1 - \rho_{j-1 \cdots 21} \alpha_j} \]  

(13)

Where,

\[ \tau_{12 \cdots j} = \frac{\tau_{12 \cdots j-1} \tau_j}{1 - \rho_{j-1 \cdots 21} \alpha_j} \]  

(14)

\[ \rho_{j-21} = \rho_j + \frac{\tau_j \rho_{j-1 \cdots 21}}{1 - \rho_{j-21}} \]  

(15)

\[ \alpha_{12 \cdots j} = \frac{\tau_{12 \cdots j-1} \alpha_{j-1}}{1 - \rho_{j-2 \cdots 21} \alpha_{j-1}} \]  

(16)

\[ \alpha_{i \cdots j} = 1 - \tau_{i \cdots j} - \rho_{i \cdots j} \]  

(17)

Then solar radiation of each part of plant layer can be calculated by multiplying incident solar radiation above green roof by total absorptivity \( \alpha_{12 \cdots i-j} \):

\[ R_{e,f,i} = \alpha_{12 \cdots i-j} \times R_{ln} \]  

(18)
2.2.3 Energy balance of plant layer

\[ \left( \rho C_p \right)_p (L_f d_f LAI) \frac{dT_f}{dt} = R_{sf} + R_{lf} + H_f + E_f \]  
\[ H_f = 2LAI \left( \frac{(T_f - T_c)}{(r_p)} \right) \]  
\[ E_f = 2LAI \left( \frac{(\rho C_p)_{a} (e_f - e_c)}{(r_a + r_p)} \right) \]  

where \((\rho C_p)_p\) is volumetric heat capacity of plant layer, \(d_f\) is leaf thickness, \(T_f\) is average temperature of each part of plant layer, \(\tau\) is time, \(H_f\) and \(E_f\) are sensible heat and latent heat transfer of each part of plant layer respectively, \(r_s\) is leaf boundary layer resistance, \(r_st\) is leaf stomatal resistance, \(T_c\) is average temperature of canopy space, \(e_f\) is saturated vapor pressure of plant temperature, \(e_c\) is vapor pressure of canopy space, \(\gamma\) is psychometric constant, \((\rho C_p)_a\) is volumetric heat capacity of air.

2.2.4 Energy and moisture balance of substrate surface

\[ -\lambda_g \frac{dT_g}{dz} \big|_{z=0} - r_v \left( D_{v\theta} \frac{\partial \theta}{\partial z} + D_{vT} \frac{\partial T_g}{\partial z} \right) = R_{n,g} + H_g + E_g \]  
\[ \rho_w \Delta z \frac{d\theta}{dz} = -\frac{\partial (q_l + q_v)}{\partial z} - \frac{E_g}{r_v} - S + P \]  
\[ H_g = \left( \frac{(\rho C_p)_a (T_g - T_c)}{(r_{gs})} \right) \]  
\[ E_g = \left( \frac{(\rho C_p)_a (e_g - e_c)}{(r_{gs} + r_{ra})} \right) \]  

where \(\lambda_g\) is thermal conductivity of substrate layer, \(T_g\) is temperature of substrate layer, \(r_v\) is latent heat of moisture, \(D_{v\theta}\) and \(D_{vT}\) are transfer coefficients of water vapor under gradient of moisture and temperature, \(\theta\) is volumetric water ratio of substrate layer, \(R_{n,g}\) is net radiation of substrate surface, \(H_g\) and \(E_g\) is sensible heat and latent heat transfer of substrate surface, \(\rho_w\) is density of liquid water, \(\Delta z\) is grid step of substrate layer, \(q_l\) and \(q_v\) are liquid water and gas water transfer, \(S\) and \(P\) are evaporation water loss and precipitation, \(r_{gs}\) and \(r_{ra}\) are water vapor resistance of substrate surface and canopy space, \(e_g\) is saturated water vapor of substrate layer.

2.2.5 Energy balance of canopy air

\[ \left( \rho C_p \right)_a (L - d_f LAI) \frac{dT_c}{dt} = -H_f - H_g - H_a \]  
\[ H_a = \left( \frac{(\rho C_p)_a (T_c - T_r)}{(r_a)} \right) \]  
\[ \left( L - d_f LAI \right) \frac{dq_{ci}}{dt} = \frac{E_f}{r_v} + \frac{E_g}{r_v} + \left( \frac{(\rho C_p)_a (e_c - e_r)}{\gamma r_v} \right) \]  

Where \(H_f\) and \(H_g\) are sensible heat transfer from plant and substrate surface to canopy space, and \(H_a\) is sensible heat transfer from reference height to canopy space, \(T_r\) is temperature of reference height, \(T_c\) is temperature of canopy space, \(e_{ci}\) is water vapor pressure of reference height, \(L\) is height of canopy space, and \(q_{ci}\) is absolute humidity of canopy space.

2.2.6 Coupled hygrothermal transfer of substrate layer

\[ \rho_w \Delta z \frac{\partial \theta}{\partial z} = -\frac{\partial (q_l + q_v)}{\partial z} - S \]  
\[ \left( \rho C_p \right)_g \frac{\partial T_g}{\partial t} + \left( \rho C_p \right)_w q_l \frac{\partial T_g}{\partial z} = -\frac{\partial q_h}{\partial z} \]  
\[ q_l = \left( -\left( D_{\theta} \frac{\partial \theta}{\partial z} + D_{T} \frac{\partial T_g}{\partial z} - K \right) \right) \]  
\[ q_v = -\left( D_{\theta} \frac{\partial \theta}{\partial z} + D_{T} \frac{\partial T_g}{\partial z} \right) \]  

where \((\rho C_p)_g\) is volumetric heat capacity of substrate layer.
\[ q_h = -\lambda_g \frac{\partial T_g}{\partial z} - \nu \rho_w (D_{vt} \frac{\partial T_g}{\partial z} + D_{v\theta} \frac{\partial \theta}{\partial z}) \tag{33} \]

Where \((\rho C_p)_g\) is volumetric heat capacity of substrate layer, and \(q_h\) is the total of sensible and latent heat transfer in substrate layer, \(D_{vt}\) and \(D_{v\theta}\) are liquid water transfer under the gradient of water ratio and temperature, \(K\) is water conductivity of substrate layer.

2.2.7 Heat transfer process of structure layer

\[(\rho C_p)_s \frac{\partial T_s}{\partial t} = \lambda_s \frac{\partial^2 T_s}{\partial z^2} \tag{34} \]

Where \((\rho C_p)_s\) is volumetric heat capacity of structure layer, \(T_s\) is temperature of structure layer, \(\lambda_s\) is thermal conductivity of structure layer.

2.2.8 Boundary conditions of structure layer

\[-\lambda_s \frac{\partial T_s}{\partial z} \bigg|_{z=0} = h_{in}(T_s|_{z=0} - t_{in}) \tag{35} \]

Where \(h_{in}\) is indoor heat convection coefficient, \(R_{n,s}\) is net radiation of structure surface, \(t_{in}\) is indoor air temperature.

2.2.9 Resistance of heat and moisture transfer

According to the SVAT theory of Shuttleworth (Shuttleworth, et al., 1990), the turbulent resistance below and above canopy surface as well as canopy boundary layer resistance can be calculated as follows,

\[ r_a^s = \frac{h_{exp}(n)}{n \kappa_h} \left( e^{-(nZ+h)} - e^{-(n(Z_0+d_p)/h)} \right) \tag{36} \]

\[ r_a^a = \frac{1}{k_u} \ln \left[ \frac{Z-a}{h-a} + \frac{h}{n \kappa_h} \left[ \exp \left( n \left[ 1 - (Z_0 + d_p)/h \right] \right) - 1 \right] \right] \tag{37} \]

\[ r_a^c = \frac{r_h}{2LAI} = \left( \frac{100}{n} \right) \left( \frac{w}{u_h} \right)^2 \left[ 1 - e^{-n/(2Z)} \right]^{-1} / 2LAI \tag{38} \]

Stomatal vapor resistance of plant layer and substrate surface vapor resistance is from the study of Tabares-Velasco (Tabares-Velasco and Srebric, 2012).

\[ r_{st} = \frac{r_{s,\min}}{2LAI} f_1(R_s) f_2(T_f) f_3(\theta) f_4(e_f - e_r) \tag{39} \]

\[ f_1(R_s) = 1 + e^{-0.034(R_s-3.5)} \tag{40} \]

\[ f_2(T_f) = e^{0.3(T_f-273.15)+258} \tag{41} \]

\[ f_3(\theta) = \frac{\theta_{\max} - \theta_{\min}}{\theta_{\max} - \theta_{\min}} \tag{42} \]

\[ f_4(e_f - e_r) = 4 \times 10^{-3} + e^{-0.73 \times 0.622 \times 10^3 (e_f - e_r)} \tag{43} \]

\[ r_{gs} = 34.5 \times \left( \frac{\theta}{\theta_{\max}} \right)^{-3.3} \tag{44} \]

2.3 Numerical model of common roof

2.3.1 Heat balance of outer surface of structure layer

\[-\lambda_s \frac{\partial T_s}{\partial z} \bigg|_{z=h} = R_{n,s} + h_{out}(T_s|_{z=h} - T_{out}) \tag{45} \]

where \(h_{out}\) is outdoor heat convection coefficient.
2.3.2 Heat transfer of structure layer

\[(\rho C_p)_s \frac{\partial T_s}{\partial t} = \lambda_s \frac{\partial^2 T_s}{\partial z^2}\]  

(46)

2.3.3 Boundary condition of structure layer

\[-\lambda_s \frac{\partial T_s}{\partial z}
|_{z=0} = h_{in}(T_s|_{z=0} - t_{in})\]  

(47)

2.4 Methods of calculating equivalent thermal resistance

In order to quantify the relative benefit of green roof compared with common roof from the viewpoint of long-term thermal performance, equivalent thermal resistance based on hotbox method is adopted. Under the same climate, common roof with thermal resistance has the same heat insulation effect as green roof, this thermal resistance is called equivalent thermal resistance. It reflects the average thermal insulation effect. In Chinese rule of energy conservation in mixed climate, the added resistance value of green roof is fixed to be 0.9 m²·K/W. As is illustrated in Fig 4. The basic interior temperature of hotbox is set to be 25°C in summer and 20°C in winter, and typical meteorological year weather data of Shanghai are used in the simulation. Summer simulation begins from 6/01 to 9/30, and winter simulation is from 12/01 to 3/30, and typical weather year data are used.

\[\bar{R} = \frac{(\bar{T}_{s3} - \bar{T}_{s1})}{\bar{q}}\]  

(48)

\(\bar{T}_{s3}\): Average outer surface temperature of corresponding common roof. \(\bar{T}_{s1}\): Average inner surface temperature of corresponding green roof. \(\bar{q}\): Heat flux through corresponding green roof. \(\bar{R}\): Equivalent thermal resistance.

3. Results and discussion

3.1 Green roof and common roof's model validation

The observation data on typical summer and winter days are used to validate the two roof models, and input parameters of green roof and common roof models are shown in table 1. During the measurement, the average outdoor temperature and relative humidity for summer are 24.6°C and 81% respectively, and 5.5°C and 55% respectively for winter. In order to evaluate two roof models, the following parameters are adopted: green roof's foliage temperature, soil surface temperature, soil water ratio and heat flux through green roof, common roof's inner surface and outer surface temperature as well as heat flux through common roof. Fig. 5~Fig. 6 shows that good agreement was obtained between the results of numerical model and measured data.
Table 1: Input parameters of green roof and common roof models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average LAI</td>
<td>5(summer), 1(winter)</td>
<td>Thermal capacity of structure layer(J/m3K)</td>
<td>2358333</td>
</tr>
<tr>
<td>Height of plant(cm)</td>
<td>15(summer), 5(winter)</td>
<td>Thermal conductivity of structure layer (W/m K)</td>
<td>0.234</td>
</tr>
<tr>
<td>Minimum stomata resistance(s/m)</td>
<td>750</td>
<td>Depth of structure layer(cm)</td>
<td>24</td>
</tr>
<tr>
<td>Emissivity of plants</td>
<td>0.95</td>
<td>Reflectivity of structure layer surface</td>
<td>0.2</td>
</tr>
<tr>
<td>Reflectivity of leaves</td>
<td>0.3</td>
<td>Soil depth (cm)</td>
<td>4</td>
</tr>
<tr>
<td>Soil conductivity (W/m·K)</td>
<td>0.374 * (θ)^0.403</td>
<td>Soil conductivity (W/m·K)</td>
<td>0.3</td>
</tr>
<tr>
<td>soil thermal capacity(J/m3K)</td>
<td>600*1000</td>
<td>Soil water conductivity (m/s)</td>
<td>2.37 * 10^-5 * (θ)^2.4.42</td>
</tr>
<tr>
<td>Soil water capacity (pa-1)</td>
<td>1.575 * (θ^-4.35)</td>
<td>Emissivity of soil surface</td>
<td>0.9</td>
</tr>
<tr>
<td>Soil reflectivity</td>
<td>0.2</td>
<td>Field water capacity of substrate layer</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Figure 5 Model validation of green roof in summer (left) and winter (right). a) Foliage temperature of canopy layer, b) Outer surface temperature of substrate layer, c) Heat flux through green roof, d) Average water ratio of substrate layer.

Figure 6 Model validation of common roof in summer (left) and winter (right). a) Outer surface temperature of structure layer, b) Inner surface temperature of structure layer, c) Heat flux through roof.
3.2 Green roof long-term thermal performance evaluation

Based on hot box method, the average thermal performance of green roof and common roof is shown in Table 2. Green roof's added thermal resistance is about 8.12 in summer and 0.29 in winter under this setting condition. It can be deduced that green roof's equivalent thermal resistance is not a fixed value in different season, and different factors should be considered during evaluation.

<table>
<thead>
<tr>
<th>Items</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Common roof</td>
<td>Green roof</td>
</tr>
<tr>
<td>( T_{s3} ) (CR) (oC)</td>
<td>25.49</td>
<td>25.06</td>
</tr>
<tr>
<td>( \dot{q}_c ) (CR) (W/m(^2))</td>
<td>4.19</td>
<td>0.51</td>
</tr>
<tr>
<td>Equivalent thermal resistance (m(^2)K/W)</td>
<td>1</td>
<td>9.12</td>
</tr>
</tbody>
</table>

Based the model above, there are mainly two types of factors that may affect green roof's thermal performance, i.e., external factors and internal factors. According to sensitive analysis, the following factors have significant effect on green roof's equivalent thermal resistance. As is illustrated in Fig. 7 (1), in summer, indoor temperature's effect is opposite to outdoor temperature. And when indoor temperature is larger, green roof's equivalent thermal resistance will be larger. Relative humidity's effect is also opposite to indoor temperature, higher relative humidity weakens evapotranspiration of plants, so heat flux into the room becomes larger. Improving the frequency of irrigation also helps to enhance evapotranspiration, so it increases the equivalent thermal resistance. But this benefit shrinks when irrigation frequency becomes shorter and shorter. Although these factors have a significant effect in summer, their effect in winter is limited. The main reason lies in that plant is almost dead (average LAI becomes small) in winter, its shading and transpiration effect decrease a lot. And green roof's effect in winter mainly depends on substrate layer's property. Significant internal factors are shown in Fig. 7(2). LAI has a great effect on shading and plant's transpiration, a larger LAI in summer but a lower value in winter will have more thermal benefit. Thermal conductivity of substrate layer has a similar effect on equivalent thermal resistance as thermal conductivity of structure layer in both seasons, and decreasing thermal conductivity can improve green roof's thermal insulation. However, as the conductivity of structure layer decrease, the relative benefit of green roof becomes small compared with the corresponding common roof. Similar to plant's LAI, Reflectivity of structure layer has an opposite effect on green roof's thermal performance in summer and winter. In both seasons, as reflectivity rise, the surface temperature \( T_{s3} \) of common roof gets smaller. But temperature difference (\( T_{s3} - T_{s1} \)) is opposite, so equivalent thermal resistance get larger in winter but smaller in summer.

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4. Conclusion

This paper proposes a new model of green roof system, and based on this method, it is found that green roof has a better insulation effect than corresponding common roof no matter in summer or in winter of Shanghai. In addition, green roof's equivalent thermal resistance is not a fixed value and it is affected by internal and external factors significantly, such as Plant's LAI, outdoor temperature etc. By using the method mentioned above, it is able to have a quick and relative accurate evaluation of green roof's thermal performance, and judge whether green roof system reaches the insulation rule of local energy conservation.

5. Reference


Environmental sustainability of prefabricated modular residential buildings compared to traditional equivalent: Two case studies in Perth, Australia.

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Abstract

The share of prefabricated modular residential buildings in the Australian construction market is growing mainly because they are quicker to erect on-site than traditional construction, and often cheaper; but how about their carbon footprint and more particularly their thermal performance?

To bring some light on this question, this paper uses two case studies where existing prefabricated modular buildings (a detached house and a multi-storey residential building) are compared to their equivalent in traditional on-site construction methods. The thermal performance is assessed using 3D modelling and energy simulation, while carbon footprint is assessed by Life Cycle Analysis.

The thermal simulations showed that these prefabricated modular buildings perform better in winter but the study also shows that low inertia modular buildings can require more cooling energy in the summer in certain climate zones. Looking at the overall carbon footprint of the construction elements, the LCA shows that prefabricated buildings are not always less carbon intensive than their traditional equivalent and a wise choice of materials remains a necessity.

The discussion emphasises the importance of the local context and particularly the role of thermal inertia in summer for Mediterranean Climate. It also demonstrates the importance of operating energy in the overall carbon footprint of a building and, more generally, how prefabrication can easily achieve a lower carbon footprint than on-site construction.

Keywords: Prefabricated, Modular, Carbon Footprint, Thermal Performance, Life Cycle Analysis, Energy Efficiency
1. Introduction

Globally, the construction industry is an important consumer of resources and producer of waste (40% of global resources and 40% of global energy according to the 2009 report from the United Nations Environment Programme), while at the same time, construction remains a necessity that grows inevitably with the population growth. The materials and the technology exist to reduce the environmental impact of buildings and early adopters such as Josh Byrne (Byrne, Eon & Newman 2014) have shown that building eco-friendly houses with minimal extra capital investment is possible, but this is not mainstream anywhere in the world and particularly not in Australia.

One solution to mainstream this performance lies in the industrialised construction method, also called off-site construction or simply prefabrication, which has been recognised a leaner and more efficient method of construction (D. Krug, 2013).

This paper proposes to analyse the differences in operating energy and carbon footprint of two existing prefabricated modular residential buildings compared to Australian standard-practice equivalent using traditional on-site construction method. More specifically, a detached house and a multi-storey apartment block.

The literature review shows that a few researchers have already addressed the carbon and the energy embodied in the building itself (Monahan and Powell in 2001), and some have shown that operating energy is the most important part of the carbon footprint of a building (Aye et al. 2012). The approach of comparing a prefabricated modular building to a traditional building to assess the carbon footprint difference was found twice in the literature: A study in China (Cao et al. 2015) where the two buildings were of similar typologies but not equivalent; and in the USA (Kim 2008) where the modular house was compared to a traditional equivalent but of very similar specifications. This latter study focused on the difference in the carbon footprint of the construction process rather than on the building itself.

2. Background of the two case studies

The first case study looks at the Stella B17 building of the ADARA project designed and manufactured by the Hickory Group. It was one of the first prefabricated modular multi-storey residential buildings in Western Australia. The building is made of fully finished volumetric modules manufactured in its established Melbourne factory, and shipped to Perth. These modules are equipped with double-glazed windows and walls and floors are made up of steel frame. The floors also received a steel sheet and a plywood board. The building is also constituted of a concrete structure built on-site: the ground level car park and first level floor, as well as two cores integrating the lift shafts and staircases. The 96 modules were then piled up by crane to make 77 units on six floors. After this the façade elements were added to dress up this elegant building.

The second case study concerns a group of 22 houses from BGC Residential, prefabricated in its factory in Canning Vale (WA) and erected in Banksia Grove, a suburb North of Perth-metro. BGC Residential belongs to the BGC Group, a major player in the Australian construction industry, who decided a few years ago to start a pilot program to build prefabricated houses. The houses are made up of two or three fully finished modules made of steel frame walls and roof structure, and concrete slab for the floor. They were transported to site and delivered by truck without the need of a crane. The garage and the alfresco are the only elements of the house constructed on-site. The 22 houses are an arrangement of 2 or 3 modules making 7 concepts with different facade colours and orientations.
3. Methodology

3.1 Carbon footprint

In our case, the carbon footprint will be evaluated by calculating the GreenHouse Gases (GHG) emitted during the life of the building, from the extraction of its raw materials down to its deconstruction and transport to the landfill or recycling plant.

Life Cycle Analysis (LCA) is the method chosen here to estimate the amount of GHG of our modular buildings. The unit of measurement used in our LCA is the kilogram of CO2 equivalent per occupant per year of the life of the building, expressed as kgCO2eq/occ/y. This measures the Global Warming Potential (GWP) (US EPA 2013) of various impacts, and means the volume of GHG emitted by the building throughout its life.

The tool used to model the LCA was ETool, a software compliant to ISO14040 2006, ISO14044 2006, BS EN 15978 2011 standards.

For both the multi-storey building and the detached houses, all household energy consumption – beside heating and cooling – and all water consumption were assumed to be the same between the modular buildings and the traditional equivalents.

3.2 Operating Energy

The research being based on the comparison between two equivalent buildings from two different construction methods, the thermal performance of the buildings envelops – and consequently the heating and cooling loads - are to be the most significant elements to study. Therefore, it was decided to give particular attention to these elements.

The buildings were first digitized as 3D models using Building Information Modelling (BIM) on CYPECAD MEP (from CYPE software. CYPECAD MEP then calculates the yearly heating and cooling demand, by hourly steps, using the EnergyPlus engine, a program developed by the U.S. Department of Energy. This is typically expressed as a function of energy per metre square (kWh/m2).

Weather conditions, from ASHRAE weather files, were factored into the thermal performance modelling to consider how the building will perform in a particular climatic scenario. Additionally, Internal comfort temperatures (set points) have been set to 21°C in winter and 24°C in summer.

The detailed load allowed to study the thermal behaviour of the building and extract important information to understand the yearly results. The yearly results – heating and cooling loads - were then introduced in eTool to estimate the GHG of this part of the operating energy of the buildings.

3.3 The traditional equivalent

For both the LCA and the Energy Simulation, the traditional equivalent was modelled using the specifications given by the respective builders which would correspond to standard-practice aiming at compliance. The equivalent of Hickory apartment block was modelled using concrete external walls without insulation, brick internal walls and single-glazed windows. The BGC modular house equivalents were modelled using double brick cavity external walls, single brick internal walls, thicker on-site poured concrete slab and terra cotta roof tiles on timber structure.

The windows specification did not change (single glazed). The air tightness of the modular and traditional buildings was considered the same.

This base methodology was used in the two case studies but because they happened at different times, the parameters and assumptions were not exactly the same.
3.4 Specificities of the Multi-storey building
The Hickory building, Stella B17, was the first one to be assessed with this method and it was modelled with all the expected internal loads (from the occupants’ bodies, the lighting and appliances) to simulate a building in occupation. In eTool, the occupancy calculator estimated an average occupancy of 124.45 persons in the whole building, and a design life of 150 years for both the modular building and the traditional equivalent.

3.5 Specificities of the detached houses
The BGC project came later and we decided that, for the purpose of a comparison, the houses could be considered without occupancy, thus modelled and simulated with no internal loads.

It was also decided to model and simulate the 22 modular houses for Thermal Performance (TP) but to take only best and worst performing modular houses to model their traditional equivalent for the comparison of TP. Finally, the best performing modular house was chosen to be compared with its traditional equivalent for the assessment of carbon footprint. In eTool, the occupancy calculator estimated an average occupancy of 2.83 persons per house and a design life of 70 years for both the modular house and the traditional equivalent.

4. Results and discussion
4.1 Multi-storey residential building
4.1.1 Heating and Cooling loads
The results for Perth Weather are represented in Table 1 below:

<table>
<thead>
<tr>
<th></th>
<th>MODULAR</th>
<th>TRADITIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[MWh]</td>
<td>[kWh/m²]</td>
</tr>
<tr>
<td>Heating</td>
<td>26.59</td>
<td>4.94</td>
</tr>
<tr>
<td>Cooling</td>
<td>340.59</td>
<td>63.28</td>
</tr>
<tr>
<td>TOTAL</td>
<td>68.22</td>
<td>62.83</td>
</tr>
</tbody>
</table>

Unexpectedly, the modular construction is not performing as well as the traditional one despite the thermal insulation in the external walls and the double-glazed windows. These elements assist the thermal performance in winter but something is missing in summer. To understand what can explain this difference in cooling load, the same two buildings were simulated in different climate than the Class 4 “warm temperate” of Perth (Building Code of Australia (BCA)). They were simulated in Port Hedland, Class 1 “Hot humid summer, warm winter” and in Melbourne, Class 6 “Mild temperate”. The results are represented in Table 2 and Table 3 below:
Table 2: Thermal performance of Stella B17 in Port Hedland compared to Perth

<table>
<thead>
<tr>
<th>MODULAR</th>
<th>PERTH</th>
<th>PORT HEDLAND</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[MWh]</td>
<td>[kWh/m²]</td>
</tr>
<tr>
<td>Heating</td>
<td>26.59</td>
<td>4.94</td>
</tr>
<tr>
<td>Cooling</td>
<td>340.59</td>
<td>63.28</td>
</tr>
<tr>
<td>TOTAL</td>
<td>68.22</td>
<td>206.83</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRADITIONAL</th>
<th>PERTH</th>
<th>PORT HEDLAND</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[MWh]</td>
<td>[kWh/m²]</td>
</tr>
<tr>
<td>Heating</td>
<td>39.78</td>
<td>7.39</td>
</tr>
<tr>
<td>Cooling</td>
<td>298.39</td>
<td>55.44</td>
</tr>
<tr>
<td>TOTAL</td>
<td>62.83</td>
<td>218.43</td>
</tr>
</tbody>
</table>

Table 3: Thermal performance of Stella B17 in Melbourne compared to Perth

<table>
<thead>
<tr>
<th>MODULAR</th>
<th>PERTH</th>
<th>MELBOURNE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[MWh]</td>
<td>[kWh/m²]</td>
</tr>
<tr>
<td>Heating</td>
<td>26.59</td>
<td>4.94</td>
</tr>
<tr>
<td>Cooling</td>
<td>340.59</td>
<td>63.28</td>
</tr>
<tr>
<td>TOTAL</td>
<td>68.22</td>
<td>65.35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRADITIONAL</th>
<th>PERTH</th>
<th>MELBOURNE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>[MWh]</td>
<td>[kWh/m²]</td>
</tr>
<tr>
<td>Heating</td>
<td>39.78</td>
<td>7.39</td>
</tr>
<tr>
<td>Cooling</td>
<td>298.39</td>
<td>55.44</td>
</tr>
<tr>
<td>TOTAL</td>
<td>62.83</td>
<td>49.83</td>
</tr>
</tbody>
</table>

In both cases, the modular version performs better than the traditional. Heating being not required in Port Hedland the result is not significant for the comparison, but this time the cooling load is lower for the modular building. On the contrary, the thermal performance in Melbourne follows the same trend as in Perth (modular performing better than traditional in winter but worse in summer) even if the overall performance is, this time, to the advantage of the modular building.

These results lead us to analyse the particularity of the summer conditions in these three locations, and the two major differences were the humidity and the variance between night and day temperatures. The latter made us think that the lack of thermal inertia in the modular building compared to the all-concrete (walls and floors) traditional equivalent didn’t allow to make the most of the lower nocturnal temperatures in Perth and Melbourne.

This hypothesis was verified by simulating internal walls made of bricks and finding 8% reduction in cooling load. The approach of using bricks in the modular building to increase thermal mass is technically feasible but not workable in terms of the construction process, cost and transport. The second factor that influences cooling energy demand is solar gain, which is the amount of heat that penetrates inside the building through the windows. Reducing solar gain can easily be achieved by tinting the windows as shown in Table 4 below. In summer, solar rays penetrate the building the most when the sun is the lowest in the sky, at sunrise and sunset, through the east facing and the west facing sides of the building.
Table 4: Thermal Performance of the modular building with East and West windows tinted

<table>
<thead>
<tr>
<th></th>
<th>MODULAR TEST 4</th>
<th>TRADITIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[MWh] [kWh/m²]</td>
<td>[MWh] [kWh/m²]</td>
</tr>
<tr>
<td>Heating</td>
<td>26.59 4.94</td>
<td>33.37 6.20</td>
</tr>
<tr>
<td>Cooling</td>
<td>340.59 63.28</td>
<td>280.36 52.09</td>
</tr>
<tr>
<td>TOTAL</td>
<td>68.22</td>
<td>58.29</td>
</tr>
<tr>
<td></td>
<td>39.78 7.39</td>
<td>298.39 55.44</td>
</tr>
</tbody>
</table>

This low cost and easy fix solution improved drastically the performance of the building in summer though it reduced slightly its performance in winter.

4.1.2 Carbon footprint

The Figure 1 below shows the carbon footprint, expressed as Global Warming Potential (GWP) of the modular building compared to the traditional equivalent:

![Figure 1: GWP over the whole life of Stella B17 Modular vs Traditional equivalent](image-url)

The GHG from the building elements (foundations, envelop, fit-out, appliances, building services...) happen only once, at the construction stage, and their carbon footprint is broken down throughout the life of the building. However, the GHG from the production of the operating energy and water used during the life of the building happen every year. This graph reveals that over the life of a building, the impact of the operating energy, dominated by heating and cooling, is predominant in the whole carbon footprint of the building.
To better visualise the differences in construction between modular and traditional, we have removed from the graph the operating energy and water, as shown in Figure 2 below:

Looking at all the materials and services involved in fabricating, transporting and erecting these buildings, the modular building has a carbon footprint 6% more than it’s equivalent in traditional construction. To better understand this situation, the next graph Figure 3 shows the same comparison but this time focusing on the elements of the buildings that are different between the two construction methods:

In this graph, we have removed elements similar to the two buildings and we see that steel frame, plywood and bathroom structure; all three specific to the modular construction, account for 30% of these selected materials and services. The modules’ structure is made of steel frame and steel sheets for the floors (aggregated under “Steel frame” in the graphs). Moreover, this modular building uses quite a lot of concrete for the ground floor and the two cores. Consequently, the carbon footprint of the structural elements of the modular building is higher that the concrete used in the traditional equivalent.

In a second order comes the additional carbon footprint of the double-gazing and the insulation in the walls, but these elements participate to reducing the operating energy which, as we saw, is more important than the carbon footprint of construction materials. Finally, the transport of the modules, from Melbourne to Perth for that particular project, also add to the overall deficit of the modular building.
Hebert, L Environmental sustainability of prefabricated modular residential buildings compared to traditional equivalent: Two case studies in Perth, Australia.

For this particular project and without changing drastically the original design, one of the low hanging fruits would be to replace carbon intensive materials with a mainstream low carbon equivalent. For example, replacing the carpets with a timber floor.

4.2 The detached houses

4.2.1 Heating and Cooling loads

The 22 modular houses were modelled, along with their next neighbouring buildings to simulate the shadow, to calculate the heating and cooling loads for Perth weather.

The best and worst performing modular houses, number 21 and 12, were selected to be compared to their traditional equivalent (after modelling them) as shown in Table 1 below.

Table 1 Thermal Performance of best and worst modular houses vs traditional equivalents

<table>
<thead>
<tr>
<th>Construction</th>
<th>House #</th>
<th>HEATING [kWh/m²]</th>
<th>COOLING [kWh/m²]</th>
<th>TOTAL [kWh/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modular</td>
<td>21</td>
<td>35.57</td>
<td>4.18</td>
<td>39.75</td>
</tr>
<tr>
<td>Traditional</td>
<td>21</td>
<td>61.63</td>
<td>1.73</td>
<td>63.36</td>
</tr>
<tr>
<td>Modular</td>
<td>12</td>
<td>42.06</td>
<td>5.44</td>
<td>47.50</td>
</tr>
<tr>
<td>Traditional</td>
<td>12</td>
<td>65.53</td>
<td>1.87</td>
<td>67.40</td>
</tr>
</tbody>
</table>

The added insulation of the modular houses (in the walls) helps contain the heat better in the winter and requires less energy to keep the house at 21°C. From Table 1 we see that house 21 modular requires 42% less energy in winter than its equivalent in traditional construction and house 12 modular 36% less than traditional. Both constructions benefit from a concrete floor slab and have similar low inertia ceilings, but the traditional house has a heavier thermal inertia thanks to its brick walls (external and internal) compared to the light steel-frame construction of modular. This added inertia helps retain the coolness of the night in summer, hence requiring less energy to keep the house at 24°C. From Table 1 we see that house 21 traditional requires 59% and house 12 traditional 56% less energy in summer than its equivalent in modular construction. Though this lower performance in summer has a minimal impact on the overall annual energy load.

4.2.2 Carbon footprint

Figure 4 below shows the carbon footprint, expressed as Global Warming Potential (GWP) measured in kgCO2eq/occ/y, of the modular house #21 compared to its traditional equivalent:

![Figure 3 BGC house 21 Modular vs Traditional - Global Warming Potential](image-url)
As for the multi-storey building, the carbon footprint of operational energy is dominant in the life cycle assessment of the building.

Again the operating energy and water are removed from the graph Figure 5 in order to better visualise the differences in construction between modular and traditional:

![Figure 4 BGC house 21 Modular vs Traditional - Carbon Footprint of Material and Services](image)

Looking at all the materials and services involved in fabricating, transporting and erecting these two houses, the modular building has a carbon footprint 26% less important than it’s equivalent in traditional construction. The next graph Figure 6 shows the same comparison but this time focusing on the elements of the houses that are different between the two construction methods:

![Figure 5 Comparison of GWP (in kgCO2eq/occ/y ) of selected materials and services of traditional and modular BGC houses](image)

In this graph, we have removed elements similar between the two houses. We observe that the mineral-based construction elements of the traditional house, namely the concrete, the roof tiles, the bricks and the mortar, account for the major part of the difference between modular and traditional constructions. These are carbon intensive materials mainly due to their energy intensive fabrication process. A focus on the roof shows that despite the fact that the timber structure of the traditional house is three times less carbon intensive than the steel-frame of the modular house, the weight of the terra cotta roof tiles makes this carbon intensive element predominant in the roof category.
Additionally, the People & Equipment category is 29% less carbon intensive for modular. That is because modular benefits from an industrialised fabrication process involving less staff and less equipment. For example, the prefab concrete slab takes less staff than the traditional slab with on-the-spot custom-made formworks. Steel roof structures are easier to assemble in a factory than timber structures on-site, and the same can be said for the steel structure of the walls compared to the on-site erection of traditional walls brick by brick or the use of plasterboards versus hand laid plaster for finish. But more importantly, the fabrication and installation process of modular being 126 days shorter than for traditional, that is 126 round trips the staff doesn’t have to make to work on this one house, hence less carbon emissions from their vehicles. For this particular project and without changing drastically the original design, the modular house could improve its carbon footprint even more by adopting a prefabricated roof structure made of timber trusses.

5. Conclusion and lessons learned

Other studies have looked at different factors of sustainability between modular and traditional construction, such as construction waste, embodied energy, construction time and cost. These two case studies comparing two similar buildings of two different construction methods teach us some lessons from the thermal performance and carbon footprint perspective.

On the thermal performance:

1. If the lighter construction of modular buildings has many advantages, it also represents in general a weak point for the thermal performance in summer.
2. More specifically, this weakness is particularly impacting the high-rise building typology rather than the low-rise house typology, because of the higher window area and compactness. Indeed, multi-storey buildings are less shaded by eaves and surrounding built or natural environment. Moreover, compared to a house, average units tend to have less surfaces in contact with the exterior (heating load) and still a fair amount of glazing (cooling load).
3. But thermal inertia is beneficial to summer thermal performance only when night temperatures drop low enough below day temperatures. The thermal performance results of the multi-residential building in the 3 different climate zones showed us that there were significant differences. The lesson to draw is consideration of the local context is necessary.
4. That same case study also showed that solar gain is a key to easy thermal performance improvement and should be considered right from design stage to limit cost and ensure elegant integration of solar design.

On Carbon footprint:

1. Operating energy is a predominant element of the carbon footprint of a building in its life cycle. Unless the building is near passive house standard (i.e. close to zero operating energy from heating and cooling), then operating energy is the low hanging fruit to reduce Global Warming Potential of buildings over their life time.
2. Consideration of the carbon intensity of materials should be given right from the design stage to allow for exploration of environmentally friendly alternatives at minimum, if not zero, extra cost.

These lessons are the result of the study of these 2 particular projects and further research is necessary to refine and generalise this knowledge.

The author believes that off-site construction can offer a real advantage over on-site construction when it comes to carbon footprint and operating energy; while still retaining the other more outspoken benefits (waste, time …).

The manufacturing process of off-site construction being more repetitive and controlled than on-site construction, it naturally welcomes continuous improvement. Therefore, off-site construction
appears to be the key to achieve the evolution required from the building sector to play its role in reducing the national level of GreenHouse Gas emissions in line with the target set recently in Paris (COP21).

The Hickory group has embraced continuous improvement from the start, both for their manufacturing process and their products. They learned very quickly from the Stella B17 experience and the next generation of modules was already designed to achieve better summer performance and use less carbon intensive materials.

To take this topic further, the author has engaged in a doctoral research to identify and define the links between off-site construction and operating energy.

6. References


7. Annexes

Annexe 1 Architect view of Hickory’s Stella B17 building

Annexe 2 3D Model for Thermal Performance Simulation
Environmental sustainability of prefabricated modular residential buildings compared to traditional equivalent: Two case studies in Perth, Australia.

Annexe 3 Lay out of the 22 modular houses

Annexe 4 Street view of a BGC modular house
Annexe 5 Model of a modular house for Thermal Performance Simulation
Impact assessment of inhabitants on the economic potential of energy efficient refurbishment by means of a novel socio-technical multi-agent simulation

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Abstract

Purpose / Context – Studies of building design and economic feasibility for energy-efficient refurbishments often utilise average temperatures for the heated space in a dwelling. As even small deviations have a significant impact on the resulting energy demand, an occupant-centred simulation is necessary for more precise evaluations and recommendations.

Methodology / Approach – An Agent-based model (ABM) with only two agent types was derived. On the one hand, the technical view is included by means of a building agent that resembles a multi-room building. On the other hand, individual inhabitant agents are able to interact with the building agent to make sure they feel comfortable with resulting climate conditions in the rooms they occupy. To model realistic behaviour, inhabitant agents are negotiating about temperature setpoints and change e.g. their level of clothing if necessary.

Results – It is possible to derive realistic demand situations from different types of household under consideration. Both resulting temperature levels and heat demand differ significantly from one household composition to the other. The insulation level of the building has an impact on these figures which has to be analysed in detail.

Key Findings / Implications – In fact, the reference temperatures given in current technical standards do not reflect the behaviour of occupants. Therefore, the potential for energy demand reductions and corresponding economic feasibility have to be considered on a more individual per-household basis.

Originality – The proposed agent model was designed from scratch and closes the gap between technical and social view in an integrated socio-technical perspective.

Keywords – Space heating, thermal comfort, socio-technical interaction, multi-agent simulation, agent-based modelling
1. Introduction

Despite strong political efforts, numerous countries have to cope with a rate of modernisation that remains lower than expected. One issue for (German) homeowners is that a change of the building hull often results in a legal liability to renovate to a higher level of energy refurbishment. However, a certain reference temperature must be used for the assessment of economic feasibility, which completely neglects the personal heating habits and preferences. As raising the heating set point by one degree leads to an increase in energy demand of roughly six percent, this is a high leverage for the actual energy consumption, and therefore is likely to have a big impact on investment decisions. To find the correct energy demand of residential buildings, simplified estimates for the annual energy consumption can be calculated by application of the formulas provided by the established standards, e.g. (DIN V 4108-6:2003-06). However, average setpoint temperatures have to be used throughout the year. Here, the link to the actual thermal sensation is clearly missing. Therefore, this paper will focus on small groups of inhabitants in residential situations and show the extent to which an individual’s preference in thermal comfort leads to shifts in temperatures and heat demand. The shift of the estimated temperature setting in residential environments is quantified for different social compositions by introducing a new multi-agent simulation (MAS) approach. A sensitivity analysis is conducted to reveal effects of both personal factors and the building hull on temperature set points and the corresponding energy demand.

Main contributions are: 1) The developed MAS is capable of simulating social interactions of human beings concerning their thermal comfort, 2) the findings are validated by common standards for space heating, 3) the interplay of building hull and occupants' thermal preferences is analysed, and 4) findings show that the possible (economical) energy demand reductions for different social compositions vary significantly. The remainder of this paper is structured accordingly: After recapitulating the basics of Thermal Comfort, the MAS is derived according to the ODD protocol in section 2. Afterwards, the assumptions and model details are validated to then analyse the extent to which types of households drive the energy demand (section 3). Eventually, conclusion and outlook are given.

2. Methodology

The methodology presented in this paper builds on previous work of the same authors that deals with the detailed derivation of the mathematical background of personal thermal sensation (Hinker, Pohl, & Myrzik, 2015). To facilitate the understanding of the ABM, the findings will be presented in accordance with the extended ODD protocol (Grimm et al., 2010), which guides through the description of agents by first giving an overview, then showing the design concepts used, and eventually going into details of the implementation (hence the name ODD).

2.1 Thermal Comfort evaluations in thermal building simulations

Despite the advanced and standardised application of Thermal Comfort metrics (ASHRAE 55; ISO 7730:2005), one shortcoming is that only groups of people and their average sensation can be reflected, whereas typical constellations in the residential environment consist of few people. Finding a solution to this problem was the focus of the authors’ previous contribution (Hinker et al., 2015), in which a personal Thermal Comfort model was derived from the PMV model. In the personal model a person rates the surrounding climate with his or her personal Thermal Sensation Vote (TSV) on the PMV-scale. The TSV is calculated in a similar manner as the PMV, except activity level and clothing insulation are subjective to the person. Additionally, the preferred thermal sensation (TSV_{pre}) does not necessarily have to be zero and different people may show different sensitivities to thermal changes and also allow different deviations from their TSV_{pre} before regarding a climate as intolerably uncomfortable.
Consequently, the interaction of building and inhabitant has to be modelled in an integral concept with the right balance between level of detail and simplification. This can be satisfied by a thermal 3R2C model that allows the choice of arbitrary time step increments and reflects the thermal behaviour of buildings satisfactorily. However, to be most realistic concerning the resulting average heating temperature and resulting energy demands, multiple rooms have to be simulated. To this end, the simulation of one larger shoebox model is not a good compromise as heating habits differ for different types of rooms (Kane, Firth, & Lomas, 2015). Besides, presence of occupants in a room drives the energy demand, so the likeliness of heating many or even all rooms at the same time is low. In this study, the calculation kernel of VDI 6007 (VDI 6007) was used.

2.2 Discussion of the novel multi-agent design according to extended ODD protocol

Agent-based models (ABM) or Multi-Agent Simulations (MAS) with related applications have been developed before (Bruse, 2007; Hauser, 2013; Wu, 2007). However, the concepts were not discussed in detail and many of the necessary information were missing. In the proposed design, one inhabitant is resembled by one agent that interacts with an arbitrary number of other inhabitant agents and the building agent. As the focus was laid on socio-technical interactions, and their consequences for the heating demand, the following thoughts were used to derive the model for the inhabitant agents:

- People implicitly know about the well-being of their relatives or housemates. It can be argued that the exact level of comfort is not easy to determine while situations with high discomfort (too hot or too cold) are obvious and can be identified by all household members. Having this in mind, it is assumed in this work that the thermal comfort of other persons can be estimated with a Gaussian error that decreases with the actual level of dissatisfaction.
- ISO 7730 defines three classes of thermal comfort which can indirectly be used to derive individual thermal preferences in both desired ideal temperature and acceptable deviation. These individualised preferences are assigned to people mostly randomly. Only babies, children and elderly people have a preconfigured bias towards higher temperatures.
- Thermostatic radiator valves (TRVs) can be used continuously, so any temperature from 8°C to 28°C is thinkable for off-the-shelf TRVs in theory. However, markings/indicators on TRVs propose a way of interaction that only makes use of certain steps. This was also acknowledged by literature. Consequently, only certain temperature setpoints are used in the simulation.

2.2.1 Purpose (Overview)

The impact of inhabitants with their individual preferences, sensitivities and habits shall be simulated in a context where they can interact with one another and with the building so that resulting average temperature levels and the heating demand can be derived for arbitrary building configurations (that is thermal properties) in a most realistic way.

2.2.2 Entities, state variables and scales (Overview)

**Building agent:** climatic environment by (indoor) ambient temperature $T_{air}$ [$^\circ$C], radiant temperature $T_{rad}$ [$^\circ$C], air velocity $v_{air}$ [m/s] and relative humidity $rh$ [%]. As air velocity and air humidity are not part of the 3R2C-model of the building, these parameters must be assumed constant. However, this is no drawback as e.g. ISO 7730 states that air humidity has almost no relevance for the resulting comfort, so it can be reduced to a constant 50%. The velocity can be considered to be within the required interval below 0.2 m/s without introducing relevant errors.

**Inhabitant agent:** Any inhabitant agent can interact with the building in the following ways: enter or exit the building, change rooms, change TRV setpoints in the current room. If more than one agent
is present in a room, their thermal comfort can be estimated with a certain error. Inhabitant agents can estimate the effect of any interaction with either the room or other inhabitants. More precisely, the effect of e.g. increasing/lowering temperatures or changing clothes on their own Thermal Comfort can be seen directly, while the effect on other agents’ Thermal Comfort can at least be estimated. Hereby, agents act social, as their objective function also dictates to avoid an impairment of anyones Thermal Comfort. Rooms are thermally simulated but do also have a specific function for the ABM, because they can either be used as common rooms or bedrooms. While common rooms are always shared, access to bedrooms may be restricted to some inhabitants. As in ISO 7730, the unit of measurement for the insulation level of clothing is [clo]. Inhabitants can change their clothing in discrete steps of 0.25 clo within (0.25, 1.25), as this reflects typical combinations of clothing parts (ASHRAE 55). In case there should be more than one agent present and there is a conflict concerning the Thermal Comfort a hierarchy of inhabitants is introduced as an elegant way to resolve them. An inhabitant of lower hierarchy will not change TRV-setpoints for his/her own sake if discomfort for a higher hierarchy inhabitant is anticipated. Changes of clothing are always permitted of course. Lower hierarchy inhabitants will also try to actively improve higher hierarchy inhabitants’ comfort.

2.2.3 Process overview and scheduling (Overview)

The full process scheduling can be seen from the following Figure 1:

![Figure 1](image_url)

Figure 1 Involved agent types, interactions and data sources used for parametrisation

The building agent sends a message with the new time step to all inhabitant agents and waits for their messages concerning room and TRV changes. The simulation is advanced in time steps of 30 minutes, which preserves the transient behaviour of the building and enables a realistic number of adoptions and measures for the inhabitant agents. Shorter time steps (e.g. minute-wise) would lead to an unstable state where lots of measures could be conducted, which would make a penalty mechanism necessary. Each inhabitant agent undergoes a chain of behaviours to consider both their own and the Thermal Comfort of their roommates, which is structured in three different steps comprising 1) perceive & poll, to calculate own thermal sensation and estimate that of others, 2) decide & negotiate, to check which actions are possible and how they would influence others, and 3) act & wait to synchronise with the building agent, as discussed in (Hinker et al., 2015).

2.2.4 Design concepts

**Emergence**: By feeding each inhabitant agent of the simulation with (constant) thermal preferences, hierarchy levels, and a daily schedule of building occupancy, the sum of all inhabitant agents manipulates the temperature of one room at a time. Subsequently, together they form a power demand for heating that sums up in an unforeseeable manner by individual actions, so temperatures per room and the resulting energy demand are visible emergent outcomes.
**Interaction:** There are two coupling mechanisms involved. On the one hand, as the inhabitant agents know each other's thermal comfort (well enough) they act accordingly and proactively. On the other hand, there is a thermal interaction (heat conduction) between individual rooms.

**Stochasticity:** Hierarchy is kept constant over the course of one simulation and is assigned on a stochastic basis upon start, unless it is specifically declared. Occupancy throughout the day varies stochastically but only within predefined hourly time-frames. Metabolic activities vary stochastically when a inhabitant is awake.

**Observation:** The personal state of an inhabitant agent is available for clothing level, metabolic activity, and individualised thermal sensation in each time step. For all rooms in a simulated dwelling, the setpoint for the TRV and the resulting heating power are given for each time step as well.

### 2.2.5 Initialisation (Details)

The first time step of the simulation is defined to be at midnight of September 1st, which is the start of the heating period in the given climate. The simulation thus ends after 273 simulated days at midnight of May 1st. Initially, all inhabitants are situated in their corresponding bedrooms and in a sleeping state (not actively influencing their environment). Also, TRVs in all rooms are set to three, which equals a setpoint of 20°C. As the capacities utilised in the 3R2C-model are not precharged for the simulation, the impact of weather and new setpoints is effectively reduced for the very first time steps.

### 3. Validation and results

After the depiction of an exemplary day's simulation outcome, the validation of the model by comparison with calculations from a standard is conducted. Afterwards, the specific meaning of the social compositions in the context of further simulations are discussed from two different socio-technical perspectives, which is an occupancy centered life-cycle assessment for buildings and the meaning of energy-related refurbishments.

#### 3.1 Interaction of inhabitants and building

To show the general functionality of the MAS, the course of a regular winter day of one inhabitant agent is discussed (cf. Figure 2).

The agent wakes up in room 1 at time step 18 (9:00am) and immediately rates the surrounding climate as too cold. It estimates the effect of possible actions it could take to counter this and determines that its level of clothing of 0.25 clo is inadequate for the current temperature. Thus, it puts on more clothes, resulting in a clothing level of 1.25. 30 minutes later it still feels too cold. As its clothing level is already at the maximum, the only other option is an increase in TRV-setpoints. It increases the TRV-setpoint to 3.5, resulting in a room temperature of roughly 23°C, which the agent considers comfortable. For the next 10 time steps no changes are necessary. Then, the agent enters room 3. Luckily, his room mate (not shown) already reduced the TRV-setpoint in this room from 5 to 2.5 one hour earlier so room 3 is at a comfortable temperature level now. After another time step the agent leaves the building and returns in time step 40, entering room 2. After three time steps in this room, it feels uncomfortably hot, since its activity level increased from 1.07 met to 1.67 met. The agent therefore decreases the TRV-setpoint in this room to 2, resulting in a room temperature of comfortable 22.9°C. After this, the agent changes rooms two more times, without breaching its comfort zone and eventually goes to sleep in room 1 at time step 46 (11:30pm).
3.2 Validation

External input first of all includes weather data which includes short- and longwave radiation, and ambient temperatures in the desired timely resolution. For the evaluations in this paper Test Reference Year (TRY) data for Essen, Germany is used in 30-Minute-resolution. Besides, the building model with its thermal properties has to be defined. Normally, the strongest influence has to be expected from the thermal conductivities of walls and windows, so they have to be chosen with care. For cold climates, realistic infiltration rates have to be set as well, because even if the windows are assumed to be closed, air exchange through gaps (so called gap ventilation) is always present in reality. Here, thermal conductivities of type-E and type-H buildings from German IWU typology (Institut Wohnen und Umwelt GmbH) are used in the context of both single family and multi-family houses. The ventilation rate is assumed to be at a constant rate of 0.6/h.

The validation of the behaviour of specific inhabitant agents is generally difficult as it would make extensive measured data in hundreds of dwellings necessary. However, it is possible to examine the emergent behaviour of the entire simulation with regards to plausibility and compare it to different (field) studies. The following validation is based on findings from (VDI 4655) and exemplary for the other validation examples which are not shown here. The input data for the evaluation is set up to be similar to the field studies the results are being compared to. While conductable for any building, all of the studies’ samples make use of typical thermal conductivity values for both single family houses (SFH) as well as multi-family houses (MFH) are used from the TABULA study (Institut Wohnen und Umwelt GmbH). The amount of inhabitants per dwelling ranges from one through five and five different types of inhabitants are simulated: working, non-working, retired, child and baby. The daily schedule of each inhabitant type, i.e. time spent working, at home, leisure and sleeping, is set up in accordance to (Statistisches Bundesamt, 2015). The amount of inhabitants per dwelling and inhabitant compositions resemble the German average (Statistisches Bundesamt, 2013) as this is assumed to be similar to the field study household types. The occupants’ thermal preferences vary. According factors are assigned to the occupants with a Gaussian distribution but with a small bias for retirees, children and babies towards higher TSV-preferences in comparison to working or non-working occupants (Kelly et al., 2013). The hierarchy levels are randomly distributed among inhabitants, except for babies, who always receive the highest hierarchy level of 0 (a maximum of one baby per household is allowed). For each household a typical heating period from September through May is simulated as only temperatures and heat loads in this period are of interest.
To validate that heating power is consumed in a realistic manner and that different energetic standards of buildings result in different energy consumptions, the average simulated heating power of each building type is compared to the building type’s heating load calculation according to (VDI 4655), which is used as a reference. While the heating load of single realisations may of course differ from the standard calculation due to the occupants’ individual behaviour, the average heating consumption across all simulations of one building type should be similar to the aforementioned reference calculation. This comparison is depicted for building type SFH-E in Figure 3. Depending on the simulated building type, average deviations are within a range of ±20%. However, up to ±30% are explainable if the occupants’ behaviour is accounted for (Sunikka-Blank & Galvin, 2012).

Besides, the underlying stochastic distributions for (VDI 4655) calculations are based on a low sample size, which is another factor to be considered.

### 3.3 Interaction of building hull, situation of family, and occupant behaviour

With the socio-technical focus of this work in mind, the preferences of social compositions shall be evaluated, so the interplay of individual inhabitants becomes clear and explanations for deviations of the heating demand of individual household can be derived. As stated above, occupancy, bias towards higher/lower preferred temperatures, and a sensitivity can be modelled for individuals, who then form the household composition within one dwelling. Four such exemplary compositions were defined as follows: A “typical” family undergoes a stereotypical development in the following four stages: A newly founded family including a newborn makes it necessary that one parent stays at home (I). The stay-at-home parent is able to go to work again after the child has grown old enough (II). The child is old enough to serve his/her apprenticeship and is employed afterwards, which means that the occupancy is comparable to the full-time working parents (III). The child stays with the retired parents (IV). The number of family members is thus kept constant throughout the simulation.
For the evaluation N=40 simulations were conducted for each of the four compositions. As the output is stochastic by design (cf. section 2.2.4), box-whisker-plots are used to show characteristics of the resulting temperatures and heat demands. The following Figure 4 shows the average temperatures in the simulated SFH-H building:

![Figure 4: Box-plots for average temperatures of the four social compositions (building type H)](image)

The resulting temperatures are rather high in comparison with the reference temperature. First of all, there is a big variety of possible temperature levels, and it is even possible that households achieve to stay below the reference temperature with their average temperature, so it might be more appropriate to change assumed temperatures for economic considerations depending on real occupancy and preferences. Secondly, since occupants do not use window blinds and ventilation, the results are skewed towards higher temperatures due to high levels of insolation at the beginning and end of the heating period, so there is room for improvement.

In order to see if there is an interaction between building hull and occupants, all simulations were repeated another 40 times with a second building type (type E instead of H, cf. Figure 5). Heating demand and assumed financial potential of a family in each stage are analysed now to show the discrepancy between the need and the financial possibility for refurbishment.

![Figure 5: Box-plots for heat demand of different household compositions and buildings](image)
The heating demand clearly differs from stage to stage: First, in stage (I), the heating demand is relatively low and so is the financial potential of the household since only one inhabitant is employed and they also have to take care of a newborn. In stage (II) the heating demand is more unpredictable, since both parents spend a lot of time at work causing the heating demand to strongly depend on how the child uses the heating system. The overall household income is now higher than before since two people are working. In stage (III) the heating demand reaches its minimum, since all three inhabitants spend most of their daily time at work. At the same time, the financial potential of the household is at its peak, due to the triple income of the inhabitants. In stage (IV), the heating demand suddenly increases because the parents spend a lot of time at home and have increased thermal preferences, while the child still spends most of its time at work. But at this point, the income of the household is much lower than before since there is only one income source present. This course of events shows a possible explanation for the low modernisation rate today. The perceived need for a modernisation (i.e. the heating demand) is at imbalance with a household’s financial potential for undergoing such a modernisation. At the stage of its highest overall income, a family has the lowest heating demand and therefore may not want to pay for such an investment. However, in the next stage of their lives, the heating demand sharply rises, but now the family might not have the financial potential to modernise their home anymore. Figure 5 also includes two different building types with significantly different thermal insulation properties, which allows to qualitatively assess the financial impact of an energy efficient refurbishment.

4. Conclusion and outlook

In this paper, a novel simulation environment was developed, which enables the evaluation of interactions between inhabitants themselves and the buildings occupied by them. This contribution builds on a mathematical description of the reasoning processes of individuals which was derived in previous work. The modelling of the necessary thermal simulation as a multi-room equivalent circuit model was argued in the socio-technical context, and a full description of important pillars of the developed MAS was explained in accordance with the extended ODD protocol. Furthermore, the general applicability of this approach was proven by a comparison of different studies with stochastic outcomes of the developed simulation. While smaller deviations from reference values remain, the results are promising and show that modelling from a bottom-up perspective helps to find realistic ranges of temperatures and heat demand. The results also show that there is a big influence of the individual preference for temperature levels. While one person alone could just change a setpoint at will, a group of people works in a different way and leads to different results as they have to cope with the needs of others. By explicitly simulating household compositions in their timely occurrence, the economic potential of refurbishment in cold climates becomes especially clear. Ongoing work deals with the reproduction of power peaks as they appear in reality. To this end, a more complex model of the heating system has to be implemented and calibrated. Besides, more light shall be shed on the the economic potential and reasoning process to show policy makers to what extent they can steer and support the advancement of the building stock to reduce carbon emissions.

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Thermal environment and thermal comfort in a passive residential building in the severe cold area of China

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Abstract

Purpose / Context - The outdoor climate in Harbin is more severely colder than German. Therefore, it is important to study indoor thermal environment and human thermal comfort in Harbin passive buildings by applying Germany technology. However, few studies were reported on this topic.

Methodology / Approach - A field measurement on thermal environment was carried out in a passive residential building in Harbin, as well as a subjective survey on residents’ thermal response. 25 residents in 21 apartments volunteered as the participants in this study. Among them, a continuous monitoring was conducted in 7 apartments.

Results - The results show that the mean indoor temperature was 26.2°C, which was over higher than the upper limit of ASHRAE 55-2013. The average relative humidity was 35.9%, close to the lower limit. There was a small temperature difference between the indoor air temperature and the inner surface temperature of the exterior wall, which indicates a good insulation performance and reduces discomfort induced by cold radiation. 50% residents confided that the indoor environment was over warm, and they usually adjusted clothes to the environment. The neutral temperature was 24.2°C, and 90% acceptability temperature was 23.2~25.2°C, a width of 2°C, which indicates a weak adaptation and tolerability for the residents.

Key Findings / Implications - A lower indoor temperature was recommended in operation. Not only could residents’ thermal comfort be improved, but also the energy consumption was reduced further.

Originality – Thermal environment and thermal comfort in a Harbin passive residential building was researched.

Keywords - Passive house, Thermal environment, Thermal comfort, Thermal adaptation, Field study, Severe cold area
1. Introduction

Since 1970s, some researchers in developed countries put forward the term –“zero energy building” (ZEB) or “nearly zero-energy building”, as well as some similar definition (Esbensen and Korsgaard, 1977; Voss et al., 1996; Torcellini et al., 2006). Soon later, a lot of demonstration project were built up. In recent years, low-energy buildings were constructed in China.

The technology and practice of passive house was derived in German. In 1991, the first passive architecture was constructed in Darmstadt. This kind of architecture is distinguished for good envelope insulation performance, enhanced air tightness of doors and windows, much less dependence on fossil energy, and some advanced passive technologies used to improve comfortable indoor climate, such as heat recovery. Energy consumption for heating and cooling in passive houses is far lower than that in normal buildings (Heinze and Voss, 2009).

A passive residential building was constructed as the first demonstration project in Harbin in 2013, China, which was cooperated by China and German.

Harbin is located in the severe cold area of China. The heating period lasts for 6 months. The heating energy consumption accounts for a large part of building consumption. The outdoor climate in Harbin is more severely colder than German. Therefore, it is important to study indoor thermal environment and human thermal comfort in the Harbin passive building by applying German technology. However, few studies were reported on this topic. This paper introduced the recent measurement and subjective results in the passive residential building.

2. Methodology

In the winter of 2015-2016, a field measurement on the thermal environment was carried out in the Harbin passive residential building, as well as a subjective survey on residents’ thermal response. The environmental measurements and subjective questionnaires were simultaneously conducted during the investigation. 25 residents in 21 apartments (age ranges from 25 to 84, with an average of 40.2 years, gender ratio is nearly 1:1) volunteered as the participants in this study. Among them, a continuous monitoring was conducted in 7 apartments. All the participants have fully adapted to the local climate.

2.1 Measurement

The indoor air temperature and relative humidity (RH), air speed, globe temperature, inner surface temperature and outdoor air temperature, relative humidity and air speed were measured during the field investigation.

The indoor air temperature and humidity were continuously monitored per 5 min using self-recording loggers which were placed at about 1.0 m above the floor. The indoor air temperature and humidity, globe temperature and air speed were measured near the residents. The surface temperatures were measured at five points in exterior wall and window, and the average value is considered as the surface temperature. In addition, a digital self-recorded thermometer was placed outside for monitoring outdoor temperature and humidity.

In the study, a self-recorded thermometer (WSZY-1A), a self-recorded globe thermometer (HWZY-1), and a hot-wire anemometer (Testo 425) and an infrared thermometer (Testo 830-T1) were used. The test instruments and precision refer to Wang et al. (2014).
2.2 Subjective questionnaire

Paper questionnaires were adopted. The subjective survey included the following:

1) Residents' background information (gender, age, education, etc.), clothing and activity.
2) The thermal responses of subjects, such as thermal sensation, comfort, expectation and acceptability.

The vote scales of thermal response are shown in Table 1.

Table 1: Vote scales of thermal response

<table>
<thead>
<tr>
<th>Vote</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Sensation</td>
<td>-3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot</td>
</tr>
<tr>
<td>Thermal Preference</td>
<td>-1 cooler, 0 no change, +1 warmer</td>
</tr>
<tr>
<td>Thermal Comfort</td>
<td>0 comfortable, +1 slightly uncomfortable, +2 uncomfortable, +3 very uncomfortable, +4 unbearable</td>
</tr>
<tr>
<td>Thermal Acceptability</td>
<td>acceptable, unacceptable</td>
</tr>
</tbody>
</table>

A total of 44 valid questionnaires were collected.

3. Measurement Results

3.1 Indoor climate

The statistic results of indoor climates in 21 apartments were given in Table 2.

Table 2: Thermal conditions in 21 apartments

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature (°C)</td>
<td>26.2</td>
<td>28.7</td>
<td>23.8</td>
<td>1.24</td>
</tr>
<tr>
<td>RH(%)</td>
<td>35.9</td>
<td>51</td>
<td>24.9</td>
<td>7.51</td>
</tr>
<tr>
<td>Air Speed (m/s)</td>
<td>0.05</td>
<td>0.15</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Inner Surface Temperature in the Exterior Wall (°C)</td>
<td>24.5</td>
<td>26.6</td>
<td>22.3</td>
<td>1.14</td>
</tr>
<tr>
<td>Inner Surface Temperature in the Exterior Window (°C)</td>
<td>23.3</td>
<td>27.1</td>
<td>19.3</td>
<td>2.23</td>
</tr>
</tbody>
</table>

The mean indoor air temperature was 26.2°C, 2°C higher than the upper limit recommended by ASHRAE 55-2013. The average RH was 35.9%, close to the lower limit of the standard. According to subjective responses, most residents felt dry. Therefore, effective actions should be taken to improve indoor humidity. The air speed ranged in 0.03-0.15 m/s, which met the standard. The average inner surface temperature in the exterior wall was 24.5°C, 1.7°C lower than the mean indoor air temperature. The inner surface temperature in the exterior window ranged in 19.3-27.1°C, for the high performance of low-e windows.
It is rather cold on 25 December, 2015. The outdoor temperature varied between -21.9°C and 14.3°C. The indoor/outdoor temperature and RH for a typical apartment were given in Figure 1.

As seen in Figure 1, the indoor air temperature ranged in 25.0-26.1°C, with an average of 25.4°C. The width of indoor air temperature was 1.1°C, which indicates a good stability of air temperature.

The indoor RH ranged in 33.2%-52.6%, with average of 41.8%. In addition, the RH increased significantly during daytime, when residents were active. Therefore, indoor RH was mainly influenced by residents’ activity.

3.2 Inner surface temperature in the exterior wall

The continuous monitoring results of inner surface temperature in the exterior wall for the same apartment were shown in Figure 2.
As shown in Figure 2, the inner surface temperature in the exterior wall ranged in 24.4-25.1°C, with an average of 24.7°C. Compared with the indoor air temperature, the surface temperature were gentle. The temperature difference between the indoor air temperature and the surface temperature varied in 0.46-1.02°C, with an average of 0.70°C. Therefore, the difference was very small, which suggests that the heat transfer from indoor air to the exterior wall was little. Furthermore, the good insulation performance of the exterior wall induced a small heat loss of the envelope. Due to a high inner surface temperature, with a small difference from indoor air temperature, local discomfort induced by cold radiation could be reduced.

4. Subjective Results

4.1 Clothing insulation

The residents’ clothing insulation was 0.52-1.00 clo, with an average of 0.69 clo. Figure 3 shows the frequency distribution of clothing insulation.

In the severe cold area of China, the residents’ clothing insulation was 1.37 clo for normal apartments (Wang, 2006), higher than that for this passive building. As seen in Figure 3, more than 50% of residents’ clothing insulation were in 0.5-0.7 clo. In such an overheated microclimate, to get access to the neutral, residents would prefer changing clothes. In general, when it is over warm in the passive building, residents mainly adapted to the environment by adjusting clothing.

4.2 Thermal sensation

The distributions of actual thermal sensation votes (TSV) was seen in Figure 4. The percentage of voting for “slightly cool”, “neutral” and “slightly warm” was 50%, and the percentage of voting for “warm” and “hot” was another 50%. It indicates that half residents felt warm, which means overheating in this building subjectively.
4.3 Thermal preference

As seen in Figure 5, 52% residents preferred the temperature unchanged, when 40% residents would like a lower temperature, and only 8% residents want a warmer environment. The results are in accord with thermal sensation vote, which proved that the indoor temperature was so high that residents would expect a lower temperature psychologically.
The 52% residents preferred the temperature unchanged, which means that they have adapted to the over warm environment. The overheated indoor environment in winter will not only cause energy waste, but also weaken human tolerance with the cold outdoor climate.

### 4.4 Thermal comfort

The distribution of actual thermal comfort votes (TCV) was presented in Figure 6.

![Figure 6 Distribution of residents' thermal comfort vote](image)

As seen in Figure 6, only 32% residents felt comfortable in the environment. And the other 68% residents felt uncomfortable. In general, when residents felt over warm and uncomfortable, they preferred an environment with lower indoor air temperature.

### 5. Discussion

#### 5.1 Neutral temperature

After linear regression of mean thermal sensation (MTS) votes with indoor air temperature ($t_a$), the relationship was given in Equation (1).

$$MTS = 0.5t_a - 12.083$$  \hspace{1cm} (1)

Where MTS is the mean thermal sensation vote, and $t_a$ is the indoor air temperature, °C.

The thermal neutral temperature was 24.2°C, a difference of 2.0°C from the mean indoor air temperature (26.2°C).

#### 5.2 Thermal adaptation

The adaptive theory proposed by de Dear and Brager (1998) suggested that people get access to comfort through thermal adaptations including psychological adaptation, physiological adaptation and behavioral adjustments.

There were little positive effects of behavioral adjustments on human thermal comfort in centralized heating buildings. As a result, people would adapt to the indoor environments psychologically.
and physiologically. Because physiological acclimatization could be formed in several days or weeks, and the indoor temperature was relatively constant during the heating period, residents would adapt to the environment psychologically.

In the passive building, the neutral temperature was higher than that in normal apartments, and the clothing insulation was lower than normal apartments, which both indicate residents’ adaptation to the current environment. However, this adaptation was kind of limited. When the indoor air temperature was over high, most residents would feel uncomfortable and preferred a lower temperature. As a result, a lower indoor temperature was recommended in design and operation. Not only could residents’ thermal comfort be improved, but also the energy consumption was reduced.

6. Conclusions

(1) The mean indoor air temperature was 26.2°C, 2.2°C higher than the upper limit recommended by ASHRAE 55-2013. The average RH was 35.9%, meeting the standard. And according to subjective responses, most residents felt dry.

(2) The temperature difference between the indoor air temperature and the surface temperature in the exterior wall was small, which suggests a good insulation performance of the exterior wall. And local discomfort induced by cold radiation could be reduced.

(3) The neutral temperature was 24.2°C, and 90% acceptability temperature was 23.2-25.2°C, a width of 2°C, which indicates a weak adaptation and tolerability for the residents.

(4) Half residents felt warm, which means overheating in this building subjectively. Residents mainly adapted to the environment by adjusting clothing. When residents felt over warm, they felt uncomfortable and preferred a lower indoor air temperature.

(5) A lower indoor temperature was recommended in design and operation. Not only could residents’ thermal comfort be improved, but also the energy consumption was reduced.

7. Acknowledgement

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BIM-based Multidisciplinary Building Design Practice-A Case Study

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Abstract

Purpose / Context - As the emerging digital technology, Building Information Modelling has been applied in the multidisciplinary design work for sustainable houses. This study aims to input the real-world design context into the BIM pedagogy and to demonstrate the capacity of BIM in enhancing teamwork in the cross-disciplinary collaboration.

Methodology / Approach – A case study of a Saint Lucia-based residential house project was adopted by utilizing BIM as the platform to carry on the redesign plan differing from an existing design. Nine different student design teams from the University of Nottingham Ningbo China, each team consisting of students from architecture, civil engineering, and architectural environmental engineering, worked in the BIM-based platform to provide solutions on architectural model, structural design, cost estimate, and sustainability in terms of energy efficiency. Each team’s design plan was presented and evaluated by academics, the client, and construction professionals.

Results – The case study demonstrates the capacity of BIM in assisting the cross-disciplinary project design. BIM learners gained the practical experience in the team design work. As the project deliverable, different design plans were evaluated by the client and the contractor for further developments. The BIM project experience from team members was also presented in this study.

Key Findings / Implications – The BIM education provides the insights of how colleague education could equip students with the state-of-the-art learning experience by incorporating the real-world project into the BIM pedagogy. BIM, as the coordination platform, could be fully utilized to implement the building design. This case project serves as an example of bridging the gap between BIM academia and industry. Future BIM education could continue adopting the case study-based experiential learning approach and expand BIM applications from design to the construction stage.
Originality – This work provides the case study in the pedagogical practice demonstrating the BIM-enabled multidisciplinary collaboration in architectural visualization, structural design, budget control, and sustainability strategies.

Keywords - Building Information Modelling, multidisciplinary collaboration, sustainability, cost estimate, pedagogy

1. Introduction

Building information modelling (BIM) could serve as the digital platform to enable multidisciplinary collaboration in the building project from architectural design, structural visualization, construction estimate, to building energy simulation. The following sections focus on the college BIM education leading to practical work, BIM-based multidisciplinary work, and BIM application in sustainability.

1.1. BIM education

Although BIM is expected to achieve multiple benefits in the project delivery including accurate geometrical representation of building elements, improved design quality, and better budget control as claimed by CRA Construction Innovation (2007), various barriers in achieving these benefits exist in BIM practice, one of them being the reluctance of experienced engineers or designers to switch to BIM from the traditional Computer Aided Design (CAD) as identified by Gong (2013). BIM education is important in the sense to work as pre-career training for college graduates in the fields of architecture, engineering, and construction (AEC) and to further reduce the industry investment in BIM training (Tang et al., 2015). College graduates newly entering the job market, although tending to be quicker to pick up the digital skillsets, their BIM work may need more inputs and feedback in terms of design feasibility and constructability from more experienced peers. Hence BIM education could embrace more real-world design and engineering practice rather than barely deliver the BIM software training.

It is believed that BIM education is not simply changing the engineering education tool from 2D CAD to 3D visualization (Tang et al. 2015). Instead, the collaboration was deemed the key of BIM implementation by multiple researchers from the perspectives of both academia and industry (Eadie et al., 2013; Szeda, 2013; Tang et al., 2015). BIM should not be merely adopted as the tool to generate drawings but a comprehensive approach for information management and teamwork (Sacks & Pikas, 2013). Personal BIM skills would significantly impact college graduates’ career (Russell et al., 2014), and the BIM-enabled collaborative learning environment would prepare and equip students with collaborative problem-solving skills as stated by Mathews (2013).

1.2. BIM in multidisciplinary teamwork

BIM maturity levels are defined by the BIM Working Party Strategy Paper (2011) from 2D CAD-based Level 0, 3D-enabled data environment without integrations in Level 1, managed 3D environment with certain integrations in Level 2, to fully integrated data integration by “web services” achieved in Level 3. The BIM Strategy Paper (2011) from the UK government required the industry to achieve Level 2 by 2016. It is indicated that as the AEC practice moves towards higher maturity level, the interdisciplinary collaboration would become a more urgent need.

Singh et al. (2011) provided the framework focusing on the technical requirements for BIM to serve as a collaborative platform. A case study of landmark building using BIM-server was presented by Singh et al. (2011) to develop categories for the technical requirements, one of them being the design visualization and team communication. Complicated functional and technical requirements in complex building projects such as in the healthcare sector ask BIM to support the collaboration among different disciplines in an integrated approach (Sebastian, 2011). The BIM-partnering framework and development of the collaborative BIM model for the construction pro-
cess were introduced by Porwal and Hewage (2013) in the public sector projects. BIM adoption would require certain changes in the existing practice to overcome the challenges within technical (e.g., data compatibility), procedural, and organizational (e.g., legal responsibilities) aspects (Porwal and Hewage, 2013). A BIM pilot project within the small-scale house sector recruiting project participants from multiple disciplines was presented by Sebastian et al. (2009) to demonstrate BIM’s application in the integrated design and engineering. Multiple cases within different sectors of building projects in these studies have shown that BIM, as the digital platform, could enhance the collaboration within the project design and construction among different disciplines and parties.

1.3. BIM in sustainability

The demand for sustainable building facilities with minimal environmental impact is increasing (Azhar, et al., 2011). The early design and preconstruction of a building are the most critical phases for decision making in sustainability (Azhar, 2010). Traditional computer-aided design (CAD) lacks the capacity to perform sustainability analyses in these critical phases (Azhar, et al., 2011). Kriegel and Nies (2008) indicated that BIM could aid in sustainable design in the areas including building orientation, building form and envelope, daylighting analysis, water harvesting, energy modelling, sustainable materials, and site and logistics management.

BIM and sustainability, the two emerging subjects in the AEC fields, are in the need of bridging the gap between industry and academia (Becerik-Gerber et al., 2011). Since September 2014, The University of Nottingham Ningbo China (UNNC) has been keep developing the multidisciplinary-featured BIM education by linking BIM into sustainability and bringing the real-world AEC practice into graduates’ BIM learning. The student BIM practice has also been raised from Level 1 to Level 2 to enable certain integration of project data. This study targets on the BIM-based cross-disciplinary team design adopting Autodesk Revit as the basic BIM tool with other visualization and energy simulation tools to provide the architectural plan, structural visualization, take-off cost estimate, and sustainable solutions for the Chateaux Georgia-Marigot Bay residential project located in Saint Lucia.

2. Methodology

This study focuses on the experiential learning approach to provide college graduates with BIM-based teamwork design practice. UNNC, as the first international university founded in China, launched the first BIM education module in autumn 2014. Aiming to raise the BIM education level from Level 1 to Level 2 in autumn 2015, the Chateaux Georgia-Marigot Bay residential building project was adopted as the case study. The optional BIM module was open to three major disciplines in the Faculty of Science and Engineering at UNNC. It recruited totally 54 final year undergraduate students evenly distributed from architecture, civil engineering (CE), and architectural environmental engineering (AEE) in the beginning of September 2015. These students have completed the core modules in their own fields of study but lacked the BIM operation skills or BIM-based design experience. Therefore, the BIM module is targeted at applying students’ own fields of knowledge into the case project by utilizing BIM as the collaboration platform. The students were divided into six design teams and each team consisted of members from the three major disciplines to enable the cross-disciplinary collaboration. A four-week training of Autodesk Revit in three templates (i.e., Architecture, Structure, and Mechanical) was provided to all BIM learners in early September to early October during 2015 to according them with the operation skills of Revit. Although only Autodesk Revit was instructed through the BIM module, students were encouraged to use all potential software tools to assist the team design. For example, Lumion for the architectural visualization, Navisworks in 4D scheduling, and PV Designer for the photovoltaic system design.

Figure 1 displays the key dates of the project design process from September 2015 to January 2016.
Since the beginning of September 2015, the owner of the purchased land in Saint Lucia started communicating with UNNC BIM academic staff on the plan of the holiday style residential building. At that moment the site had been levelled and the topographic maps had been obtained. Apart from the project site information, there was also an existing design plan provided from a local Saint Lucia architecture and engineering design firm in 2D CAD drawings. The land owner was seeking an alternative plan with improved architectural aesthetics, possibly lower budget, and better energy efficiency in terms of electricity consumption. During the following three weeks in September 2015, the land owner specified the project requirements in these multiple areas. A project brief was composed according to the communication results and released to the nine student BIM teams on 20 September 2015 asking for the data gathering and study of the existing design plan by 19 October 2015. Specifically, each team was requested to perform the following tasks:

1) The existing design plan to be reviewed and summarized
2) Alternative architectural forms (e.g., round house or tea house) to be reviewed
3) Alternative construction techniques to be explored, with an emphasis on prefabricated buildings such as kit house and encapsulation insulation frames
4) The micro-climate of San Lucia (e.g., wind and solar directions) to be investigated
5) The references on termite proof timber materials to be reviewed and their engineering properties to be investigated.
6) Structural design guidelines on hurricane resistance to be reviewed
7) A redesign proposal to be completed meeting the client’s requirements in architectural, structural, and building services perspectives

3. Results and Discussion

Totally nine redesign proposals were received by the deadline and assessed by the UNNC BIM academic staff strictly following the seven pre-determined evaluation criteria. For example, most of the design teams had suggested a certain type of timber materials to be used considering its local availability, unit price, and engineering properties (density, strength, termite resistance, etc.). Schematic architectural models were proposed at this stage. The feedback of the proposals were returned to each team within one week and teams were guided to continue with the design. The team design work was performed in the follow-up stages between later October and early December in 2015. The team presentation of the BIM-based final project design was delivered on 14 December 2015 and evaluated by three UNNC academic staffs. Each member of the team presented the individual contribution to the project. The design development in this discussion is divided into these subsections including the architectural plan, structural analysis, cost estimate, energy simulation, and the integration experience.
3.1. Architectural plan

Each design team started the project by converting the original architectural plan from 2D CAD into 3D visualized architectural models within the topographic context as displayed in Figure 2-a). The teams also evaluated the existing design plan before proposing the redesign model. For example, one group stated that “the existing architecture has relatively complex circulation which is not easy for people to get access to each individual rooms in a short time”, and another group commented that “the existing plan sounds easy to build but lack of sufficient connections among various spaces.” The redesign model was proposed by each team following the existing model. Figure 2-b) displayed one selected architectural model from the design teams as an example.

The rational of the architectural redesign in Figure 2-b) was presented by the team that

“The project focused on simplicity and the compactness of a kit house, yet it strives to achieve an aesthetic quality informed by the previous analysis and design experience. The tropical climate in Saint Lucia have particularly strong winds from the east and mildly hot climate all around the year. The new redesign programme offers cross ventilation as our main cooling system. The design compacts the living area and separates it from the rest area to enhance the space integration.”

In light of the BIM input in the architectural design, the architecture students claimed that the Autodesk Revit-based BIM platform was not as effective as other tools such as Sketchup or Rhinoceros in communicating ideas in the conceptual design stage. This was consistent with the findings from Thomsen (2010) that the BIM technical platform limits the choices of possible solutions, provides extra requirements than traditional projects and changes the roles in the design stage. However, the design team also stated that “BIM technical platform turned out more useful in delivering the design model into drawings, rendering and videos in the later design stages.”

3.2. Civil Engineering work

The Revit Structure template was adopted to present the structural design. Figure 3 displays the structure model continued from the redesign model in Figure 2-b).
The data of materials properties were stored in Revit by creating new families. For example, the compressive strength of the Greenheart wood at 91.7 MPa.

BIM was used to generate the take-off material spreadsheet to assist the cost estimate. The estimator from each team compared the redesign plan and the original design following certain estimate codes (e.g., Spon’s Architects’ and Builders’ Price Book, 2015). The price from the same group redesign presented in Figure 2 was provided at € 252,457.1, compared to the budget following the original plan at € 233,561.5. The higher budget following the redesign in this group mainly resulted from the sustainability strategies as described in the next section.

Detailed cost break-downs based on the quantities generated from BIM were included in each team’s work. Table 1 lists one example of the take-off estimate within the plumbing system.

Table 1: Take-off estimate of the plumbing section

<table>
<thead>
<tr>
<th>Family</th>
<th>System Name</th>
<th>Cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Tank - Horizontal</td>
<td>Domestic Cold Water 1, Domestic Cold Water 8</td>
<td>187.05</td>
</tr>
<tr>
<td>Water Heater - Tankless</td>
<td>Domestic Cold Water 1, Domestic Hot Water 1</td>
<td>426.99</td>
</tr>
<tr>
<td>Inline Pump - Vertical</td>
<td>Domestic Cold Water 1</td>
<td>161.25</td>
</tr>
<tr>
<td>Inline Pump - Vertical</td>
<td>Domestic Cold Water 1</td>
<td>161.25</td>
</tr>
<tr>
<td>Water Filter - Wall Mounted</td>
<td>Domestic Cold Water 6</td>
<td>139.97</td>
</tr>
<tr>
<td>Storage Tank - Horizontal</td>
<td>Sanitary 1, Sanitary 9, Sanitary 6</td>
<td>264.19</td>
</tr>
<tr>
<td>Water Filter - Wall Mounted</td>
<td>Sanitary 1</td>
<td>139.97</td>
</tr>
<tr>
<td>Inline Pump - Vertical</td>
<td>Sanitary 1</td>
<td>161.25</td>
</tr>
<tr>
<td>Water Heater - Tankless</td>
<td>Domestic Cold Water 1, Domestic Hot Water 3</td>
<td>426.99</td>
</tr>
<tr>
<td>Storage Tank - Horizontally</td>
<td>Hydronic Supply 1, Domestic Cold Water 1</td>
<td>264.19</td>
</tr>
<tr>
<td>Roof Drain</td>
<td>Hydronic Supply 1</td>
<td>109.65</td>
</tr>
<tr>
<td>Roof Drain</td>
<td>Hydronic Supply 1</td>
<td>109.65</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>2,552.4</strong></td>
</tr>
</tbody>
</table>

3.3. Sustainability

Sustainability was one of the project goals pursued by design teams. Each team was encouraged to explore multiple sustainability strategies but with the reasonable budget. Using the same team-work presented in Figure 2-b) as an example, the BIM team targeted on utilizing natural ventilation, thermal performance enhancement, greywater recycling, and renewable energy application. Figures 4 and 5 illustrate some of these strategies in this team project.
Based on the temperature and thermal comfort model, the natural ventilation was proposed as one passive strategy. The wind direction illustrated in Figure 4 came from the micro-climate study in Saint Lucia to enable the cross ventilation. Other passive strategies were also suggested and included in Revit families, such as the building fabrics in increasing the exterior wall’s thermal resistance. The shading devices were designed and integrated in both the visualized model and the building simulation shown in Figure 5.

Adopting these passive strategies, the energy simulation results indicated that the monthly energy consumption within the redesigned building could achieve as much as 53% of reduction per m² compared to the original design. More sustainable approaches were also incorporated in this team design including solar panels to power the air conditioning and the grey water recycling system. The grey water system was integrated in the building plumbing system together with the rainwater collection system, the sewer system, and the cold and hot water systems. According to annual energy consumption of the redesigned building at 5,923 kWh from the simulation results, the installed solar panels could contribute to 30% of the total energy from the generated electricity. Various other passive and active strategies were proposed by eight other design teams, supported by individual team’s energy simulation results in achieving energy efficiency. These strategies included but were not limited to wind turbines, different types of solar panels, and adjusted window-to-wall ratios, etc.
3.4. Discussion of BIM experience

Students from different disciplines shared their collaboration experience from this BIM teamwork. The main benefits and disadvantages of adopting BIM in the team project are listed in Table 2.

Table 2: Summary of experience learned from BIM practice

<table>
<thead>
<tr>
<th>Benefits from BIM adoption</th>
<th>Disadvantages and challenges in BIM usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Improved communication from the virtual environment provided by 3D visualization</td>
<td>• Lack of interoperability when exchanging building information among disciplines</td>
</tr>
<tr>
<td>• Enabled building information exchange</td>
<td>• Lack of sufficient families in the existing library of Revit</td>
</tr>
<tr>
<td>• Enhanced collaboration among different disciplines</td>
<td>• Lack of standards for BIM implementation</td>
</tr>
<tr>
<td>• Efficiency in converting building models into drawings and rendering</td>
<td>• Difficulty in expressing architectural ideas in the early design stage</td>
</tr>
<tr>
<td></td>
<td>• Lack of user-friendliness in MEP design</td>
</tr>
</tbody>
</table>

One example for the enhanced collaboration among different disciplines listed in Table 2 is that the visualization and design of roof overhang was not only performed by the architect considering aesthetics but also with the input from building services engineering in lowering cooling load. Besides the shared experience listed in Table 2, one BIM group commented BIM’s impact on leadership that “BIM changes the role allocation in the project. Whilst architects normally take the lead in the project adopting conventional process involving manual and CAD system, in the BIM-implemented project, the leader is supposed to be the one most familiar with BIM and capable of using BIM technologies regardless the professions, which means either architects, civil engineers or architectural environment engineers can take charge of the project as the project manager.”

This shared experience from BIM learners is highly consistent with the industry findings from Thomsen (2010) that the BIM technical platform changes the role in the design phase and creates the risk to the role of the architect being replaced by a more computer skilled designer or engineer. The similar experience from both the academic pedagogy and industry profession indicates that through proper set-up of pedagogical activities, college graduates could gain the real-world experience which would prepare themselves in their future AEC career. When Becerik-Gerber et al. (2011) stressed the importance of understanding from both industry and academia to bridging the gap between the two worlds, as both sides might face the same challenges when adopting BIM, this case study provides some hints on some of Becerik-Gerber et al. (2011)’s research questions such as whether the BIM education in universities would increase the speed of adoption in the industry. It also serves as the solid example for integration of disciplines in the AEC education as emphasized by Becerik-Gerber et al. (2011).

The pedagogical practice in this BIM case study demonstrates how BIM platform enhanced the multidisciplinary work in the pre-construction stages including architectural design, structural analysis, cost estimate, and sustainability strategies. It is worth noticing that this case study created the BIM platform with available software resources within UNNC that enabled teamwork design. Team members received the same BIM training, stayed in the similar knowledge level on BIM and their own fields of experience, and had the passion on adopting BIM in the design practice. All these factors enabled the effective communication among different disciplines in the project design. Team members from various disciplines all had early contribution in the design stage, and shared the same goal of delivering the team design plan with BIM as the collaboration vehicle. However, when moving from the pedagogy to the real-world case, more complicated factors would be counted towards the BIM implementation. For example, data compatibility issue caused by different BIM tools used among disciplines, the BIM experience level among different project teams, the client’s attitudes towards BIM, and work plan on carrying the BIM platform during the project delivery process, etc. Therefore, there would be more barriers to overcome in the industrial work to fully launch the BIM technical platform. Nevertheless, gained practical experience in BIM teamwork of the college graduates, the future AEC industry professionals, could bridge the gap between the AEC education and the job market.
4. Conclusion

This case study links the real-world design project into the BIM pedagogy with an emphasis on multidisciplinary collaboration, which motivated college AEC graduates to apply what they have learned from their own fields of expertise into practice within the BIM platform. College graduates from multiple disciplines gained the integration experience in BIM Level 2. BIM, as the communication platform, has demonstrated its potential in integrating different disciplines in multiple design stages from conceptual design, schematic design, to design development. Future BIM pedagogy could expand the BIM practice further to 4D scheduling and visualization on construction jobsites following the design stage.

AEC graduates were trained with the teamwork and problem-solving skills throughout this case study. For example, the architecture and structural engineering students happened to argue on maintaining the architectural aesthetics and the structural simplicity using the 3D visualized model until they reached the agreement. The BIM-based teamwork experience shared from the design teams was somewhat similar to the industry perceptions including how BIM affected the traditional role of architects. This conveys the information that it is feasible to adopt the experiential learning approach for BIM learners to gain the practice in the real-world context.

This case project built the connections among BIM academia, the client, and AEC professional. As the project deliverable, the nine redesign plans were sent to the land owner and the owner’s procured contractor in early January 2016 for professional assessment. These nine redesign proposals were ranked and commented with relevant feedback provided on further improvements of the current design. Future BIM pedagogy could continue the case study approach with the client providing the site information and project requirements, the college BIM team working on the design plan in an integrated approach, and the final design development being assessed by the client and AEC industry professionals.

5. Acknowledgement

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Field measurements of PM$_{2.5}$ and ultrafine particles in residential houses

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Abstract

Purpose / Context - Particulate matter (PM) is one of the main indoor air pollutions, and it can cause a wide range of diseases that lead to a significant reduction of human life. This study aimed at investigating characteristics of particle concentrations for PM$_{2.5}$ and size distribution during different activities in residential houses.

Methodology / Approach - This study was conducted between December 2013 and January 2014 in 7 houses. The measurements of indoor air were continuously in 24 hours and the instruments were kept in the living room or bed room. Mass concentrations for PM$_{2.5}$ were measured simultaneously with Dust Trak (TSI/8533). The number size distribution concentrations of particle (10–863 nm) were measured with a portable aerosol mobility spectrometer (PAMS, Kanomax/3300).

Results – In each house, the average of PM$_{2.5}$ concentration was 10–45 μg/m$^3$. The average of I/O ratio of PM$_{2.5}$ was about 0.5–1.5. Indoor PM$_{2.5}$ concentration in the living room was increased by using the gas stove, toaster oven in the kitchen and burning candles, incense sticks in the next room. Ultrafine particles with diameters in the range of 30–50 nm were generated by cooking, and the peak particle diameter of I/O ratio was around 50 nm.

Key Findings / Implications – The indoor aerosols could be affected by the difference of the ventilation equipment with air filters. The fine and ultrafine particle emissions from candles and incense sticks are generated in indoor.

Originality - This study demonstrated the increase of PM$_{2.5}$ concentrations and ultrafine particle concentrations in the living room due to cooking or other activities with the PM$_{2.5}$ monitor and PAMS.

Keywords - Indoor air quality, PM$_{2.5}$, Ultrafine particle, Size distribution, Emission source
1. Introduction

Particulate matter (PM) is one of the main indoor air pollutions, and it can cause a wide range of diseases that lead to a significant reduction of human life. The size of particles has been directly linked to their potential for causing health problems. Ki-Hyun Kim (2015) summarized the basic evidence on the health effects of particulate matter in atmospheric environments. The health effects of PM_{10} and PM_{2.5} are well known that an exposure to particulate matter is linked to adverse respiratory and cardiovascular health effects. As particles decrease in size, nano size particles are also hypothesized to increase acidity and their ability to penetrate into the lower airways.

Since most people spend the majority of their lives indoors, we are exposed to the aerosols in indoor air. Morawska et al. (2013) pointed out that the need for good characterization and quantification of exposure to indoor aerosols appears obvious. And it is essential for exposure control to confirm particle matter of outdoor origin that has penetrated indoors and particle matter generated by indoor sources so that characterization and emission of indoor sub-micron aerosols have been of great interest.

This study aimed at investigating of characteristics of particle concentrations for PM_{2.5} and size distribution during different activities in residential houses. The PM_{2.5} concentrations and number concentrations of size distributions and were monitored in 7 houses.

2. Methodology

2.1 Housed and sampling methods

The study was conducted between December 2013 and January 2014 in 7 houses. The characteristics of the houses are given in Table 1. The houses were situated in residential areas of Tokyo, Kanagawa and Chiba in Kanto region in Japan. Some houses were not equipped with mechanical ventilation systems. No houses were equipped with heating appliances that generate fine particles, such as kerosene or LPG as main fuel. The house E only had the heating and ventilation air conditioning system that had an air filter for reducing particulate matter and the air conditioning system operated all day during the measurement. The sampling points in indoor air were the living room or bed room. The measurements of indoor air were continuously in 24 hours and the instruments were kept in the living room or bed room. While outdoor air was measured for 10 min. 5 times a day, 10, 13, 16, 19 and 22 o'clock at outside of each house. The residents of each house recorded their behavior in the house, such as cooking, using the hair drier, and so on.

<table>
<thead>
<tr>
<th>Name</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>12/29</td>
<td>12/31</td>
<td>1/3</td>
<td>1/5</td>
<td>1/9</td>
<td>1/12</td>
<td>1/15</td>
</tr>
<tr>
<td>Location</td>
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<td>Fuchu, Tokyo</td>
<td>Ota, Tokyo</td>
<td>Kawasaki, Kanagawa</td>
<td>Odawara, Kanagawa</td>
<td>Chiba, Chiba</td>
<td>Meguro, Tokyo</td>
</tr>
<tr>
<td>Type</td>
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<td>Housing complex</td>
<td>Housing complex</td>
<td>Housing complex</td>
<td>Detached</td>
<td>Detached</td>
<td>Housing complex</td>
</tr>
<tr>
<td>Structure</td>
<td>Wooden</td>
<td>RC</td>
<td>Steel frame</td>
<td>RC</td>
<td>Wooden</td>
<td>Wooden</td>
<td>RC</td>
</tr>
<tr>
<td>Measurement location</td>
<td>Living</td>
<td>Living</td>
<td>Living</td>
<td>Bed room</td>
<td>Living</td>
<td>Living</td>
<td>Living</td>
</tr>
<tr>
<td>Next room</td>
<td>Kitchen</td>
<td>Kitchen</td>
<td>Kitchen, bathroom</td>
<td>Bed room</td>
<td>Kitchen</td>
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<td>Kitchen, bathroom</td>
</tr>
<tr>
<td>Number of residents</td>
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<td>1</td>
<td>5</td>
<td>5</td>
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<td>1</td>
</tr>
<tr>
<td>Pet</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>○</td>
<td>○</td>
<td>×</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>×</td>
<td>×</td>
<td>○</td>
<td>×</td>
<td>○</td>
<td>○</td>
<td>×</td>
</tr>
<tr>
<td>Heating system</td>
<td>Electric carpet</td>
<td>Air conditioning</td>
<td>Air conditioning</td>
<td>Ceramic heater</td>
<td>Fan heater</td>
<td>Air conditioning</td>
<td>Halogen heater</td>
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</tbody>
</table>
2.2 Instrumentation

Mass concentrations for PM$_{2.5}$ were measured simultaneously with Dust Trak (TSI/8533). In this study, measurements were continuous with a time resolution of 1 min.

The number concentrations of particle number size distributions (10–863 nm) were measured with a portable aerosol mobility spectrometer (PAMS, Kanomax/3300). The PAMS is an electrical mobility size spectrometer designed for portable, mobile, or handheld aerosol sampling applications consisted of a small DMA and CPC. The particle number size distribution measurements were continuous, with a time resolution of 3 min.

Another environmental factors, such as temperature, relative humidity and CO$_2$ concentration were also measured with the data recorder (T&D/TR-75Ui) in parallel.

A summary of the measuring equipment is shown in table 2.

These instruments were located on the table in the living room or bed room. The outdoor air samplings for PM$_{2.5}$ and particle size distribution were performed by carrying Dust Trak and PAMS to outside of the house.

Table 2: Measurement equipment

<table>
<thead>
<tr>
<th>Element</th>
<th>Target</th>
<th>Measuring device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative mass concentration</td>
<td>Dp&lt;2.5μm</td>
<td>DustTrak(TSI/8533)</td>
</tr>
<tr>
<td>Particle size distribution</td>
<td>10nm&lt;Dp&lt;433nm</td>
<td>PAMS(KANOMAX/3300)</td>
</tr>
<tr>
<td>General environmental factors</td>
<td>Temperature, humidity and CO$_2$ concentration</td>
<td>CO$_2$ recorder (T&amp;D/TR-76Ui)</td>
</tr>
</tbody>
</table>

2.3 Emission source of particles in indoor

It is important for indoor particulate characteristics to investigate the indoor particulate emission sources by human activities in houses. Table 3 shows the indoor particle emission sources from the previous studies. These lists are informative to find out the emission sources of particulate matter from the field measurements in indoors. The emission sources of fine particles, ultrafine particles, PM$_{2.5}$ and so on were listed as indoor activities, such as cooking, tobacco smoking, hairsplay, incense sticks and etc.
Table 3: Indoor particle emission sources

<table>
<thead>
<tr>
<th>Source/cause</th>
<th>Characteristic particle</th>
<th>Measurement method</th>
<th>Refer.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor activities (cooking, candle burning, aroma lamp, tobacco smoking, hair spray, incense sticks, open windows)</td>
<td>Particle indoor and outdoor sized 14-552 nm</td>
<td>Particle size spectrometer (SMPS 3934C, TSI Ine., USA)</td>
<td>Tareq Hussein et al. (2006)</td>
</tr>
<tr>
<td>Smoking and cooking</td>
<td>Inside and outside PM$<em>{2.5}$, PM$</em>{1.0}$, PM$<em>{0.5}$, and PM$</em>{0.25}$</td>
<td>Grimm aerosol spectrometer (Scattering light photometry and filter sampling)</td>
<td>D. Massey et al. (2009)</td>
</tr>
<tr>
<td>Gas for cooking</td>
<td>Inside and outside PN sized 7 nm-3 µm PM$<em>{10}$ and PM$</em>{2.5}$</td>
<td>Condensation particle counter Gravimetric measurement using filter methods (Harvard impactors operating)</td>
<td>Gerard Hoek et al. (2008)</td>
</tr>
<tr>
<td>Cooking</td>
<td>PM$_{2.5}$</td>
<td>Scattered light photometry</td>
<td>Mohamed F. Yassin et al. (2012)</td>
</tr>
<tr>
<td>Cooking stove</td>
<td>Oil particle concentration sized PM$_{2.5}$</td>
<td>Scattered light photometry</td>
<td>A.C.K. Lai et al. (2008)</td>
</tr>
<tr>
<td>Human activities depending on time</td>
<td>Particle number sized 0.007-0.808 µm PM$_{2.5}$</td>
<td>Condensation particle counter Scattered light photometry</td>
<td>Lidia Morawska et al. (2003)</td>
</tr>
<tr>
<td>Indoor activities including cooking</td>
<td>Indoor/outdoor particle number size distributions (3-400 nm)</td>
<td>Particle size spectrometer</td>
<td>Tareq Hussein et al. (2005)</td>
</tr>
<tr>
<td>Printer emission</td>
<td>Nano particle from laser printer</td>
<td>Particle size spectrometer</td>
<td>Naoki Kagi et al. (2007)</td>
</tr>
</tbody>
</table>

3. Results

3.1 PM$_{2.5}$

Fig. 1 shows PM$_{2.5}$ concentrations and I/O (indoor/outdoor air concentration) ratios of PM$_{2.5}$ in each house measured with Dust Trak. The mean concentrations of each house were 10-45 µg/m$^3$ except for the house B. The rapid increases of PM$_{2.5}$, more than 50 µg/m$^3$ were observed by indoor activities in some houses. The I/O ratios in each house were usually less than 1 except for the house B. The I/O ratio of the house B was also at high level. Since the no-water burning of the kettle in the kitchen was occurred during the measurement, the mean PM$_{2.5}$ concentration and I/O ratio of the house B was extreme high rather than other houses.

Fig. 2 and fig. 3 show the time changes of PM$_{2.5}$ of indoor and outdoor air, temperature, relative humidity and CO$_2$ concentrations in the house A and E, respectively. The gas stove for cooking was used in the kitchen of house A from 17:00 to 19:00, and the rises of both PM$_{2.5}$ and the CO$_2$ concentrations was observed. The house E installed the induction heater (IH) for cooking. Since the particle emission from IH cooking was relatively low, the PM$_{2.5}$ concentration by cooking was at low level. But there was the increase of PM$_{2.5}$ concentration in indoor environment at 7:00 on the next morning, and the CO$_2$ concentration also rose at the same time. Because the candles and incense sticks in the next room of the living room were used in this time, these emission sources could raise PM$_{2.5}$ concentration in living room.
Kagi, N  Field measurements of PM2.5 and ultrafine particles in residential houses

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Fig. 1  Indoor PM2.5 concentrations and I/O ratios by DustTrak in each house

Fig. 2  Time changes of (a) PM2.5 concentration and (b) temperature, relative humidity and CO2 concentration in house A

Fig. 3  Time changes of (a) PM2.5 concentration and (b) temperature, relative humidity and CO2 concentration in house E

3.2  Particle size distribution

Fig. 4 shows the I/O ratio according to the particle size distribution in house A, E, respectively.

The peak diameter of the mean I/O ratio was around 50 nm, and 50 nm particles could be generated by the indoor activity in indoor. The characteristics of particle size distributions in indoor air could be affected by the difference of the ventilation equipment and the cooking equipment in the
kitchen. Fig. 5 shows the size distribution of indoor and outdoor airborne particle during cooking in the house A and E. The main peak particle sizes in both houses were around 30 nm, in contrast to outdoor air. The gas stove and the toaster oven in the house A and E were used during sampling, a lot of 30 nm particles were generated by cooking.

4. Discussion

The indoor aerosols could be affected by the difference of the ventilation equipment that equipped with air filters (Tran Ngoc Quang et al. 2013). The house E only had the heating and ventilation air conditioning system that installed an air filter. Fig. 1 (b) and fig. 3 showed the PM2.5 concentrations in the house E. The mean PM2.5 concentration was relatively low and the trend of PM2.5 concentrations was also at low level except for particle emissions, such as burning the candle and incense stick.

E. Ge’hin et al. (2008) tested the fine and ultrafine particle emissions of candles and incense sticks and wide range of diameter, from 6 to 180 nm. The cooking activities also raise the PM2.5 concentration not only in the kitchen, but also in the living room (Mohamed F. Yassin, 2012). This study demonstrated the increase of PM2.5 concentrations and ultrafine particle concentrations in the living room due to cooking or other activities.
5. Conclusion

In this study, PM$_{2.5}$ and size distribution of ultrafine particles were monitored with Dust Trak and PAMS during different activities in 7 residential houses.

1) In each house, the average of PM$_{2.5}$ concentration was 10-45 μg/m$^3$. The average of I/O ratio of PM$_{2.5}$ was about 0.5-1.5.

2) Indoor PM$_{2.5}$ concentration in the living room was increased by using the gas stove, toaster oven in the kitchen and burning candles, incense sticks in the next room.

3) Ultrafine particles with diameters in the range of 30-50 nm were generated by cooking, and the peak particle diameter of I/O ratio was around 50 nm.

6. References


Massey D., Masih J., Kulshrestha A., Habil M., Taneja A. (2009) Indoor/outdoor relationship of fine particles less than 2.5um (PM2.5) in residential homes locations in central Indian region, Building and Environment, 44, 2037-2045.


Regenerative Sustainability and Geodesign in Byron Shire

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Abstract
Byron Shire, NSW, Australia, aims to transition to zero emissions within ten years in five sectors - energy, buildings, transport, land use and waste. This study investigates the potential of Geodesign to effectively map the shire during this transition.

A contextual study of the shire’s residential pockets is initiated using open source Geographic Information System (GIS) data and a typical case study site selected based on demographic information. CO2 equivalents from current electricity usage and offsets from renewable energy systems are added to the database and visualized in ArcGIS software. Site specific benchmarks are derived as the first step of developing a Regenerative Sustainability Design (RSD) strategy using Geodesign tools. The tenets of RS require each building to use systems that enhance overall ecosystem health by achieving positive outcomes for energy, waste, water, biodiversity, etc.

ArcGIS is used for designing built and natural environments in an integrated process. It enables evaluation of RSD alternatives against their impacts, collaborative decision making and community engagement (via apps, online surveys). Vector data can be directly quantified, multiple parameters accounted for and the on-ground situation presented to stakeholders in a legible and easy to understand format. Complex datasets can be quickly accessed and visualized in order to identify opportunities for positive contributions to the community.

This work shows the value of Geodesign for community planning processes to drive positive change. ArcGIS can assist in holistic assessments to identify the most effective retrofit opportunities, monitor the transition to zero emissions over time and inform policy.

Keywords: Zero Emissions Byron, Regenerative Sustainability, Net Positive Development, Geodesign, CO2 equivalence.
1. Introduction

Many cities, regions and countries around the world are moving away from fossil fuels and have policies in place for 100 per cent renewable energy targets. A number of these, including Byron Shire Council, were represented at the recent Climate Change Conference COP21 in Paris (COP 21, 2015). This study explores how Regenerative Sustainability and Geodesign can add value to the transition process in Byron Shire and drive positive change.

The World Green Building Council has recently announced the groundbreaking new ‘Advancing Net Zero’ project which aims to ensure that all buildings are ‘net zero’ by 2050, to help deliver on the ambition of the Paris Agreement by reducing CO₂ emissions from the building sector by 84 gigatonnes in this timeframe. Participating Green Building Councils agreed on providing training programs and launching national net zero certifications in their countries, either stand alone programs or additions to existing certification tools such as Green Star. Architecture 2030, a non-profit organisation working to reduce emissions from buildings, will be Lead Partner to WorldGBC (WorldGBC, 2016). The Green Building Council of Australia, one of initially eight participating countries worldwide, is promoting net zero as an achievable goal and has announced the introduction of a ‘net zero’ label to recognize buildings with a neutral (zero) and net positive (beyond zero) impact in energy, carbon and water (Green Building Council of Australia, 2015).

1.1 Background – Regenerative Sustainability

Integrating the built and natural environment has been fundamental to the work of architects and planners such as Christopher Alexander, Antoni Gaudi, Frank Lloyd Wright and others. The Ecological Worldview (also known as Evolutionary, Reflective/ Living Systems and Integral - holds that humanity and nature are part of an interdependent and interconnected system (Commoner, 1971; Birkeland, 2012; du Plessis, 2012, Elgin & Le Drew, 1997; Goldsmith, 1988; McHarg, 1969; Prigogine & Stengers, 1984; Wilber, 1990). Carter, Miller, and Radhakrishnan (2001) emphasise the importance of cultivating connectivity with nature and taking personal responsibility for ecological wholeness. Some have called for environmental ethics within the architectural and planning disciplines (Beatley, 1994; Birkeland, 2002; du Plessis, 2012, Fox, 2000, Pedersen Zari, 2012). Hes and du Plessis (2014) have recently discussed the notion of the Ecological Worldview and its implications on the meaning and practice of sustainable architecture.

Hes and du Plessis along with Birkeland (2008); Cole (2012); Lyle (1994); Mang and Reed (2012), Benne and Mang (2015); Dias (2015); du Plessis (2009); du Plessis and Brandon (2014) describe Regenerative Sustainability (RS) as creating a positive impact on the health of the ecosystem and biosphere; architectural design must create reciprocal relationships between buildings and the larger living system.

‘Regenerative Design’ (RD) was introduced by Landscape Architect John T. Lyle (Lyle, 1994). Similarly, circular metabolism models on the regional scale have been theorised since the 1980’s (Boyden, Millar, Newcombe, & O’Neill, 1981; Girardet, 1996).

Birkeland’s Positive Development (PD) theory, taught and published from 2003, is based on a similar philosophy with a focus on creating net positive ecological gains relative to human consumption. Unlike circular models, PD is an open system approach that suggests how built structures can be retrofitted to become a net positive living environment that actively increases ecological carrying capacity and ecosystem services beyond pre-historic conditions, as well as natural, social and economic capital (Birkeland, 2008).
The term net positive has recently been included in the discussion within the international building research community. The first eco-positive conference stream ‘Pushing the Boundaries – net positive Buildings’ at SB13 Vancouver (SB13, 2013), explored the notion that buildings can and should have a net positive impact in order to regenerate their larger region. Net zero and net positive principles are also emerging in architectural practice, yet appropriate baselines, timeframes and system boundaries need to be defined (Kibert & Fard, 2012; Cole & Kashkooli, 2013; Renger, Birkeland, & Midmore, 2015).

In this applied research, investigations are guided by the philosophy that buildings must contribute to nature rather than settling to do less harm than the norm. For the purpose of this contextual review, related design strategies are referred to as Regenerative Sustainable Design (RSD) interventions.

1.2 Geodesign – History and Definition

Adapting the built environment to geographical surroundings has been a fundamental design practice since the start of human settlement. Recently, the term ‘Geodesign’ has been introduced to describe this activity and has gained popularity since the first Geodesign Summit in 2010 (Artz, 2013). The contemporary definition of Geodesign refers to a multidisciplinary and collaborative design process that harnesses the power of Geographic Information Science (GIS) data and technologies. Geographical space, its operations and condition are described and assessed on a digital platform to derive evidence-based changes necessary for the health and well being of that space.

Miller (2012) quotes five historically significant developments essential to the genesis of Geodesign. Firstly, McHarg’s (1969) design philosophy which proposed a layered approach to regional and landscape planning based on the values of designing with nature. Secondly, the design framework for regional landscape studies developed by Steinitz eventually entitled as the ‘Framework for Geodesign’ (Steinnitz, 2012). This framework advocates the development of six models to assist in a holistic planning process, entitled as ‘Representation’, ‘Process’, ‘Evaluation’, ‘Change’, ‘Impact’ and ‘Decision’ Models. It is technology independent but has been supplemented by work in Harvard’s Laboratory for Computer Graphics and Spatial Analysis. Thirdly, the development of computer graphics led by Fisher in the late 1960s and the development of SYMAP, the first computer mapping program popular with planners. Fourthly, Miller (2012) refers to the development of GIS science led by Goodchild and others since the late 1980s. The fifth seminal development occurred when Jack Dangermond, Steinitz’ student and founder of the company ESRI, developed GIS digital technology to assist landscape planning processes by coupling Geographic Information Science and the Steinitz’ design framework. ‘Geodesign’ is ‘GIS+design’ (Batty, 2013) and Steinitz (2016) describes it as an iterative design method that uses stakeholder input, geospatial modeling, impact simulations, and real-time feedback to facilitate holistic designs and smart decisions.

1.3 Digital Monitoring for RSD

The concept of Geodesign shows synergies with the regenerative and net positive design paradigms. It adds value to RSD by assisting in brokering agreement between multiple stakeholders who need to agree upon the best course of action (Campagna, 2016). GIS tools enable the transition from 2D maps to ‘2.5D’ reliefs to 3D geographic space and the addition of a 4th dimension by geo-referencing time-dependent information. This can support designers in developing evidence-based RSD strategies for the built environment by effectively visualizing, quantifying and monitoring large, complex spatial datasets on the health, status, history and future of the planet. Qualitative and quantitative data from multiple sources such as maps, aerial photos, satellites and surveys and

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stored in large georeferenced databases can be integrated into the RSD process to support stakeholders in choosing appropriate development scenarios.

In Urban Planning, land use and natural resource management this process has been used by multidisciplinary teams extensively, permitting the facilitation of planning objectives and plan making through spatial systems analysis and public engagement (Steinitz, 2016). Smith (2016) explains how open GIS can be used to prepare online and interactive mapping to reach large audiences and highlights the effectiveness of using the technology within the built-environment discipline.

A number of Geodesign case studies are available on the Esri website; a relevant example is Masdar City, UAE where GIS is used to meet the project’s carbon neutrality and zero waste goals (ESRI, 2009). Geodesign tools and strategies applied to ZEB can assist in developing RSD interventions with stakeholders and monitor their implementation over time.

1.4 Zero Emissions Byron (ZEB)

ZEB is a community led project that was established in 2015 to achieve zero emissions shire wide within ten years, addressing the five key emission sectors energy, buildings, land use, transport and waste. It is a joint initiative of community members, the Byron Shire Council (BSC), the research organisation Beyond Zero Emissions (BZE) and the Centre for Social Change (CSC). Byron is known for its community spirit and for embracing sustainability as a fundamental life philosophy. ZEB’s framework aims to go ‘beyond zero emissions towards net positive contributions to nature’ (Zero Emissions Byron, 2016). The project can build upon many existing initiatives in the shire such as the Green Building Centre, a community-owned renewable energy provider, permaculture gardens and various community activities. An innovative virtual net metering pilot project enables sharing energy resources between buildings (Parkinson, 2015). ZEB has gained international recognition and was represented at the recent United Nations Climate Change Conference COP21 in Paris.

Buildings are a focal point in the community where all other the key emission sectors come together and a hub for social interaction, communication and education. While self-sufficient buildings have been explored for almost half a century (Vale & Vale, 1975), the value of these concepts is now increasingly being recognized (du Plessis, 2012; Pedersen Zari, 2012). An RSD strategy implemented in Byron can inspire others, create meaningful places for people and enhance the community spirit.

To date current baseline emissions have been established for the five sectors and the focus is now on community and stakeholder engagement. Retrofitting opportunities will be prioritized and new buildings encouraged to target self-sufficiency through design most suited to the sub-tropical climate, maximizing passive solar design strategies to minimize active technology and cost. BZE’s reports and cost efficiency models will support the transition process (Beyond zero emissions, 2016). BZE’s research is complemented by leading concepts in international building research and emerging practice such as regenerative design (Lyle, 1994, 1999), Cradle to Cradle (McDonough & Braungart, 2002; McDonough, Braungart,) and Positive Development (Birkeland, 2008).

1.5 Aims and Objectives

This study explores (a) the use of Geodesign in a holistic sense to support Byron to regenerate their community towards carbon neutrality and beyond (b) ArcGIS as a Geodesign tool to provide science-based evidence while managing complex datasets during the RSD process.

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A broad literature review reveals that there are essential constraints to a design discussion within the current paradigm where improvement of overall ecosystems health is an objective. These constraints are related to systems of energy, waste, water, and carbon, well-being, place, food and so on (Benyus, 1998; Birkeland, 2008; Hoxie, Berkebile, & Todd, 2011; Kennedy, 2010; Mang & Reed, 2012; Pawlyn, 2011; Renger, et al., 2015; Yeang, 1995). The objective of this study is to investigate how Geodesign can assist in addressing whole system solutions. Starting with a contextual review of Byron Shire’s residential areas, the efficacy of ArcGIS as a Geodesign tool for the RSD process is tested and the status of geo-spatial data currently available through open sources are reviewed. Initially, current electricity related carbon emissions are assessed to set first benchmarks for the transition to zero emissions.
1.6 Limitations / Opportunities

The current contextual review focusses on operational carbon emissions only. It shows the potential of ArcGIS to capture different forms of carbon impacts, for example embodied energy or biomass sequestration. CO2 equivalent is used as an indicator for quantification; however, this is only one aspect of a holistic assessment in addition to many benefits that ecosystem services provide on the physical, cultural and psychological level (Renger, Birkeland, & Midmore, 2013). Multiple RS parameters can be quantified as well as qualitative factors captured if data are available. The methodology can be extended to include other building types as well as the other ZEB sectors Energy, Land Use, Transport and Waste. Once Geoscape data on built form and vegetation are released later next year (Leary 2016) the calculations can be revised to reflect a more realistic view. Future work will test how Geodesign tools can assist in the iterative process of displaying information to and collecting missing data from the community, documenting progress, refining the RSD strategy upon feedback and monitoring the implementation. Application of an RSD strategy in governance planning and decision making, not only on the technical level, would be most effective. Geodesign can support ZEB in developing implementation programs to reach zero emissions and inform policy.

2. Methodology

A seven step methodology is employed to develop a RS strategy for Byron Shire using the Geodesign tool ArcGIS. Due to limited data availability and time, the last step is still in progress.

2.1 Choose Parameters

New South Wales (NSW) Building Sustainability Index (BASIX) has set up benchmarks and targets for energy related carbon emissions within the residential sector (BASIX, 2016), however BZE’s reports show that these can be challenged (BZE, 2016). Carbon is chosen as a parameter due to its relevance for mitigating climate change (IPCC, 2014). CO2 equivalent can be used as an indicator to overlay impacts from different sources (Renger et al., 2013, 2015), e.g. the five ZEB sectors. These can be modelled with Geodesign tools. BZE’s initial estimated average electricity use in residential buildings in the shire is used as a starting point.

2.2 Identify appropriate scale

Open GIS data was reviewed to identify an appropriate scale for RSD interventions. The majority of ABS spatial data is based on Australian Statistical Geography Standard (ASGS) since 2014. The ABS Main Structure grows smaller from Australia (country scale), to state and territory, to four levels of Statistical Areas (SA4-SA1), to Mesh Block (Australian Bureau of Statistics, 2014). Digital boundaries for Local Government Areas and Natural Resource Management Regions are also available through ABS (Australian Bureau of Statistics, 2012) and can be overlaid in ArcGIS.

The community scale is most appropriate for proposing RSD strategies because resources can be shared and benefits maximized through multi-functional design once regulatory constraints are overcome. However, smaller physical boundaries such as the Mesh Block geography within Byron’s Local Government Area (LGA) boundary are a useful starting point for quantification.

2.3 Identify a Case

Byron shire covers an area of 566 square kilometres (Byron Shire Council, 2016). Mesh Blocks reflect land use, are the smallest geographical region in the ASGS and also the smallest unit for which census data is available (Australian Bureau of Statistics, 2011b). In order to select a case study site (CSS) that best reflects the situation in the shire, the location of the 280 Mesh Blocks classified as...
residential within Byron’s LGA boundary is identified (Figure 1). A population grid for Australia based on the most recent census data from 2011 (Australian Bureau of Statistics, 2011a) is overlaid to make comparisons at a regional scale (Figure 2) and identify the typical demographic profile of Byron. From here, the two Mesh Blocks with median number of dwellings and Persons Usually Resident (PUR) are identified. The former is chosen as CSS, reviewed at a larger scale (1:5000) and cadastral and imagery data (Land and Property Information, 2014a, 2014b) is overlaid (Figure 3).

2.4 Description of Existing Energy Systems

Aerial imagery published by Land and Property Information (2014b) is used to identify lots with photovoltaic (PV) systems (Figure 3). Approximate system size is determined. The average annual electricity usage per dwelling in Byron shire has been estimated by BZE as 90 MJ per dwelling per day (Keech, 2015). This, in conjunction with ABS figures for number of dwellings is used to calculate and visualise electricity usage per lot to identify the characteristics of the CSS (Appendix: Figure 4). GIS data for emissions and/or offsets from energy suppliers or other sources such as Council and the community may become available.

2.5 Carbon Sequestration Potential of Remnant Ecosystems on Site

Remnant Ecosystems for Byron are discovered through a search on the NSW spatial catalogue (Ecograph & Terrafocus, 2012). This information is overlaid in the mesh block to identify and visualize type and location of the ecosystems in the CSS and surrounding context (Figure 5). Carbon sequestration values for these vegetation types can be sourced, the net position on emission/sequestration calculated and visualized via ArcGIS. This assessment can inform the subsequent stages of the design process, be useful for other ZEB sector groups, in particular the Land Use Group, and tie back to Council’s revegetation projects.

2.6 Determining the Net Position

The existing situation in the CSS was assessed and benchmarks for achieving carbon neutral operation established. The preliminary results of baseline emissions, offsets and future targets are shown in Table 1. These calculations can be refined beyond averages once more accurate figures on operational energy usage are available. Additional RSD parameters such as emission/offset data from the other ZEB sectors can be added. Geodesign methods and tools can assist in identifying the net position on emissions and analysing pathways to achieve ZEB’s goal of zero operational emissions. Favourable conditions and optimal locations for resource sharing between buildings to achieve net positive status for individual buildings and areas suitable for multi-functional public benefits can also be identified.

2.7 Development of Comparative Values – Work Under Progress

Work is under progress to review methodologies for collecting critical, place-specific data such as building footprints, Gross Floor Area (GFA) of dwellings and material use for the RSD strategy. Extensive data searches on open platforms revealed no information available in ESRI formats for GFA. Mapdata Services, a digital mapping company is currently working on a dataset titled Geoscape Data which will supply data on Australia’s built environment, physical structures, land and vegetation (MapdataServices, 2016). The availability of this information in the near future will enable assessment of the relation between natural systems and built form. In-house work on determining

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appropriate methodologies for updating and automating processes for collection and displaying information to monitor progress towards carbon neutrality targets and beyond will continue.

3. Results

ArcGIS has proven to be a fast and effective tool in analysing the depth of open information available through ABS, NSW Spatial Catalogue, NSW Globe, and NSW LPI Web Services. ABS data used to inform this study is available in spreadsheet and ESRI shapefile vector format which can be directly quantified. The capabilities of the software to add data and visualize results of the existing average baseline operational emissions in the residential mesh block were tested. Embodied energy of buildings technology and other emissions are not considered in this study. The potential to include carbon sinks from biomass sequestration is outlined only and subject to future research. Missing GIS data has been identified. The geo-spatial information discovered on open databases has proven to be a useful starting point for developing an effective RSD strategy. Quantitative as well as qualitative factors can be captured via Geodesign tools depending on data availability.

3.1 Energy Systems / Carbon Offsets

3.1.1 Existing Situation:

In the CSS, 22 lots with 36 dwellings are identified in the Mesh Block. Five types of lots are distinguished through ArcGIS colour coding based on total GHG emissions (Appendix: Figure 4). The variance in each lot is due to number of dwellings (single, double or multiple) and electricity offset through PV (currently only 5 per cent). Once more location specific information is added to the database, appropriate retrofit strategies can be developed. The annual electricity usage, related carbon emissions and recommended minimum future targets are shown in Table 1 below.

3.1.2 Future Target:

Strategies for achieving the future target of carbon neutral operation depend on location, building / construction type and user profile. BZE’s initial report for the ZEB project indicates that through retrofit; typically a Byron house can expect a reduction of 48 per cent in electricity use (BZE, 2015). Retrofits upfront are critical in order to minimize PV system sizes and cost. ArcGIS can assist ZEB in identifying where the highest and lowest GHG emissions occur. Based on this a location sensitive RSD strategy, implementation and monitoring program to reach the zero emissions can be developed.

3.2 Proximal Carbon Sinks

Ecosystem data overlaid on the CSS (Appendix: Figure 5) that moist to dry and swamp Sclerophyll forest and woodland; Heathland and other bushland exist on site and within close proximity. For this 2007 mapping ground-truthing is stated as work under progress at time of release. Visual reconnaissance of imagery is under progress to review accuracy of this data. Similar to the energy related CO2 equivalents, the carbon sequestration potential can be added to the database and different scenarios modelled and monitored in real-time applications.
4. Discussion

4.1 Data Availability

Extensive amount of geospatial data is available in the Australian context. ABS data has been collected on a national scale. These datasets are in different formats and can be confounding in their complexity. By using the Geodesign tool ArcGIS, ZEB can quickly derive useful regional information from these extensive nation-wide datasets. Here, a typical residential CSS at the local scale was identified and its specific characteristics reviewed. Freely available web services of Land and Property Information (2014a, 2014b) and raster data were used to inform this study. In NSW, cadastral vector data (e.g. in ESRI shapefile format) needs to be purchased from the NSW Digital Cadastral Database. Energy and vegetation related GIS data from energy providers, Council and/or agencies such as MapDataServices may become available and will be vital for the development of an effective RSD strategy, implementation and monitoring program.

4.2 Manual vs Automated Process

Due to the small size of the chosen CSS it is possible to manually review the data to extract the necessary information. For a shire wide application, automated processes need to be followed. Vector data enable direct quantification of large datasets. This will save significant time and effort for monitoring future progress towards zero emissions.

4.3 Improving Accuracy

The calculations in this contextual review are based on average values for electricity usage per dwelling and estimated installed capacity of PV systems. These can be replaced if more accurate figures become available. Once the existing situation is mapped across the chosen parameter (for

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Table 1: Net operational carbon position/yr (based on 2011 data)

<table>
<thead>
<tr>
<th>Colour Code / Description</th>
<th>Number of lots</th>
<th>PV Installed</th>
<th>Electricity use(^1) (kWh)</th>
<th>Electricity offset by PV(^2) (kWh)</th>
<th>Net electricity use (kWh)</th>
<th>Current GHG equivalent ((t \text{ CO}_2))^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Vacant(^4)</td>
<td>1</td>
<td>No</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Yellow</td>
<td>3</td>
<td>Yes</td>
<td>27594</td>
<td>9965</td>
<td>17630</td>
<td>15</td>
</tr>
<tr>
<td>Single dwelling Blue</td>
<td>3</td>
<td>No</td>
<td>55188</td>
<td>0</td>
<td>55188</td>
<td>47</td>
</tr>
<tr>
<td>Double dwelling Green</td>
<td>13</td>
<td>No</td>
<td>119574</td>
<td>0</td>
<td>119574</td>
<td>103</td>
</tr>
<tr>
<td>Single dwelling Purple</td>
<td>2</td>
<td>Yes - 1</td>
<td>6898</td>
<td>121874</td>
<td>121874</td>
<td>105</td>
</tr>
<tr>
<td>Multiple dwellings (6.8)</td>
<td></td>
<td>No - 1</td>
<td>128772</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td></td>
<td>331128</td>
<td>16864</td>
<td>314266</td>
<td>270</td>
</tr>
</tbody>
</table>

\(^1\) Based on estimated average daily electricity use of 90 MJ/dwelling * 365 days * 0.28 (conversion factor MJ to kWh). Assumed to be drawn from grid. Source: (Keech, 2015).

\(^2\) Based on average daily electricity production of 4.2kWh * 365 days * 0.25 (conversion factor). Source: Solar choice (2010)

\(^3\) Based on NGA factors for NSW = 0.86 (Australian National Greenhouse Accounts, 2015)

\(^4\) Vacant lot at time of the census. Recently been redeveloped. Excluded to maintain consistency within the study.
example, energy, carbon, waste, water etc.), appropriate system boundaries and timelines can be set. However, too detailed calculations can distract from the larger goal to reach zero emissions; it is more effective to focus on maximizing positive contributions.

4.4 Development of RSD Scenarios

ArcGIS can assist in identifying patterns hidden within the vast amounts of conventional data available such as extensive ABS data in spreadsheet format. Factual numbers provide a backing that empowers the RSD process. ZEB can rapidly compare locations and draw conclusions on the character of specific places in Byron. Applied in a holistic sense, this Geodesign tool can assist in revealing optimal locations for creating net positive community benefits. Based on GIS mapping of existing circumstances, location sensitive, user specific and most cost-effective retrofit strategies can be developed. Multiple scenarios can be compared and assessed (Larondelle, Frantzeskaki, & Haase; Pettit et al., 2015; Smith, Bishop, Ford, & Williams, 2009) to identify the best pathways for ZEB to acquire and monitor its zero emissions target.

4.5 Staging and Implementation of Design Interventions

ABS’s Mesh block geometry is freely available. The efficacy with which analysis is performed at this scale implies that mesh block geometry could be used to monitor RSD interventions shire wide in the further development of the ZEB project. Mesh blocks for other building types can be identified and the framework developed within this contextual review extended to the other ZEB sector groups Energy, Land Use, Transport and Waste. Additional parameters such as waste, water, food, health, well-being and so on can be investigated and monitored over time.

4.6 Emerging Technologies

Software such as ESRI’s CityEngine is a promising technological advancement that could be used to generate 3D urban environments to validate the RSD strategy. This would provide visualisations for RSD scenarios depicting the appearance of Byron’s built and natural environment as it tracks towards zero emissions (e.g. 3d scenes, videos, fly-throughs). Such visualisations would assist in exploring how our dynamic earth systems may change and how we may thoughtfully support this change (Dangermond, 2009). Further, dynamic simulations of our constructed and natural systems can support the management of design inter-ventions that create a healthier planetary system (Jackson & Simpson, 2012) and effectively communicate this to the Byron community.

5. Conclusion

Transitioning to a zero emissions world requires an understanding that humans and nature are an inter-connected and interdependent system. The complexity with which this system changes can be made more comprehensible through the use of Geodesign tools currently available on the market. GIS is widely used in different disciplines but few examples have been discovered where the technology is used to implement zero emission targets. ArcGIS is a powerful tool for supporting the integrated design of built and natural environments. Complex data can be customized, directly quantified and displayed in an easy to understand format, across different scales from regional to local. The technology can be used to document progress and monitor the implementation of the RSD strategies by developing public platforms showing real-time web maps and/or 3D scenes.

The Geodesign methodology developed in this study shows the potential for an effective mapping of the existing situation in Byron Shire, monitoring towards its future zero emission targets and...
identifying opportunities for net positive contributions to the region and community. The present investigations address zero operational carbon in buildings only; however this can be extended to a full life cycle approach and monitoring the transition in the other ZEB sectors Energy, Transport, Land Use and Waste.

The usefulness of interactive Geodesign tools towards encouraging community participation during the design and implementation process can become essential to the success of ZEB. Stakeholder opinions and missing data can be collected and integrated to refine the RSD strategy. Qualitative as well as quantitative RSD parameters can be captured, depending on data availability, and the most suitable transition programs developed. This digital mapping for ZEB could inform existing projects within BSC and policy. Other councils and LGAs with similar aspirations as Byron shire could also benefit from the application of Geodesign to monitor regenerative and net positive development.

6. Acknowledgements

This research is conducted as part of the requirements of a PhD candidature of Amrita Kambo who is supported by a WRE scholarship from QUT. The first author is extremely grateful for the immense support and guidance that has come from the supervisory team. Gratitude is expressed towards ZEB and BZE for providing a research context.

7. References


HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.


Leary, Paul. 2016. Personal communication regarding Geoscape data for regional NSW.


HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.


8. Endnotes

Both authors are members of the Zero Emissions Byron (ZEB) Buildings Group. The co-author is a representative of this group.
9. Appendix

![Figure 4: Case Study Site – Energy Systems – Existing Situation](image.png)
Figure 5: Case Study Site - Proximal Carbon Sinks
Analysis on Design Data of Low Energy Housing in Japan

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Abstract

Purpose / Context – In order to achieve low energy housing, it is important to quantitatively and comprehensively determine the effectiveness of energy saving technologies and to evaluate the energy conservation performance of an entire house. Low Energy Housing with Validated Effectiveness (LEHVE) is one of the measures for home energy saving in Japan. The evaluation procedure of LEHVE can quantitatively show the energy saving effect of each technology, such as insulation and equipment, and total energy consumption of a house in the design phase. The LEHVE’s evaluation procedure is not mandatory, however it is widely used in Japan and its outcome has developed into Japan’s Energy Saving Standard.

Methodology / Approach – Design data of newly-built houses are investigated using the LEHVE’s evaluation procedure to evaluate the energy conservation performance in both mild climate region and hot humid climate region in Shikoku island, Japan. The present situation of energy conservation performance of newly built housing is analysed using the obtained data of the both regions. In the analysis, energy consumption, energy reduction rates and adoption rates of elemental technologies, such as natural energy application technology, heat control technology of building envelopes and energy-efficient equipment technology, have been yielded.

Results – 370 cases of design data of newly built timber houses in Japan, which were obtained between FY 2013 and FY 2015, have been analysed based on the LEHVE’s evaluation procedure. 265 cases of design data were obtained in mild climate region and 105 cases were obtained in hot humid climate region. As the analysis results, it is suggested that the energy conservation performance of the newly built houses has been improved year by year in the both regions.

Key Findings / Implications – The energy conservation performance of the newly built houses in both mild climate region and hot humid climate region has been improved year by year. However, some natural energy application technologies, such as wind utilisation or daylight utilisation, have not been widely adopted in the houses even though the both regions have suitable climates for use of natural energy.

Originality – Energy conservation performance of housing can be estimated by using the LEHVE’s evaluation procedure. 370 cases of the latest design data of newly built housing have been obtained in Shikoku island where only dozens of data had been available by previous studies.
Keywords – Low energy housing, Primary energy consumption, Energy conservation performance, Energy saving technology

1. Introduction

Efforts to prevent global warming are important issues internationally. In Japan, carbon dioxide emissions have been increasing especially in the household sector (Agency for Natural Resources and Energy, 2015). In order to reduce energy consumption of housing, various measures have been conducted such as developing the Japan’s Energy Saving Standard for newly built housing. Analysing the specific energy consumption of housing is essential to take energy-saving measures. The Low Energy Housing with Validated Effectiveness (LEHVE) is one of the measures for evaluating energy consumption of housing. LEHVE is defined as “housing that uses much natural energy as possible according to the way of living and housing site conditions, such as climate and site characteristics, while increasing the standards of liveability and convenience by carefully designing and selecting buildings, equipment and appliances. Thereby such housing is able to reduce energy consumption during occupancy by up to 50% compared to housing that was common around 2000, and it will be able to be put to practical use by 2010” (Building Research Institute, 2010). The LEHVE’s evaluation procedure is not mandatory, however it has been widely used by engineers in Japan and its outcome has developed into Japan’s Energy Saving Standard and the International Standard (ISO 13153, 2012).

There are loads of researches about housing’s energy consumption by measurement surveys and questionnaire surveys in Japan (Hasegawa and Inoue, 2004; Inoue, Mizutani and Tanaka, 2006; Murakami et al., 2006). However, most of these research works have not investigated the energy consumption of each energy use, such as heating, cooling, ventilation and so on, but just the total energy consumption of a house. Because it is not easy to estimate the energy consumption of the each energy use simultaneously with considering structures, areas of housing, lifestyles and family structures. Therefore, the LEHVE’s evaluation procedure, which is conducted by fixing some conditions such as living conditions of family and attributes of a house itself, is useful.

Statistical analyses of home energy consumption are important to better understand present situations of the energy conservation performance of housing. In this study, an investigation for design data of newly built housing has been conducted for three years.

2. Method

2.1 LEHVE’s evaluation procedure

Design guidelines for LEHVE are published targeting three climate regions, which are cold climate region, mild climate region and hot humid climate region (National Institute for Land and Infrastructure Management, Building Research Institute and IBEC, 2010; 2012). The target regions of this study are mild climate region and hot humid climate region in Sikoku island (Shown in Figure 1). The evaluation procedure of LEHVE can quantitatively show energy saving effect of each technology, such as insulation and equipment. In this evaluation procedure, 13 elemental technologies (shown in Table 1) are evaluated: five types of “natural energy application technology” which are use and control of wind, daylight utilisation, photovoltaic power generation, solar radiation heat utilisation and solar water heating; two types of “heat control technology of building envelopes” which are insulated building envelope planning and solar shading method; and six types of “energy-efficient equipment technology” which are heating and cooling system planning, ventilation system planning, domestic hot water system planning, lighting system planning, introduction of high-efficiency consumer electronics and treatment and efficient use of water and kitchen waste. Most of the evaluations on energy saving effect are conducted by using a model house plan established under certain given conditions, such as a permanent condition of an approximately 120...
Kawata, K Analysis on design data of low energy housing in Japan

m² wooden house plan (shown in Figure 2) and living conditions for a family which consist of a 

husband and a wife with two children.

In the evaluation, numerical values indicating energy saving effect are presented in the form of 

“energy consumption ratio”. The higher number of level means that higher energy saving effects 

can be achieved. Quick references for the energy consumption ratio of each elemental technology 

type for mild climate region and hot humid climate region are shown in Table 2 and 3. The refer-

ence values (Level 0) are set based on common design details of wooden house for family of four 

as typical primary energy consumption at 2000 in each region. The resent Energy Saving Stan-

dard levels are include in some elemental technologies, for example, level 3 technology of the 

insulated building envelope planning is same as the level of the Energy Saving Standard.

The design value of primary energy consumption is calculated by multiplying reference values and 

the energy consumption ratio for adopted technologies in each energy use, which are heating, 

cooling, ventilation, domestic hot water, lighting and home electronics. The total value of annual 

primary energy consumption is given by totalling up the each calculated value of the every use.

As for photovoltaic power generation, the total design value of home energy consumption includ-

ing P.V.’s effect is calculated by subtracting the annual primary energy consumption reduction 

based on the capacity of solar cells from the total annual primary energy consumption of the other 

use.

Table 1 List of elemental technogies

<table>
<thead>
<tr>
<th>Elemental technology</th>
<th>Use of energy to be reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural energy applied technology</td>
<td></td>
</tr>
<tr>
<td>Daylight utilisation</td>
<td>Lighting</td>
</tr>
<tr>
<td>Photovoltaic power generation</td>
<td>Electricity</td>
</tr>
<tr>
<td>Solar hot water heating</td>
<td>Domestic hot water</td>
</tr>
<tr>
<td>Solar radiation heat utilisation</td>
<td>Heating</td>
</tr>
<tr>
<td>Insulated building envelope planning</td>
<td>Solar shading method</td>
</tr>
<tr>
<td>Solar water heating</td>
<td>Domestic hot water</td>
</tr>
<tr>
<td>Heat control technology of building envelopes</td>
<td></td>
</tr>
<tr>
<td>Heating and cooling system planning</td>
<td>Cooling / Heating</td>
</tr>
<tr>
<td>Ventilation system planning</td>
<td>Ventilation</td>
</tr>
<tr>
<td>Domestic hot water system planning</td>
<td>Domestic hot water</td>
</tr>
<tr>
<td>Lighting system planning</td>
<td>Lighting</td>
</tr>
<tr>
<td>Introduction of high-efficiency consumer electronics</td>
<td></td>
</tr>
<tr>
<td>Treatment and efficient use of water and kitchen waste</td>
<td></td>
</tr>
</tbody>
</table>

As for photovoltaic power generation, the total design value of home energy consumption includ-

ing P.V.’s effect is calculated by subtracting the annual primary energy consumption reduction 

based on the capacity of solar cells from the total annual primary energy consumption of the other 

use.
Table 2 Quick reference for energy consumption ratio of elemental technology level (for mild climate region / in the case of partial intermittent heating and cooling)

<table>
<thead>
<tr>
<th>Use</th>
<th>Reference energy consumption</th>
<th>Elemental technology</th>
<th>Energy consumption ratio (reference consumption is 1.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Insulated building envelope planning</td>
<td>1.0 0.8 0.65 0.55 0.45</td>
</tr>
<tr>
<td>Heating</td>
<td>12.7GJ</td>
<td>Solar radiation heat utilisation</td>
<td>1.0 0.95 0.9 0.8 0.6</td>
</tr>
<tr>
<td>Heating</td>
<td></td>
<td>Heating system planning</td>
<td>1.0 0.8 0.7 0.6</td>
</tr>
<tr>
<td></td>
<td>Solar shading method</td>
<td>1.0 0.85 0.7 0.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling</td>
<td>1.0 0.8 0.7 0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind utilisation/control</td>
<td>1.0 0.9 0.8 0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling system planning</td>
<td>1.0 0.8 0.7 0.6</td>
<td></td>
</tr>
<tr>
<td>Ventilation</td>
<td>4.7GJ</td>
<td>Ventilation system planning</td>
<td>1.0 0.7 0.6 0.4</td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>24.5GJ</td>
<td>Domestic hot water system planning</td>
<td>1.0 0.9 0.8 0.7 0.5</td>
</tr>
<tr>
<td>Lighting</td>
<td>10.6GJ</td>
<td>Daylight utilisation</td>
<td>1.0 0.98 0.95 0.9</td>
</tr>
<tr>
<td></td>
<td>Lighting system planning</td>
<td>1.0 0.7 0.6 0.5</td>
<td></td>
</tr>
<tr>
<td>Consumer electronics</td>
<td>23.5GJ</td>
<td>Introduction of high-efficiency consumer electronics</td>
<td>1.0 0.8 0.6</td>
</tr>
<tr>
<td>Cooking</td>
<td>3.9GJ</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>82.3GJ</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

In regard to energy consumption in “cooking”, since there are no significant differences among devices, only reference energy consumption is set. “Treatment and efficient use of water and kitchen waste” is not included in this table.

Table 3 Quick reference for energy consumption ratio of elemental technology level (for hot humid climate region / in the case of partial intermittent heating and cooling)

<table>
<thead>
<tr>
<th>Use</th>
<th>Reference energy consumption</th>
<th>Elemental technology</th>
<th>Energy consumption ratio (reference consumption is 1.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Insulated building envelope planning</td>
<td>1.0 0.8 0.5 0.45</td>
</tr>
<tr>
<td>Heating</td>
<td>5.7GJ</td>
<td>Solar radiation heat utilisation</td>
<td>1.0 0.95 0.8 0.6</td>
</tr>
<tr>
<td>Heating</td>
<td></td>
<td>Heating system planning</td>
<td>1.0 0.95 0.85 0.75 0.7</td>
</tr>
<tr>
<td></td>
<td>Solar shading method</td>
<td>1.0 0.95 0.75 0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling</td>
<td>1.0 0.95 0.85 0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wind utilisation/control</td>
<td>1.0 0.95 0.88 0.82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling system planning</td>
<td>1.0 0.95 0.85 0.75</td>
<td></td>
</tr>
<tr>
<td>Ventilation</td>
<td>1.0GJ</td>
<td>Ventilation system planning</td>
<td>1.0 0.9 0.5 0.3</td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>19.2GJ</td>
<td>Domestic hot water system planning</td>
<td>1.0 0.9 0.7 0.5 0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating system planning</td>
<td>1.0 0.9 0.8 0.7</td>
</tr>
<tr>
<td>Lighting</td>
<td>11.3GJ</td>
<td>Daylight utilisation</td>
<td>1.0 0.98 0.95 0.9</td>
</tr>
<tr>
<td></td>
<td>Lighting system planning</td>
<td>1.0 0.7 0.6 0.5</td>
<td></td>
</tr>
<tr>
<td>Consumer electronics</td>
<td>19.9GJ</td>
<td>Introduction of high-efficiency consumer electronics</td>
<td>1.0 0.8 0.6</td>
</tr>
<tr>
<td>Cooking</td>
<td>4.4GJ</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>66.5GJ</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

In regard to energy consumption in “cooking”, since there are no significant differences among devices, only reference energy consumption is set. “Treatment and efficient use of water and kitchen waste” is not included in this table.
2.2 Outline of investigation on housing’s design data

In the investigation, design data of newly built housing in mild climate region and hot humid climate region are obtained at Shikoku island via home builders from FY 2013 to FY 2015. The design data include lists of adopted elemental technologies based on the LEHVE’s evaluation procedure and other design data such as various drawings, building materials’ specifications and facilities’ specifications.

Annual primary energy consumption and energy reduction rates to the total reference value are calculated using the LEHVE’s evaluation procedure by analysing the obtained data. Moreover, in order to grasp average adopted technologies in each region, adaption rates of the levels of each elemental technology are investigated. Furthermore, yearly changes of energy conservation performance of newly build housing have been analysed using the “average plan”. The average plan is defined as a house employing elemental technology levels with the highest adoption rates.

3. Results and Discussion

In the investigation, 370 cases of design data of newly built timber houses in Japan are obtained for three years from FY 2013 to FY 2015. 265 cases are obtained in mild climate region and 105 cases are obtained in hot humid climate region (shown in Table 4). The figure in parentheses indicates the adoption number of photovoltaic power generation as an included number. All of the obtained data are just adopted partial intermittent heating and cooling use.

As shown in Table 2 and Table 3, each elemental technology have energy conservation target levels. The higher number of level shows the higher energy saving effects can be achieved.

<table>
<thead>
<tr>
<th>Table 4 The number of obtained data by year</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY 2013</td>
</tr>
<tr>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>Mild climate region</td>
</tr>
<tr>
<td>106 cases (36 cases)</td>
</tr>
<tr>
<td>91 cases (31 cases)</td>
</tr>
<tr>
<td>68 cases (32 cases)</td>
</tr>
<tr>
<td>265 cases (99 cases)</td>
</tr>
<tr>
<td>Hot humid region</td>
</tr>
<tr>
<td>41 cases (2 cases)</td>
</tr>
<tr>
<td>40 cases (10 cases)</td>
</tr>
<tr>
<td>24 cases (4 cases)</td>
</tr>
<tr>
<td>105 cases (16 cases)</td>
</tr>
</tbody>
</table>

2.3 Adopted technologies and energy consumption in mild climate region

2.3.1 Level of adopted technologies

Adoption rates of each Elemental technology level have been found by analysing all of the obtained data in mild climate region over three years, shown in Table 5. The darker collar cell represents higher adoption rates. The results are indicated for each category of elemental technologies.

(1) Natural energy application technology

Wind utilisation and control technology is popular as over 70% of the houses have adopted the level 1 or higher level technologies. Daylight utilisation is also popular. Solar radiation heat utilisation technology is not widely popular but 66% of the houses are achieving level 2 or higher level technologies considering improvements in the thermal performance of windows. Photovoltaic power generation system is installed in 37% of the houses.
(2) Heat control technology of building envelopes
In insulated building envelope planning technology, almost all the house have adopted level 3 or higher level of insulation which is equivalent to the latest Energy Saving Standard in Japan. From the view point of solar shading, 63% of the houses have level 2 technologies which is equivalent to the latest Standard and remaining houses have higher level’s solar shading technologies.

(3) Energy-efficient equipment technology
96% of the heating equipment has consisted of air conditioners. Focusing on the cooling data, 37% of the houses have adopted a low efficiency air conditioner with coefficient of performance (COP) of less than 4.0, and 19% of the houses have high efficiency equipment with a COP of 6.0 or higher. 61% of ventilation systems are level 1 and most of them are through-the-wall ventilation systems optimising the combination of a fan and an outside air unit (exhaust-only). 88% of water heaters are installing electric water heaters with natural refrigerant heat pomp (CO2 HP water heaters) or latent heat recovery water heaters as level 2 technologies. 68% of the houses have installed high-frequency lamps. However 32% of the houses have installed not high-frequency lamps but incandescent lamps. From the view point of consumer electronics, over 90% of the houses are equipped with energy efficient products that use low standby power.

Table 5 Adoption rate of elemental technology level (for mild climate region / three-year totals)

<table>
<thead>
<tr>
<th>Use</th>
<th>Reference energy consumption</th>
<th>Elemental technology</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>12.7GJ</td>
<td>Insulated building envelope planning</td>
<td>0%</td>
<td>1%</td>
<td>0%</td>
<td>87%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solar radiation heat utilisation</td>
<td>32%</td>
<td>2%</td>
<td>43%</td>
<td>21%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heating system planning</td>
<td>31%</td>
<td>32%</td>
<td>18%</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>Cooling</td>
<td>2.4GJ</td>
<td>Wind utilisation/control</td>
<td>27%</td>
<td>46%</td>
<td>23%</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Solar shading method</td>
<td>0%</td>
<td>0%</td>
<td>63%</td>
<td>37%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cooling system planning</td>
<td>37%</td>
<td>28%</td>
<td>16%</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>Ventilation</td>
<td>4.7GJ</td>
<td>Ventilation system planning</td>
<td>19%</td>
<td>61%</td>
<td>18%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>24.5GJ</td>
<td>Domestic hot water system planning</td>
<td>3%</td>
<td>6%</td>
<td>68%</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Lighting</td>
<td>10.6GJ</td>
<td>Daylight utilisation</td>
<td>26%</td>
<td>25%</td>
<td>26%</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lighting system planning</td>
<td>32%</td>
<td>34%</td>
<td>20%</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>Consumer electronics</td>
<td>23.5GJ</td>
<td>Introduction of high-efficiency</td>
<td>6%</td>
<td>15%</td>
<td>79%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooking</td>
<td>3.9GJ</td>
<td>consumer electronics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>82.3GJ</td>
<td>Electricity</td>
<td>63%</td>
<td>7%</td>
<td>30%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3.2 Annual primary energy consumption and energy reduction rate

The energy reduction rate of newly built houses for each year from FY 2013 to FY 2015 in mild climate region is shown in Figure 3. In this figure, two types of energy reduction rates are indicated. One is including P.V.’s effect and another one is not including P.V.’s effect. The number above the box plots indicates the mean value. The mean value of the energy reduction rate including P.V. of FY 2015 is 10.7 percentage points higher than the value of FY 2013 and is 8.9 percentage points higher than FY 2014’s value. Moreover, the mean value of energy reduction rate not including P.V. of FY 2015 is also higher than the previous years. As the results, the energy conservation performance of newly built houses has been improved year by year.

The levels of adopted elemental technologies and the primary energy consumption of the average plan for each year are shown in Figure 4. The grey parts in the radar chart indicate the level of adopted technologies. The levels of some natural energy application technologies such as solar radiation heat utilisation and daylight utilisation have been improved. The levels of Heating, cooling and lighting system planning technologies have been also improved. In FY 2015, the annual primary energy consumption is 4.8 GJ less than the value of FY 2013 and the energy reduction rate is 5.7 percentage points higher than the value of FY 2013.
2.4 Adopted technologies and energy consumption in hot humid climate region

2.4.1 Level of adopted technologies

Adoption rates of each Elemental technology level have been found by analysing all of the obtained data in hot humid climate region over three years, shown in Table 6.

(1) Natural energy application technology
Solar radiation heat utilisation technology is not popular as 54% of the houses have not adopted any technologies. Regarding to the wind utilisation and control technology, 52% of the houses have adopted level 2 and higher level technologies, however 40% of the houses have not adopted any technologies. The highest level of daylight utilisation technology has been adopted in 22% of the houses; however, 44% of the houses have not adopted any daylight utilisation technologies. Only 4% of the houses have adopted solar water heating technologies. Furthermore, Photovoltaic power generation systems have been adopted in only 15% of the houses. In hot humid climate region, natural energy application technologies have not been adopted widely even though there are high possibilities of energy reduction using the natural energy.

(2) Heat control technology of building envelopes
In insulated building envelope planning, 90% of the houses adopted the level 3 technology which is equivalent to the latest Energy Saving Standard and remaining houses have the higher level...
technologies. From the view point of solar shading method technology, all of the houses have the solar shading performance above the latest Energy Saving Standard’s level. Moreover 53% of the houses adopted the highest level of solar shading technologies.

(3) Energy-efficient equipment technology
All of the heating and cooling equipment have consisted of an air conditioner. Focusing on the heating data, 82% of the houses have adopted the level 2 or higher level technologies, which have been installed the systems with a COP of 4.0 or higher and considered about an adjustment of device capacities. 89% of ventilation systems are exhaust-only use and 58% of houses have not adopted any elemental technologies. In hot water system planning, 84% of the houses have adopted water heaters of level 3 technology, which are mostly CO2HP water heaters. In hot humid climate region, the adoption rate of level 1 or higher level technologies in lighting system planning is 89% which is higher than the value of mild climate region. From the view point of consumer electronics, 96% of the houses have adopted energy efficient products.

Table 6 Adoption rate of elemental technology level
(for hot humid climate region / three-year totals)

<table>
<thead>
<tr>
<th>Use</th>
<th>Reference energy consumption</th>
<th>Elemental technology level</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>5.7GJ</td>
<td>Insulated building envelope planning</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Solar radiation heat utilisation</td>
<td>54%</td>
<td>1%</td>
<td>29%</td>
<td>14%</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heating system planning</td>
<td>18%</td>
<td>25%</td>
<td>11%</td>
<td>18%</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>Cooling</td>
<td>5.0GJ</td>
<td>Wind utilisation/control</td>
<td>40%</td>
<td>10%</td>
<td>41%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solar shading method</td>
<td>0%</td>
<td>0%</td>
<td>47%</td>
<td>53%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling system planning</td>
<td>13%</td>
<td>5%</td>
<td>45%</td>
<td>37%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Ventilation</td>
<td>1.0GJ</td>
<td>Ventilation system planning</td>
<td>58%</td>
<td>31%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>19.2GJ</td>
<td>Domestic hot water system planning</td>
<td>5%</td>
<td>6%</td>
<td>6%</td>
<td>63%</td>
<td>21%</td>
</tr>
<tr>
<td>Lighting</td>
<td>11.3GJ</td>
<td>Daylight utilisation</td>
<td>41%</td>
<td>27%</td>
<td>10%</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lighting system planning</td>
<td>11%</td>
<td>57%</td>
<td>19%</td>
<td>12%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumer electronics</td>
<td>19.9GJ</td>
<td>Introduction of high-efficiency consumer electronics</td>
<td>3%</td>
<td>23%</td>
<td>74%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooking</td>
<td>4.4GJ</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>66.5GJ</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use</th>
<th>Reference energy consumption</th>
<th>Elemental technology level</th>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>—</td>
<td>Photovoltaic power generation</td>
<td>85%</td>
<td>3%</td>
<td>12%</td>
<td></td>
</tr>
</tbody>
</table>

2.4.2 Annual primary energy consumption and energy reduction rate
The energy reduction rate of newly built houses for each year from FY 2013 to FY 2015 in hot humid climate region is shown in Figure 5. In this figure, two types of energy reduction rates are indicated. One is including P.V.’s effect and another one is not including P.V.’s effect. The number above the box plots indicates the mean value. The mean value of energy reduction rate including P.V. of FY 2015 is 12.9 percentage points higher than the value of FY 2013. Though it is 2.0 percentage points lower than the FY 2014’s value, the mean value of energy reduction rates not including P.V. in FY 2015 is higher than the value of the previous years.

The levels of adopted elemental technologies and the primary energy consumption of the average plan for each year are shown in Figure 6. The grey parts in the radar chart indicate the level of adopted technologies. Comparing the technology levels for each year, technology levels of solar radiation heat utilisation and daylight utilisation have decreased from FY 2013 to FY 2015. On the other hand, the levels of heating system planning technologies have been improved to the highest level in FY 2015. Therefore, in FY 2015, the annual primary energy consumption is 4.0 GJ less than the value of FY 2013 and the energy reduction rate is 6.0 percentage points higher than the value of FY 2013.
4. Conclusion

In this study, the investigation of newly built housing’s design data have been conducted for the purpose of evaluating the energy conservation performance from FY 2013 to FY 2015. Totally 370 cases of design data of newly built timber houses have been obtained in Japan. 265 cases of design data have been obtained in mild climate region and 105 cases have been obtained in hot humid climate region. The obtained data have been analysed based on the LEHVE’s evaluation procedure. In the analysis, energy consumption, energy reduction rates and adoption rates of elemental technologies, such as natural energy application technology, heat control technology of building envelopes and energy-efficient equipment technology have been estimated. Furthermore, Adaption rates of the levels of each elemental technology have been investigated. Yearly changes of energy conservation performance of newly build housing have been analysed using the “average plan”. The average plan is defined as a house employing elemental technology levels with the highest adoption rates.

As the results, the levels of adopted technologies have been generally improved yearly. Moreover, from the comparison results of energy reduction rates of each year, it is indicated that the energy conservation performance of the newly built houses have been improved year by year in both target regions. In most of the houses, the performance of insulation and solar shading has been better than or equal to the performance required by the latest Japan’s Energy Saving Standard. Regarding to energy-efficient equipment technologies, it can be considered a sort of energy conservation levels. However, there are certain possibilities of improvement for energy conservation.
of some technologies such as the heating, cooling and lighting systems planning. On the other hand, especially in hot humid climate region, the adoption rates of solar radiation heat utilisation technologies and photovoltaic power generation technologies are low even though there are high potentials of utilising solar radiation. In addition, wind utilisation technologies have not been employed generally. Therefore, Natural energy application technologies are recommended to be adopted more widely in newly built housing in Shikoku Island, Japan.

5. References


ISO 13153 (2012): Framework of the design process for energy-saving single-family residential and small commercial buildings


This Subtropical Life: Are New Apartment Buildings Providing Locally-Appropriate Outcomes for Apartment Living in Brisbane?

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Australia
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Abstract

Purpose / Context. The purpose of this paper is to present data and discussion on a critical review of a sample of multi-storey and mixed use residential buildings in the subtropical city of Brisbane in order to understand how contemporary buildings are achieving local authority policy outcomes and resident-identified attributes of locally-appropriate subtropical living.

Methodology / Approach. This research used the Brisbane City Council’s Multiple Dwelling Code’s Acceptable Outcomes in four performance criteria to objectively measure the performance of a sample of 15 contemporary MSRB from five to thirty storeys approved post-2011. A landmark building, Torbreck, completed in 1961 was also analysed. Development-Approved documents (architectural drawings) were accessed from the Council’s online system for planning applications, and a content analysis was conducted.

Results. Few cases demonstrate Code compliance on all issues, though smaller developments performed better than large scale projects. Some generalisations were derived in terms of emerging trends: cross-ventilation is unsupported by generic centre-core spatial configurations; facades are extensively glazed regardless of solar orientation; external shading strategies are unsophisticated and private outdoor space is extremely limited.

Key Findings / Implications. Socially, the poor performance of large scale buildings means that more people have less choice in controlling comfort and energy use in their private dwellings. The paper recommends reviewing the Multiple Dwelling Code and its role in the regulatory environment in order to strengthen policy outcomes.

Originality. This research is the first to analyse Development Approval data against measurable metrics of a local government planning code aimed at liveability.

Keywords multi-storey and mixed-use apartment buildings, natural ventilation, air-conditioning, subtropical, multiple dwelling code
1. Introduction

Residents of Brisbane’s multi-storey residential buildings have expressed a preference for natural ventilation rather than air-conditioning and they desire autonomy regarding control over indoor climate comfort and noise (Rosemary Kennedy, Buys, & Miller, 2015). They also desire privacy and acceptable outdoor space for everyday home-based activities. The multi-storey residential and mixed-use buildings (MSRBs) housing type in subtropical Brisbane is developing in response to demographic change and urban consolidation planning policies that are aimed at reducing greenhouse gas emissions. The problem is that these buildings may not be providing residents with locally-appropriate outcomes in their individual dwellings.

The Multiple Dwelling Code - Brisbane City Council Planning Scheme ePlan, City Plan 2014, Section 9.3.14 (MDC) seeks to align built outcomes with residents’ expectations for quality residential environments and policy-makers’ sustainability objectives. The MDC pays particular attention to key socio-environmental factors that provide important amenity for both residents and adjoining neighbours of multiple-dwelling developments (such as thermal comfort, air movement, acoustics, daylighting, visual and aural privacy, outdoor private space, and maximising opportunities to capitalise on the subtropical climate).

The purpose of this paper is to present data and discussion on a critical review of a sample of current multi-storey and mixed use residential buildings (MSRBs) both completed and planned (that is, Development Approval in place) in order to understand how contemporary buildings are performing in terms of achieving local authority policy outcomes for locally-appropriate subtropical living. The study focused on the physical attributes of MSRBs that are likely to affect occupants’ experiences of thermal comfort and privacy in their dwellings as part of the larger residential and neighbourhood environment.

2. Background

2.1 Brisbane’s climate

The prevalent desire for natural ventilation and outdoor living in Brisbane is not surprising given the city’s macroclimatic subtropical conditions. Temperature conditions generally fall within a range most people find comfortable: summer air temperature averages 19° to 29° C; winter averages are 9° to 21° C. Mean monthly Relative Humidity ranges from 60% - 71% throughout the year. The effect of humidity on human comfort is most noticeable when air movement is low and air temperature is high. However, extremes are rare and on average, the region experiences one Degree Day over 35°C annually (Bureau of Meteorology, 1989).

In Australia, 42% of total energy consumption in residential buildings is for heating and cooling systems (Pears, 2005). In theory, in Brisbane’s mild subtropical climate, where ambient outdoor temperatures are within a comfortable range for much of the year (Hyde, 2000; Miller, Kennedy, & Loh, 2012) buildings can be designed to effectively respond to the climate without significant inputs of energy. Nevertheless, residents and designers of subtropical MSRBs are confronted with conundrums: for example, naturally ventilated dwellings in MSRBs may be subject to unacceptable levels of external noise and loss of acoustic privacy through external openings; on the other hand, air-conditioned dwellings with few effective openings could be perceived as lacking individual choice in control over both indoor comfort and household energy consumption for this purpose. Resident-identified preferences for climate control in their dwellings are linked to approaches to design for thermal comfort. Effective design for the National Construction Code Climate Zone 2 requires a hybrid or composite built response to both tropical humid conditions and cool temperate conditions.

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1 The extent of air movement on perception of temperature has been studied and the ANSI/ASHRAE Standard 55-2004: Thermal Environmental Conditions for Human Occupancy provides a standard guide to the air speed required to offset a temperature rise.
When formulating building principles that aim to minimise energy use for climate control, the interaction of factors that affect heat gain or loss are paramount (Givoni, 1998; Hui, 2001). Taking the structural approach, ‘passive’ strategies that regulate heat and air flow are: appropriate solar orientation; building form that supports effective natural ventilation; material thermal properties; and construction methods. Strategic placement of openings and external projections produce pressure differentials that induce air movement and, if adjustable, can regulate velocity of air movement. On the other hand, using the mechanical approach, only the façade regulates heat flow, in conjunction with ‘active’ technology such as air conditioning that compensates for lack of structural controls. Table 1 sums up the differences between structural and the mechanical approaches but realistically, the desired outcome may lie somewhere on a continuum from structural controls to mechanical controls.

Table 1 Indoor climate control for thermal comfort

<table>
<thead>
<tr>
<th>Structural approach</th>
<th>Mechanical approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural Passive strategies</td>
<td>Technological Active strategies</td>
</tr>
<tr>
<td>Passive orientation, building form and materials</td>
<td>High air-conditioning loads</td>
</tr>
<tr>
<td>Climate-interactive</td>
<td>Climate-defensive</td>
</tr>
<tr>
<td>Occupant interaction</td>
<td>Limited occupant choice</td>
</tr>
<tr>
<td>Discretionary control</td>
<td>No interaction /automatic</td>
</tr>
<tr>
<td>Active choice - behavioural</td>
<td>Passive behaviour</td>
</tr>
<tr>
<td>Occasional energy use</td>
<td>Continuous energy use</td>
</tr>
<tr>
<td>Economical</td>
<td>Energy efficient</td>
</tr>
<tr>
<td>Varying conditions</td>
<td>Monotonous conditions</td>
</tr>
</tbody>
</table>

2.2 The Multiple Dwelling Code - Brisbane City Council, City Plan 2014

The Multiple Dwelling Code (MDC) unequivocally links the city’s character and identity, and residents’ way of life, to the local subtropical climate and landscape. Table 2 shows the MDC’s assessable development performance outcomes (POs) most relevant to individual dwelling design in terms of factors connected to attributes that affect occupant control, views, access to cross ventilation, spaciousness, outdoor living and privacy. The acceptable outcomes (AOs) associated with these identify specific metrics which are suitable to form the basis of objective measurement and analysis of what the typical apartments are like to live in.
### Table 2 The MDC’s assessable development performance outcomes most relevant to individual dwelling design (Source: Brisbane City Council Planning Scheme Part 9.3.14 Multiple Dwelling Code, 2014)

<table>
<thead>
<tr>
<th>Performance Outcome</th>
<th>Acceptable Outcome Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO 20 Development includes buildings that exhibit subtropical design character and</td>
<td>1 of: Dual aspect / greater than 2.4m ceilings / Habitable rooms with 2 windows or openings;</td>
</tr>
<tr>
<td>sub tropical living</td>
<td>Weather and sun protected external doors and windows to habitable rooms;</td>
</tr>
<tr>
<td></td>
<td>Sun-shading or deep recesses on North;</td>
</tr>
<tr>
<td></td>
<td>Sun-protection on West.</td>
</tr>
<tr>
<td>PO 28 Development must provide attractive and functional private open space for</td>
<td>12m² minimum balcony area</td>
</tr>
<tr>
<td>residents</td>
<td>3.0m minimum dimension</td>
</tr>
<tr>
<td>PO 29 Development provides a resident with functional outdoor living space that</td>
<td>Solar access (form, materials, orientation)</td>
</tr>
<tr>
<td>receives natural light but is shaded to protect the resident from direct sunlight</td>
<td></td>
</tr>
<tr>
<td>PO 36 Development provides screening and partial enclosure of balconies.</td>
<td>Screening or solid balustrades (form and materials, and orientation)</td>
</tr>
</tbody>
</table>

#### 3. Research methods and results

##### 3.1 Method

The research focused on a sample of multi-storey residential and mixed use buildings from five to 30 storeys in Brisbane’s medium and high-density zones. Buildings in the Central Business District covered by the City Centre Neighbourhood Plan were not within the scope. Building usage is primarily Class 2 (Apartments) under the National Construction Code (Building Code of Australia Volume 1) but may be multiple classifications, for example Hotel (Class 3), Commercial or Professional offices (Class 5), Retail (Class 6).

Firstly, multi-unit developments within scope were identified by searching and accessing documents on Brisbane City Council’s online system for planning and development applications, PD Online: http://www.brisbane.qld.gov.au/planning-building/planning-guidelines-tools/online-tools/pd-online-resources Post-2011 Building Completion references were identified. A sample of 15 projects was purposively selected to take into account characteristics such as various scales of development; variety of configurations (in plan and section); variety of localities and locations (to reflect various street character and volume of traffic). Data collected by this method included approved architectural drawings (plans, sections and elevations). In addition, the Torbreck Apartment building completed in 1960, situated at 182 Dornoch Terrace, Highgate Hill was selected as a benchmark case. This building is an AIA Significant building of the 20th Century and known for its liveability (Centre for Subtropical Design, 2006). The requisite drawings were accessed from a QUT Centre for Subtropical Design case study (2006). A range of spatio-structural case data and design-related variables were measured by conducting a content analysis of approved documents.
3.2 Limitations

The research was conducted as a desk-top study. Field observations to assess any differences between approved designs and built outcomes or to identify resident modifications were not undertaken (as construction had not necessarily been completed on all approved projects). The research does not include estimates of energy consumption and associated CO₂-equivalent emissions of various MSRB’s. Other important factors that affect heat gain or loss such as insulation, glazing type and frame type, colour of externals walls, cladding or glazing were not investigated in the scope of this study. Neither was glazing reviewed to calculate envelope R-Values, U-Values, shading co-efficients, conductance and light transmission – while important, these data were not available through the planning documentation source.

3.3 Results and Analysis

Table 3 summarises base building metrics of the sample. 16 cases include separate 21 buildings (four of the cases include multiple buildings). The total number of dwellings represented by the sample is 2199 and total predicted occupancy 3376 residents. The majority of dwellings are two-bedroom/two-bathroom types. One multi-tower case (ID14) accounts for 42% of total dwellings and more than one-third of total potential occupants in this sample; one-bedroom/one-bathroom type dwellings predominate in this case. Dwellings with three bedrooms or more are rare in the sample.

The sample provided little variety in terms of building form, spatial configuration or shape complexity. All cases, including the benchmark case, feature multi-floor towers with either basement or podium parking. Most comprise tall, free-standing towers of rectangular volume organized with dwellings clustered about a central lobby or internal double-loaded corridor (DL) and vertical access core. Overwhelmingly the sample represents repetitively stacked typical floor layouts that produce one-level living. Analysis of the Floor Area Ratios (FAR) of typical floor plates revealed that the smaller developments achieved the highest yield; while the lowest ratio of private-to shared use occurred in the largest tower in Case 15. Table 4 summarises the performance of the sample against the AO metrics of POs 20, 28, 29 and 30. Each of the AOs is discussed in the following sections.

3.3.1 PO 20 / AO Dual Aspect

When looking at the concept of ‘dual aspect’, the MDC is ambiguous in that it does not specify this to mean the potential for individual apartments within the building to be cross-ventilated, and could be interpreted as the overall building simply having aspects in two directions. The interpretation used in this analysis is ‘apartments have external openings on two sides, usually the ends’. Maximum building plan depth of 10m - 12m from one external facade to another is usually recommended. The sample was examined for typical floor plate configuration and dwelling configuration (deep or shallow; wide or narrow; single or dual orientation). An initial observation is that the vast majority of the sample features a central lobby or internal corridor and vertical access core as the primary spatial configuration. This strategy generally precludes cross-ventilation of dwellings. Some of the lower scale developments up to seven storeys feature edge cores (refer Table 3) that offer the structural potential for cross-ventilation, though it is seldom achieved.
Kennedy, R

This subtropical life: are new apartment buildings providing locally appropriate outcomes for apartment living in Brisbane?

Table 3 Summary of Case Study Building Characteristics

<table>
<thead>
<tr>
<th>ID</th>
<th>Locality</th>
<th>No of stores</th>
<th>Building Form (no of levels)</th>
<th>Spatial Configuration</th>
<th>Other uses</th>
<th>F-I-F height (m)</th>
<th>Typical Floor Area Ratio*</th>
<th>No of dwellings</th>
<th>No of Occupants **</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>W'gabba</td>
<td>5</td>
<td>Tower Basement carpark</td>
<td>Edge-core DL</td>
<td></td>
<td>3.0</td>
<td></td>
<td>19</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>St Lucia</td>
<td>5</td>
<td>Tower Gr Lev carpark</td>
<td>Edge-core DL</td>
<td></td>
<td>2.9</td>
<td></td>
<td>17</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>Windsor</td>
<td>5</td>
<td>Tower Gr Lev carpark</td>
<td>Edge-core DL</td>
<td></td>
<td>2.9</td>
<td></td>
<td>14</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>New Farm</td>
<td>5</td>
<td>2 Towers Basement carpark</td>
<td>DL=Double Loaded SL=Single Loaded</td>
<td>2.9</td>
<td>15.1</td>
<td>21</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Highgate Hill</td>
<td>5</td>
<td>Tower Basement carpark</td>
<td>Central Core Point access DL</td>
<td>2.9</td>
<td>17.1</td>
<td>20</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ltwyche</td>
<td>5</td>
<td>Tower Gr Lev carpark</td>
<td>Edge-core DL</td>
<td></td>
<td>2.7</td>
<td></td>
<td>16</td>
<td>27</td>
</tr>
<tr>
<td>7</td>
<td>Ltwyche</td>
<td>7</td>
<td>Tower Podium &amp; Basement carpark</td>
<td>Central Core Point access DL</td>
<td>2.7</td>
<td>9.1</td>
<td>18</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Kelvin Grove</td>
<td>7</td>
<td>Tower Basement carpark</td>
<td>Central-core DL</td>
<td>2.8</td>
<td>8.1</td>
<td>38</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sth Bris</td>
<td>7</td>
<td>Tower Gr Lev carpark</td>
<td>Edge-core Point access</td>
<td>2.8</td>
<td>14.1</td>
<td>17</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ind'pilly</td>
<td>7</td>
<td>Tower Gr Lev carpark</td>
<td>Edge-core DL</td>
<td></td>
<td>2.6</td>
<td></td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>11</td>
<td>Sth Bris</td>
<td>20</td>
<td>Tower Podium parking (6)</td>
<td>Central-core DL</td>
<td>GF restaurants</td>
<td>3.0</td>
<td>7.1</td>
<td>140</td>
<td>196</td>
</tr>
<tr>
<td>12</td>
<td>Sth Bris</td>
<td>10</td>
<td>Tower Basement parking</td>
<td>Central-core DL</td>
<td>GF tenancies</td>
<td>2.7</td>
<td>7.1</td>
<td>48</td>
<td>72</td>
</tr>
<tr>
<td>13</td>
<td>Sth Bris</td>
<td>15</td>
<td>Tower Basement parking</td>
<td>Central-core DL</td>
<td></td>
<td>3.0</td>
<td>7.1</td>
<td>135</td>
<td>197</td>
</tr>
<tr>
<td>14</td>
<td>Fort. Valley</td>
<td>30</td>
<td>3 Towers (25) above Podium (5) &amp; Basement parking</td>
<td>Central-core DL</td>
<td>2.9</td>
<td>10.1</td>
<td>352</td>
<td>517</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>West End</td>
<td>30</td>
<td>3 Towers (12, 27, 28) above Podium (5 and Various) &amp; Basement parking</td>
<td>Central-core DL</td>
<td>3.0</td>
<td>Podium lev 3-5</td>
<td>601</td>
<td>1012</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Highgate Hill</td>
<td>22</td>
<td>2 Towers Podium and Gr Lev parking</td>
<td>Central-core DL &amp; External-core SL</td>
<td>2.8</td>
<td>8.1</td>
<td>91</td>
<td>169</td>
<td></td>
</tr>
</tbody>
</table>

* Floor Area Ratio (FAR) of typical apartment floor plate (Net Saleable Area to Common Area)
**Occupancy rates calculated according to the **Green Star Multi Unit Residential V1 Green House Gas Emissions Guide GBCA 2009).
Table 4 Summary of case study building performance against the Multiple Dwelling Code parameters

<table>
<thead>
<tr>
<th>ID</th>
<th>PO 20</th>
<th>PO28</th>
<th>PO29</th>
<th>PO36</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dual Aspects</td>
<td>Ceiling &gt; 2.4 m</td>
<td>All habitable rooms have 2 external openings protected</td>
<td>North shading</td>
</tr>
<tr>
<td>1</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>2</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>3</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>4</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>5</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>partial</td>
</tr>
<tr>
<td>6</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>7</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>8</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>Y</td>
<td>partial</td>
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<tr>
<td>9</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>partial</td>
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<tr>
<td>10</td>
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<td>Y</td>
<td>partial</td>
</tr>
<tr>
<td>11</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>12</td>
<td>N&amp;Y</td>
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<tr>
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<td>Y</td>
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<td>Y</td>
</tr>
<tr>
<td>14</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>15</td>
<td>N&amp;Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>16</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

*Balustrade transparency used as a proxy for screening to private outdoor space

*Some POSs meets this requirement

All dwellings are cross-ventilated in only three cases including the benchmark Case 16. Several cases feature dwellings with openings on at least two external walls at 90° orientation. These make up the majority of dwellings in the smaller scale developments which typically include single-sided dwellings as well. Though double-orientation 90° apartments occupy the corners of rectangular floor plates, the majority of apartments in the larger developments are single-sided. Apart from Case 16 (Torbreck) most bathrooms and some kitchens in the sample are internalised and rely on artificial light and mechanical ventilation.

3.3.2 PO20 / AO Floor-to-ceiling > 2.4m for habitable rooms

Extrapolating for ceiling heights, from ‘finished floor’ information listed in Table 3, it is evident that all the cases meet this AO. This is to be expected as 2.4m is the minimum height for habitable rooms under the NCC regulations. The average ceiling height across the sample is 2.85m; the minimum is 2.4m (Case 10, 7 storeys at Indooroopilly); the maximum is 3.0m achieved by Cases 1, 11, 13, 15 (Various – 5, 20, 15 and 30 storeys). As the MDC is currently worded, this outcome is easily achievable and negates the requirement to achieve either dual aspect, or two openings to every room.
3.3.3 PO20 / AO Two openings to all habitable rooms

On the face of it, most cases meet this measure. However, ambiguity also surrounds this metric because it simply specifies that habitable rooms (defined under the NCC as living rooms and bedrooms) should have more than one opening and does not specify whether any or all openings should be to the exterior. Case 11 demonstrates a series of narrow and deep configurations that feature internalised bedrooms that have two openings; these lead to the adjoining living room and the bathroom respectively. Thus there is no direct access to external windows from these bedrooms. While it is prohibited to use bathrooms to ventilate an adjoining habitable room (ABCB, 2013) habitable rooms with no external openings are allowable under the ‘borrowed light and ventilation’ clauses of the NCC, providing that minimum opening areas to adjoining habitable rooms are met. Accepted methods of determining opening size requirements depend on area calculations but not on rates of airflow. As the MDC is currently worded, this AO is not strong in its support for achieving low-energy liveability through structural means.

3.3.4 PO20 / AO Weather and sun protected external doors and windows to habitable rooms.

Most cases feature overhead or side protection to external openings, though the efficacy of these awnings or screens may be questionable. Also, some but not all openings are protected in some cases. Many cases in the sample rely on the balcony of the unit above to provide weather protection to external openings below. Large towers deploy awning style windows, with regulated limited opening range to, ‘self-protect’.

3.3.5 PO20 / AO Sun-shading or deep recesses on North; Sun-protection on West.

Using the available architectural drawings, the following metrics were calculated to gain an understanding of external envelope materials and the need for solar protection.

- Glazing-To-Exterior wall ratio (WWR) – indicator of façade transparency (solar transmittance – light and heat) and proxy indicator for thermal mass in the façade.
- Openable area to glazing ratio – indicating how much of a glass façade is actually openable.

In terms of the actual material characteristics of external envelopes of the sample, the WWR ranged from 0.2 to 1.0 indicating 100% fully glazed external walls. Smaller scale buildings generally perform well in these parameters. However, the largest developments and largest buildings have the greatest extent of unshaded external glazing due to the use of curtain wall technology. It is possible that low-e high performance glass is specified in these cases, but this was not verified through document analysis. Deployment of glazing on external walls is irrespective of solar orientation. In other mid-range cases, shading controls are not extensive, regardless of exposure to the sun, and are often ‘clip on’ and thus somewhat easy to remove at any stage in the project procurement process, or over the life of the building. Again, many cases in the sample rely on the balcony edge of the unit above to provide shade to external walls below.

Case 16, Torbreck features maximum glazing and openings to the North, and more thermal mass to the long East and West elevations. External shading strategies are comprehensive. This case incorporates adjustable devices to take into account the changing path of the sun daily and seasonally as well as structural shade devices which are integrated elements of the design.

3.3.6 PO28 / AO Development must provide attractive and functional private open space for residents; 12m² minimum balcony area; 3.0m minimum dimension.

In terms of space and form, private outdoor living spaces varied quite widely. Very few dwellings in the sample had outdoor living spaces that exceeded 12m². In half the cases, the primary private outdoor space fell well below both the minimum required area, and the 3.0m minimum dimension. While the width of balconies varied across the cases, depths varied widely and many were extremely shallow including 460mm for one 45sqm one-bedroom type. The benchmark case, Tor-
Kennedy, R  This subtropical life: are new apartment buildings providing locally appropriate outcomes for apartment living in Brisbane?

breck (ID16) also features narrow balconies, especially T2, known as the Garden Block. These are full width to the apartments and approximately 1.1m deep.

3.3.7 PO 29 Development provides a resident with functional outdoor living space that receives natural light but is shaded to protect the resident from direct sunlight.

Even if an outdoor space meets minimum space requirements, the functionality of private outdoor living spaces is compromised if they are climatically uncomfortable due to direct sun, not enough sun, or glare. Generally the sample performed very badly on this AO with only 25% of cases having well-resolved designs that offered occupants usable, comfortable POS. Most cases incorporated glass balustrades that offered no sun protection and inhibited air flow to balconies.

3.3.8 PO 36 Development provides screening and partial enclosure of balconies.

The sample shows a distinct trend to the use of glass as the most common balustrade material on balconies. Clear glass is found on smaller scale buildings. Many examples do not feature partial enclosure or screening to enhance visual privacy, acoustic comfort or solar protection. The type of glass can make a difference to the level of privacy residents gain. For example, low-e glass in use on large buildings sometimes presents as dark and opaque unless in full sun, or at night, when objects and activities are clearly visible from the outside.

Lack of screening or inappropriate selection of materials can affect both residents and their neighbours when it comes to visual and acoustic privacy.

4. Discussion

The research has identified performance gaps between the MDC (planners’ performance expectations) and actual design of MSRBs. As the sample size is small and the review is not exhaustive, an inductive approach is used to develop generalisations from the set of criteria observed. Overall, the sample suggests that the design approach utilised in contemporary MSRBs in Brisbane is producing little diversity in terms of building configurations, spatial characteristics and basic floor layouts. The formula produces repetitive designs with internalised shared corridors, and stairwells. Few concessions to the subtropical climate and residents’ home-based lifestyle preferences are in evidence. As a result, MSRBs may not be providing residents with locally-appropriate outcomes in their individual dwellings.

The findings demonstrate that most multi-residential buildings need improved design to provide more locally-appropriate outcomes for high density living in Brisbane. A general observation is that the more ‘glamorous’ heavily-marketed large scale developments tend to perform less well than smaller scale buildings in providing opportunities for residents to choose how they moderate their environment and behaviour around comfort and energy use.

Table 5 summarises how contemporary MSRB in Brisbane are performing in terms of the structural approach to thermal comfort.
Table 5 Comparison between the structural approach emerging MSRB design trends in Brisbane (Source: Kennedy, 2016 unpublished)

<table>
<thead>
<tr>
<th>Structural (Architectural) approach</th>
<th>Emerging Trends</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive strategies</td>
<td>Active strategies for climate control; centralised or split-system air conditioning</td>
</tr>
<tr>
<td>Solar Orientation; Typical floor plate aspect ratio (L x W) maximises N/S orientation and minimises E/W exposure</td>
<td>Primary view takes precedence over solar orientation. Aspect ratio is determined by site dimensions.</td>
</tr>
<tr>
<td>High ceiling</td>
<td>Ceiling heights range from minimum legal (2.4m) to 3.0m</td>
</tr>
<tr>
<td>Cross-ventilation (wind-induced) Dwellings require openings on at least two sides</td>
<td>Compact vertical cores support mostly single-sided dwellings and some double-orientation 90° dwellings.</td>
</tr>
<tr>
<td>Greater extent of external walls with optimised fenestration</td>
<td>Extent of external walls available to individual dwellings is highly variable; does not prioritise optimal balance between openness, transparency, shading and thermal mass.</td>
</tr>
<tr>
<td>External shading of walls and openings</td>
<td>Unshaded glazing features extensively. External shading appears to be designed for aesthetic rather than liveability reasons. Lacks adjustability. Protection against heat and glare is left to resident to deal with internally.</td>
</tr>
<tr>
<td>Balance between thermal mass and façade transparency</td>
<td>High rate of façade transparency</td>
</tr>
<tr>
<td>Occupant interaction</td>
<td>Some interaction predicted</td>
</tr>
<tr>
<td>Wider range of conditions tolerable - temperature differential between indoors and outdoors less pronounced</td>
<td>Range of temperature differential between indoors and outdoors not assessed specifically.</td>
</tr>
</tbody>
</table>

BCC has established that ‘structural’ design approaches are suitable for multi-residential development Brisbane. But evidently, the current ‘passing standard’ is too low to achieve acceptable design to enhance the lived experience for Brisbane residents and neighbours (including surrounding community) with the result that ‘mechanical’ design approaches unsuitable for low-energy futures are dominating new construction. Utilising the mechanical approach makes it possible to create a greater number of separate dwellings on a typical floor plate by clustering them around a double-loaded corridor and air-conditioning the dwellings. Then, because the built form does not support cross-ventilation, air-conditioning is framed as essential technology for quality of life in Queensland’s humidity. Paradoxically, air-conditioning technology that internalises climate is also used to compensate for large expanses of external glazing. These types of developments also noticeably impact the community’s perceptions of the look and feel of the wider city fabric as well as the energy-density of inner-urban environments.

Climate-responsive architecture for MSRBs in the hybrid subtropical climate (Hollo, 1995) requires immediate attention with suitable hybrid design solutions (R Kennedy, 2010). Focussing solely on objective measures (such as thermal comfort) does not ensure good design and does not necessarily account for occupants’ overall well-being. However, it is notable that the benchmark Case 16 building architecture employs a full suite of structural controls including materials’ thermal properties, cross-ventilation, and orientation, and is one of the most successful high-rise apartment buildings in the country. The evidence presented in this paper seems to point to the need to reform the Multiple Dwelling Code and introduce regulatory mechanisms to give it more authority.

The analysis also found that some aspects of the MDC presented ambiguous acceptable outcomes. It will be important to remove these ambiguities to provide clear policy and regulatory direction. Around Australia, reducing the impact of speculative MSRB development on liveability is on the agenda of governments and peak bodies. However, these approaches (Hodyl, 2015; Vic Govt 2015; NSW Govt 2002, 2015) are mainly focussed on planning density controls and neither address sub-
tropical living specifically nor the root problems in the current system that result in generic design. Current practices are NCC-compliant yet are not meeting the spirit of the NCC which emphasises that correctly designed fundamental structural controls are essential to achieve the thermal performance of building envelopes, and to reduce the size and operating load of mechanical equipment need to air-condition a building. While structural controls are built in and remain in place for the life of the building, technological systems may be replaced many times over (ABCB, 2010). Essentially, this means that energy source is not a substitute for good design (Kennedy 2015). Even if powered by renewable energy rather than fossil fuels, a building that does not have fundamental architectural elements of design suitable to the climate, is not meeting the requirements of a well-designed building. In NSW, State Planning Policy has long supported sustainable residential apartment development. In Brisbane, there is a disconnect between local and state regulatory environment which curtails the efficacy of planning intent when it comes to requiring sustainable subtropical design for MSRBs. Future research will investigate:

- How can planning policy address spatial and volumetric configuration of a multi-residential/mixed use building to provide cross ventilation (and overall amenity)?
- How can planning policy address approaches to vertical circulation to aid cross ventilation (and overall amenity)?
- How can planning policy address materials and shading strategies to produce locally-appropriate outcomes?

5. Conclusion

This research has identified systemic problems of MSRB design in the subtropical city through critical design analysis based on measurable indicators derived from the Multiple Residential Code. The findings provide evidence and commentary on current application of the MDC and evidence that high-density residential buildings being developed are not delivering on BCC’s longer term sustainability and energy goals. This research lays the groundwork for developing more robust performance requirements for liveability in the subtropical city.

But what performance metrics might be appropriate and flexible enough to support positive innovation? At the same time, these metrics need to be robust enough to convince commercially motivated private sector developers that they can maximise financial returns and make a positive contribution to sustainable city form, and to Brisbane’s identity as a liveable subtropical city, into the future.

6. Acknowledgments

This research was conducted on behalf of the Independent Design Advisory Panel of the Brisbane City Council.

7. References


Design Decision-making towards Energy-efficiency Upgrades of Residential Building Façade Refurbishment

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Abstract

Due to the low-regulated but high energy consumption residential stock and the energy standards required in China, awareness has been raised that refurbishment of the existing residential buildings is the solution to upgrade energy-efficiency. Cities in Northern China, such as Beijing, Harbin, Shenyang and Dalian, have conducted residential refurbishment for years. However, the design of refurbishment is often problematic, resulting in the malpractice of monotonous forms and fuzzy performance. Regulations and standards that come mostly as energy-consumption requirements fail to guide specific design solutions and to address the diversity of individual projects. The applied retrofit methods can be only measured at the end of retrofitting construction process, with little indication for design. Therefore, this paper aims at a design decision-making approach to address detailed design strategies and support energy-efficiency refurbishment of residential buildings. Based on itemising residential building façade components, collecting existing façade constructional information, and compiling green design strategies on façade system, the energy performance of each green design strategy is evaluated. Integrated design strategies, in accordance with the evaluated results, are proposed. Then those integrated strategies are systematically assessed with computer simulations and physical model testing for optimisation and informed choices. This approach can provide integrated green design strategies that quantify the impact of residential building façade components refurbishment, as well as decision-making information towards energy-efficiency upgrade for designers and related groups, such as contractors and home owners.

Keywords - residential building, green strategies, energy-efficiency, upgrade, refurbishment
1. Introduction

In the recent two decades, the level of urbanization in China has been raised along with the rapid development of urban residential building construction, and cities have retained enormous residential building stock. However, due to the rapid development, the existing residential building stock cannot meet the increased living requirements, and awareness has been raised that refurbishment of the existing residential buildings is the solution to improve living qualities. On one hand, refurbishment instead of demolition has advantages in economic, cultural, social, and environmental aspects, as well as holding a sense of belonging. On the other hand, there is a relatively large possibility to reduce energy consumption of existing residential buildings, due to the low energy conservation design standard, especially in the Northern China heating areas. Energy efficiency upgrade of existing residential buildings is of great significance.

During the "Twelve-Five" period of China, cities in Northern China heating areas, such as Beijing, Tianjin, Harbin, Shenyang, and Dalian, had conducted residential refurbishment for years and achieved phased progress. But according to the preliminary investigation on those refurbishments, problems still exist, as follows:

1. There is lack of basic database for existing residential buildings, leading to targeted strategies deficiency;
2. Regulations and standards that come mostly as constructional requirements fail to guide specific design solutions and address the diversity of individual projects;
3. The effect of the existing residential building refurbishments cannot be quantified, resulting in the malpractice of monotonous forms and fuzzy performance;
4. The design planning is overlooked in the early stage and the applied refurbishment methods can be only measured at the end of refurbishment construction process, with little indication for future design.

Based on previous research studies and a number of case studies, more than one third (36%) energy consumption can be reduced from early stages of design (Mario Cucinella Architects, 2016). Moreover, in the design of sustainable architecture, the most important strategies are strengthening the thermal performance of building envelopes and using passive strategies to reduce the basic energy consumption, shown as Figure 1 (Rodriguez, 2012; Xing, Hewitt & Griffiths, 2011).

![Figure 1: Costs and benefits of sustainable strategies (Rodriguez, 2012)]
Therefore, to solve the problems of refurbishing existing residential buildings in China, the direction of this research study is defined as using passive green building design strategies to improve energy efficiency in existing residential buildings. This study takes the existing residential buildings built in the 1980s and 1990s in Northern China heating areas as research objects, aiming at a design decision-making approach to address detailed design strategies and support energy-efficiency refurbishment of residential building facade.

2. Objectives

Based on the issues of existing residential building refurbishments and the aim of this study, the objectives of this research include:

1. To investigate and understand the classification and typification of existing residential buildings: In this study, the constituent elements of existing residential building facade in Northern China heating areas need to be classified and compiled. This classification and typification is beneficial to understand the complexity of the existing residential building conditions. It is also the theoretical basis to simplify the design process dealing with building envelope elements;
2. To select suitable passive design strategies: Appropriate passive design strategies are the basis for refurbishment design. The criteria of selecting appropriate passive design strategies rely on the full use of simulation and measurement technology;
3. To establish a scientific evaluation system: Comparative analysis and quantisation effects are the core standards and basis to evaluate selected passive design strategies. The integrated passive design strategies on each building envelope element are comprehensively evaluated, and then the optimal integrations of appropriate passive design strategies that can meet the targeted energy consumption are selected as means for refurbishment.

3. Theoretical Framework

A research framework represents the whole research process from the very beginning to the end. Base on a framework, a research study can be expended to detailed research contents and design approaches. According to the research objectives, the framework of this study can be shown as follows:

1. To investigate no less than 80 1980s-1990s typical existing residential building case studies in Northern China heating areas by large-scale data acquisition method. The gathered data of investigated case studies are used for the classification and typification of existing residential buildings;
2. To select appropriate passive design strategies. Passive design strategies are arranged to establish a database from which design strategies can be chosen for the final integrations;
3. To form an existing residential building refurbishment information model for each to be refurbished residential building. The information model is based on the classification and typification of existing residential buildings and passive design strategy database;
4. To calculate and quantify the energy consumption for heating and cooling of each to be refurbished residential building with integrations of passive design strategies by computer simulation and physical model testing;
5. To make an energy consumption target for each to be refurbished residential building;
6. To select the design integrations those meet the targeted energy consumption and make adjustments for optimisation.

4. The Research Contents and Approaches

Research Content 1: Classification and typification of existing residential building facade

Due to the different conditions (built time, structural types, construction methods and degrees of aging) of existing residential buildings, classification and typification of existing residential building facade is beneficial to understand the complexity of the building conditions and to simplify the
design process. Classification refers to the facade components that have great influence on the overall thermal performance. Based on the residential building case studies (shown in Figure 2), the facade components can be concluded as external walls, windows, roofs, balconies, and stairwells. Typification means each component’s types of construction materials, insulation measures, thermal performance, and with or without special configuration on structural node. Figure 3 presents a typification of external walls in Dalian City, China.

Prototypes of existing residential buildings can be summarised by the classification and typification, together with considering the shape coefficient of buildings, the facade orientations, and glazing ratio of existing residential buildings.

<table>
<thead>
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<th>1980s typical residential buildings in Dalian</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Photos" /> <img src="image2.png" alt="Photos" /> <img src="image3.png" alt="Photos" /></td>
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<th>1990s typical residential buildings in Dalian</th>
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</tbody>
</table>

Figure 2: Case studies of residential buildings (based on case studies in Dalian, China)
Research Content 2: Compiling and selection of appropriate passive design strategies

Passive design strategies that can be used as means for the refurbishment of residential building façade system are selected and compiled (Figure 4). Active strategies that can upgrade the energy efficiency, such as efficient heating equipment, renewable energy technologies, and other retrofit methods that can affect existing residential building energy-efficiency, such as increasing floor numbers, alternation of the internal space, are not considered in this study.

Based on the Research Content 1 and 2 (itemising residential building façade components, collecting existing façade constructional information, and compiling passive design strategies on façade system), a residential building refurbishment information model can be formed. A model
consists of building facade information, passive design strategies used in winter and summer, as shown in Figure 5. This model is the fundamental information for Research Content 4, 5, and 6 for further integrations and simulations of energy performance.

Research Content 3: Energy building refurbishment information model (with exemplary strategies)

According to the climatic conditions in Northern China heating areas, this study simulates energy consumption by using existing residential building prototypes that Research Content 1 provides. Energy consumption measures winter heating and summer cooling energy demand. The standards for heating and cooling are in accordance with temperatures that maintain the indoor thermal comfort and prevent overheating. Figure 6 illustrates the heating energy consumption requirement in winter as an example. The simulation is calculated by hour, year-round basis, and the unit of measurement is kWh / m² per year. This study does not consider the forms of heating or cooling source.
Research Content 4: Energy-efficiency upgrades comparison

Each compiled passive design strategy is applied on existing residential building prototypes. The effects are simulated, and the energy consumption reduction of refurbished prototypes is calculated and compared with the energy consumption of pre-refurbished prototypes. The higher a reduction is, the more effective the compiled passive design strategy can provide on energy efficiency upgrades. It is worth noting that the total value of building energy efficiency upgrade is not the sum of value every passive design strategy offers. The improved value of each passive design strategy only reflects the impact of this strategy on the effect of improving the overall energy efficiency. Theoretically, each applied strategy plays a role in the promotion of building energy efficiency. However, the real effect of energy efficiency upgrade depends on the suitability of strategies and conditions of existing residential buildings, such as building shape coefficient, facade orientation, and glazing ratio.

Both Research Content 3 and 4 take the computer simulation as the key research method. DesignBuilder was chosen as the computer simulation software in the design stage: DesignBuilder is based on building energy simulation programs (EnergyPlus), checking building energy, carbon emission, daylighting, natural ventilation and comfort performance. In this study, DesignBuilder provides advanced modelling tools, and enables measurement and assessment of building facade related thermal performance, visual effects, and energy consumption.

Research Content 5: Optimization for the integrated passive design strategies

Integrated design strategies, in accordance with the evaluated results from Research Content 4, are proposed. Then those integrated strategies are systematically assessed with computer simulations and physical model testing for optimisation.

Together with computer simulation, physical model testing platform is also a method in this study to calculate the energy consumption. Prototypes and refurbishment strategies of existing residential buildings are physically modelled in a large scale, focusing on the construction typification of facade components (external walls, windows, roof structure, balconies and staircases). The results of physical model measurements are used for analysing and optimising the effects of the integrations of passive design strategies. Physical model testing also verifies the feasibility and operability of computer simulations.

5. Discussions

This research study attempts to explore a design approach to improve energy efficiency in existing residential buildings by utilising passive design strategies. The study takes existing residential buildings built between 1980 and 2000 in Northern China heating areas as research objects. This study can provide integrated passive design strategies that quantify the impact of residential building facade components refurbishment, as well as decision-making information towards energy-efficiency upgrade for designers and related groups, such as contractors and home owners.

The research methods involve case studies and energy performance calculation. Existing residential buildings in different cities of Northern China heating areas are investigated. And based on the case studies, the early stage of this study has laid a solid foundation for energy performance calculation. The key methods of energy performance calculation rely on computer simulations and physical model testing. These approaches are relatively reliable and repeatable. However, the feasibility of this method has not been fully verified due to time limits. A comprehensive consideration of inspection process is needed in the future research plan.

6. Acknowledgement

This work was supported by Dalian University of Technology “the Fundamental Research Funds for the Central Universities” (grant no. DUT15RC(3)013).
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The regulating effect of S. trifasciatavar. laurentii on indoor environment

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Abstract

Purpose / Context - Indoor air pollution in China has become increasingly serious, which has aroused wide concern among the public. The purpose of this paper is to study the effect of S. trifasciatavar. laurentii on indoor environment.

Methodology / Approach - An investigation in a house with two same bedrooms (experimental one and control one) was conducted during heating period in Jinan, Shandong, China. Indoor CO₂ concentration, indoor air temperature and humidity, PM2.5 and PM10 concentration in two bedrooms were collected.

Results – The results showed experimental room with three pots of S. trifasciatavar. laurentii was 1.6% higher in the room air relative humidity, 0.997 ℃ lower in temperature, 15.5% lower in PM2.5 concentration, 16.4% lower in PM10 concentration than the control room without plants. Also, each 1m² leaf area of S. trifasciatavar. laurentii absorbed 2039.96mg CO₂ per hour. For Chinese common housing, 15m² bedroom needs about 4-5 pots of S. trifasciatavar. laurentii.

Key Findings / Implications – The quantitative data in this study are very promising for future indoor environmental management.

Originality - The possibility of reducing urban air pollution by lowering energy requirements of city buildings is also encouraging and nature’s ability to cost-effectively mitigate urban pollution is impressive, and its development is urgently needed.

Keywords - S. trifasciatavar. laurentii; indoor environment; indoor CO₂ concentration; indoor air temperature and humidity
1. Introduction

In recent years, indoor air pollution has become a worldwide concern. Due to the need of building energy efficiency, the airtightness of modern buildings is improved and the indoor ventilation is reduced, which makes indoor air pollutants such as CO$_2$, dust, bacteria and so on are not easy to spread [1]. The transpiration is the phenomenon that, moisture in gas state, through the plant’s surface, loss out of the body. The transpiration and culture medium can release moisture into the air, thereby increase the indoor humidity. Photosynthesis is the physiological processes that plants convert carbon dioxide and water into organic material and oxygen, through the light reaction and carbon reaction under the irradiation of visible light. Crassulacean acid metabolism plant can absorb CO$_2$ at night because of the particularity of the stomatal.

Some literature demonstrated that S.trifasciatavar.laurentii are net CO$_2$ absorbing state throughout all-weather [2-3]. In order to further study the effect of S.trifasciatavar.laurentii on indoor environment, in February 2016, an investigation in a house with two same bedrooms (experimental one and control one) was conducted during heating period in Jinan, Shandong, China.

2. Material and Methods

2.1 Materials

This investigation chosen 3 pots similar-sized, healthily-growing S.trifasciatavar.laurentii with no pests and diseases. The plants were purchased at nursery market in Jinan. Before the experiment, the plants were watered for a week; and in experiment time, they were forbidden watering. In order to adapt the test environments, the plants were held in test room for one week and clean the leaves and dust.

The paper-cut weighing method were used, which means painted the leaf on the standard graph paper and cut the paper then weighing. According to the weight and the area is directly proportional: leaf area = area of the whole paper * the weight of the cut paper/ the weight of the whole piece of paper [4].

2.2 Instruments

The investigation used PM2.5detector (CW-HAT200, the detection sensitivity is 0.001mg) to detect indoor PM2.5 and PM10 at 9:00 and 15:30 every day, used temperature and humidity instrument (testo 175H1) to detect indoor temperature and humidity peer 30 minutes, and used CO$_2$ concentration detector (Lutron MCH-383SD) to detect inddor CO$_2$ concentration peer 30 minutes during the experiment.

2.3 Study sites and time

The test was during 3-6th and 10-15th February, 2016, in Jinan, Shandong Province. The test room is brick structure and centrally heated without obvious pollution, and have no interior decoration and furniture replacement in the past five years. The net area of the two selected bedrooms is 17.11m$^2$, and the net volume is 43.63m$^3$. Each of the bedrooms have 4 windows which size is 2.9m*1.3m.

During the experiment, door and windows were closed in the evening because of no ventilation, and people did daily life in test room. The number of air changes in the two rooms was detected by the method of carbon dioxide attenuation, before the start of the experiment. The air change of room A is 28.29% per hour, and room B is 28.31%. So it can be considered that the sealing performance of the two rooms is the same.
2.4 Methods

The room A which has two people living at night without any plant was taken as a control group. The room B which also has two people living at night, has 3 pots of S.trifasciatavar.laurentii which placed in 1.2m distance from the balcony to ensure that the sun during the day. The data of two rooms were measured at the same time, and people movements of these rooms should be similar during the test time.

The PM2.5detector, temperature and humidity instrument 1, CO₂ concentration detector (data shows that the distribution of CO₂ is uniform in the closed room, and the CO₂ concentration is the same in any location of the room) were placed at the same position of the two rooms. with the same highly of people sit high breathing; placed the temperature and humidity instrument 2 and 3 at the same position in the two rooms respectively (i.e. near the plant placement in the room B and near the head of a bed in both rooms); placed CO₂ concentration detector, temperature and humidity instrument, PM2.5detector outside the window.

3. Results

3.1 Regulating effect of plants on indoor CO₂

The indoor CO₂ concentration was detected at 22:00 in the afternoon to 9:00 in the next morning during February 3 to 6 and February 10 to 15. People kept to entered both of the rooms at 22:00, and left at 7:00am on 4-5th February; at 8:00am on 6th February; at 8:30am on 10-15th February. As shown in Figure 1, on 3-5th February, the maximum CO₂ concentration of room A is 2291ppm, 2340ppm, 2445ppm respectively, and the Room B is 2035ppm, 1805ppm, 1887ppm respectively. In this three days, the average CO₂ concentration of room A is 1677 ppm, 1609ppm, 1987ppm respectively, and the room B is 1589 ppm, 1475ppm, 1667ppm respectively. The average CO₂ concentration of the three-days of room B is 180ppm lower than room A. Due to the door of both rooms remained closed after getting up in the morning on 5th February, the start concentration of CO₂ was significantly higher than the first two days.

![Figure 1 The CO₂ concentration of two rooms on 3-5th February](image)

As shown in Figure 2, the maximum CO₂ concentration of room A is 2820ppm, 2790ppm, 2585ppm, 2375ppm, 2328ppm respectively, and the Room B is 2035ppm, 2019ppm, 1918ppm, 1920ppm, 1746ppm respectively on 10-15th February; the average CO₂ concentration of room A is 2248ppm, 2212ppm, 2146ppm, 1882ppm, 1898ppm respectively, and the room B is 1907ppm, 1622ppm, 1648ppm, 1678ppm, 1541ppm. The average CO₂ concentration of the five-day of room B is 398ppm lower than room A. The doors and windows remained closed expect of the access of people in the morning and afternoon during the experimental period.
As shown above, the CO₂ concentration in the two rooms were at a peak at about 7:00am, and the people getting up at 7:00. Therefore, we selected 9 hours’ data from 22:00 to 7:00 to analysis. The average CO₂ concentration of room A was increased by 1332.25PPM per day by two people (i.e. the average data of 7:00 minus the data of 22:00 the day before), so the average CO₂ emission of per people was 74.01PPM per hour, which was recorded as M1. Two people and 3 pots of S.trifasciatavar.laurentii made the CO₂ concentration of room B increased by an average of 905.25PPM per day. Thus 3pots of S.trifasciatavar.laurentii made the CO₂ concentration of room B decreased by an average of 427PPM compared to room A (i.e. the absorption of S.trifasciatavar.laurentii on 9 hours at night). Because the total leaf areas of the selected plants is 1.8288m², so we can calculate the absorption of per unit time and per unit area of S.trifasciatavar.laurentii is 25.94PPM/m²*h, which was recorded as M. According to M1 and M, the required leaf area to absorb the CO₂ emission by one people per hour is 2.84m². The volume of the tested room is 43.6305m³, so the required leaf area of one people in unit space is 0.065m²/m³.

3.2 Effects of plants on indoor temperature and humidity
Li, N  The regulating effect of S.trifasciatavar.lautentii on indoor environment

Figure 4 Outdoor relative humidity data during the experiment

Figure 3 and Figure 4 is the data of outdoor meteorological during the experiment. Except for the 12 and 13th February was rainy and snowy, the other time was sunny. During 4-6th February, the average outdoor temperature was 0 degrees Celsius, and the relative humidity was about 42%. The average outdoor temperature was about 6 degrees Celsius during 11-14th February. The outdoor average relative humidity was 45% during 11-12th February. The average relative humidity was about 80% during 12-14th February. During the experiment, the average wind speed was 2-3m/s.

In experiment time, the average temperature of the bedside of room A and B was 24.2 and 23.5 degrees Celsius respectively, and the average relative humidity was 28.54% and 29.38% respectively; the average temperature of the center of room A and B was 24.75 and 24 degrees Celsius respectively, and the average relative humidity was 27.45% and 28.24% respectively; the average temperature of the location next to the plant of room A and B was 24.18 and 22.64 degrees Celsius respectively, and the average relative humidity was 28.55% and 31.72% respectively.

Figure 5 Indoor temperature data of the two rooms next to the plants

The location where nearby plants was chosen and analyzed data, because the temperature and humidity of the location of bedside and the center of the room had no obvious changes. As shown in Figure5, the trend of the temperature and humidity variation was consonant, and the change of indoor temperature and outdoor environment were related. When the room began to have sunlight, indoor temperature gradually increased, peaking in about 2 o’clock in the afternoon. It is the time that the outdoor temperature was highest and then gradually decreased. The change of the indoor temperature was not obvious, and tend to be gentle. As shown in Figure 5, the temperature of the location next to the plants of room B was 1.54 degrees Celsius lower than room A, which shows that the transpiration of plant has a cooling effect on the indoor environment.
As shown in Figure 6, the change of indoor relative humidity is consistent, and the room B was 3.36% higher than room A. It shows that the transpiration of plant has a humidifying effect on the indoor environment. Because the external environment has a great influence on plant transpiration, so it also has a great influence on the cooling and humidity of plants. Due to sun exposure, the indoor temperature increased obviously and the relative humidity decreased at noon. Also because there were no personnel stay during the day, and people entering the room will also cause the increase in relative humidity, so the two rooms achieved the lowest value of indoor relative humidity at noon.

![Figure 6 Indoor relative humidity data of the two rooms next to the plants](image)

3.3 Regulating effect of plants on indoor PM2.5

In order to avoid the personnel activity influence of indoor PM2.5 values, the test time was selected at 9:00 and 15:30 (i.e. an hour after the people get up in the morning and at noon). The doors of two rooms remained closed before the detection started. Figure 7 shows the data of PM2.5 of two rooms and outdoor during the experiment, and the Figure 8 shows the data of PM10.

![Figure 7 The value of PM2.5 of two rooms and the outside](image)
As shown above, the data of PM2.5 and PM10 of the room B with plants were lower than the room A without plants. The value of PM2.5 of room B was 15.5% lower than room A, and the value of PM10 was 16.4% lower than room A. These proved that leaf has good effect of dust detainment.

The value of indoor PM2.5 has a great related to the outdoor PM2.5, therefore, it’s better to close the doors and windows to avoid the PM2.5 from the outside into the room.

4. Discussion

4.1 Indoor greening and building energy efficiency

The researchers had investigated the energy consumption of humidifier and air purify. It is found that the total power consumption was 1.6-2.2 billion degrees and 1.3-2.3 billion degrees respectively of annual winter by Beijing families which used the humidifier and air purify. The demand of humidifier and air purify were increasing year by year, thus the humidifier and air purify energy consumption will become an inseparable part of building energy consumption [9]. This experiment proved that the plants can improve the indoor temperature, humidity and air quality. Therefore, if more and more comprehensive experiments will be done and the fixed quantify experimental conduction can be used to the design of the indoor environment, the energy consumption will be reduced significantly.

4.2 Problems in this experiment

In this experiment for the effect of plants on indoor air quality, we only collected the data of indoor CO2 concentration but the O2 concentration was not collected. The data collection was not comprehensive. In addition, we only used 3 pots of plants in the experiment, and didn’t considering whether the effect of plants on indoor environment will reach a limit value or not with the increase of leaf area. Finally, the effects of plants on the indoor environment need longer time to comparison and observation, and the experimental period in this experiment should be extended.

5. Conclusion

(1). S.trifasciata.var.laurentii absorbed 2039.96mg (i.e. 25.94PPM) CO2 per unit area and time in the night, has a certain role in the regulation of indoor CO2 concentration.

(2). In the circumstances that the frequency of ventilation is 0.28/h, the quality of CO2 release of a person is same as the absorption by S.trifasciata.var.laurentii with 0.065m² leaf area in the night. For Chinese common housing, 15m² bedroom needs about 4-5 pots of S.trifasciata.var.laurentii.
(3). *S.trifasciatavar.laurentii* can regulate indoor temperature and humidity, the average humidity of room B with 3 pots of *S.trifasciatavar.laurentii* was 1.60% higher than room A with no plants, and the average temperature of room B was 0.997 lower than room A.

(4). *S.trifasciatavar.laurentii* has good effect of dust detainment, the value of PM2.5 and PM10 of room B were 15.5% and 16.4% lower than room A respectively.

6. **ACKNOWLEDGEMENT**

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7. **References**


An Overview of Sustainable Assessment Tools of BREEAM, LEEDv4 and GB

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Abstract

Purpose / Context - Sustainability has become an important issue in building construction sector. The tools of sustainable building assessment have been developed to evaluate the environmental impacts of buildings around the world. Chinese green building assessment tool (GB) was established later than other tools from developed countries. Therefore, the aim of this paper is to improve the evaluation method in Chinese green building assessment. Two famous assessment tools of BREEAM (2011) from the UK and LEEDv4 from the US are taken as examples for comparison analysis.

Methodology / Approach – The method of this research is to investigate the similarities and differences of assessment criteria and indicators among three assessment tools by conducting a comparison with other countries’ green building standards.

Results – The results have found that when compared with major sustainable development categories, there is no obvious difference. However, in sub-criteria of each category, when compared with BREEAM and LEED, GB tool does not take more items into consideration and lacks more quantitative criteria, such as classifying building types, transport in sustainable site and energy efficient operation. Since each assessment tool has its own specialty to satisfy its local condition, GB assessment tool will follow the local standards and strategies to improve the deficiency of the original evaluation criteria.

Originality – This research provides constructive suggestions of the essential sustainable criteria for the future development of Chinese green building assessment.

Keywords - Sustainability, Green building, Sustainable green building assessment
1. Introduction

Global warming and climate change have become important issues in the world, and immediate actions should be taken to avoid serious consequences for future generations (IPCC, 2011). The research has shown that building sector accounts for a great amount of energy and resource consumption, leading to the damage of our environment (Emmanel, 2004). This may come from the absence of lacking environmental assessment tools capable of evaluating our built environment. Worldwide governments or environment-related institutions have gone into the development of such systems to assess the performance of buildings. Therefore, there has been great development of sustainable building environmental assessment tools since 1990s. Many tools have gained considerable success in the application of evaluation of green buildings (Cole, 2004; Seo et al., 2006). For example, In England, the Building Research Establishment Assessment Method (BREEAM) was the first tool developed for sustainable building design. Subsequently, Leadership in Energy and Environmental Design (LEED) in the USA in 1996, and Comprehensive Assessment System for Building Environment Efficiency (CASBEE) in Japan in 2002 have also been developed.

In China, due to the country’s fast-paced urban development since 1980s, construction-related environmental problems have been increasing rapidly, leading to great damage of ecology and human’s health. Based on nation’s statistical data, the share of building energy consumption in total energy consumption in China rose from 10% in 1978 to 30% in 2006, and continues to maintain growth (Han et al., 2006). In recent years, the data shows that building energy consumption accounts for 46.7% of the total society energy consumption and 60% of carbon emissions in cities comes from maintaining building’s function (Zhang, 2010). In consequence, environmental issues related to building construction have been paid more and more attention to. Due to the lack of building assessment in China, the first assessment system of Chinese green building (GB/T50378) was established in 2006, providing the standard of evaluation of sustainable buildings. However, the development of assessment system is not complete and needs ongoing improvement. The aim of this paper is first to investigate the essential evaluation criteria among LEED, BREEAM and Chinese green building (GB) from literature review. Further, different criteria will be compared and analyzed, providing constructive suggestions for future improvement of Chinese green building assessment.

2. Environmental Assessment Method

Environmental assessment methods have been developed to suit different territory. However, understanding various assessment features is the first step.

2.1 BREEAM

BREEAM was the first assessment tool developed in the UK in 1990. The latest version of BREEAM discussed in this paper is the method developed in 2011 (BREEAM, 2016). Main sustainable categories include management, health and wellbeing, energy, transport, materials, water, waste, land use and ecology, pollution and innovation. Assessed buildings include various types, such as residence, retail, industry unit, office, court, school, healthcare, prison and so on. Besides, BREEAM utilized a fixed weighting systems shown in Table 1 developed through the national consultative process (Sev, 2011). The assessment involves the comparison of main issues related to predictable practices and performance level. Afterwards, credits are given in ten categories. Each category has its specific criteria, with weighted credits that can be cumulative and added together to produce ‘a single overall score on a scale of Pass, Good, Very Good, Excellent and Outstanding’ (BREEAM, 2016).
Table 1 BREEAM environmental weightings

<table>
<thead>
<tr>
<th>Category</th>
<th>Weightings%</th>
<th>Credits available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Health and wellbeing</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Energy</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>Transport</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Water</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Materials</td>
<td>12.5</td>
<td>12</td>
</tr>
<tr>
<td>Waste</td>
<td>7.5</td>
<td>7</td>
</tr>
<tr>
<td>Land use and ecology</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Pollution</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Innovation</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

2.2 LEED

The first LEED assessment was developed in the US. in 1998. LEED is a voluntary certification program developed through a process involving major stakeholders to provide a framework for evaluating building performance and meeting sustainability goals (Zimmerman, 2007). The method has been modified and improved for several times. The basic assessment category with credits shown in Table 2 includes location and transportation, sustainable site, indoor environmental quality, water efficiency, energy and atmosphere, materials and resources, innovation and regional priorities. LEED uses a simple additive method (1 for 1) with all criteria weighted equally, not using a complicated weighting system. In this research, the latest assessment version of LEED v4 is taken into consideration (LEED, 2016).

Besides, the classification of assessed buildings includes building design and construction (BD+C), interior design and construction (ID+C), operations and maintenance (O+M), neighborhood and development (ND) and homes. Buildings cover many types, such as residence, school, retail, commercial building, multifunction building, healthcare and so on. With regards to certified ratings, there are four levels: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), Platinum (80+ points).
Table 2 LEED credits

<table>
<thead>
<tr>
<th>Category</th>
<th>Possible points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location and transportation</td>
<td>16</td>
</tr>
<tr>
<td>Sustainable sites</td>
<td>16</td>
</tr>
<tr>
<td>Water efficiency</td>
<td>11</td>
</tr>
<tr>
<td>Energy and atmosphere</td>
<td>33</td>
</tr>
<tr>
<td>Materials and resources</td>
<td>13</td>
</tr>
<tr>
<td>Indoor environmental quality</td>
<td>16</td>
</tr>
<tr>
<td>Innovation in design</td>
<td>6</td>
</tr>
<tr>
<td>Regional priority</td>
<td>4</td>
</tr>
</tbody>
</table>

2. 3 GB/T50378

The China Building Science Research Institute developed a two-stage green building rating system, the Chinese Green Building Label-3, or called 3-Star Rating in 2006 (GB, 2006). The rating system is managed by The Ministry of Housing and Urban-Rural Development (MOHURD) and building certified by the China Green Label Office at the China Green Technology Center. In the first stage, the building may earn a Green Design Building Label, so the project can be marketed as a green building to potential tenants. Second, the building may earn a Green Building Operation Label. The rating tool assigns a score based on the predicted performance of the building, using a simple adaptive approach, the same as LEED, with all criteria weighted equally. MOHURD-authorized universities rate 1-Star- and 2-Star building applications or local governments, while 3-Star building applications are rated by MOHURD. Sustainable categories also include construction and operation management, land efficiency and outdoor environment, energy savings & energy utilization, material saving & utilization of material resources, indoor environmental quality. Assessed building types including residential and public buildings are considered.

3. Results and Discussion

3.1 Types of assessed buildings

Table 3 indicates types of assessed buildings from three assessment tools. Public buildings and residential buildings are two major types. GB tool lacks detail classification of assessed buildings but the latest version of more assessed building types is still under development. BREEAM includes nine types of buildings, among which eight types belong to public buildings and one type residential building. LEED contains five main categories, in which various types of buildings are taken into account. Basically, assessment tools are focused on buildings but in LEED, the category of neighborhood development involves larger scale of planning such as well-connected community.
Table 3 Classification of assessed buildings in three assessment tools

<table>
<thead>
<tr>
<th>Comparison items</th>
<th>BREEAM</th>
<th>LEED</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessed building</td>
<td>Public buildings: retail, industry unit, office, court, school, healthcare, prison, multi-function building, unusual building</td>
<td>Interior design 1, building design &amp; construction 2, building operation and maintenance 3, homes 4, neighborhood development 5</td>
<td>Public buildings and residential buildings</td>
</tr>
<tr>
<td>Residential buildings</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Commercial interiors, retail and hospitality; 2. new construction, core & shell, schools, retail, hospitality, data centers, warehouses & distribution centers, and healthcare; 3. existing buildings, schools, retail, hospitality, data centers, and warehouses; 4. single family homes, low-rise multi-family (one to three stories), or mid-rise multi-family (four to six stories); 5. plan and built project

3.2 Category of different tools

3.2.1 The basic contents of category

Table 4 shows there is no great difference in the most of the categories. However, compared with assessment tools of LEED and GB, BREEAM includes categories in a more detail manner. For example, categories of land use, pollution and transport are included in sustainable site selection in LEED, and land saving and outdoor environment in GB. The category of “Waste” is highlighted in BREEAM because BREEAM regards waste treatment very essential at the end of building’s life; however, LEED and GB cover waste issue in categories of materials and resources, and material saving and resource use. The category of “Regional priority”, which BREEAM and GB lack, is a special indicator in LEED, which addresses geographically specific environmental priorities. Besides, BREEAM and LEED take the category of “Innovation” in the assessment, which provides design teams and projects the opportunity to achieve exceptional performance above the requirements. GB tool in China does not include this category, which may hinder creativity and inspiration of designers.
Table 4 Main contents of category

<table>
<thead>
<tr>
<th>Comparison items of category</th>
<th>BREEAM</th>
<th>LEED</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic contents of category</td>
<td>Land use and ecology</td>
<td>Sustainable site</td>
<td>Land saving and outdoor environment</td>
</tr>
<tr>
<td>Pollution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Water efficiency</td>
<td>Water saving and water resources use</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>Energy and atmosphere</td>
<td>Energy and use</td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>Materials and resources</td>
<td>Material saving and resources use</td>
<td></td>
</tr>
<tr>
<td>Health and well-being</td>
<td>Indoor environmental quality</td>
<td>Indoor environmental quality</td>
<td></td>
</tr>
<tr>
<td>Different category</td>
<td>Waste</td>
<td>Innovation</td>
<td>Operational management</td>
</tr>
<tr>
<td></td>
<td>Innovation</td>
<td>Regional priorities</td>
<td></td>
</tr>
</tbody>
</table>

3.2.2 The contents of criteria

The major function of environmental assessment approaches is the examination of building performance. A list of criteria should be ranked to evaluate the degree to which the assessed buildings are environmentally friendly, meeting the goal of sustainability. Criteria from different methods are discussed in the following.
(1) Sustainable site:

The purpose of this category shown in Table 5 is to mitigate the pollution on construction site, including destruction of bioactivity and biodiversity. This category also aims to deliver a good level of communication, through access to public services and relevant facilities and adequate provision for pedestrians, drivers and cyclists (BREEAM, 2016; USGBC, 2016). In BREEAM, this category was divided into Land use and ecology and Transport, which can be equivalent to the Sustainable site category in LEED. In this regard, while BREEAM and LEED are similar in terms of criteria, LEED pays more attention to Brownfield redevelopment and Public transportation access (USGBC, 2016). Most of the criteria in GB are similar to BREEAM and LEED, but more categories in Transport are Pedestrian and cyclist safety and Car parking capacity.

Table 5 Sustainable site and ecology criteria

<table>
<thead>
<tr>
<th>Sustainable site and ecology</th>
<th>BREEAM</th>
<th>LEED</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction site</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site selection</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Site protection</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Ecological value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polluted land</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Mitigation ecological impact</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Enhance site ecology</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Biodiversity protection</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessibility</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Density development</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Community connectivity</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Pedestrian and cyclist safety</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Car parking capacity</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
</tbody>
</table>
(2) Water efficiency:

Water resource is one of the most important environmental issues and water conservation has great impact on local water cycle balance. Therefore, assessment systems tries to manage action towards water use effectively. The goals are to reduce the water consumption and enhance the possibility of water recycling. BREEAM, LEED and GB approaches all focus on these related issues in Table 6. The criteria of “Recharge of ground water” in GB, which BREEAM and LEED do not list in the assessment criteria, enhances a balance between water cycle and ecology, moistening soil and enriching the ground water resource.

Table 6 Water efficiency criteria

<table>
<thead>
<tr>
<th>Water efficiency</th>
<th>BREEAM</th>
<th>LEED</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Rain water harvesting</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Grey water recycling</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Innovative wastewater technology</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Water fixture and conservation strategy</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Irrigation system</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Recharge of ground water</td>
<td>●</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.
(3) Energy efficiency:

Energy consumption leads to environmental damage such as global warming, acidification effect, air pollution and so on. In consequence, energy efficiency has the largest proportion of credits distributed among the environmental categories. The categories of “Energy performance” and “Natural resources” are all regarded important in three assessment tools shown in Table 7. Energy consumption criteria in LEED accounts for the greatest proportion of credits [USGBC, 2016]. “Efficient operation” indicates the evaluation of energy consumption and CO₂ emissions. In LEED and BREEAM, it is necessary to use supplementary tools and guidance to estimate the amount of these environmental burdens, such as Standard Assessment Procedure (SAP), American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). However, GB assessment does not include the criteria of energy monitoring and CO₂ mitigation strategy. The reason may come from the fact that in China, technology for supporting energy monitoring was not broadly used and some strategies and regulations related to CO₂ reduction are still under development [Ye et al., 2013].

Table 7 Energy efficiency criteria

<table>
<thead>
<tr>
<th>Energy efficiency</th>
<th>BREEAM</th>
<th>LEED</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation rate</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Internal lighting</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>External lighting</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot water system</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Heat transmission</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Natural resources</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Renewable energy technology</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Efficient operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy monitoring</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimum performance and energy saving</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>CO₂ mitigations strategy</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
</tbody>
</table>
(4) Material resource criteria:

Material resource is considered an important category in the most of the assessments due to its life cycle process from raw material extraction, transportation, manufacturing and disposal phase. Table 8 shows that BREEAM has more specific criteria in this category. The reason may come from the fact that BREEAM has developed a large material database, containing over 1500 specifications used in different types of buildings (BREEAM, 2016). This can help designers to select more sustainable materials in their design process. In LEED, reusability and maintenance of construction materials are paid much attention to. However, GB assessment has developed the criteria of “Hazardous substances of materials”, which BREEAM and LEED do not include. In the 21st century, environmental pollution in China has already become serious in building construction sector, not only from the stage of construction but also from the stage of building’s demolition; thus, managing materials with hazardous substances becomes very crucial.

Table 8 Material criteria

<table>
<thead>
<tr>
<th>Material</th>
<th>BREEAM</th>
<th>LEED</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material with low environmental impact</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Use of non-renewable-virgin materials</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Reuse of structural materials</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Use of non-structural materials</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Insulation material</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Material efficiency over its life cycle</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Hazardous substances of materials</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
</tbody>
</table>

(5) Indoor environmental criteria:

This category in BREEAM is called “health and wellbeing” and “indoor environmental quality” in LEED and GB. Indoor environmental quality is considered to be one of the major objectives in assessment tools. The goal is to reduce harmful impacts on human health, such as noise, lighting system, ventilation and thermal comfort. It can be found in Table 9 that BREEAM makes noise criteria more detail including sound insulation and absorption. Besides, GB includes most of the criteria but lacks criteria of CO2 monitoring and visual comfort. CO2 density is strongly related to human indoor comfort, affecting people’s concentration when working. Visual comfort may not be the direct factor that affects human’s health but in order to increase work efficiency and create a better living place, it is suggested that these two criteria should be contained in the GB assessment.
Table 9 Indoor environment criteria

<table>
<thead>
<tr>
<th>Indoor environment</th>
<th>BREEAM</th>
<th>LEED</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise and acoustics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise level</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Sound insulation</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sound absorption</td>
<td>●</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting and illumination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting controllability</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Glare measure and control</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Daylight factor</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Ventilation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation system</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Air purification supply</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Air quality sensors-CO₂ control</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Thermal comfort</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual comfort</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Temperature comfort</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Humidity comfort</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Future green building development in China

In addition to green building assessment criteria discussed above, some essential issues related to the future development of green building in China should be concerned because these issues influence further development of green building assessment tool in China.

In spite of some national and local standards that have been existed already, a complete system on the design, construction, operation and evaluation of green building is not well-established. Although different areas have their own climate conditions in China, specific standards for different regions are required. In China, green building is still in the initial stage, and related policies, regulations and evaluation system are under development and need to be improved. Factors such as regional economic development level, resources usage, climate conditions and construction characteristics should be taken into consideration when green building standards and assessment tools are developed. As for evaluation systems, they should include quantitative standards with higher qualities, so research and application on quantitative and qualitative index must be enhanced. To promote green building development, the government must cultivate an independence
third-party certification agency to evaluate before implementing design proposal, under construction process and building materials and devices.

4. Conclusion

It is not so easy for any single assessment method to be suitable for every region in the world because each territory has its particular individual specifications in terms of geographical and cultural variations. However, by comparative study of different assessments, some information related to assessed criteria can be obtained to broaden and deepen the insufficiency of contents in each assessment. Above all, it can be found that main assessed categories from different assessment tools do not differ much. But when evaluation of building types is compared, it is necessary for GB tool to be more specific in classifying various types of buildings, thus developing a more scientific-based evaluation of green buildings. Besides, in sub-criteria of each category, when compared with BREEAM and LEED, GB tool does not take more items into consideration and lacks more quantitative criteria. But this will be improved until the latest version of GB tool is proposed. On the other hand, GB tool still has some environmentally-friendly criteria that LEED and BREEAM do not cover, such as recharge of ground water and hazardous substances of materials. Since the climate in different areas in China is different, GB standards and criteria should adjust to local conditions and provide different guidances to various situations. More works will be done in the future related to local sustainability factors and local environmental policy.

5. References


HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.
Community Centre Improvement to Reduce Air Conditioning Peak Demand

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Abstract

Purpose / Context - Many developed countries experience late afternoon or evening electricity peaks. In summer peak demand regions, these peaks are most likely the results of residential air conditioning demand.

Methodology / Approach - This research is to investigate the air conditioning peak demand reduction potential from a variety of building and operational improvement options in a community centre case. Scenarios of increased thermal mass (rammed earth), more efficient glass sliding door options and control methods are simulated.

Results – Building improvement with integrated control performs best at reducing air conditioning peak demand and energy consumption. However, the control method is the most cost effective way of reducing the peak demand.

Key Findings / Implications – The integrated design and operation strategy for the community centre would significantly alleviate the peak demand pressure on electricity network infrastructure and energy so as to lower the carbon footprint onto the environment.

Originality – This study examined a residential community centre case from both design and operation aspects. The simulation is completed in half hourly intervals under real world tariffs.

Keywords - building improvement; thermal mass; operational strategy; air conditioning control; demand side management
1. Introduction

Electrical performance of residential housing and communities impacts significantly on residents, investors, utilities and society. Peak demand is the most important factor for electricity infrastructure from transmission to distribution to community networks, because high peak demand may lead to excessive heating of conductors and the failure of electricity supply. Australia’s electricity peak load is in the evening from 4pm to 9pm (AEMO, 2015) confirming that load from the residential sector has the strongest demand on the electricity network, rather than industrial or commercial loads.

With more sustainability features, such as large amounts of indoor thermal mass in the building structure as well as furnishing (Reddy, Norford, & Kempston, 1991) and better management of heat transfer, sustainable housing can be utilised to store more coolness for longer time periods in regions of summer peak demand, or more warmth for longer time periods in regions of winter peak demand. In essence, sustainable residential buildings could be viewed as thermal energy storage devices. However, it needs investigation to confirm whether adding thermal mass as thermal energy storage will reduce air conditioning (A/C) peak demand in individual cases.

As a form of thermal energy storage (TES), building thermal mass can be used to reduce peak demand (Reddy et al., 1991; Reynders, Nuytten, & Saelens, 2013). In fact, building structure is a large thermal mass for energy storage but its drawback is that its efficiency in terms of energy discharged verses energy charged is low (in the range of 26.47%–41.61% for different weighted buildings (Xue, Wang, Sun, & Xiao, 2014)), compared to electro-chemical batteries’ efficiency of 65% to 98% (Christiansen & Murray, 2015). In reality, once the building is designed and constructed, there are no extra costs for using building thermal mass as energy storage.

As a part of operational strategies, demand side management can be used to reduce residential neighbourhood peak demand (Pezeshki, Wolfs, & Ledwich, 2014), improve electricity network reliability (Narimani, Nourbakhsh, Ledwich, & Walker, 2015) and increase household photovoltaic energy local consumption (Liu, Ledwich, & Miller, 2015). When operational strategies are adopted, building thermal mass performs better to reduce peak demand. Where summer peak demands are larger than winter’s, pre-cooling using building thermal mass can effectively shave electricity peak demand, maintain comfort levels as well as avoid creating a new peak in a later time (Katipamula & Lu, 2006; Liu, Ledwich, & Miller, 2016; Perez, Baldea, & Edgar, 2016; Xue et al., 2014). Pre-cooling can also potentially reduce the risk of high charges when the electricity price is volatile (Marwan, Ledwich, & Ghosh, 2012). These studies have opened a gate for cross-disciplinary research between mechanical and electrical disciplines; however existing studies often did not consider the real world demand tariff in smaller time intervals of half hour or less and missed the justification for their proposals’ implementation cost.

Efficiency improvement measures can reduce peak demand averagely at network scale, e.g. building insulation improvement. Through improvement in roof insulation, A/C peak demand could be reduced on averagely by 14.3% in Australian capital cities according to two simulated houses configurations (Samant et al., 2013). However, whether efficiency improvement would always reduce A/C peak demand of individual cases in hot climates needs further investigation.

To achieve a reasonable outcome considering efficiency, costs, benefits and technology, communities need evaluation of different building improvement options and operational strategies, including demand side management – control of electrical appliances.

This study considers a South East Queensland community centre building with a central A/C as the largest electrical load. The aim of this research is to investigate which building improvement measure, increased indoor thermal mass or improvement in glazing performance characteristics, reduces the A/C half hourly peak demand the most and which strategy is more cost effective. It further aims...
to determine how integration of these methods with operational strategies could further reduce peak demand.

The methodology is described in Section 2. Section 3 presents the simulation results for the case studies. Section 4 extends the study in the discussion with the combination of improvement in building design, efficiency and operational strategy.

2. Methodology

This section illustrates the methodology to quantify the reduction of half hourly A/C peak demand in a real Queensland community centre with different building improvement measures. The electricity demand tariff in Queensland is based on the highest half hour electricity consumption in a month. For the community case, the rates are $31.1025AUD per kilowatt (kW) for peak demand and $0.1192AUD per kilowatt hour (kWh) for energy (Queensland Competition Authority, 2015). The onsite meter records the highest half hourly electricity consumption. If the immediate past half hour recording is higher, the recorder will be updated. Site energy auditing identified that the community centre air conditioner is the largest load. This study is focused on how to reduce peak demand from the air conditioner in half hourly intervals.

Table 1: Building and Air Conditioner Parameters

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heat Transfer Coefficient (HTC)</td>
<td>3.0446</td>
<td>W/m²·K</td>
</tr>
<tr>
<td>2</td>
<td>Eastern Wall</td>
<td>2.6394</td>
<td>W/m²·K</td>
</tr>
<tr>
<td>3</td>
<td>HTC Southern Wall</td>
<td>1.9027</td>
<td>W/m²·K</td>
</tr>
<tr>
<td>4</td>
<td>HTC Western Wall</td>
<td>1.0331</td>
<td>W/m²·K</td>
</tr>
<tr>
<td>5</td>
<td>HTC Ceiling</td>
<td>0.667</td>
<td>W/m²·K</td>
</tr>
<tr>
<td>6</td>
<td>Eastern Wall Area</td>
<td>77.32</td>
<td>m²</td>
</tr>
<tr>
<td>7</td>
<td>Southern Wall Area</td>
<td>45.59</td>
<td>m²</td>
</tr>
<tr>
<td>8</td>
<td>Western Wall Area</td>
<td>50.4</td>
<td>m²</td>
</tr>
<tr>
<td>9</td>
<td>Northern Wall Area</td>
<td>53.4</td>
<td>m²</td>
</tr>
<tr>
<td>10</td>
<td>Ceiling Area</td>
<td>356.85</td>
<td>m²</td>
</tr>
<tr>
<td>11</td>
<td>Indoor Thermal Mass</td>
<td>5.95</td>
<td>MJ/K</td>
</tr>
<tr>
<td>12</td>
<td>Air conditioner input power (cooling)</td>
<td>14</td>
<td>kW</td>
</tr>
<tr>
<td>13</td>
<td>Energy Efficiency Ratio (Cooling)</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Desired Temperature Band</td>
<td>24–26</td>
<td>°C</td>
</tr>
<tr>
<td>15</td>
<td>Simulation Initial Temperature</td>
<td>25</td>
<td>°C</td>
</tr>
<tr>
<td>16</td>
<td>Outdoor Temperature</td>
<td>34</td>
<td>°C</td>
</tr>
</tbody>
</table>

From site energy auditing and computer modelling (regulatory accredited software BERS Pro), the building, air conditioner and simulation parameters are listed in Table 1. These parameters are used in MATLAB environment to simulate the central air conditioning operation and indoor temperature with state space models (Liu et al., 2016). The main structure of the building is concrete, however there are large areas of glazing. 21% of the external wall area consists of energy inefficient single glazed sliding doors, providing an option to consider more energy efficient glazing for better energy saving and better financial performance over the long term. The heat transfer coefficient through the concrete floor is neglected because of relatively high ground temperature (over 17°C all year) and the insulation effect of floor covering, minimising heat loss through the floor.

This building is mainly used for community residents for morning tea, lunch, meetings and other functions. The scope of the simulation is one zone only - the main hall. Other parts of the building (e.g. kitchen and offices) are not conditioned by the same air conditioner nor connected directly to the main hall. The purpose of the modelling is to simulate the reduction of peak demand. The electricity demand of air conditioning is at its maximum at high temperatures, therefore the 90th percentile maximum temperature (34°C) is selected for the modelling (Bureau of Meteorology, 2016).
Peak demand always occurs in one half hour. Based on 38 months of site data, 82% of the site monthly peak demands occurred between 4:30pm to 6:30pm when there is no significant indoor metabolic heat load or solar radiation. Site energy auditing identified that the indoor heat loads in the peak time are from lighting and appliances at idle so the simulation considered indoor heat loads constant at 8327.1W.

The following equation is used to calculate Indoor temperature ($T_{in}$).

$$T_{in}(k+1) = \Delta T_{ac}(k) + \Delta T_{be}(k) + \Delta T_{hl}(k)$$

$\Delta T_{ac}$: temperature change due to A/C work
$\Delta T_{be}$: temperature change due to heat transfer through building envelope
$\Delta T_{hl}$: temperature change due to indoor heat loads

Scenario 0 is the base scenario representing the current situation on site. It will build the baseline for comparison with other scenarios.

Scenario 1 is to examine if a certain level of increased building indoor thermal mass would reduce A/C half hourly peak demand. Thermal mass options include rammed earth, concrete, concrete blocks, bricks or water. For this community centre, prefabricated 300mm thickness rammed earth blocks are selected because of aesthetics, easy maintenance, indoor space limitations and specific heat capacity. These rammed earth blocks are $375AUD/m^2$ with a thermal mass of 1673 kJ/m$^3$.K (Reardon, McGee, & Milne, 2013). Considering minimum purchasing requirements and budget limitations, the limit for purchasing the rammed earth is from 2 to 30m$^2$. This limit is included in the MATLAB Particle Swarm Optimisation algorithm (PSO) (Kennedy & Eberhart, 1995) to identify the optimal thermal mass increase for A/C peak demand reduction. The optimisation objective function is the maximum A/C half-hourly demand reduction.

Because large areas of the external walls are glass, from an efficiency point of view, Scenario 2 is to improve the glass thermal performance ($U$ values W/ m$^2$.K) through evaluation of various glass sliding door options. Solar heat gain is not an important factor in selecting glass types for this building because of long eaves on the building exterior providing excellent east and west shading and electricity monthly peak demand mostly occurring between 4:30pm and 6:30pm when solar radiation is not strong. Therefore $U$ values of the glass sliding doors are considered to be the selection criteria. Figure 1 presents the candidate glass sliding door unit costs ($AUD per m^2$) against their corresponding $U$ values (watt per m$^2$ per Kelvin). Glass sliding door products are often custom made and quoted. The pricing used in Figure 1 includes glass, frame, flyscreens and features to match with existing configuration for the purposes of reducing the community centre building envelope heat transfer, not improvement in solar heat gain, aesthetics or structure.

![Figure 1 Glass Sliding Door Unit Cost vs U Values](image-url)
Scenarios 0, 1 and 2 have standard thermostat controlled central A/C. In these scenarios, the A/C works in warming up and cooling down cycles. A consistent initial temperature of 25°C has been used for these scenarios.

Scenario 3 is to examine if operational improvement, i.e. different operational strategies can reduce the A/C peak demand for the community centre. The operational strategies include pre-cooling to the lower band of the temperature range and increasing the thermostat setting by 1°C or 2°C. Higher thermostat settings are not considered due to occupant thermal comfort requirements.

Lastly, the integrated approaches of increased thermal mass, improved glazing and operational strategies are simulated to examine if the combination of these strategies would reduce peak demand and energy consumption further.

3. Results

This section presents the case study results from simulating the A/C operation in the MATLAB environment. Based on site data, 93% of daily peaks happened during 15:30 to 20:30. Therefore, a 5-hour simulation period is chosen to cover the length of possible peak timing.

3.1 Scenario 0 – Base Scenario without any improvement

Figure 2 represents the base scenario without any building improvement. There are 12 operating cycles. Figure 3 shows the peak demand is 7.4667kW from the 3rd 30min interval. This reading is the largest 30min electricity demand in the simulation horizon. The triangular shapes are the de-
mand reading in each 30min. The peak demand is updated every time after 30min if the immediate past 30min has a higher reading. Electricity consumption in this scenario is 30.1kWh. Based on the community case electricity tariff (Queensland Competition Authority, 2015), the total cost of demand and energy for this time period is $235.82AUD.

3.2 Scenario 1 – Increase Building Thermal Mass

Iterations of the PSO algorithm determined that 2.5m$^2$ of 300mm thick rammed earth needs to be added to the existing building to provide the optimal thermal mass to reduce peak demand. Thermal mass increase beyond this value or less than this value will not reduce the A/C peak demand more than the 2.5 m$^2$ optimal increase. Figure 4 below presents the indoor temperature profile of the community centre with the optimal indoor thermal mass to reduce A/C peak demand. This scenario has less operation cycles (10 cycles) compared to the base scenario (12 cycles). This added thermal mass would be able to reduce peak demand by 1.4kW however this scenario would consume slightly more energy (30.3kWh) compared to the base scenario (30.1kWh) mainly due to the cooling of more thermal mass.

![Figure 4](image)

**Figure 4** Scenario 1 Indoor Temperature

3.3 Scenario 2 – Improve Glass Sliding Door

Figure 5 presents the peak demand reduction compared with the cost of different glazing options. Higher glazing costs do not guarantee more peak demand reduction because there is no difference in the number of air conditioner working cycles within the same timeframe. For this same reason, when there is no significant difference in U values, the energy consumed by the A/C in the simulation period may be the same. This phenomenon is shown in Table 2 improvement options for glazing with U values of 1.1 to 2.4. Results of evaluating various glazing options are listed in Table 2.

![Figure 5](image)

**Figure 5** Scenario 2 Peak Demand Reduction vs Cost
Table 2: Scenario 2 Cost and Benefit Analysis of Glass Sliding Door Options

<table>
<thead>
<tr>
<th>Options</th>
<th>U Values (W/m²·K)</th>
<th>Energy Consumed (kWh)</th>
<th>Air Conditioner Peak Demand (kW)</th>
<th>Peak Demand Reduction (kW)</th>
<th>Improvement Cost ($AUD)</th>
<th>Ratio of Peak Demand Reduction to Improvement Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Scenario</td>
<td>6.9</td>
<td>30.1</td>
<td>7.4667</td>
<td>N.A.</td>
<td>0</td>
<td>N.A.</td>
</tr>
<tr>
<td>Improved</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario</td>
<td>4.4</td>
<td>28</td>
<td>7</td>
<td>0.4667</td>
<td>2576</td>
<td><strong>0.00018</strong></td>
</tr>
<tr>
<td></td>
<td>2.4</td>
<td>25.6667</td>
<td>6.5333</td>
<td>0.9334</td>
<td>13679</td>
<td>0.00007</td>
</tr>
<tr>
<td></td>
<td>1.8</td>
<td>25.4333</td>
<td>6.5333</td>
<td>0.9334</td>
<td>18307</td>
<td>0.00005</td>
</tr>
<tr>
<td></td>
<td>1.1</td>
<td>25.4333</td>
<td>6.5333</td>
<td>0.9334</td>
<td>28892</td>
<td>0.00003</td>
</tr>
</tbody>
</table>

On the last column of Table 2, the ratio of peak demand reduction to improvement cost is used as the performance indicator. The larger the indicator value is, the better the performance. The best performing ratio is highlighted in bold. Glazing with 4.4 U value is the best option in this scenario.

3.4 Scenario 3 – Operational Improvement to Include Operational Strategies

Previous literature (Katipamula & Lu, 2006; Xue et al., 2014) has demonstrated that pre-cooling thermal mass can be used to alleviate peak demand. However, for this community centre case, simple pre-cooling will not reduce peak demand as shown in Table 3 (initial pre-cooling at 23 or 24°C), because the precooling effect wears out quickly in the first half hour of the five hour simulation duration. The same performance indicator is used, showing increase of the temperature band by 2°C is the best option (Table 3).

Table 3: Scenario 3 Options

<table>
<thead>
<tr>
<th>Options</th>
<th>Strategy</th>
<th>Energy Consumed (kWh)</th>
<th>Air Conditioner Peak Demand (kW)</th>
<th>Peak Demand Reduction (kW)</th>
<th>Improvement Cost ($AUD)</th>
<th>Ratio of Peak Demand Reduction to Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Scenario</td>
<td>Normal cyclic operation</td>
<td>30.1</td>
<td>7.4667</td>
<td>N.A.</td>
<td>0</td>
<td>N.A.</td>
</tr>
<tr>
<td></td>
<td>Pre-cooling, Initial at 24°C</td>
<td>30.1</td>
<td>7.4667</td>
<td>0</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Pre-cooling, Initial at 23°C</td>
<td>28.9333</td>
<td>7.4667</td>
<td>0</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>Operational Strategies</td>
<td>Uplift Temp. Band by 1°C, Initial at 25°C</td>
<td>28</td>
<td>7.4667</td>
<td>0</td>
<td>300</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Uplift Temp. Band by 2°C, Initial at 25°C</td>
<td>25.6667</td>
<td>6.5333</td>
<td>0.9334</td>
<td>300</td>
<td><strong>0.0031</strong></td>
</tr>
</tbody>
</table>
4. Discussion

The best performing options of Scenario 1, 2 and 3 are listed in Table 4. The integrated scenarios are further presented in the last three rows. The bold numbers are the best performing in respective columns.

Table 4: Best Performing Options and Integrated Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Energy Saving (kWh)</th>
<th>Peak Demand Reduction (kW)</th>
<th>Electricity Charge ($AUD)</th>
<th>Improvement Cost ($AUD)</th>
<th>Ratio of Charge Reduction to Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Base Case</td>
<td>N.A.</td>
<td>N.A.</td>
<td>235.82</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>1</td>
<td>Increase Thermal Mass</td>
<td>-0.2</td>
<td>1.4</td>
<td>192.3042</td>
<td>938</td>
<td>0.0464</td>
</tr>
<tr>
<td>2</td>
<td>Improve Glass Sliding Door</td>
<td>2.1</td>
<td>0.4667</td>
<td>221.0551</td>
<td>2576</td>
<td>0.0057</td>
</tr>
<tr>
<td>3</td>
<td>Uplift Temp Band by 2°C</td>
<td>4.4333</td>
<td>0.9334</td>
<td>206.2625</td>
<td>300</td>
<td><strong>0.0985</strong></td>
</tr>
<tr>
<td>4.1</td>
<td>Integrate the above 1 &amp; 3</td>
<td>4.9</td>
<td><strong>1.8667</strong></td>
<td>177.1778</td>
<td>1238</td>
<td>0.0474</td>
</tr>
<tr>
<td>4.2</td>
<td>Integrate the above 2 &amp; 3</td>
<td><strong>5.3667</strong></td>
<td>1.4001</td>
<td>191.6367</td>
<td>2876</td>
<td>0.0154</td>
</tr>
<tr>
<td>4.3</td>
<td>Integrate the above 1 to 3</td>
<td><strong>5.3667</strong></td>
<td><strong>1.8667</strong></td>
<td><strong>177.1222</strong></td>
<td>3813</td>
<td>0.0154</td>
</tr>
</tbody>
</table>

In Scenario 1, the optimal indoor thermal mass increase is 1254.75kJ/K which is 21% increase to the existing thermal mass. It can reduce peak demand by 1.4kW but results in slightly higher energy consumption than the base Scenario 0 due to the cooling of additional thermal mass. In Queensland Australia, demand is measured in half hour intervals. If demand is measured in longer intervals (e.g. hourly) or the building has poor thermal performance, increasing indoor thermal mass may reduce the A/C peak demand more because more thermal mass may be able to reduce the number of cooling down-warming up cycles in the longer interval, reducing the demand measurement.

Scenario 2 performs last in peak demand reduction and second last in the energy reduction. It is not a particularly successful option due to its high cost. This option can still be viable if this cost barrier could be removed. For example, the high glazing cost in Australia may not exist in other countries due to market size, population, competition and distance to manufacturers. It may also be possible to retrofit low-e film to the existing glazing to achieve similar U value improvement at a reduced cost, changing the charge reduction to cost ratio.

Scenario 3 shows that pre-cooling alone does not reduce A/C peak demand or result in financial savings in the half hourly demand charge case. From an investment point of view, uplifting the temperature band by 2°C in Scenario 3 is the overall best option when the ratio of electricity charge reduction to improvement cost is considered as the performance indicator. When design improvements and operational strategy are combined, Scenario 4.3 performed the best in energy saving, peak demand reduction and electricity charge reduction however, its ratio of charge reduction to improvement is not high.

The limitation of this research is that it has not included life cycle cost benefit analysis, battery energy storage or other efficiency measures (e.g. efficiency of appliances, ceiling and roof insulation). Peak demand and energy consumption could be reduced further if battery energy storage and other building and appliance efficiency measures are employed.
5. Conclusion

This research investigated the half hourly peak demand reduction potentials under real world tariffs with a variety of building and operational improvement scenarios. The time interval of half hour is smaller than most of the existing literature. Results show that most of the scenarios would reduce energy consumption; however not all the discussed efficiency measures would reduce A/C peak demand. The most cost effective option considered is the operational improvement by uplifting the A/C temperature band. However, the integrated approach of design improvement and incorporating operational strategy performed best at reducing peak demand and energy usage. The reduced peak demand and energy usage would directly mean less carbon footprint to the environment. Future work includes developing intelligent operational strategies to manage electricity demand with batteries and optimising community electrical infrastructure.

6. Acknowledgement

The authors gratefully thank the support of Australian Research Council Linkage project (LP130100650) and the case study community in Rochedale South, Queensland, Australia.

7. References


HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.


Low Cost Sensor Network for Indoor Air Quality Monitoring in Residential Houses: Lab and Indoor Tests of Two PM Sensors

Akwasi Bonsu Asumadu-Sakyia, Mawutorli Nyarku, Mandana Mazaheri, Phong Thai, Lidia Morawska, Rohan Jayaratne

Abstract

Purpose / Context – The purpose of our work is to investigate: a) the sensor responses of the two different low-cost PM sensors to concrete dust and indoor environment and activities; b) the evaluation of the measuring performance of two low-cost PM sensors and their potential application in indoor air quality monitoring.

Methodology / Approach – The chamber and indoor tests of Sharp sensor GP2Y1010AU0F (Sharp sensor) and Shinyei sensor PPD42NS (Shinyei sensor) were conducted. Otherwise, the sensor board of Sharp and Shinyei sensors was located in the indoor environment for over 24 h.

Results – Lab and indoor tests of the Sharp sensor and Shinyei sensor were conducted and they showed a good agreement with the reference instruments (DustTrak and AirBeam) and respond quickly to the concrete dust concentration change above 50 µg/m³ as well as repond well to cooking activity when locating in the indoor environment.

Key Findings / Implications – The Sharp sensor and Shinyei sensor were all able to detect PM2.5 in the chamber test and indoor environment. However their ability to monitoring PM concentration in ambient concentrations (around 10~20 µg/m³) still need further validation and improvement.

Originality – The collected data of indoor air quality and environmental parameters will also be a reference to adjust the HVAC system and energy use based on individual’s behaviour. The lab and indoor tests of these two PM sensors are the first step to put the low cost sensors into practice.

Keywords - indoor environment quality; sensor network; indoor/outdoor relationship; indoor air quality monitoring; low cost PM sensor
1. Introduction

Indoor air quality has become a hot issue since the modern building and houses are more airtight and space saving which are not good for air circulation and exchanging. Otherwise, people are spending a large percentage of them daily time in indoor environment. Indoor air contaminants can affect the occupant’s health, comfort and then influence their working performances and may be related to Sick Building Syndrome (SBS) and Building Related Illness (BRI) (Zampolli, Elmi et al. 2004, Kim, Jung et al. 2010, Saad, Saad et al. 2013).

Among various air pollutants in indoor environment, particulate matter (PM) has been a crucial role in air pollution since it poses adverse impact on human health and living environment (Ashmore and Dimitroulopoulou 2009). A large number of researches have been done on PM pollution (Agus, Young et al. 2007, Morawska, Johnson et al. 2009, Buonanno, Marini et al. 2012, Snyder, Watkins et al. 2013), however, the state of the art monitoring techniques are always being bulky, complicated, expensive and time consuming, the promising sensing technologies of PM are effective tool to be utilized in the air pollution monitoring area.

There are a few kinds of PM sensor monitor available in the market. The DC1100 Pro Air Quality (Dylos) is a Laser Particle Counter with two different size ranges. The small channel (0.5> Micron) can detect bacteria and mold. The Large channel (2.5> micron) is able to detect dust and pollen and it costs 290 USD (http://www.howmuchsnow.com/arduino/airquality/grovedust/). Other PM measuring devices such as AirBeam, AirBot, Air Quality Egg and Electronic Nose Sensor are available in the market or under developing (http://www.treehugger.com/clean-technology/environmental-sensors.html). Several dust sensing projects has been done (Holstius, Pillarisetti et al. 2014, Austin, Novosselov et al. 2015, Wang, Li et al. 2015), however few of them were investigated in the real indoor environment. In order to investigate the performance of the low-cost PM sensor and its ability to measure the PM concentration in the air, a series of measurements of sensors were conducted in the chamber together with the DustTrak and indoor environment (a living room of a typical house) together with Airbeam.

The aim of the job is to investigate: a) the sensor responses of the two different low-cost PM sensors to concrete dust and indoor environment and activities; b) the evaluation of the measuring performance of two low-cost PM sensors and their potential application in indoor air quality monitoring.

2. Methodology

2.1 PM Sensors

The low-cost PM sensors investigated were Sharp dust sensor GP2Y1010AU0F (Sharp sensor) and Shinyei PPD42NS dust sensor (Shinyei sensor). These two sensors are all working by light scattering but they varied in details. And the price of them are around USD10 and easy available in the market.

The Detecting principle of Sharp sensor is that the light emitter (Light Emitting Diode) and the light detector (Photodiode) are spotted with a lens and a slit. When dust and/or cigarette smoke exists inside of it, the light from light emitter is refracted by particles and the amount of scattered light is detected (Budde, El Masri et al. 2013). Current in proportion to amount of the detected light comes out from the detector and the device makes analog voltage output (Pulse output) after the amplifer circuit amplifies the current from the detector (KHADEM and SGĂRCIU 2014). The Shinyei sensor is working by that an light beam provided by the infrared led and the light scattered by particles at a forward angle of about 45° is picked up by photodiode, a lens in front of the photodiode focuses into a detection region in the air flow and close to the LED light portal (Allen, Austin, Novosselov et al. 2015). The Shinyei particle sensor PPD4NS is used to create Digital (Lo Pulse) output to Particulate Matters (PM). Lo Pulse Occupancy time (LPO time) is in proportion to PM concentration. The air sample is drawing by a heater resistor. The minimum detectable particle
size is approximately 1μm with a detectable range of concentration of 0~28,000 pcs/liter (KHADEM and SGARCUI 2014).

During the test period, 4 Sharp sensors and 4 Shinyei sensors were assembled on one board as shown in Figure 1 and the Sharp and Shinyei sensors read and store PM concentration outputs at 1-s intervals.

![Sensor board architecture (left: 4 Shinyei sensors, right: 4 Sharp sensors)](image)

**2.2 DustTrak**
DustTrak Aerosol Monitors are battery-operated, data-logging, light-scattering laser photometers which can simultaneously measure both mass and size fraction in real-time. It can measure PM1, PM2.5, Respirable, PM10, and Total PM size fractions. The detecting particle size range is 0.1 to 15 μm and the Aerosol Concentration Range is 0.001 to 150 mg/m³ (DustTrak-DRX aerosol monitor datasheet).

**2.3 AirBeam**
AirBeam is a wearable air monitor that maps, graphs, and crowdsources your pollution exposures in real-time via the AirCasting Android app (http://www.takingspace.org/aircasting/airbeam/). It uses a Shinyei PPD60PV sensor as the sensing element and measures PM$_{2.5}$ at 5-min intervals. In the indoor test, we use the Airbeam data as a reference to see the indoor PM$_{2.5}$ concentration variation.

**2.4 Testing procedures**
The sensor board of 4 Sharp and 4 Shinyei sensors were first tested in the chamber together with DustTrak. The concrete dust was blow into the chamber to test the sensor responses. The DustTrak were fitted with a PM$_{2.5}$ filter and the measuring time was set to 5 s. The timeline of chamber test are listed in Table 1.

<table>
<thead>
<tr>
<th>Time</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:04:06</td>
<td>Start (in the chamber) with DustTrak and fan on</td>
</tr>
<tr>
<td>13:08:45</td>
<td>Blow the Concrete dust</td>
</tr>
<tr>
<td>13:39:40</td>
<td>Vacuum on to decrease the aerosol concentration</td>
</tr>
<tr>
<td>13:47:35</td>
<td>Turn off the fan</td>
</tr>
<tr>
<td>14:42</td>
<td>Stop</td>
</tr>
</tbody>
</table>

Table 1 Timeline and activities in lab test.
Later, the sensor board of 4 Sharp and 4 Shinyei sensors were put in the living room of a house together with Airbeam for over 24 h. During the measuring time, the house was occupied by two persons with normal daily activities such as cleaning, washing and cooking. The timeline for the indoor test are listed in Table 2.

Table 2 Timeline and activities in indoor test.

<table>
<thead>
<tr>
<th>Time</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>21/05/2016 16:10</td>
<td>Start together with Airbeam</td>
</tr>
<tr>
<td>16:45-20:~(no exact time)</td>
<td>Cooking and eating</td>
</tr>
<tr>
<td>20:~ 22/05/2016 12:00</td>
<td>One person in the living room</td>
</tr>
<tr>
<td>12:00-14:00</td>
<td>Cooking</td>
</tr>
<tr>
<td>14:00-16:35</td>
<td>One person in the living room</td>
</tr>
<tr>
<td>16:35-17:00</td>
<td>bake + fry+eating</td>
</tr>
<tr>
<td>18:07</td>
<td>Stop test</td>
</tr>
</tbody>
</table>

3. Results and discussion

3.1 Chamber test with concrete dust

Figure 2 presented the response of DustTrak and Sharp and Shinyei sensors to concrete dust in a Chamber environment. As it was depicted in Figure 2 (a), the sharp sensors are sensitive to concrete dust and respond quickly to concrete dust. Otherwise, the 4 Sharp sensors are in good agreement with each other and respond quickly to a concrete dust concentration increasing.

As from Figure 2 (b), it is obvious that the Shinyei sensors are also able to detect the concentration variation of concrete dust as the sensors output decreasing together with the DustTrak readings. However, the sensors outputs keep stable after the DustTrak readings went down to 50 $\mu$g/m$^3$ and these may indicate the detection size range of both two kinds of sensors are lower than the DustTrak. Otherwise, the Shinyei sensor 1 and 3 were not sensitive and sensor outputs always became 0 when the dust concentration are very low. The variability (called “noise”) in the Shinyei outputs are much bigger compare with the Sharp sensors.
Figure 2 Time series of DustTrak readings with sharp (a) and shinyei (b) sensor output in Chamber test.
From Fig.3 (a), the linearity between Sharp outputs and DustTrak reading were good ($R^2=0.58-0.67$), and the Sharp sensor outputs ranges were very small while the DustTrak readings were below 50 $\mu$g/m$^3$. As it was presented in Figure 3 (b), the linearity between Shinyei outputs and DustTrak readings were high ($R^2=0.89-0.91$), but sensor outputs were stable and close to 0 when the DustTrak readings are below 50 $\mu$g/m$^3$.

Figure 3 Linearity of DustTrak readings vs sharp (a) and shinyei (b) sensor output in chamber test
3.2 Indoor test
Because the values of AirBeam are PM$_{2.5}$ concentration in every 5 minutes. To plot, the average of every 5 minutes of the Sharp and Shinyei sensors outputs have been calculated. As it was shown in Figure 4 (a), Sharp sensors outputs increased and have peaks at 5 pm of both two day because of cooking activities. The same trend was found in AirBeam data. These demonstrated that the Sharp sensors can respond to PM$_{2.5}$ concentration changes due to indoor activities. From Figure 4 (b), the Shinyei sensors were presenting small peak values at 5 pm of both day, it was illustrated that the Shinyei sensors can respond to cooking emissions. However, the Shinyei outputs were varied greatly during daytime (9 am to 3 pm) of the second day. It was later analyzed and found to be caused by the strong sunlight shining on the sensor board through the window. And both Sharp and Shinyei sensors outputs settled down at night (from 10 pm-9 am the next day) when no one are walking around or occupied in the living room.

Figure 4 Time series of Airbeam readings with sharp (a) and shinyei (b) sensor output in indoor test
4. Conclusion
The low-cost Sharp and Shinyei PM sensors were evaluated in the lab and indoor environment. The Chamber tests indicate that both Sharp and Shinyei sensors respond to particles concentration > 50 µg/m³ and they respond in line with the DustTrak but the responses of unfiltered signals are noisy. Otherwise, the problem of both sensors is that whether they are able to detect PM2.5 at a low concentration range need to be validated and strengthened.

Some measures will be applied in the future work to reduce the noisy and improve the sensitivity of sensors. The first step will be increasing the measuring time intervals of both sensors to every 30 s or every 5 min or even longer. The second way is to cover the sensor board with light-proof materials to prevent the influence of light. Later a fan can be added to both sensors to increase the PM concentration rather than the passive measuring of Sharp sensors or relying on the resistor heater in the Shinyei sensors.

Since only a small part of work has been done, the future work will be focus on the calibration of the PM sensors and their practical application in residential houses. The multiple parameters including temperature, humidity, and light intensity on PM sensor performance need to be conducted and validated. Besides, other reference PM measuring methods such as SMPS, TEOM, APS will be used to calibrate sensor performance. The low cost PM and gas sensor will be used inside the houses as well as outdoors to quantify the levels of the indoor air pollutants and the relationship between indoor and outdoor pollutants.

5. References
DustTrak-DRX aerosol monitor datasheet
Allen, T. "ShinyeiPPD42NS_Deconstruction_TracyAllen."
Effects of Night-time Bedroom Temperature on Morning Blood Pressure during Winter: A Multilevel Analysis

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Abstract

Purpose / Context - To analyse the association between night-time temperature in the bedroom and morning blood pressure (BP)

Methodology / Approach - Data were obtained from field surveys conducted from November 2014 to March 2015 on indoor temperature, home BP, sleep, and personal attributes. One hundred and twelve participants (73 households) were classified into three groups by the window glazing and the presence or absence of a solar floor heating system in their homes. Group 1 was single glazing and no solar floor heating system. Group 2 was double glazing and no solar floor heating system. Group 3 was double glazing and a solar floor heating system.

Results – The night-time temperature in the bedroom and morning temperature in the living room in Group 3 were higher than those of Groups 1 and 2. After adjusting for personal factors, a 1°C decrease of night-time temperature was significantly associated with a 0.61 mmHg increase of morning systolic blood pressure (SBP) in Group 1, and a 0.92 mmHg increase of morning SBP in Group 2. The temperature in Group 3 did not show a significant association with morning SBP.

Key Findings / Implications – There was no effect on morning BP when the night-time temperature was over 18°C, whereas on mornings below 18°C SBP increased as the temperature decreased.

Originality - The findings of this study may help improve indoor thermal environments to control hypertension and prevent cardiovascular disease, and thus reduce the medical costs associated with cardiovascular disease.

Keywords - Indoor Thermal Environment, Bedroom Temperature, Sleep, Morning Blood Pressure, Field Survey
1. Introduction

In Japan, cardiovascular disease is a major cause of death, and deaths from cardiovascular disease occur in homes most frequently during the winter. Cardiovascular events occur frequently in the morning (Omama, 2006). The main risk factor for cardiovascular disease is hypertension, and it is estimated that in 2010, 43 million people in Japan—one-third of the population—had hypertension. Therefore, reducing the average blood pressure (BP) of the whole country via a population approach is an urgent priority. In recent years, early morning hypertension has attracted attention. There are two types of early morning hypertension: one where BP rapidly rises early in the morning, and one where BP rises during sleep and persists after waking (Kario, 2010). Morning home BP is a strong predictor of cardiovascular disease, such as coronary artery disease (Kario, 2016; Hoshide, 2016). Indoor temperature shows a stronger association than outdoor temperature with BP in colder months (Saeki, 2014). Therefore, a sufficient temperature needs to be maintained in the morning and also during sleep. However, there have been few studies focusing on night-time temperature and BP. Therefore, in this work, we analyse the association between night-time temperature in the bedroom and BP by multilevel analysis.

2. Methods

2.1 Participants

The field study was conducted from November 2014 to March 2015. The study area included Tochigi, Ibaraki, Saitama, Chiba, Tokyo, Kanagawa, Yamanashi, and Nagano prefectures. From among adult residents (men and women aged 35–74 years), 169 participants (100 households) were recruited through a local construction firm. The study was approved by the Keio University Science and Technology Bioethics Board (No. 26-11).

2.2 Study protocol

The indoor temperatures, home BP, and sleep were measured for 2 weeks by the participants. Questionnaires about housing performance and personal attributes were also conducted. The questionnaire on personal attributes covered individual characteristics, such as age and sex; lifestyle indicators, such as smoking, alcohol consumption, antihypertensive drug use, clothing amount, heating devices, and bedclothes; and health conditions, such as diseases that can cause hypertension. Body mass index (BMI) was measured by using a body composition monitor (HBF-252F, Omron Healthcare Corporation). The questionnaire on housing performance covered aspects of the indoor thermal environment such as window glazing, window frames, and the presence or absence of a solar floor heating system. This system heats the under-floor with air heated by a solar heat-collecting device on the roof.

2.3 Indoor air temperature

The indoor temperatures, home BP, and sleep were measured for 2 weeks by the participants. Questionnaires about housing performance and personal attributes were also conducted. The questionnaire on personal attributes covered individual characteristics, such as age and sex; lifestyle indicators, such as smoking, alcohol consumption, antihypertensive drug use, clothing amount, heating devices, and bedclothes; and health conditions, such as diseases that can cause hypertension. Body mass index (BMI) was measured by using a body composition monitor (HBF-252F, Omron Healthcare Corporation). The questionnaire on housing performance covered aspects of the indoor thermal environment such as window glazing, window frames, and the presence or absence of a solar floor heating system. This system heats the under-floor with air heated by a solar heat-collecting device on the roof.
2.4 Home blood pressure

Home BP monitoring is an easy standardised tool for measuring BP at home. It was measured by participants twice a day, after getting up in the morning (morning BP) and before bedtime at night (evening BP) both in the living room. Participants measured their BP with an upper-arm BP monitor (HEM-7251G or HEM-7252G-HP, Omron Healthcare Corporation), in accordance with the guidelines of the Japanese Society of Hypertension (JSH, 2014). Participants were instructed to take two consecutive measurements on each occasion, and the average of the two values was used for the analysis.

2.5 Sleep

Sleep was measured by participants at home with a non-contact sleep monitor (HSL-102-M, Omron Healthcare Corporation), which determines sleep or wake by detecting body movement with an electric wave sensor. This monitor measures the time in bed, total sleep time (TST), sleep efficiency (SE), sleep onset latency (SOL), and wake after sleep onset (WASO). TST is the sum of all sleep epochs between sleep onset and wake time. SE is the ratio of the TST to time in bed multiplied by 100. SOL is the interval between bedtime and sleep onset (initial sleep epoch). WASO is the sum of all wake epochs between sleep onset and waking time (Hashizaki, 2014).

2.6 Definitions of night-time and morning temperature

We determined night-time and morning temperatures as follows.

1. Night-time temperature: mean temperature in the bedroom during time in bed, which was measured with a sleep monitor
2. Morning temperature: temperature when BP was measured in the morning

2.7 Statistical methods

For continuous variables, mean (standard deviation; SD) was reported. Mean values were compared by using the t-test. The proportions of the groups were compared by using the chi-squared test. The magnitude of the associations between night-time temperature and morning systolic blood pressure (SBP) were verified by using a two-level linear regression analysis consisting of day-level variables (temperature and SE) and participant-level variables (age, sex, BMI, smoking, antihypertensive drugs, clothing amount, and bedclothes). Regression coefficients were estimated by restricted maximum likelihood. The applicability of multilevel analysis was verified by the intraclass correlation coefficient (ICC) and the design effect (DE) of the null model. If the ICC was over 0.10 and the DE was over 2.0, the data were considered in its configuration (Shimizu, 2014). To suppress multicollinearity in multilevel models, correlation coefficients between independent variables were assessed. If the correlation coefficient was greater than 0.40, one variable was not introduced into the model. All p-values were two-sided, and p < 0.05 was considered statistically significant. All statistical analyses were performed by using SPSS 23.0 software

3. Results

3.1 Characteristics of housing and participants

In this study, 169 people aged 35 years or older (100 households) were recruited, and their eligibility was assessed according to the validation criteria. Of the 169 participants, 7 were excluded because of refusal to participate the study, 2 were excluded due to missing questionnaire data, 1 was excluded due to missing temperature data in the bedroom, 11 were excluded due to missing home BP data, and 36 were excluded due to missing sleep data (Figure 1, Table 1).
After exclusion of 57 people, 112 participants (73 households) were classified into three groups by window glazing and the presence or absence of a solar floor heating system in their house. Group 1 was single glazing with no solar floor heating system (36 participants, 22 households). Group 2 was double glazing with no solar floor heating system (40 participants, 26 households). Group 3 was double glazing with a solar floor heating system (36 participants, 25 households). There were no houses with single glazing and a solar floor heating system.

Of the 73 households (mean building age ± SD: 15.2 ± 14.7 years), 65 (89.0%) were detached houses. The building age of Group 1 was significantly higher than that of Group 2 and 3 (31.3 years vs. 11.2 and 5.2 years; \( p < 0.001 \)). There were 21 houses (95.5%) with aluminium window frames in Group 1, 14 houses (53.8%) in Group 2, and 4 houses (16.0%) in Group 3. In contrast, there were no houses (0.0%) with insulated resin frames in Group 1, 6 houses (23.1%) in Group 2, and 13 houses (52.0%) in Group 3 (Table 2).

![Figure 1 Flow diagram of participants](image)

**Table 1: Validation criteria of the measurements**

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Validation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home BP</td>
<td>Measurement period: over 5 days</td>
</tr>
<tr>
<td>Temperature</td>
<td>No data logger error in the bedroom</td>
</tr>
</tbody>
</table>
| Sleep        | Measurement period: over 5 days which meet the following criteria  
|              | - Time in bed over 3 h  
|              | - SE within \([\text{Av.SE}} ± 2 \times \text{SDSE}]\)  
|              | \([\text{Av.SE}}: \text{average SE of all participants}]  
|              | \([\text{SDSE}}: \text{SD of SE of all participants}]\) |
Table 2: Characteristics of the 73 houses

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 73)</td>
<td>(n = 22)</td>
<td>(n = 26)</td>
<td>(n = 25)</td>
<td></td>
</tr>
<tr>
<td>Structure, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detached house</td>
<td>65 (89.0)</td>
<td>17 (77.3)</td>
<td>23 (88.5)</td>
<td>25 (100.0)</td>
<td>0.01</td>
</tr>
<tr>
<td>Multi-unit housing</td>
<td>8 (11.0)</td>
<td>5 (22.7)</td>
<td>3 (11.5)</td>
<td>0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Building age, mean (SD), y</td>
<td>15.2 (14.7)</td>
<td>31.3 (13.5)</td>
<td>11.2 (10.4)</td>
<td>5.2 (3.7)</td>
<td>c, f, h</td>
</tr>
<tr>
<td>Window glazing, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Single</td>
<td>21 (28.8)</td>
<td>21 (95.5)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Double</td>
<td>50 (68.5)</td>
<td>0 (0.0)</td>
<td>26 (100.0)</td>
<td>24 (96.0)</td>
<td></td>
</tr>
<tr>
<td>No answer</td>
<td>2 (2.7)</td>
<td>1 (4.5)</td>
<td>0 (0.0)</td>
<td>1 (4.0)</td>
<td></td>
</tr>
<tr>
<td>Window frames, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Old wooden</td>
<td>1 (1.4)</td>
<td>1 (4.5)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>New wooden</td>
<td>3 (4.1)</td>
<td>0 (0.0)</td>
<td>1 (3.8)</td>
<td>2 (8.0)</td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>39 (53.4)</td>
<td>21 (95.5)</td>
<td>14 (53.8)</td>
<td>4 (16.0)</td>
<td></td>
</tr>
<tr>
<td>Aluminium (double)</td>
<td>7 (9.6)</td>
<td>0 (0.0)</td>
<td>4 (15.4)</td>
<td>3 (12.0)</td>
<td></td>
</tr>
<tr>
<td>Insulation (resin)</td>
<td>19 (26.0)</td>
<td>0 (0.0)</td>
<td>6 (23.1)</td>
<td>13 (52.0)</td>
<td></td>
</tr>
<tr>
<td>No answer</td>
<td>4 (5.5)</td>
<td>0 (0.0)</td>
<td>1 (3.8)</td>
<td>3 (12.0)</td>
<td></td>
</tr>
<tr>
<td>Solar floor heating system, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Present</td>
<td>25 (34.2)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>25 (100.0)</td>
<td></td>
</tr>
</tbody>
</table>

SD, standard deviation.

C: p < 0.001, Group 1 vs Group 2; f: p < 0.001, Group 1 vs Group 3; h: p < 0.01, Group 2 vs Group 3 by paired t-test.

Of the 112 participants (mean age ± SD: 52.4 ± 10.4 years old), 62 (55.4%) were men. Slightly more participants in Group 1 compared with Groups 2 and 3 reported a current smoker (16.7% vs. 15.0% and 11.1%; p = 0.79), slightly more were taking antihypertensive drugs (8.3% vs. 7.5% and 5.6%; p = 0.41), and slightly more reported a history of cardiac disease, cerebrovascular disease, diabetes, hyperlipidaemia, kidney disease, or hypertension (38.9% vs. 25.0% and 19.4%; p = 0.16) but the differences were not significant (Table 3). The amount of clothing of Group 2 was significantly more than that of Group 3 (0.69 vs. 0.62 clo; p < 0.01). The proportion who did not use a heating device in the bedroom was higher in Group 1 than in Groups 2 and 3 (41.7% vs. 27.5% and 13.9%; p = 0.03). Significantly more participants in Group 3 compared with Groups 1 and 2 reported using a bed instead of a futon (83.3% vs. 55.0% and 27.8%; p < 0.001), and few used an electric blanket or hot-water bottle (13.9% vs. 25.0% and 38.9%; p = 0.10) (Table 3).

3.2 Basic status of participants

There were significant differences among the three groups in night-time and morning temperatures. The night-time temperatures in the bedroom in Group 3 were higher than those in Groups 1 and 2 (18.3°C vs. 11.6 and 13.6°C; p < 0.001 and p < 0.01). The morning temperature in the living room in Group 3 was also higher than those of Groups 1 and 2 (18.2°C vs. 14.8 and 17.1°C; p < 0.001 and p < 0.05).

The baseline survey of home BP and sleep showed similar results among the three groups for morning SBP (120.0 vs. 122.2 vs. 121.2 mmHg; not significant (n.s.)), DBP (78.6 vs. 79.5 vs. 80.3 mmHg; n.s.), time in bed (399.7 vs. 420.6 vs. 406.4 min; n.s.), TST (359.4 vs. 385.5 vs. 372.0 min; n.s.), SE (90.4 vs. 92.4 vs. 92.2%; n.s.), SOL (5.6 vs. 5.0 vs. 4.6 min; n.s.), and WASO (20.6 vs. 17.1 vs. 15.7 min; n.s.) (Table 4).
Table 3: Baseline characteristics of the 112 participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (n = 112)</th>
<th>Group 1 (n = 36)</th>
<th>Group 2 (n = 40)</th>
<th>Group 3 (n = 36)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (SD), y</td>
<td>52.4 (10.4)</td>
<td>52.5 (9.9)</td>
<td>51.5 (10.2)</td>
<td>53.2 (11.2)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>62 (55.4)</td>
<td>19 (52.8)</td>
<td>21 (52.5)</td>
<td>22 (61.1)</td>
<td>0.70</td>
</tr>
<tr>
<td>BMI, mean (SD), kg/m²</td>
<td>22.9 (3.5)</td>
<td>22.8 (3.8)</td>
<td>22.7 (2.7)</td>
<td>23.4 (3.9)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Current smoker, n (%)</td>
<td>16 (14.3)</td>
<td>6 (16.7)</td>
<td>6 (15.0)</td>
<td>4 (11.1)</td>
<td>0.79</td>
</tr>
<tr>
<td>Daily alcohol intake, n (%)</td>
<td>28 (25.0)</td>
<td>9 (25.0)</td>
<td>8 (20.0)</td>
<td>11 (30.6)</td>
<td>0.65</td>
</tr>
<tr>
<td>Antihypertensive drugs, n (%)</td>
<td>8 (7.1)</td>
<td>3 (8.3)</td>
<td>3 (7.5)</td>
<td>2 (5.6)</td>
<td>0.41</td>
</tr>
<tr>
<td>Disease history, n (%)</td>
<td>31 (27.7)</td>
<td>14 (38.9)</td>
<td>10 (25.0)</td>
<td>7 (19.4)</td>
<td>0.16</td>
</tr>
<tr>
<td>Clothing amount, mean (SD), clo</td>
<td>0.65 (0.14)</td>
<td>0.65 (0.17)</td>
<td>0.69 (0.11)</td>
<td>0.62 (0.12)</td>
<td>h</td>
</tr>
<tr>
<td>Heating device in bedroom, n (%)</td>
<td>0.69 (0.12)</td>
<td>0.69 (0.13)</td>
<td>0.70 (0.11)</td>
<td>0.69 (0.12)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>34 (30.4)</td>
<td>8 (22.2)</td>
<td>16 (40.0)</td>
<td>10 (27.8)</td>
<td>0.22</td>
</tr>
<tr>
<td>Fan heater</td>
<td>7 (6.3)</td>
<td>3 (8.3)</td>
<td>4 (10.0)</td>
<td>0 (0.0)</td>
<td>0.11</td>
</tr>
<tr>
<td>Heater</td>
<td>24 (21.4)</td>
<td>9 (25.0)</td>
<td>11 (27.5)</td>
<td>4 (11.1)</td>
<td>0.18</td>
</tr>
<tr>
<td>Kotatsu (heated table)</td>
<td>3 (2.7)</td>
<td>2 (5.6)</td>
<td>1 (2.5)</td>
<td>0 (0.0)</td>
<td>0.14</td>
</tr>
<tr>
<td>Electric heating carpet</td>
<td>2 (1.8)</td>
<td>2 (5.6)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>0.10</td>
</tr>
<tr>
<td>Floor heating system</td>
<td>28 (25.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>28 (77.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nothing</td>
<td>31 (27.7)</td>
<td>15 (41.7)</td>
<td>11 (27.5)</td>
<td>5 (13.9)</td>
<td>0.03</td>
</tr>
<tr>
<td>Bedclothes, n (%)</td>
<td>62 (55.4)</td>
<td>10 (27.8)</td>
<td>22 (55.0)</td>
<td>30 (83.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Futon</td>
<td>50 (44.6)</td>
<td>26 (72.2)</td>
<td>18 (45.0)</td>
<td>6 (16.7)</td>
<td></td>
</tr>
<tr>
<td>Additional bedclothes, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down quilt</td>
<td>77 (68.8)</td>
<td>18 (50.0)</td>
<td>31 (77.5)</td>
<td>28 (77.8)</td>
<td>0.01</td>
</tr>
<tr>
<td>Electric blanket/hot-water bottle</td>
<td>27 (24.1)</td>
<td>14 (38.9)</td>
<td>10 (25.0)</td>
<td>3 (13.9)</td>
<td>0.10</td>
</tr>
</tbody>
</table>

BMI, body mass index; SD, standard deviation.

‘Heater’ includes kerosene, gas, electric, far-infrared, and oil heaters, and wood stoves.

h: p < 0.01, Group 2 vs Group 3 by paired t-test.

3.3 Relationship between night-time temperature and morning systolic blood pressure

Figure 2 shows the results of the relationship between night-time temperature and morning SBP for Groups 1 to 3, with each point showing the temperature and SBP data for one day for one participant. The solid line shows the linear regression line of each participant. The ranges of night-time temperature were slightly different among the groups. Group 1 had many points at 5–10°C (range: 4.0–21.0°C), Group 2 had many points at 10–15°C (range: 3.0–21.5°C), Group 1 had many points at 15–20°C (range: 10.3–27.3°C). For SBP, Group 2 had some points over 155 mmHg. For each regression line, 71 (63%) participants showed a negative slope, indicating that an increase in SBP was associated with a decrease in temperature.
Table 4: Baseline status of 112 participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total (n = 112)</th>
<th>Group 1 (n = 36)</th>
<th>Group 2 (n = 40)</th>
<th>Group 3 (n = 36)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night-time, mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedroom</td>
<td>14.5 (4.2)</td>
<td>11.6 (3.5)</td>
<td>13.6 (3.3)</td>
<td>18.3 (2.8)</td>
<td>a, f, i</td>
</tr>
<tr>
<td>Morning, mean (SD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living room</td>
<td>16.7 (3.6)</td>
<td>14.8 (3.8)</td>
<td>17.1 (3.7)</td>
<td>18.2 (2.2)</td>
<td>a, f, g</td>
</tr>
<tr>
<td>Bedroom</td>
<td>13.8 (4.2)</td>
<td>10.8 (3.6)</td>
<td>13.1 (3.3)</td>
<td>17.5 (2.7)</td>
<td>b, f, i</td>
</tr>
<tr>
<td>Toilet</td>
<td>13.1 (4.3)</td>
<td>9.8 (2.6)</td>
<td>12.2 (3.7)</td>
<td>17.5 (2.0)</td>
<td>b, f, i</td>
</tr>
<tr>
<td>Morning home BP (mmHg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP, mean (SD)</td>
<td>121.2 (14.7)</td>
<td>120.0 (13.9)</td>
<td>122.2 (17.4)</td>
<td>121.2 (12.4)</td>
<td>n.s.</td>
</tr>
<tr>
<td>DBP, mean (SD)</td>
<td>79.4 (10.6)</td>
<td>78.6 (10.0)</td>
<td>79.5 (12.1)</td>
<td>80.3 (9.7)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Sleep</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time in bed, mean (SD), min.</td>
<td>409.3 (64.8)</td>
<td>399.7 (64.4)</td>
<td>420.6 (64.4)</td>
<td>406.4 (65.6)</td>
<td>n.s.</td>
</tr>
<tr>
<td>TST, mean (SD), min.</td>
<td>372.8 (65.3)</td>
<td>359.4 (63.4)</td>
<td>385.5 (63.9)</td>
<td>372.0 (67.8)</td>
<td>n.s.</td>
</tr>
<tr>
<td>SE, mean (SD), %</td>
<td>91.7 (6.1)</td>
<td>90.4 (6.7)</td>
<td>92.4 (6.2)</td>
<td>92.2 (5.3)</td>
<td>n.s.</td>
</tr>
<tr>
<td>SOL, mean (SD), min.</td>
<td>5.1 (3.4)</td>
<td>5.6 (3.5)</td>
<td>5.0 (3.4)</td>
<td>4.6 (3.1)</td>
<td>n.s.</td>
</tr>
<tr>
<td>WASO, mean (SD), min.</td>
<td>17.8 (20.3)</td>
<td>20.6 (25.0)</td>
<td>17.1 (20.9)</td>
<td>15.7 (13.5)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

SBP, systolic blood pressure; DBP, diastolic blood pressure; TST, total sleep time; SE, sleep efficiency; SOL, sleep onset latency; WASO, wake after sleep onset; SD, standard deviation.

a: p < 0.05, b: p < 0.01, Group 1 vs Group 2; f: p < 0.001, Group 1 vs Group 3; g: p < 0.05, i: p < 0.001, Group 2 vs Group 3 by paired t-test

Figure 2 Relationship between night-time temperature and morning SBP for a) Group 1, b) Group 2, and c) Group 3.
3.4 Effect of night-time temperature on morning systolic blood pressure: multilevel analysis

Multilevel linear regression analysis was performed to clarify the association of night-time temperature with morning SBP adjusted for personal attributes (Table 5). The analysis was performed within each group because there were strong correlations between sex and daily alcohol intake, antihypertensive and disease history (correlation coefficient = 0.49, 0.45), daily alcohol intake and disease history were not used in the model, in order to suppress multicollinearity. Because the ICC of the three groups were over 0.10 and the DE of three groups were over 2.0, there was a hierarchical data structure and multilevel analysis was suitable for these data.

A 1°C decrease in night-time temperature was significantly associated with a 0.61 mmHg increase in morning SBP in Group 1, and a 0.92 mmHg increase of morning SBP in Group 2 independent of age, sex, BMI, current smoking, antihypertensive drugs, night-time clothing amount, bedclothes, and additional bedclothes. In contrast, night-time temperature in Group 3 and SE in all groups did not show a significant association with morning SBP.

Table 5: Multilevel analysis of the relationship between night-time temperature and morning SBP

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Adjusted β (95% CI)</th>
<th>p-value</th>
<th>AIC</th>
<th>ICC</th>
<th>DE</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1 [Group 1]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night-time temperature</td>
<td>-0.61 (-1.06, -0.16)</td>
<td>&lt;0.01</td>
<td>2694</td>
<td>0.19</td>
<td>2.92</td>
<td>36 s x days</td>
</tr>
<tr>
<td>SE</td>
<td>-0.08 (-0.10, 0.27)</td>
<td>0.38</td>
<td></td>
<td></td>
<td></td>
<td>= 391</td>
</tr>
<tr>
<td><strong>Model 2 [Group 2]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night-time temperature</td>
<td>-0.92 (-1.55, -0.29)</td>
<td>&lt;0.01</td>
<td>3399</td>
<td>0.18</td>
<td>2.92</td>
<td>40 s x days</td>
</tr>
<tr>
<td>SE</td>
<td>-0.02 (-0.27, 0.22)</td>
<td>0.82</td>
<td></td>
<td></td>
<td></td>
<td>= 472</td>
</tr>
<tr>
<td><strong>Model 3 [Group 3]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Night-time temperature</td>
<td>-0.45 (-1.23, 0.32)</td>
<td>0.23</td>
<td>3110</td>
<td>0.30</td>
<td>4.30</td>
<td>36 s x days</td>
</tr>
<tr>
<td>SE</td>
<td>-0.11 (-0.42, 0.20)</td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
<td>= 437</td>
</tr>
</tbody>
</table>

95% CI, 95% confidence interval; AIC, Akaike’s information criterion; ICC, intraclass correlation coefficient; DE, design effect; SE, sleep efficiency.
Adjusted for age, sex, BMI, current smoking, antihypertensive drugs, night-time clothing amount, bedclothes, and additional bedclothes.
Adjusted β expresses the change of morning SBP per 1°C increase in night-time temperature or 1% increase in SE.

4. Discussion

Our data from 112 participants (73 households) were classified into three groups by window glazing and the presence or absence of a solar floor heating system in their houses (Figure 1). The housing for Group 1 was assumed to meet thermal insulation performance equivalent to the 1980 standards in Japan, because the housing had aluminium window frames and the buildings were older. The housing for Groups 2 and 3 were assumed to meet thermal insulation performance equivalent to the 1999 standards in Japan because the housing had double aluminium or insulated window frames and the buildings were newer (Takayanagi, 2011). Thus, Group 1 had low thermal insulation performance, and Groups 2 and 3 had high thermal insulation performance. The night-time and morning temperatures in Group 3 were significantly higher than those in Groups 1 and 2. The night-time temperature of Group 3 was over 18°C, as recommend in the Cold Weather Plan for England 2015 as follows: “Heating homes to at least 18 °C (65 °F) in winter poses minimal risk to the health of a sedentary person, wearing suitable clothing.” (PHE, 2015). Because the temperature in Group 2 was not over 18°C, it was necessary to increase the thermal insulation performance and use a suitable heating device to keep warm.
The night-time temperatures of Groups 1 and 2 showed significant associations with morning SBP (Group 1: adjusted $\beta$, -0.61; $p < 0.01$. Group 2: adjusted $\beta$, -0.92; $p < 0.01$) in the multilevel linear regression model adjusting for potential confounders, in contrast to the night-time temperature of Group 3, which did not show a significant association (adjusted $\beta$, -0.45; $p = 0.23$). This suggests that night-time temperatures over 18°C have no effect on morning SBP, whereas for night-time temperatures under 18°C, morning SBP increases with a decrease in temperature. Previous work has shown a 1 mmHg increase in the morning surge that is associated with a 3.3% increase (95% confidence interval, 0.8–5.8%) in the risk of cardiovascular events (Gosse, 2004). Therefore, our findings suggest that improving the indoor thermal environment should help prevent cardiovascular disease and moving to a well-insulated house may decrease the prevalence of hypertension (Ikaga, 2011).

The present study had sample selection bias; the number of elderly people who had high SBP was low, and thus the number of people taking antihypertensive drugs was also low. Therefore, the small numbers of these individuals became a factor in non-significant explanatory variables in the multi-level models. To confirm our results, it is necessary to increase the number of participants from a variety of age groups and with various characteristics.

Because this study is a cross-sectional study, it is possible to estimate only the effect of improved home environment on home BP. To confirm any actual effects implied by the data, it is necessary to perform prospective studies with the participants, such as observations of participant's BP after moving from a house with low thermal insulation to one with high thermal insulation.

5. Conclusion

This study analysed the relationship between night-time temperature and morning BP based on field surveys from November 2014 to March 2015. The following findings were obtained.

1) The night-time temperatures in the bedroom in Group 3 were higher than those in Groups 1 and 2 (18.3°C vs. 11.6 and 13.6°C; $p < 0.001$ and $p < 0.01$). The morning temperatures in the living room in Group 3 were also higher than those in Groups 1 and 2 (16.2°C vs. 14.8 and 17.1°C; $p < 0.001$ and $p < 0.05$).

2) After adjusting for personal factors, a 1°C decrease in night-time temperature was significantly associated with a 0.61 mmHg increase in morning SBP in Group 1, and a 0.92 mmHg increase in morning SBP in Group 2. The temperature in Group 3 did not show a significant association with morning SBP.

6. Acknowledgements

The authors gratefully acknowledge the cooperation of Mr. Masakazu Tsutsumi (Omron Healthcare Corporation), Mr. Keisuke Yamada (Omron Corporation), OM Solar Corporation, and the study participants. The authors are also grateful to Mr. Wataru Umishio, Mr. Naoto Takayama, Ms. Chika Ohashi, and Ms. Eri Honda for their assistance with the data analysis. This study was supported in part by a Grant-in-Aid for Scientific Research (A) (No. 26249083; Principal Investigator: Prof. Toshihara Ikaga).

7. References


A study on development of new-type air cleaner for creating healthy indoor environments

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Abstract

Indoor air pollution caused by the cigarette smoke consists of wide range pollutants is a big problem for threatening human health. Air cleaners are expected as one of effective countermeasures against this environmental problem. However, few air cleaners correspond to various sorts of indoor pollutants. So, we developed new air cleaning method used with additive agents supply system for air pollutants. This new air cleaning method is called as “Mist-wash” technology.

Cigarette smoke includes a great variety of gaseous pollutants and particle-formed pollutants. In present study, we determined the removal performance on the volatile organic and carbonyl compounds included in the cigarette smoke. The air cleaner used with new technology indicated that the VOC CADR was very big and it showed around 150m³/h.

This new air cleaner was confirmed to be effective countermeasure against VOC pollution. And moreover, it turned out that with operation of the new air cleaning method, air cleaner’ removal performance of VOC and formaldehyde was improved up to 87% and 73% respectively.

Keywords - air cleaners, additive agents supply system, air cleaning technology, tobacco smoke
1. Introduction

1.1 New air cleaning system

An additive agents supply system is attracting attention as new air cleaning system. In this technology, liquid agents for deodorization and bacteria elimination are automatically supplied into removal layer (Fig.2), to maintain strong air cleaning performance during a long period. In this system, fixed amount of liquid agents corresponding to odorants and chemical substances are dispensed in additive bottle A and liquid agents corresponding to microbes are dispensed in additive bottle B (Fig.1). For example, in the room where human waste smell and chemical substance are in problem, it is required to remove effectively odor substance such as ammonia, hydrogen sulfide and methyl mercaptan, and chemical substances such as formaldehyde etc. Therefore, the liquid agents corresponding to odor substances and toxic chemical substances such as formaldehyde is put into bottle A.

In addition, bacteria, virus and allergen are trapped in dust collecting filter and bacteria produce unpleasant MVOC (microbial volatile organic compounds). Therefore, the fixed amount of liquid agents for sterilization and inactivation are dispensed in bottle B and are added to the filter regularly and automatically to suppress growth of bacteria, and to prevent production of MVOC and generate or leak of growing bacteria into the room.

1.2 Background and purpose of this study

In a room, air pollution by microbe, suspended particulate matters, odor substances and toxic chemical substances becomes a big problem and expectation for air cleaner is high and the air cleaner capable to remove wide range of air pollutants efficiently is being required. From this kind of circumstance, the authors examined new air cleaning systems and carried out the research and development oriented to air cleaner. In Fig.3, the removal test results of the air cleaner for virus in this study were shown and extremely high removal performance was demonstrated.

Especially, microbe particles such as virus, mite, mould and pollen, and chemical substances contained in cigarette smoke, fatty acid, ammonia and sulfur based compounds contained in body odor and human waste are the substances to be removed.

In present study, problematic cigarette smoke was focused and the removal performance on chemical substances contained in cigarette smoke was revealed.
In addition, the improvement degree of pollutant removal performance of the air cleaner by utilizing the additive agents supplying system was validated.

Fig. 3 Change of virus concentration in the test chamber during operating the Mist-wash technology

1.3 Component and toxicity of cigarette smoke

Cigarette smoke contains various kinds of gaseous and particulate pollutants. Typical gaseous pollutants are carbon monoxide, carbonyls, nitrogen oxide, hydrogen cyanide, ammonia, organic compounds and nitroso amines, and typical particulate pollutants are nicotine and tar\(^1\). The component of cigarette smoke generated from a domestic cigarette were shown in Table 1. It is said that cigarette smoke consists of 4,000 kinds of chemical substances and about 200 kinds of toxic substances\(^2\).

Typical health effects of cigarette smoke are described as following. Carbon monoxide is the cause to introduce deficiency of oxygen, drop of athletic capability and arteriosclerosis. Nicotine makes blood vessel shrink and causes rising of blood pressure. It is highly addictive.

Formaldehyde, benzene and nitroso amines are also included in cigarette smoke and those substances are carcinogenic. More than 60 kinds of other carcinogens have been confirmed.

In present study, removal performance of toxic chemical substances by new type air cleaner was experimentally revealed based on GB/T 18,801-2008\(^3\).
A study on development of new type air cleaner for creating healthy indoor environments

Table 1  Ingredients of the cigarette smoke

<table>
<thead>
<tr>
<th>Component</th>
<th>Main steam smoke</th>
<th>Sub steam smoke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide (mg)</td>
<td>11.6</td>
<td>48.7</td>
</tr>
<tr>
<td>Nicotine (mg)</td>
<td>0.958</td>
<td>5.03</td>
</tr>
<tr>
<td>Tar (mg)</td>
<td>11.8</td>
<td>24.4</td>
</tr>
<tr>
<td>Formaldehyde(μg)</td>
<td>37.9</td>
<td>439</td>
</tr>
<tr>
<td>Acetaldehyde(μg)</td>
<td>560</td>
<td>1689</td>
</tr>
<tr>
<td>Carbonyls (μg)</td>
<td>1087.6</td>
<td>3935.2</td>
</tr>
<tr>
<td>Nitrogen oxide (μg)</td>
<td>128</td>
<td>2080</td>
</tr>
<tr>
<td>Ammonia (μg)</td>
<td>15.5</td>
<td>6701</td>
</tr>
<tr>
<td>Benzene(μg)</td>
<td>25.8</td>
<td>294</td>
</tr>
<tr>
<td>Toluene(μg)</td>
<td>35.9</td>
<td>583</td>
</tr>
<tr>
<td>Organic compounds (μg)</td>
<td>376.87</td>
<td>3880.5</td>
</tr>
<tr>
<td>Nitroso amines (ng)</td>
<td>240.8</td>
<td>269</td>
</tr>
</tbody>
</table>

*Component generated from a cigarette (Moebius, Japan Tobacco)

2. Outline of test

2.1 Test methods

The evaluation test controlled at temperature of 23 ± 1.0℃ and relative humidity of 50 ± 5%RH was carried out using environmentally controllable large-sized chamber conforming to the standard test methods of air cleaner, GB/T 18801.

In removal test of chemical substances contained in cigarette smoke, cigarette smoke was generated in chamber using smoke evacuator (Japan Electrical Manufacture’s Association Standard, JEM1467) and the removal performance of generated chemical substances was evaluated.

In regard to hydrogen sulfide, the gas of fixed concentration was fed from gas cylinder to test chamber and the removal performance was evaluated.
2.2 Measurement methods

(1) VOC was measured by solid-phase sampling-thermal desorption-GC/MS method, using GC, Clarus 500 made in Perkin-Elmer Corp.
(2) Aldehydes were measured by DNPH cartridge-HPLC method, using HPLC, L-2000 series made in Hitachi, Ltd.
(3) Ammonia was measured by absorption bulb sampling-ion chromatography method, using ICS-1600 made in Thermo Fisher Scientific Inc.
(4) Hydrogen sulfide was measured by solid-phase sampling-thermal desorption-GC/MS method, using GC, Clarus SQ8T made in Perkin-Elmer Corp.

2.3 Air cleaner for test

In present study, the new-type air cleaner shown in Fig.4 was used as testing object. High dust collection and gas removal capabilities of this new air cleaner have been recognized in various kinds of tests. The air cleaning characteristics was described as follows.

2.3.1 Filter configuration

First, in present test, the additive agents supply system was not operated and the attached activated carbon deodorizing filter and dust collecting filter were tested. The filter specification is as follows (Fig.5).

- Prefilter: Saran net (546×440×3mm)
- Dust collecting filter: HEPA filter (541×435×65mm)
- Deodorizing filter: activated carbon filter (273×440×30mm)

The activated carbon of deodorizing filter was mixture type at fixed ratio of four kinds of granular activated carbons, which are specified to each absorptions of basic gas such as ammonia etc., acid gas such as hydrogen sulfide etc., volatile organic compounds such as styrene etc., and aldehydes.
2.3.2 Applicable space of additive feeding system

By this system, odors, chemical substances and microbes in all kinds of architectural spaces such as institutions for the aged, medical facilities, play facilities and cohabit houses with pet can be removed, because the liquid agents corresponding to pollutants to be removed are added in removal layer (Fig.6).

![Fig. 6 Adaptation of Mist-wash technology for targeted facilities or pollutants](image)

3. Results and discussion

3.1 Removal performance of chemical substances in cigarette smoke

The chemical substance concentrations in the testing room during operation of air cleaner were shown in Table.2. The very big CADR (clean air delivery rate) of 144 m³/h was obtained for highly toxic benzene and high removal performance was confirmed. For other VOCs, the removal performances equal to or higher than that for benzene were shown.

The formaldehyde removal performance of activated carbon filter used in this study was lower than that for VOCs.

The test results described above were obtained during non-operation of additive agents supply system and removal performance will be improved by the operation of the system.

The test results of VOCs and formaldehyde removal performances during the operation of the system were shown in Fig.7. Depending on the kinds of liquid agents used, the degrees of improvement (recoverability) of removal performances were different. By assuming that the value of removal performance during non-operation of the system was 100, the value for VOCs was increased to 187 and the removal performance for formaldehyde was improved to the value of 143.

In the similar way, the values of 175 for VOCs and 129 for formaldehyde with liquid B and the values of 150 for VOCs and 173 for formaldehyde with liquid C were obtained as the results of removal performance improvement.
Table 2: The CADR of each chemical substance

<table>
<thead>
<tr>
<th>Component</th>
<th>Natural decrease [μg/m³]</th>
<th>During operation of air cleaner</th>
<th>CADR [m³/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-32.5 min</td>
<td>-2.5 min 5 min 12 min 20 min 30 min 60 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td>80</td>
<td>97</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>151</td>
</tr>
<tr>
<td>Methyl ethyl ketone</td>
<td>21</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.1</td>
</tr>
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<td></td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td>Benzene</td>
<td>33</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
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<td></td>
<td></td>
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<td>5.3</td>
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<td></td>
<td></td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td>Toluene</td>
<td>55</td>
<td>49</td>
<td>31</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>17</td>
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<td>8.1</td>
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<td></td>
<td></td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td>Ethyl benzene</td>
<td>14</td>
<td>6.2</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td>m,p-Xylene</td>
<td>18</td>
<td>15</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.9</td>
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<td></td>
<td></td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td>Styrene</td>
<td>11</td>
<td>9.4</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>2.6</td>
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<td></td>
<td></td>
<td></td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N.D.</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>90</td>
<td>87</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>52</td>
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<td></td>
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<td>45</td>
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<td>36</td>
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<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

Fig. 7: The change of CADR on VOCs and formaldehyde with use of Mist-wash technology
3.2 Removal performance of odorants in cigarette smoke

The results of removal performance of ammonia generated in cigarette smoke were shown in Table 3 and Fig. 8, and the results of removal performance of hydrogen sulfide generated from gas cylinder were shown in Table 4 and Fig. 9.

3.2.1 Removal performance of ammonia

While the concentration of ammonia was about 450 ppb which was almost steady before the air cleaner operation, the concentration of ammonia in chamber suddenly decreased by starting cleaner operation and it became one of third of the initial concentration after 30 min. from the start of operation. The CADR indicated of 61.6 m³/h was obtained and the value was significantly larger than values of 5.83~28.7 m³/h reported by domestic manufacturers.

Table 3 Change of ammonia concentration in the test chamber during operating the air cleaner

<table>
<thead>
<tr>
<th>Component</th>
<th>Ammonias concentration[ppb]</th>
<th>CADR [m³/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural decrease</td>
<td>During operation of air cleaner</td>
</tr>
<tr>
<td></td>
<td>-32.5min</td>
<td>-2.5min</td>
</tr>
<tr>
<td>Ammonia</td>
<td>443</td>
<td>446</td>
</tr>
</tbody>
</table>

Fig. 8 Change of ammonia concentration in the test chamber during operating the air cleaner
3.2.2 Removal performance of hydrogen sulfide

While the concentration of hydrogen sulfide was about 1 ppm which was steady before the air cleaner operation, the concentration of hydrogen sulfide in chamber suddenly decreased by starting cleaner operation and it became one of forth of the initial concentration after 10 min. from the start of operation. The air cleaner in present study showed the removal performance of CADR was 200 m³/h.

Table 4 Change of hydrogen sulfide concentration in the test chamber during operating the air cleaner and CADR

<table>
<thead>
<tr>
<th>Component</th>
<th>Hydrogen sulfide concentration[ppm]</th>
<th>CADR [m³/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural decrease</td>
<td>During operation of air cleaner</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>-30min 0min 5min 10min 20min 30min</td>
<td>200</td>
</tr>
<tr>
<td>Natural decrease</td>
<td>1.0 1.0 0.53 0.28 0.07 0.05</td>
<td>200</td>
</tr>
</tbody>
</table>

Fig. 9 Change of hydrogen sulfide concentration in the test chamber during operating the air cleaner

Generally speaking, it was recognized that the odorants such as ammonia and hydrogen sulfide were difficult to be removed by air cleaner[6,4]; however, it was revealed that the air cleaner used as testing object in this study had high odorant removal performance. In the air cleaner in this study, the filter in which the activated carbons corresponding to basic gas and acid gas were mixed at fixed ratio, and the additive feeding system is installed to improve removal performance of pollutants such as odorants. However, the system was not operated in present study. The removal performance will be improved by the operation of the system.

3.2.3 The effect of additive feeding system

The improvement degrees of removal performance of ammonia, hydrogen sulfide and acetaldehyde were shown in Fig.10 when the additive feeding system was operated.
4. Summary

The test of air cleaner installed the additive agents supply system which is attracting attention as novel air cleaning technology was carried out and the following results were obtained.

1) New type air cleaner showed high removal performance for toxic chemical substances derived from cigarette smoke, even without the operation of the additive agents supply system. The removal performances for VOCs, ammonia and hydrogen sulfide were measured as the clean air delivery rates (CADR). The values of 150 m$^3$/h for VOC, 61.6 m$^3$/h for ammonia and 200 m$^3$/h for hydrogen sulfide were obtained and high removal performances were confirmed.

2) When the additive agents supply system was operated, the removal performances for formaldehyde, VOCs, ammonia, hydrogen sulfide and acetaldehyde were improved.

3) Depending on the kinds of liquid agents used, the degrees of improvement (recoverability) of removal performances were different. By assuming that the value of removal performance during non-operation of the system was 100 %, the value for VOC was increased to 187 % using liquid A and the removal performance for formaldehyde was improved to the value of 143 %.

In the similar way, the values of 175 % for VOCs and 129 % for formaldehyde with liquid B and the values of 150 % for VOC and 173 % for formaldehyde with liquid C were obtained as the results of removal performance improvement.

5. References

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Abstract

In Australia, residential buildings accounted for about 20-30% of the total electricity consumption and 30-50% of the total peak demand. The residential sector is considered as one of the fastest growing GHG emission sources and considered as the 'lowest hanging fruit' for carbon mitigation. It also plays a key role for the management of peak demand of the grid.

Starting from 1950s, scientists from CSIRO have been developing methodology and models (tools) to simulate building performance, particularly for residential buildings, including AccuRate for residential building thermal performance design and energy star rating, AusZEH design tool for overall residential building energy design and retrofit. In this study we will give a review of these tools, including the ideas and methodology behind the development of the tools. The validations and case study of the tools will also be presented.

Originality - A brief review of tools developed in CSIRO for building performance simulation.

Keywords - Thermal performance simulation, residential building, Chenath engine, AccuRate, AusZEH design tool
1. Introduction

40% of global energy and 25% of global water are used in buildings and the building sector is the largest contributor to global greenhouse gas (GHG) emissions (http://www.unep.org). In Australia, approximately 20-30% of the state electricity is consumed in residential buildings. The residential buildings offer the greatest potential for achieving GHG emission reductions.

Energy consumption in buildings is dependent upon the building energy performance, installed equipment and appliances, occupant behaviour and local climate. To investigate potential energy savings in buildings, we have two options: empirical (monitoring) study and modelling. Empirical study can only be used for existing buildings. They are normally time-consuming and expensive. Compared to monitoring study, modelling simulation is cheaper and quicker to be used for new and existing buildings. Worldwide, hundreds of tools (models) have been developed for building energy performance simulation (www.buildingenergysoftwaretools.com).

To understand fundamental of building energy performance, scientists of CSIRO put decades of effort in the development of methodologies and tools for building simulation. Building thermal performance simulation tools can be classified into two groups: one based on finite difference technique and another on response factor analysis, which are described in the following.

2. Models based on finite difference techniques

Program TEMPER (Wooldridge, 1970), based on a finite difference method, calculates the sensible and latent air conditioning loads of space heating and cooling for a specified indoor air condition (air temperature and humidity) within a building, or alternatively, the indoor air conditions given a specified heating or cooling effect. The indoor air temperature is derived from a heat balance on the enclosure or zone, which is defined as a volume of air within the building envelope that has a uniform air dry bulb temperature. Twenty zones are permitted.

Heat flows to the indoor air are convective in nature, which include:
- from all internal surfaces to air;
- from all internal sources (e.g., people, lighting) to air;
- outdoor to indoor heat transfer through infiltration or ventilation.

The model can predict hourly load or temperature profile.

BUNYIP is an extended version of TEMPER to model various installations within commercial buildings (Moller and Wooldridge, 1985). A flexible component-based air-handling system model is developed to model many different system types. Chillers and boilers can be configured in many ways in the plant model. To reduce run time, BUNYIP uses a reduced weather data set, derived from several years of actual weather data. The user can select from up to ten output reports covering performance and diagnostics, and view the results using the spreadsheet interface.

Since BUNYIP was first released in 1984, it has been progressively improved, tested and refined. Energy Express is the latest release of BUNYIP, which includes a graphic user interface and many new features and retains the simulation “engine” (Moller, 2006). Energy Express has two versions: Energy Express for Architects (EEA) and Energy Express for Engineers (EEE). Both versions offer:
- Ability to compare a range of alternative designs;
- Uses a reduced weather data set (actual weather data recorded for several years) to reduce run time;
- A simple air conditioning model for architects to evaluate building envelope designs without requiring detailed information on the air-conditioning;
- Windows user interface - to make data input easier and quicker;
- 2D CAD facility- for geometric data input and editing.
Ren, Z. Tools developed in CSIRO for building design and thermal performance evaluation

Energy Express for Engineers offers extra features:
- Peak load calculation for sizing equipment;
- A customizable detailed HVAC model more suitable for design engineers;
- Graphic editing of air handling system layout;
- Use the thermal plant model to configure boilers and chillers in different ways.

Energy Express is a computer program for calculating energy consumption and peak demand of air conditioning in commercial buildings. However, Energy Express is not an optimisation tool (i.e., it cannot calculate the "optimum" energy efficient design nor recommend an improvement strategy. Rather, it assist the designer in moving toward such a design by evaluating performance). Some HVAC systems, such as active solar heating, ground source heat pumps, in-slab heating/cooling, and radiant heating systems, are not included.

For Energy Express, the major problem involves simplifying calculation of heat transfer through an opaque element (such as a wall) by a finite difference method using invoking homogenisation, which may cause inaccuracy in some circumstances (Delsante and Ren, 2007). It would require a new implementation of the finite difference method to eliminate the homogenisation issue in Energy Express. The new version of Energy Express will also need be validated via BESTTEST (Judkoff and Neymark, 1995). These two major jobs have not been completely yet due to resources shortage.

3. Models based on response factor analysis

In 1953, Roy Muncey, from Division of Building Research (CSIRO, Melbourne), published a paper "Calculation of temperatures inside buildings having variable external conditions" in the Australian Journal of Applied Science. The paper described the response factor technique for one-zone building. Since then, Muncey and his colleagues made further development of the theory of the response factor technique for simulating the thermal performance of buildings (Muncey, 1963; Muncey and Spencer, 1966; Muncey and Spencer, 1969; Muncey, Spencer and Gupta, 1970; Walsh and Delsante, 1983). In the response factor method, each building element is treated as a multi-layer slab. The frequency response of the slab is calculated via matrix multiplication over the range of frequencies for which the response is non-zero. In the frequency domain, a heat balance is applied for each zone, giving the zone frequency response to sinusoidal external drivers (e.g. outdoor temperature). The frequency response is converted to a zone transient response via linear system theory. The outdoor temperature, solar radiation, and other heat flow drivers are approximated as a series of the transient response of a unit step or triangular pulse, which can be easily derived.

Based on the work mentioned above, the following related programs were developed:

CARE- A harmonic analysis/synthesis method suitable only for hourly calculations up to about one month in length;

STEP- The response factor technique developed by Muncey in 1960s for single zone buildings and climatic data input only from ‘cards’;

SUSTEP- A more efficient version of STEP. All four walls (N-E-S-W) are of the same material and all four windows are of the same material. Therefore computing time is reduced;

ZSTEP- Further development of STEP by Walsh and his colleagues for the simultaneous calculation of the thermal performance of up to ten zones in a building. For a given building and location the program calculates hourly energy consumption and temperatures of the zones when real or synthesized climatic data are used over as long a period as required. ZSTEP can be used for both residential and commercial buildings, although the heating and cooling modes were developed mainly for residential buildings (Delsante and Spencer, 1983).
In 1993, Nationwide House Energy Rating Scheme (NatHERS) was initially as a result of a commitment by Australia’s Commonwealth, State and Territory governments to improve the energy efficiency of buildings, as part of their Greenhouse Response Strategy. At that time the scheme was identified as the House Energy Rating Scheme (HERS) and aimed to provide a standardised approach to rate the thermal performance of Australian houses. The rating would be based on the computer simulation of the building, using hourly calculations over a full year, which was decided quite early in the development process. The CHEETAH package, further development of ZSTEP by CSIRO Division of Building, Construction and Engineering (the version of ZSTEP3 used as the core of CHEETAH) (Delsante, 1987), was chosen as the basis of the simulation tool. The improvements to the glazing model and the modelling between a concrete slab floor and the ground were made to the CHEETAH thermal engine (Delsante, 1997). The original software tool, which was also known as NatHERS, was released in 1994 with the simulation engine named as Chenath (taken from CHEETAH and NatHERS). NatHERS was adopted in 2003 as the benchmark simulation tool for compliance to newly established energy efficiency standards of BCA (Building Code of Australia) (NatHERS, 2015).

In 2005, the Chenath engine was significantly improved and was incorporated into the first commercial release of the approved 2nd generation benchmark software, AccuRate, in 2006. AccuRate is a greatly improved version of the software NatHERS (Delsante, 2005). The key improvements include improved natural ventilation modelling (Li, Delsante and Symons, 2000), user-defined constructions, improved modelling of roofspaces, sub-floor spaces, skylights and horizontal reflective air gaps, and the availability of many more zones. AccuRate was tested against the other major international software models using BESTTEST (Delsante, 2004). Figures 1 and 2 gives the results for annual heating energy of the base buildings with lightweight walls & floor and heavyweight walls & floor, respectively. The results for heating energy are quite satisfactory. The results of annual cooling energy of the base building with lightweight walls & floor and heavyweight walls & floor are shown in Figures 3 and 4, respectively.
Figure 2 High-mass annual heating energy. The reference program ranges are shown as horizontal lines (adopted from Delsante, 2004).

Figure 3 Low-mass annual cooling energy. The reference program ranges (where set) are shown as horizontal lines (adopted from Delsante, 2004).
The results of annual cooling energy are on the high side but also satisfactory except for case 920, which is slightly above the reference range. In general, the AccuRate simulation engine agrees well with the reference programs.

During 2007-08, the natural ventilation model was significantly improved (Ren and Chen, 2010), including globally convergent method used to replace the Newton-Raphson method for solving the non-linear pressure equations; density variation and mass conservation incorporated in the new air flow model; and the engine convergence stability improved greatly by solving technical issues related to the existing ventilation model (See Table 1). The new air flow model has been incorporated in the current Chenath engine.

Table 1: Convergence test results

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Hours simulation diverged</th>
<th>Hours simulation run out of iteration limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Engine</td>
<td>New Engine</td>
<td>Existing Engine</td>
</tr>
<tr>
<td>House No. 1</td>
<td>733</td>
<td>0</td>
</tr>
<tr>
<td>House No. 2</td>
<td>31</td>
<td>0</td>
</tr>
</tbody>
</table>

AccuRate Sustainability Tool is a major upgrade of the AccuRate tool, which supports two working modes (rating mode and non-rating mode). Currently, only the building envelope energy rating is legislated and therefore included in the regulatory mode (i.e. rating mode). In non-rating mode, new sustainability assessment modules have been incorporated, including lighting (Ren and Chen, 2009), hot water (Ren, Chan and Chen, 2009a), water (Ren, Chan and Chen, 2009b), space heating and cooling (Chen and Chan, 2011a, 2011b).

AusZEH design tool was developed for low/zero carbon house design/retrofit considering building envelope, installed equipment and appliances, occupancy profiles and local climate (Ren et al., 2014). The Chenath engine was modified for short time-step calculations (such as half-hour) as it
required, and also for new features related to the building operations in practice, such as thermostat setting of timing and temperature for air conditioning. Modules on appliances, hot water, water, lighting and occupancy profiles have been developed and implemented into the tool for design purpose. AccuRate user interface (GUI) was also upgraded to accommodate the new features. Module of PV battery system has also been developed recently to analyse the impact of the new technologies on the housing energy reduction (Ren, Grozev and Higgins, 2016).

4. Summary

Starting from 1950s, scientists from CSIRO spend decades of effort to develop methodology and tools to understand and evaluate building thermal performance and energy consumption of buildings. With the culmination of decades of research by CSIRO, AccuRate becomes the NatHERS benchmark software for energy rating in Australia. Chenath engine is the endorsed calculation engine used by AccuRate to predict thermal flows within residential buildings.

For the purposes of building design and estimation of whole building energy consumption, Energy Express and AusZEH design tool were developed for commercial and residential buildings respectively, although there is room for improvement, especially for Energy Express.

5. References


Housing design for temperate climates: the priority to energy sufficiency

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Abstract

Building physics is a well-established field of knowledge. Still, that is yet to be consistently translated into practice through state-of-the-art performance, exploring the potential of adaptive comfort and passive thermal behaviour to excel in terms of energy sufficiency in a dialogue with the local climate.

This is particularly relevant and well suited in temperate climates, where forefront knowledge for the past 40 years shows it is straightforward to build houses offering healthy and comfortable environments with no or very little need for additional heating and, even less, cooling, while also dismissing the need for active systems. This means exploring the building’s sufficiency even before caring about the efficiency of possibly unnecessary ‘add-on’ equipment.

A consistent approach to building design must be adopted in which constraints and parameters with highest impact on the building’s performance in its location and climate are set right from the start of the design process. Those can be, either, fairly location-agnostic (e.g. insulating from the outside while keeping thermal mass indoors), or, definitely, location- and climate-driven (e.g. window sizing and orientation), while others still more occupant- and activity-related (e.g. setting requirements for effective adaptive comfort and healthy building operation).

Only a holistic understanding and definition of those parameters in the pre-design stage can guarantee that the subsequent design explores the full potential for energy sufficiency and comfortable and healthy environments.

This paper will explore the above, proposing a rationale towards a better housing building stock, and demonstrating the enormous potential for low-energy housing for millions of citizens.

Keywords – Sufficiency; energy; residential buildings; conceptual design; constraints
1. Introduction

In addition to being solid and durable, buildings must also provide safe, healthy and comfortable environments to their occupants. From a structural perspective, long-held knowledge of construction technologies and materials have allowed buildings to stand easily for several decades, or even centuries, with barely any maintenance or concern. On the other hand, the design of healthy and comfortable interior spaces still faces the challenge of wisely adapting buildings to their local climate while also keeping in mind the cultural factors inherent to all architectural expressions. And this has become ever more important with the advent of pernicious influences on architectural and construction solutions between very different parts of the world.

In locations with severer climates, i.e. cold or hot/humid, it is difficult for a building to achieve comfort conditions on its own; therefore, designing formulas tend to follow a set of well-known strategies. For instance, in Northern European countries, good building design calls for high insulation, tight envelopes and mechanical ventilation with heat recovery (among other aspects). Conversely, in hot and humid climates, air conditioning and closed windows are an almost certainty. In these cases, indoor/outdoor difference is generally too large to be feasibly tackled by passive solutions alone, and, consequently, the use of ‘add-on’ equipment for heating and/or cooling becomes imperativer. The conditions offered by temperate climates, however, call for a different approach.

Proper attention to the local climate should result in architectural options and constructive solutions that promote a significant reduction of heating and cooling needs through the careful use of building physics. When properly explored in temperate climates, this should result in smaller or even no thermal equipment/systems being required to fulfill the specified comfort needs. This approach has been called ‘energy sufficiency’ and should be prioritized to the ‘energy efficiency’ associated to the energy equipment or systems (Fernandes, 2016).

The sufficiency approach has been briefly discussed by both the 5th Intergovernmental Panel on Climate Change Report (Lucon, 2014) and the International Energy Agency’s report on ‘Modernizing Building Energy Codes’ (IEA, 2013). In the former, it is pointed out that current indicators refer too much to ‘efficiency’ instead of ‘sufficiency’ and, in the latter, that energy sufficiency must be the first design consideration in the path towards low-energy and low-carbon buildings. When applied to building design, the sufficiency approach prioritizes solutions that reduce and fine-tune the building’s energy needs, towards a minimization of CO₂ emissions, therefore, contributing to the global sustainability.

As part of the strategy to achieving energy sufficiency, the adaptive concept for comfort (ASHRAE, 2004) has shown that, in many cases, buildings may provide adequate comfort conditions to occupants without the need for heating or cooling systems (Matias et al., 2009; Roulet, 2005; Clausen, 2003). This outcome, which is particularly relevant to buildings in temperate climates, results from the linear correlation observed between the indoor comfort temperature in naturally acclimatized buildings and the outdoor temperature (Nicol, 2002).

While building designers should properly address the building’s thermal aspects, evidence shows that this is yet to be done correctly and consistently. One of the main culprits is the fact that building thermal assessment is generally performed only after the architectural choices have been essentially established, i.e. at an advanced point of the building design process. At this late stage, the most important decisions have already been made and it is generally too late to change the design significantly.

This paper revisits results published elsewhere (Pereira, 2016) and goes beyond the analysis there presented in questioning the strategies and tools that can help address the above issues, particularly by exploring the ways building design for energy sufficiency should consider the site’s and the building physics’ constraints and potentialities, all while using a simple and accessible language and methodology that can be applied right from the initial design stages.
2. Methodology

The methodology used in this work has been previously described in detail (Pereira, 2016). In summary, a standard assessment procedure, namely the one formerly used in Portugal in the Building Energy Certification System (RCCTE, 1990), was used as a basis of calculus to estimating the heating and cooling needs in a number of representative reference architectural spaces, and conducting a sensitive analysis over particularly relevant design parameters.

All the reference spaces have the same internal volume (300 m³) but differ in their façade’s thermal conductance ranging from 1.12 to 0.18 W/°C.m². This is modelled through different conditions of thermal insulation in walls and/or roof, or by assuming a different number of walls in contact with the exterior, for instance, the reference space can be modelled as if it was above or below or right next to one or more heated spaces). Windows are assumed as standard double-glazing and air infiltration is assumed at an average 0.6 ACH⁻¹ (or about 200 m³/h), both fairly typical for recent construction solutions in Portugal without particularly airtight envelopes.

From a large number of possible design parameters, an early analysis and mapping of their impacts in the building’s thermal performance picked up five as being of particular relevance and, hence, were the ones explored in this work, namely:

- thermal insulation – here explored through the façade’s thermal conductance, as discussed above;
- thermal inertia – defined by the amount of exposed internal thermal mass and categorized as either “heavy” or “weak” according to the standard assessment ranges;
- window orientation – particularly relevant in terms of north and south;
- window size – defined as a percentage relative to the floor area and ranging from 5% up to 40%;
- window shading – two conditions analysed, either very little shading through internal curtains or high shading through opaque external shading devices.

Portugal has a temperate/moderate climate all-around, serving as a good basis to model the buildings’ performance in this type of climate. Figure 1 shows Portugal’s location within the world map coloured according to the Köppen climate classification (Peel, 2007). Despite being almost fully covered by Mediterranean type climate (Csa and Csb in the Köppen classification), there are variations in local climates that are relevant to explore. Thus, architectural spaces in four distinct
cities were modelled within the sensitivity analysis (also shown on the right-hand side in figure 1), namely:
- Bragança: coldest winters, mild summers (continental influences);
- Évora: cold winters, hottest summers (continental influences);
- Porto: mild climate all year-round (oceanic influences);
- Lisboa: warm winters, hot summers (oceanic influences).

Only the most relevant aspects and observations for a limited number of combinations of these parameters are presented and discussed here.

3. Results and discussion

Figure 2 shows the results for estimated annual heating and cooling needs for each location while varying the façade's conductance and window size. Thermal inertia is set to “heavy”, windows face south and are lightly shaded internally. This is a fairly common occurrence in typical Portuguese buildings. Some observations are immediately evident:
- As expected, the coldest climate (Bragança) presents the highest heating needs while the warmest climate (Évora) presents the highest cooling needs;
- Buildings with lower façade conductance (darker curves in figure 1) always present lower heating and cooling needs but the impact is significantly higher for heating (e.g. heating needs are cut by about 2/3 when the façade’s conductance is reduced from 1.12 to 0.18 W/m².°C, regardless of climate); however the impact on cooling needs is fairly small;
- Larger windows facing south always result in a reduction of heating needs but, conversely, lead to higher cooling loads in the absence of adequate external shading thus resulting in excessive solar gains in the summer;
- The lowest total thermal energy needs are found in Lisboa for spaces with very low glazed areas (lowest heating needs due to warm winters and low cooling needs due to small windows); however, the situation is inverted when bigger windows are used, in which case Porto becomes the best case (it gains significantly from having larger windows in terms of heating needs reduction and the impact of solar gains in the summer is lower than in Lisboa).
One of the biggest benefits of a temperate climate comes from the large potential for useful solar gains which frequently are enough to reduce heating needs to essentially zero in well-designed spaces. That much is illustrated in figure 2 where the heating needs curve for the best insulated space reaches zero (or comes close) in all the tested locations.

However, those same solar gains can very quickly become detrimental if solar shading is not adequately considered. Figure 3 illustrates this for two of the locations (Porto and Lisboa), for simplicity. In the exact same conditions as before but now considering external and opaque solar shading during periods of excessive solar radiation, the cooling needs are drastically reduced, potentially reaching a point where comfort can be guaranteed by simple actions by occupants (e.g. cross-ventilating spaces or using a simple indoor fan). In fact, this result shows how simple construction (e.g. brick or concrete) with good external insulation, standard heavy thermal inertia (i.e. no light materials such as plasterboard or wood covering the internal walls) and without any mechanical ventilation, heat recovery, air-tightness or other extraneous solutions can easily result in a building whose total thermal needs stay below 10 kWh/m².year in a temperate climate.
The proper consideration to window size and orientation in temperate climates becomes even better illustrated by a scenario where openings are oriented towards north (i.e. no direct solar radiation can get inside during winter and only very little can during the summer in the Northern hemisphere), as shown in figure 4. In this case, as expected, bigger window openings directly correlate with significantly increased heating needs. On the other hand, while cooling needs are reduced when compared to the scenario with the windows facing south, the gains do not quite reach the same values as using proper external shading.

Lastly, thermal inertia is another of the parameters that has significant importance in achieving thermal comfort in temperate climates, particularly in places with large daily thermal amplitudes, as the case of the locations with continental influences, farther from the thermal levelling effects of the sea, here represented by Bragança and Évora. When comparing a scenario with weak thermal inertia, shown in figure 5, with the one with heavy inertia in figure 2, the effect becomes clear when the windows are bigger. In particular, the heat storage capacity of the space becomes saturated past a certain point and extra solar gains through bigger windows no longer result in decreasing heating needs. While not as visually obvious, there is a similar impact in the cooling needs, which are slightly raised at the largest window sizes.
While not particularly innovative, these results intend to illustrate in a very simple and straightforward way how a very simple methodology can be used to assess particularly relevant design parameters. They show how even within a small country like Portugal, the buildings’ thermal performance is still quite sensitive to some of the broad options made during its design. When the thermal performance assessment is performed only after the design has been mostly set, the opportunity to make significant changes is rarely there and, when that happens, the usual outcome is to compensate for the design’s weaknesses by installing HVAC equipment. In temperate climates, as here shown, this is frequently not required if only the buildings are designed properly. Thus, it should become standard practice to perform this sort of assessment, based on applying the existing tools for building energy certification (or similar) on simplified reference spaces, to assess local potential for passive design, even before any design comes to mind.

 Furthermore, by knowing which constructive solutions offer the best chances to explore the site’s potential, the architect can eliminate, right from the start, conceptual designs that will likely not meet the requirements for good thermal performance. Still, within this framework there will be a large number of designs and innovative solutions to explore but always with a higher probability of the final design having a good thermal performance.

 Going further, the potential for this sort of analysis can be seen even more broadly, not only from a building design perspective but also from an urban planning perspective or even from a regional regulation (or best practices recommendations) point of view. The analysis is agnostic enough to be generally applicable to a number of locations within a region, where climate and orography are similar, notwithstanding the fact that each building design will still have its specific constraints and that its relationship with its particular site should be carefully analysed within this framework. It can also help better inform urban planners in terms of valuing the buildings’ energy sufficiency potential in a certain area, particularly by keeping in mind the possible orientations of façades, distances and solar obstructions between buildings, etc.

 It is too common for regulations and recommendations to be set nationwide (or even at international level as frequently seen within the EU), and this almost always ends up being inadequate in most locations. In fact, either the regulations are too broad to really direct the local practice in any particular direction or, conversely, are too prescriptive or detailed and thus only really appropriate to a minority of the locations. If within a small country such as Portugal, large differences can be found between different design constraints, then these will be even more pronounced between very different climates. While the most recent recast of the European Performance of Buildings Directive (EPBD, 2010) tries to take into consideration the local realities of each country, it does not go far enough and, instead, should aim at promoting clear standard practices within regions that can guarantee that the regulations and construction practices are the best at, first, guaranteeing energy sufficiency of the building stock, and then, second, promoting high energy efficiency of the equipment (where needed). This is not expected to be corrected in this year’s second recast. Furthermore, the current designation of nearly zero energy buildings (nZEB), used in the regulation, is not clear enough and does not convey the best message. While it correctly aims at promot-
ing a priority to the reduction of energy needs, followed by high energy efficiency of equipment and, lastly, promoting the use of local renewable energy sources (which seems close enough to the message this paper tries to convey above), the fact is that it is not clearly stated in this way, leaving the definitions of the concept to each of the member states and failing to create a methodological infrastructure that can guarantee a high quality building stock. The work here presented demonstrates that this purpose is easily achievable with the already existing tools and knowledge.

4. Conclusion

Standard building assessment tools are now common in many parts of the world and consist of simple tools and calculation methods with which one can easily estimate the thermal performance of buildings. By using this framework over a simple reference space within a particular location, one can easily run a sensitivity analysis in regards to particularly relevant design parameters and thus constrain them into the best ranges. In the same way a design is constrained by local orography, urban planning and construction rules, it should also be informed by these in order to maximise the local potential for the building’s energy sufficiency and, consequently, act locally towards a better building stock and globally for a lower environmental impact.

While this strategy helps optimising the building design process towards achieving better thermal performance, it can also be used in a broader way in informing local and national authorities and professionals about the local potentials for a better building stock, and helping them think and assess some of the construction and design solutions that are most appropriate to a particular location and climate. Hopefully, this will work on top of the globalization of knowledge, materials and construction technologies, helping adapt alien construction and architectural practices into the local reality and thus avoiding some of the gross mistakes that have been seen far too often all throughout the world.

5. Acknowledgments

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6. References


Research on Rural Heating Design Temperature Based on Residential Behavior Pattern

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Abstract

Purpose / Context - Rural heating design temperature is closely related to building thermal performance design, indoor plain layout and energy consumption.

Methodology / Approach - Focus on residential behavior pattern, this paper studied the rural heating design temperature based on the site research.

Results – Firstly, a site research is carried out taken rural region in south Liaoning province as an example, which in terms of the plain layout of yard and interior, residential behavior, residential clothing and activity, indoor thermal environment, residential thermal sense and so on. Secondly, based on site research, the influence of current residential behavior pattern on their clothing and activity intensity is analyzed. Thirdly, the subordination relation curves between indoor temperature and thermal sense subsets are established by means of fuzzy theory.

Key Findings / Implications – Based on maximum membership principle, rural residential heating design temperature is determined. And it is from 12 to 16 centigrade for master room.

Originality - This paper will offer theoretical foundation to the design of heating system in rural new rural construction.

Keywords - behavior pattern, heating design temperature, fuzzy statistics, thermal comfort, thermal sense
1. Introduction

With the advancement of society and improvement of living standard, people have higher requirements on indoor thermal environment (Guo and Wang, 2008; Li, Liu and Yao, 2007; Wan and Song, 2007; Wang, Y. Liu, J. Liu and Wang, 2010). Indoor thermal environment has a close relationship not only to human comfort and health, but also to building energy consumption and pollutant emission, even the sustainable development of resources. However, there still exist many rural residences with low indoor temperature in winter in China, which caused by the below reasons. One is the serious cold air infiltration and cold radiation caused by the worse thermal performance of building envelope and the unreasonable plain layout. The other is the low energy efficiency. Furthermore, the energy supplied to room is low for the restriction of residential economy (Ma, Shao, Zhang, Zhou, Liu and Tang, 2015). To improve indoor thermal environment, it is necessary to optimize thermal performance of building envelope, indoor plain layout and heating system. And the optimization degree is decided by the heating design temperature.

Urban residential heating design temperature ranges from 16 to 24 centigrade, which is required by standards (Ministry of Construction, PRC, 2003). However for the difference in life mode and behavior pattern between rural and urban, urban heating design temperature cannot be applied to the rural residence. How to determine rural residential heating design temperature? Against this problem, many researches were made in China. Jin Hong (Jin, Zhao and Wang, 2006) researched current situation of rural residence in severe cold area and the difference in thermal comfort between rural residents and urban residents. She integrated investigation data analysis, theoretical calculation and the rural development tendency, suggesting that the heating temperature should be from 15 to 18 centigrade. Taking Yinchuan as an example, Zhu Yiyun and Liu Jiaping (Zhu and Liu, 2010) analyzed factors that influence indoor thermal environment on the basis of the local residential characteristic, peasants’ life habit and clothing and heating system. They proposed the indoor thermal environment indicator that is suit to rural residence in northwest. Focus on serve cold area, Zhang Wei (Zhang, 2012) proposed indoor heating design temperature based on the use time and interior plain layout through combing the development tendency of yard and the calculation on subjective temperature. Zhang Yufeng (Zhang, 2015) investigated rural residential life habit and thermal behavior. He proposed the acceptable temperature respectively suitable to different ventilation measures, which provides theoretical basis to the design of passive and active building in hot summer and warm winter area.

Furthermore, a series of rules were published by Ministry of Housing and Urban-rural Development. Energy saving technical guidance to rural housing in severe and cold area published in 2009 presents that heating temperature in master room is from 14 to 18 centigrade. Design standard for energy efficiency of rural residential buildings published in 2013 presents heating design temperature in master functional room is 14 centigrade (MOHURD, 2013). This standard provides basis to the energy-saving design of rural construction.

Rural heating design temperature aims to provide people with comfort indoor thermal environment. Its value is determined by residential thermal sense. Except environment temperature, residential clothing, activity and expectation also have influence on residential thermal sense. Those factors have a close relationship with residential life mode, behavior and daily routines. In other word, residential life mode, behavior and daily routines decide their clothing and activity, further affect the determination of heating design temperature. However in existing researches, most are in terms of thermal sense, clothing, activity intensity, indoor temperature. They hardly refer to residential behavior pattern that decides people’s clothing, activity intensity and thermal sense, which cause them fail to reveal the basis of determining rural heating design temperature.

Therefore, it is necessary to make research on rural heating design temperature from the prospect of residential behavior pattern. On the basis of rural site research in south Liaoning province, this paper discusses the method of heating design temperature based on residential behavior pattern.
2. Study on residential behavior pattern

A site research on 5 rural residences in south Liaoning province was carried out during 23 January to 27 January. To have a general grasp of residential life mode, activity and clothing, comfort demand on indoor thermal environment and so on, researchers live with residents in their houses during the investigation. Through measurement and communication with residents, rural residential basic information, production mode, and local cultural tradition were gained. Residential activity routines were learned through continuous record on their activity and clothing in yard by monitor system. In addition, to acquire the thermal environment condition, a continuous temperature test on different function room was made. At the same time, questionnaire investigation was carried out, including residential age, sex, activity room and intensity, clothing and thermal sense on surrounding environment.

2.1 Rural residential plain layout

2.1.1 Rural residential plain layout of interior

In research district, rural residences are unified constructed by the government, with the same areas and plain layout. Figure 1 gives rural residential indoor plain layout. In addition to the common rooms that can meet residential basic living requirement, such as bedroom and kitchen, there are also other functional rooms, such as washing room, living room, dining room and so on. In general, the function of rooms is relatively perfect.

![Figure 1 Rural residential indoor plain layout](image-url)

2.1.2 Rural residential plain layout of yard

An obvious characteristic of yard in rural residence in south Liaoning province is spacious, with the length of 15 meter and the width of 12 meters. Figure 2 portrays typical yard scene in local rural residence. A path of red brick lies between the outside door and the entrance to house as the main passageway to residence. Two open spaces are respectively beside the path used for growing vegetables, feeding poultries, storing firewood and so on. The plain layout of different residences varies with residential habit, but it is essential consistent for the existence of vegetable garden, poultry ring, straw heap and so on, which is decided by residential life style and habit.
2.2 Residential behavior pattern

2.2.1 Residential activity routines and clothing in yard

Based on residential activity in yard and inside the house, their behavior can be divided into three types, Busy type, Going-out type and House-oriented type.

For residents of Busy type, the notable characteristic is that they go out of the house frequently during the whole daytime and they spend more time out of the residence than inside the residence. For the long time of staying outdoors, to keep warm they have to wear thick and the clothing hardly changes in a day. Figure 3 shows the typical residential activity time and clothing in yard in a day. The horizontal axis is time and the vertical axis is the duration time in yard.

For residents of Going-out type, the notable characteristic is that they are not inside the residence or in the yard in most time during the day. They usually go home at meal and go out after dinner. Their activity and clothing status are given in Figure 4.
For residents of House-oriented type, they spend most time doing housework and recreation inside the house during the whole daytime but they go to the yard frequently in three time bucket, respectively in morning, at noon and at dusk. This is decided by the mode of cooking, heating and production. In rural district of south Liaoning, cooking and heating have a close relationship. The high-temperature flue gas generated by cooking flows into Kang to supply heat to room and the heat source is biomass energy, such as straw and firewood. Heating radiator as the other heating system is equipped in some residences and its heat source is coal. During the cooking in three time bucket, people need to go to the yard to take wood. And they usually take coal at the same time for convenience. In addition, they need to feed poultry before or after the meal. All of these decide that residents need shuttle indoor and outdoor frequently.

Figure 5 gives the typical House-oriented residential activity and clothing status in yard. According to the statistics, people stay in yard within a few minutes every time. However they still wear thick for the low outside temperature. Owing to the fact that they shuttle between indoor and outdoor frequently, so it is not convenient for them to frequently put on or off coats. Based on this reason, there is a little change on residential clothing no matter they are indoor or in the yard in a day. And they still wear thick even indoors, only at noon when indoor temperature reaches the highest, they may take off coat.

2.2.2 Residential activity routines in interior

Kang, which is used for rest, entertainment, having dinner and so on, is the master activity space in countryside of the northeast China. And master bedroom with Kang is the room where people stay at most times. Based on the investigation data, residents stay in master bedroom almost 17 hours, even to 20 hours. Figure 6 gives the percent of residential activity duration in different functional rooms.
3. Determination of rural heating design temperature

In rural residence, the duration time that people stay in master bedroom is longer than they stay in other rooms, and the activity intensity is lower. Therefore, people have higher demand on heating temperature in master bedroom. Taking master bedroom as an example, this paper studied the method of determining rural residential heating design temperature.

Heating design temperature is decided by residential thermal sense which is a fuzzy concept with large fuzziness. The first step to evaluate fuzzy concept is to divide the fuzzy grade. In present researches, ASHARE 7 point scales are widely adopted. And -3, -2, -1, 0, 1, 2, 3 represent for the grade of thermal sense, respectively represents cold, cool, slightly cool, moderate, slightly warm, warm, hot. Owing to the difference in linguistic expression and comprehension between English and Chinese, it is hardly to distinguish the limits between the contiguous thermal sense grades for Chinese. Therefore, the description of thermal sense should be easy to understood and chosen by residents. And thermal sense of groups who are served by the environment for a long time should be used to describe and evaluate environmental thermal comfort rather than thermal sense tested by researches. In this investigation, 5-grade thermal sense is adopted, referring to freezing cold, stretching out hands, moderate, feeling hot without sweat, feeling hot with a little sweat.

Choosing 2 centigrade as an interval, then the operating temperature is divided into several ranges. In every temperature range, thermal senses are statistic though fuzzy statistical method. And the central temperature in a temperature range is taken as independent variable. Though above method, the subordination curve of temperature to residential thermal sense in master room is gained, given in Figure 7.

The subordination curve gained is not normal. However, in theory it should be normal, meaning that the maximum membership degree is 1 in every fuzzy subset. Fig. 7 shows that the temperature span of fuzzy subset is large, from 8 to 14 centigrade, and the membership degree of cross point between contiguous thermal sense degrees is small, about 0.4. In general, the fuzzy subset is similar to triangular distribution or normal distribution. But triangular distribution can’t meet the requirements of large temperature span and low crossing at the same time. Normal distribution is adopted here. The subordination curve is given in Figure 8.

According to maximum membership principle, when the membership of a certain temperature to a fuzzy subset is bigger than it to other fuzzy subsets, then this temperature relatively belongs to this fuzzy subset. Based on this principle, rural heating design temperature in master room is determined. Freezing cold temperature is lower than 8 centigrade. Stretching out hand temperature is from 8 to 12 centigrade. Moderate temperature ranges from 12 to 16 centigrade. Feeling hot without sweat temperature is from 16 to 20 centigrade and feeling hot with a little sweat temperature is higher than 20 centigrade.
4. Discussion

4.1 Applicability of heating design temperature

In three kinds of behavior patterns proposed in this paper, Busy type and Going-out type are widely common in men, while House-oriented type is widely common in women. It is in accordance with the ancient pattern that men plowed the fields and women wove cloth. From this point, behavior pattern is the inheritance of history, reflecting Chinese traditional culture to some degree. Therefore, it will not change in a short time.

Rural heating design temperature discussed in this paper is proposed under residential current behavior pattern. Residential behavior pattern is comprehensive role of traditional culture, social development, economy and production mode, and it has certain persistence, however it will still change with the advancement of society and improvement of economy. At the same time, heating design temperature should make corresponding change.

4.2 Accuracy of heating design temperature

Owing to Busy type and Going-out type stay outside for a long time which is longer than they stay in interiors during the daytime, so the data of thermal sense largely come from the House-oriented type, who stay most time in interiors. Furthermore, most of House-oriented are women, therefore heating design temperature proposed in this paper gives more priority to women.

In addition, restricted by time and manpower, this investigation was carried out focus on one village. And the number of household investigated was less. To increase sample capacity, investigation lasted 5 day. However, the number of data was still finite. Therefore, the accuracy of heating design temperature remains further study.

4.3 Indicator of heating design temperature

Operating temperature, the synthetic action of radiation temperature and air temperature, is as indicator of heating design temperature in current paper, which is decided by the heat dissipation characteristic of local heat source. If thermal convection is stronger than thermal radiation for heat source, then air temperature can be as indicator of heating design temperature.

5. Conclusion

Taking rural area in south Liaoning province as an example, a site survey was carried out, referring to the plain layout of yard and interior, indoor thermal environment, residential behavior pattern and thermal sense. The conclusions are as follows.

Firstly, residential behavior pattern is divided into three type based on residential activity routines in yard and inside the house, respectively is Busy type, Going-out type and House-oriented type. This pattern is the inheritance of traditional culture that men plowed the fields and women wove cloth.

Secondly, for House-oriented type, their behavior pattern is shuttling between indoor and outdoor frequently in three time bucket, respectively in morning, at noon and at dusk, which is decided by the mode of cooking, heating and production. Furthermore, the behavior pattern decides residential thick clothing.
Thirdly, the subordinate curve of temperature to thermal sense grade is gained though fuzzy statistical method, and the moderate temperature is from 12 to 16 centigrade under residential current behavior pattern.

6. References


Evaluation of Domestic Passive Ventilation Systems in Mild Climate Region and Hot Humid Region in Japan

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Abstract

Purpose / Context – The purpose of this study is to investigate indoor environment and energy saving performance of houses, which employ passive ventilation systems, built in mild climate region and hot humid region in Japan.

Methodology / Approach – In this study, investigation of passive ventilation systems, such as passive stack ventilation systems and solar heating panels, have been conducted by two steps. The first step is real measurement of indoor environment and heating energy in houses employing passive ventilation systems. The second is analysis of total primary energy consumption of heating, cooling and ventilation by using a computational program based on the extended heating degree method.

Results – From the measurement results, a passive ventilation system can be used in the regions from the viewpoint of the indoor environment. From the calculations results, a passive stack ventilation system with a self regulating damper yields less energy than typical mechanical ventilation systems. It is confirmed that a solar heating panel have a positive effect on heating energy reduction even in hot humid region.

Key Findings / Implications – In mild climate region, indoor environment of the house employing a passive stack ventilation system have almost met the reference values of the Act on Maintenance of Sanitation in Buildings in Japan. A solar heating panel works well as an assistant heating system on houses even in hot humid region. In mild climate region and hot humid region, a passive stack ventilation system which is generally adopted in cold climate regions can be used with less energy by employing a self regulating damper than typical mechanical ventilation systems.

Originality - In mild climate region and in hot humid region, where passive ventilation systems are generally not employed in housing, primary energy consumption and indoor environment of houses employing passive ventilation systems are evaluated by real measurement and computational calculations.

Keywords - Passive Ventilation, Domestic Ventilation, Mild Climates, Hot Humid Climate, Primary Energy Consumption

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1. Introduction

The Energy Saving Standard for houses in Japan was amended in 2013. The amended standard requires applying to the standard values, such as insulation performance and primary energy consumption, for each of 8 zones in Japan as shown in Table 1. Additionally, using the official program “Program for calculating primary energy consumption in house” and selecting a type of equipment employed in house, primary energy consumption in house can be estimated. Within the program, passive ventilation systems cannot be selected as a ventilation system but only typical mechanical ventilation systems can be selected. The passive ventilation, which is just adopted in cold climate region in Japan, is considered to reduce the operating energy of ventilation in mild climate region and in hot humid region, if it works in heating season. Therefore, this study aims at investigation about the indoor environment and the energy performance of houses employing passive ventilation systems in mild climate region and hot humid region in Japan.

Table 1: Zone classification of the Energy-Saving Standard in Japan and climate classification

<table>
<thead>
<tr>
<th>Zone</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Cold climate</td>
<td>Mild climate</td>
<td>Hot humid climate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical City</td>
<td>Kushiro</td>
<td>Sapporo</td>
<td>Morioka</td>
<td>Sendai</td>
<td>Nigata</td>
<td>Tokyo</td>
<td>Kochi</td>
<td>Naha</td>
</tr>
</tbody>
</table>

2. Methodology

In this study, investigations of passive ventilation systems have been conducted by real measurement and calculations using computational program.

2.1 Measurement

Real measurement has been conducted in 2 houses employing passive ventilation systems and the reference house. Measuring items and measuring instruments employed are shown in Table 2 and the outlines of subject houses are shown in Table 3. The House A which is the reference house employs a mechanical exhaust only ventilation system (MEO) and a central heat pump air-conditioner under the basement floor. The House B employs a passive stack ventilation system with a self regulating dumper by sensing humidity and a central heat pump air-conditioner on the basement floor. Moreover, The House B is measured during heating period with the aim of evaluating its performance. The House C employs a wall-mounted solar heating panel warming up supply air by using solar radiation as a passive ventilation system, a heat pump air-conditioner and a mechanical exhaust only ventilation system.

Table 2: Measuring items and instruments

<table>
<thead>
<tr>
<th>measuring item</th>
<th>instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature &amp; Relative Humidity</td>
<td>Thermometer RTR-53, RVR-52</td>
</tr>
<tr>
<td>CO₂ concentration</td>
<td>KNS-CO2S</td>
</tr>
<tr>
<td>Power consumption</td>
<td>KNS-WP-WL</td>
</tr>
</tbody>
</table>
Table 3: Subject houses

<table>
<thead>
<tr>
<th>House A (reference house)</th>
<th>House B</th>
<th>House C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>Tokyo</td>
<td>Tokyo</td>
</tr>
<tr>
<td><strong>Zone</strong></td>
<td>Mild climate (zone 6)</td>
<td>Mild climate (zone 6)</td>
</tr>
<tr>
<td><strong>Completion date</strong></td>
<td>December 2013</td>
<td>March 2014</td>
</tr>
<tr>
<td><strong>Family member</strong></td>
<td>husband and wife</td>
<td>husband and wife and two children</td>
</tr>
<tr>
<td><strong>Floor area</strong></td>
<td>93.8 m²</td>
<td>90.2 m²</td>
</tr>
<tr>
<td><strong>Q value</strong></td>
<td>2.08 W/m²·K</td>
<td>1.91 W/m²·K</td>
</tr>
<tr>
<td><strong>n50</strong></td>
<td>6.42</td>
<td>2.81</td>
</tr>
<tr>
<td><strong>Ventilation system</strong></td>
<td>Mechanical Exhaust Only Ventilation System</td>
<td>Passive Stack Ventilation System</td>
</tr>
<tr>
<td><strong>Heating &amp; cooling system</strong></td>
<td>Underfloor air conditioner (heating) Air conditioner (cooling)</td>
<td>Floor type air conditioner (heating) Air conditioner (cooling)</td>
</tr>
</tbody>
</table>

*including air supply by solar heating panel

2.2 Estimation of primary energy consumption related to ventilation

Estimation of primary energy consumption of each whole-house ventilation system including a solar heating panel has been carried out. The primary energy consumption related to ventilation must be considered energy of heating and cooling as well as power input of operation, because ventilation load affect energy consumption of heating and cooling. Therefore total energy consumption of heating, cooling and ventilation operation is calculated by using program based on the extended heating degree method. The conditions for computational calculation are shown in Table 4 and the model house for calculation is shown in Figure 1.

Table 4: Calculation conditions of model house

<table>
<thead>
<tr>
<th>Setting items</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>City</td>
<td>Tokyo, Kochi, Naha</td>
</tr>
<tr>
<td>Floor area</td>
<td>120.8 m²</td>
</tr>
<tr>
<td>Insulation Performance</td>
<td>2013 energy-saving standard for houses in Japan</td>
</tr>
<tr>
<td>n50</td>
<td>4.02</td>
</tr>
<tr>
<td>Whole-house Ventilation System</td>
<td>[a] Mechanical Exhaust Only ventilation system (MEO) [b] Balanced ventilation with heat recovery (MEO during cooling and in-between season) [c] Balanced ventilation with heat recovery [d] Passive stack or hybrid ventilation</td>
</tr>
<tr>
<td>Heating and Cooling method</td>
<td>Central air-conditioning System, continuous use</td>
</tr>
<tr>
<td>Air Conditioning rate</td>
<td>0.92</td>
</tr>
<tr>
<td>Ventilation rate</td>
<td>160 m³/h (with self regulating dumper: 173 m³/h)</td>
</tr>
<tr>
<td>Net Air Volume rate</td>
<td>0.95 ([b] (heating season)) and ([c])</td>
</tr>
<tr>
<td>COP of air-conditioner</td>
<td>3.0</td>
</tr>
<tr>
<td>Heat Exchange Efficiency</td>
<td>Sensible heat exchange efficiency: 0.65 Latent heat exchange efficiency: 0.40</td>
</tr>
<tr>
<td>Specific Fan Power [W/(m³/h)]</td>
<td>[a] 0.144, [b] 0.315 (heating season) 0.159 (in-between and cooling season), [c] 0.315, [d] 0.14 (SFP of MEO)</td>
</tr>
</tbody>
</table>
3. Results and Discussion

3.1 Measurement

3.1.1 Indoor Environment

Indoor air temperature, relative humidity and CO$_2$ concentration were measured. These measurement values are compared with the reference values of the Act on Maintenance of Sanitation in Buildings in Japan (shown in Table 5) since the standard for residential building indoor environment in Japan is not established.

<table>
<thead>
<tr>
<th>measuring item</th>
<th>reference value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$ concentration</td>
<td>1000 ppm</td>
</tr>
<tr>
<td>Temperature</td>
<td>17°C-28°C</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>40 %RH-70%RH</td>
</tr>
</tbody>
</table>

Table 5: Measuring items of the Act on Maintenance of Sanitation in Buildings in Japan

(1) House A (reference house)

The measuring results of air temperature and relative humidity of each room are shown in Figure 2 and 3. The grey areas in the diagrams indicate the range of the reference value of the ACT. Air temperature of the living is within the reference value at a rate of 79%. In the Bedroom1, the air temperature is within the reference value at a rate of 65 % and the rate of relative humidity within the reference value is 86%, larger than one of other rooms because a humidifier was employed there.
(2) House B

The measuring results of air temperature, relative humidity and CO₂ concentration of each room are shown in Figure 4, 5 and 6. The air temperature of the loft, the living and the bedroom1 meet almost the reference value. Although the real measurement is conducted without occupants, the relative humidity of the house is approximately 40%RH in each room. This is believed to be due to using self regulating dumper by sensing humidity. The CO₂ concentration of both rooms is within the reference value in most of the measurement period. This result shows that passive stack ventilation system can be used as a whole house ventilation system during heating season even in mild climate region.
(2) House C

The measuring results of air temperature, relative humidity and CO₂ concentration of each room are shown in Figure 7, 8 and 9. The air temperature of living is the highest in house C and meets the reference value at a rate of 65%. The CO₂ concentration of both rooms is within the reference value in most of the measurement period. It is comparatively low relative humidity and very low CO₂ concentration in the living because of supply air to living by solar heat panel during the working.

![Figure 6 CO₂ concentration of each room in the House B](image)

![Figure 7 Air temperature of each room in the House C](image)

![Figure 8 Relative humidity of each room in the House C](image)
3.1.2 Heating energy

Measuring results of the heating energy consumption and day average outdoor air temperature are shown in Figure 7. The House B uses more energy for heating than the House A under same daily average outdoor air temperature. One of the reasons is considered that House B has no internal heat generation including occupants. House C uses less energy for heating than House A when daily average outdoor air temperature is below 9°C. Therefore solar heating panel is recognized a positive effect as assistant heating system. However when it is over 9°C, House C uses more energy for heating than the House A. This reason is believed the occupants opened the window by habit.

3.2 Estimation of primary energy consumption related to ventilation

Primary energy consumption of heating, cooling and ventilation calculated by using the computational program is shown in Figure 11 and 12. In Tokyo and Kochi, the balanced ventilation system with heat recovery which is switching MEO during in-between season and cooling season yields less total energy than other ventilation systems. In Naha, the mechanical exhaust only ventilation system uses less than other ventilation systems. The passive stack ventilation system yields more total primary energy consumption than typical mechanical systems in all zones. It is thought to be affected by heating load of excess ventilation whose rate is larger than 160m³/h when the outside temperature is low condition. Therefore, the primary energy consumption of passive stack ventilation has been additionally calculated under the condition of adopting the self regulating damper. As a result of the additional calculation, the primary energy consumption calculated has been reduced as shown in figure 13. Notice that in warm climate region and in hot humid region such as Tokyo (zone 6) and Kochi (zone 7), the passive stack ventilation system which is generally used in cold climate region is available with less primary energy consumption than typical mechanical ventilation systems by adopting self regulating damper. In addition if a house employs a solar heating panel, it has been confirmed that the primary energy consumption was decreased approximately 0.6 GJ, expect in Naha where the heating load is less than 1.0 GJ.
Shimada, Y  Evaluation of domestic passive ventilation systems in mild climate region and hot humid region in Japan

HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.

<table>
<thead>
<tr>
<th></th>
<th>Tokyo (zone 6)</th>
<th>Kochi (zone 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Exhaust Only</td>
<td>18.79</td>
<td>18.25</td>
</tr>
<tr>
<td>Balanced Ventilation with Heat Recovery (MEO during between season and cooling season)</td>
<td>16.46</td>
<td>17.02</td>
</tr>
<tr>
<td>Passive Stack Ventilation</td>
<td>19.53</td>
<td>17.92</td>
</tr>
<tr>
<td>Passive Stack Ventilation (MEO during between season and cooling season)</td>
<td>17.68</td>
<td>17.02</td>
</tr>
<tr>
<td>Passive Stack Ventilation</td>
<td>18.73</td>
<td>17.73</td>
</tr>
</tbody>
</table>

* SHP: employing solar heating panel

Figure 11 Primary energy in Tokyo and Kochi calculated by using the program

<table>
<thead>
<tr>
<th></th>
<th>Naha (zone 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Exhaust Only</td>
<td>13.06</td>
</tr>
<tr>
<td>Balanced Ventilation with Heat Recovery (MEO during between season and cooling season)</td>
<td>13.10</td>
</tr>
<tr>
<td>Balanced Ventilation with Heat Recovery</td>
<td>15.48</td>
</tr>
<tr>
<td>Passive Stack Ventilation</td>
<td>19.24</td>
</tr>
</tbody>
</table>

* SHP indicates with solar heating panel

Figure 12 Primary energy consumption in Naha calculated by using the program

<table>
<thead>
<tr>
<th></th>
<th>Tokyo (zone 6)</th>
<th>Kochi (zone 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive Stack Ventilation</td>
<td>18.46</td>
<td>17.73</td>
</tr>
<tr>
<td>Passive Stack Ventilation (MEO during between season and cooling season)</td>
<td>17.92</td>
<td>17.12</td>
</tr>
</tbody>
</table>

* SHP indicates with solar heating panel

Figure 13 Primary energy consumption of passive stack ventilation system with a self regulating damper calculated by using the program
4. Conclusion

In this study, investigation the indoor environment and primary energy consumption of houses employing passive ventilation systems in mild climate region and hot humid region has been conducted. The real measuring results have shown that indoor environment in house employing a passive stack ventilation have fulfilled almost the reference values of the Act on Maintenance of Sanitation in Buildings in Japan. Measuring results of heating energy consumption have indicated that a solar heating panel works well as an assistant heating system on houses in hot humid region. In addition, the calculation results of the computational program also have suggested that a solar heating panel reduces heating energy consumption. A passive stack ventilation system without self regulation dumper has consumed more energy than other ventilation systems. However, in case of a passive stack ventilation system adopting self regulating damper, the primary energy consumption has been reduced. Notice that a passive stack ventilation system which is generally used in cold climate region can be used with less primary energy consumption than typical systems by adopting self regulating damper in mild climate region and hot humid region such as Tokyo (zone 6) and Kochi (zone 7). From results, this study has shown the availability of passive ventilation systems in mild climate region and hot humid region.

5. References


IBEC. (2013), Methods and explanation of calculation and judgment in conformity 2013 energy Saving Standards, Japan


Field Studies to Investigate Impact of Increasing R-value of Building Envelope on Winter Indoor Relative Humidity of Auckland Houses

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Abstract

Purpose / Context - The study investigates relationships of winter indoor relative humidity and R-value of building envelope of the Auckland houses.

Methodology / Approach – Field study of indoor micro climatic conditions. Air temperatures and relative humidity adjacent to floors and ceilings of different indoor spaces of the two houses with different R-value in their envelopes and shaded outdoor spaces were continuously measured and recorded at 15 minute intervals, 24 hours a day, by Lascar EL-USB-2 USB Humidity Data Logger during the winter months.

Results – The study identifies the differences of winter indoor relative humidity of Auckland houses with different insulation and glazing in their envelopes and the major problems of building thermal design of local house with lightweight timber frame construction.

Key Findings / Implications – Increasing R-value in building envelope of Auckland houses in accordance with the requirements from NZS 4218:1996 to NZS 4218:2009 can significantly increase 19.6% of winter time when indoor relative humidity are 40% and 60%. Maintaining indoor relative humidity between 40% and 60% can minimize the indirect health effects.

Originality – Quantitative relationships between R-value in building envelope and winter indoor relative humidity, and the identified thermal design problems of local houses with lightweight timber frame construction can be good references for improving indoor health conditions of the future Auckland housing development.

Keywords - Building Envelope, Indoor Health, Insulation, House, Relative Humidity
1. Introduction

Auckland has a temperate climate with comfortable warm, dry summers and mild, wet winters. Common problems of indoor micro-climatic conditions of Auckland houses are low air temperature and high relative humidity during the winter (Figure 1). The World Health Organisation recommends a minimum indoor temperature of 18°C for houses; and 20-21°C for more vulnerable occupants, such as older people and young children (WHO 1987). The current New Zealand Building Code does not have a general requirement for the minimum indoor air temperature, although it has a requirement of 16°C for more vulnerable occupants, such as older people and young children (DBH 2001; SNZ 1990). The previous study shows that most of the health effects such as bacteria, viruses, fungi, mites, respiratory infections, allergic rhinitis, asthma, etc. have increases associate with increase of indoor relative humidity (Figure 2). Maintaining indoor relative humidity between 40% and 60% can minimize the indirect health effects (Arundel et al. 1986). High relative humidity during the Auckland winter is a major issue for building indoor health conditions. The abundance of two major causes of allergy, mites and fungi, increase proportionately with average indoor relative humidity. New Zealand has some of the highest levels of house dust mite allergens in the world (Siebers, Wickens, and Crane 2006). Visible mould growth on indoor surfaces is a common problem in over 30% of New Zealand houses (Howden-Chapman et al. 2005). Mould growth is likely on almost any building material if the relative humidity exceeds 75-80% (Coppock and Cookson 1951; Block 1953; Pasanen et al. 1992). One option to prevent mould growth on indoor surfaces is to control the indoor humidity level under the threshold (80%) of mould gemmation. If the mould spores never start gemmation then moulds will not grow on indoor surfaces (ASHRAE 1993; Su 2006). According to international and national standards, the indoor relative humidity should be lower than 60% for indoor air quality (ASHRAE 1992; ASHRAE 2001; SNZ 1990). High relative humidity can not only cause some physical discomfort but also negatively affect indoor health conditions.

Figure 1 Auckland monthly mean temperature and relative humidity (source: NIWA)

Figure 2 Health effects and indoor relative humidity (source: Arundel et al. 1986)
On 25 November 1977 legislation was introduced making it compulsory for new homes to be insulated and these requirements came into force on 1 April 1978 (SNZ 1977, BIA 1992). Minimum R-values for building elements (Roof: 1.9, Wall: 1.5, Floor: 0.9 for New Zealand Climate Zone 1) were required in accordance with NZS 4218P:1977. In 1996, the standard was updated and the new regulations came into force at the end of 2000 (SNZ 1996, DBH 2000). Minimum R-values for building elements (Roof: 1.9, Wall: 1.5, Floor: 1.3 for New Zealand Climate Zone 1) were required in accordance with NZS 4218P:1996. There are no R-value requirements for glazing and not limitation of ratio of window to wall. In 2004, the standard was again updated, the main change being a limitation of the proportion of window area and the use of double glazing under the Schedule Method (SNZ 2004). Minimum R-values for building elements (Roof: 1.9, Wall: 1.5, Floor: 1.3, Glazing: 0.15 for New Zealand Climate Zone 1) were required in accordance with NZS 4218:2004. In 2009, the standard was again updated (SNZ 2009). The new term ‘construction R-value’ has been introduced to distinguish the performance values from insulation material R-values. There are new requirements for high thermal mass construction to ensure that the thermal mass is adequate and effective, conceding that thermal mass is relevant when considering R-values. Increased R-values are aligned with New Zealand Building Code Clause H1 (DBH 2007). Minimum R-values for building elements (Roof: 2.9, Wall: 1.9, Floor: 1.3, Glazing: 0.26 for New Zealand Climate Zone 1) were required in accordance with NZS 4218:2009 (SNZ 2009).

Two Auckland houses were selected for the field studies of winter indoor micro-climatic conditions associated with different insulation and glazings in their envelopes. House 1 is a two-storeyed and brick-tile townhouse built in 2000 having four bedrooms with a total floor area of 210 m² and single glazed windows. Insulation in its envelope is in accordance with NZS 4218:1996. House 1 had two occupants and used an electronic heater (an oil-filled radiator) for space heating in the master bedroom only for the evening and night time during the field study. House 2 is a two-storeyed and brick-tile townhouse built in 2012 having five bedrooms with a total floor area of 250 m² and double glazed windows. Insulation in its envelope is in accordance with NZS 4218:2009. House 2 had two occupants and did not use any space heating during the field study, although there is a heat pump. Air temperatures and relative humidity adjacent to floors and ceilings of different indoor spaces of the two houses and shaded outdoor spaces were continuously measured and recorded at 15 minute intervals, 24 hours a day, by Lascar EL-USB-2 USB Humidity Data Logger during the winter of 2014.

This field study not only investigates and identifies the difference of relative humidity of houses with different insulation, but also difference of percentage of winter time, when indoor relative humidity meets or does not meet the guidelines of healthy conditions. All field study data of relative humidity of indoor and outdoor have been converted into percentages of winter times when indoor relative humidity is greater than or equal to 40%, 50%, 60%, 70%, 75%, 80% and in the range of 40% to 60% for the purposes of comparing indoor thermal comfort and healthy conditions of the three houses with different insulation and glazing in their envelopes and different heating methods. The study also investigates and identifies the major problems of house thermal design, which negatively impact indoor health conditions related to indoor relative humidity, in a climate with a mild and wet winter.

2. Indoor Health Conditions of the Two Houses

Winter mean air temperatures of different indoor spaces of House 2 are 0.6°C – 1.7°C higher than House 1 indoor spaces without space heating (Table 1). Although occupants in House 1 used a heater in the master bedroom during the field study, mean air temperature of the master bedroom of House 2 is still 1°C higher than the master bedroom of House 1 and percentages of winter time, when indoor air temperatures are higher than or equate to 16°C, 18°C and 20°C, are higher than the master bedroom of House 1. For the whole house, indoor mean air temperature of House 2 is 1.1°C higher than House 1 and percentage of winter time of House 2, when indoor air temperatures are higher than or equate to 18°C (the minimum requirement of thermal comfort and health conditions), is 17.5% higher than House 1 (Table 2). Increasing R-value of building envelope and
using double glazed windows can not only improve winter indoor thermal conditions but also improve winter indoor health conditions related to relative humidity as indoor relative humidity decreases with increase of indoor air temperature. Winter mean relative humidity of different indoor spaces of House 2 are 3.2% – 5.1% lower than House 1 (Table 3). Percentages of winter time of House 2, when indoor relative humidity is higher than 60%, is 4.3% – 21.6% lower than House 1 (Table 3). For the whole house, the percentage of winter time of House 2 when indoor mean relative humidity is between 40% and 60%, is 19.6% higher than House 1 (see Table 4).

Major indirect health effects in Auckland houses during the winter such as bacteria, viruses, fungi, mites, respiratory infections, allergic rhinitis and asthma increases associated with increase of indoor relative humidity. According to the relationships between the major indirect health effects and indoor relative humidity (Arundel et al. 1986) and the field study data of winter indoor relative humidity of House 1 and House 2, figure 3-4 show winter indoor health conditions related to the health effects such as bacteria, viruses, fungi, mites, respiratory infections, allergic rhinitis and asthma of House 1 and House 2. The percentage of winter time of House 2 when indoor mean relative humidity is between 40% and 60%, which can minimize the indoor indirect health effects, is higher than House 1. Winter indoor health condition of the House 2 is better than the House 1.

### Table 1: Percentages of winter time and air temperature ranges of different indoor spaces

<table>
<thead>
<tr>
<th>Indoor spaces</th>
<th>≥16°C</th>
<th>≥18°C</th>
<th>≥20°C</th>
<th>≥22°C</th>
<th>≥24°C</th>
<th>≥26°C</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>House 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>34.7%</td>
<td>4.6%</td>
<td>0.1%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>15.5</td>
</tr>
<tr>
<td>Downstairs bedroom</td>
<td>11.2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>14.2</td>
</tr>
<tr>
<td>Upstairs master bedroom</td>
<td>69.2%</td>
<td>32.7%</td>
<td>6.7%</td>
<td>0.1%</td>
<td>0%</td>
<td>0%</td>
<td>16.9</td>
</tr>
<tr>
<td>Corridor</td>
<td>34.0%</td>
<td>2.9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>15.3</td>
</tr>
<tr>
<td>House 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>78.7%</td>
<td>21.8%</td>
<td>1.0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>16.8</td>
</tr>
<tr>
<td>Downstairs bedroom</td>
<td>28.3%</td>
<td>4.9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>14.8</td>
</tr>
<tr>
<td>Upstairs master bedroom</td>
<td>71.1%</td>
<td>44.9%</td>
<td>18.7%</td>
<td>6.4%</td>
<td>0.9%</td>
<td>0.1%</td>
<td>17.9</td>
</tr>
<tr>
<td>Corridor</td>
<td>76.2%</td>
<td>30.7%</td>
<td>4.0%</td>
<td>0.2%</td>
<td>0%</td>
<td>0%</td>
<td>17.0</td>
</tr>
</tbody>
</table>

### Table 2: Percentages of winter time and mean indoor air temperature ranges of the two houses

<table>
<thead>
<tr>
<th></th>
<th>≥16°C</th>
<th>≥18°C</th>
<th>≥20°C</th>
<th>≥22°C</th>
<th>≥24°C</th>
<th>≥26°C</th>
<th>Mean</th>
<th>Max.</th>
<th>Min.</th>
<th>Fluctuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>House 1</td>
<td>35.3%</td>
<td>3.9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>15.5</td>
<td>19.8</td>
<td>11.4</td>
<td>8.4</td>
</tr>
<tr>
<td>House 2</td>
<td>61.0%</td>
<td>21.5%</td>
<td>2.5%</td>
<td>0.01%</td>
<td>0%</td>
<td>0%</td>
<td>16.6</td>
<td>22.1</td>
<td>11.2</td>
<td>10.9</td>
</tr>
</tbody>
</table>

### Table 3: Percentages of winter time and relative humidity ranges of different indoor spaces

<table>
<thead>
<tr>
<th>Indoor spaces</th>
<th>≥40%</th>
<th>≥50%</th>
<th>≥60%</th>
<th>≥70%</th>
<th>≥75%</th>
<th>≥80%</th>
<th>40% - 60%</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>House 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>100%</td>
<td>100%</td>
<td>90.8%</td>
<td>34.7%</td>
<td>12.3%</td>
<td>0%</td>
<td>9.2%</td>
<td>67.7%</td>
</tr>
<tr>
<td>Downstairs bedroom</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>71.4%</td>
<td>38.2%</td>
<td>13.4%</td>
<td>0%</td>
<td>73.4%</td>
</tr>
<tr>
<td>Upstairs master bedroom</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>69.7%</td>
<td>24.6%</td>
<td>8.8%</td>
<td>0%</td>
<td>64.3%</td>
</tr>
<tr>
<td>Corridor</td>
<td>100%</td>
<td>100%</td>
<td>90.4%</td>
<td>35.6%</td>
<td>15.6%</td>
<td>1.5%</td>
<td>0.6%</td>
<td>67.9%</td>
</tr>
<tr>
<td>House 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living</td>
<td>100%</td>
<td>100%</td>
<td>69.2%</td>
<td>11.8%</td>
<td>1.3%</td>
<td>0%</td>
<td>30.8%</td>
<td>62.8%</td>
</tr>
<tr>
<td>Downstairs bedroom</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>95.7%</td>
<td>41.4%</td>
<td>12.6%</td>
<td>2.5%</td>
<td>68.6%</td>
</tr>
<tr>
<td>Upstairs master bedroom</td>
<td>100%</td>
<td>100%</td>
<td>97.5%</td>
<td>58.6%</td>
<td>8.0%</td>
<td>0.3%</td>
<td>0%</td>
<td>61.1%</td>
</tr>
<tr>
<td>Corridor mean</td>
<td>100%</td>
<td>100%</td>
<td>69.7%</td>
<td>10.8%</td>
<td>1.2%</td>
<td>0.04%</td>
<td>30.3%</td>
<td>63%</td>
</tr>
<tr>
<td>Outdoor</td>
<td>100%</td>
<td>100%</td>
<td>97.4%</td>
<td>86.6%</td>
<td>77.8%</td>
<td>68.4%</td>
<td>2.6%</td>
<td>85%</td>
</tr>
</tbody>
</table>

### Table 4: Percentages of winter time and mean relative humidity ranges of the two houses

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*HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.*
3. Major Problems of Local House Thermal Design

Winter indoor mean air temperatures of House 2 are generally higher than House 1 and relative humidity of House 2 are generally lower than House 1 (Table 2 and Table 4). Fluctuations of winter indoor air temperatures and relative humidity of House 1 and House 2 are both large (Table 2, Figure 5-6). House 1 and House 2 are lightweight timber frame construction with internal insulation and external cladding. For this type of lightweight building envelope without sufficient thermal mass in the walls, the indoor space air temperature is heated up quickly by solar radiation and rising outdoor air temperatures during winter daytime and also cooled down quickly during winter night time. House 2 with more insulation (higher R-value) and double glazed windows in building envelope can increase the winter indoor mean air temperature, but cannot make indoor the air temperature more stable. As indoor relative humidity increases or decreases associated with decrease or increase of indoor air temperature, large fluctuations of winter indoor mean air temperature can result large fluctuations of winter indoor mean relative humidity, which can negatively impact indoor thermal comfort and health conditions.

Indoor mean air temperatures of living room, upstairs mast bedroom, corridor of House 2 are 1-1.7°C higher than House 1. Indoor mean air temperature of southern downstairs bedroom of
House 2 is only 0.6°C higher than House 1 (Table 1). Indoor relative humidity of Southern downstairs bedrooms of both House 1 and House 2 are significantly higher than other indoor spaces (Table 3). Southern downstairs indoor spaces do not have any direct sunlight during the winter and are on the cold side of the house. Floor areas of southern bedrooms are commonly smaller than the northern bedrooms and the other spaces; the floor area of the southern downstairs bedroom (10.3m²) of House 2 is smaller than the master bedroom (17.7m²) and the open living space (68.2m²). A southern bedroom with a smaller floor area could potentially result in big ratios of external wall area to indoor space volume or window area to floor of that room. Negative impact of a big ratio of window to floor could overrule or degrade the positive impact of higher insulation levels and double glazed windows on indoor thermal comfort and health conditions of a particular indoor space, especially a southern indoor space.

4. Conclusion

According the field study data of House 1 and House 2, increasing R-value of building envelope from 1.9 for roof, 1.5 for wall, 1.3 for floor and 0.13 for glazing, as required by the New Zealand building standards in 1996, to the 2009 requirements of 2.9 for roof, 1.9 for wall, 1.3 for floor and 0.26 for glazing significantly improves winter indoor thermal conditions. Increasing R-value of building envelope and using double glazed windows can not only improve winter indoor thermal conditions but also improve winter indoor health conditions related to relative humidity. Maintaining indoor relative humidity between 40% and 60% can minimize the indirect health effects. Percentages of winter time of House 2 with sufficient insulation and double glazing windows, when indoor mean relative humidity is between 40% and 60%, is 19.6% higher than House 1 with insufficient insulation and single glazed windows.

Although upgrading insulation and using double glazing windows can significantly increase 19.6% of winter time when indoor relative humidity are 40% and 60%, there is still 71.6% of winter time
when indoor relative humidity is higher than 60%. An Auckland house with sufficient insulation and double glazing windows needs space heating to achieve winter indoor thermal comfort and health condition. Local conventional lightweight timber frame construction houses can cause large fluctuations of winter indoor air temperatures and relative humidity. For this type of lightweight building envelope without sufficient thermal mass in the walls, increasing insulation and adding double glazing windows in building envelope can increase the winter indoor mean air temperature and decrease the winter indoor mean relative humidity, but cannot make indoor air temperature and relative humidity more stable. For both of two houses, winter indoor air temperatures in southern downstairs bedrooms are apparently lower than other indoor spaces and relative humidity are also apparently higher than other indoor spaces. Adding more insulation and further the limiting window area on the southern external wall could be an option to increase indoor air temperature and decrease relative humidity of southern downstairs bedroom.

5. References


NIWA https://www.niwa.co.nz/education-and-training/schools/resources/climate


Sanitation infrastructure and their potential impacts on human health: A case study of Tembalang sub-district in Semarang City, Indonesia

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Abstract

Purpose / Context - The provision of reticulated sanitation infrastructure has not kept pace with the rapid urbanization, which can be witnessed in Indonesia. In addition, lack of proper sanitation infrastructure treaty led to pollution of groundwater. The most common system used for human excreta disposal system in Indonesia is septic tank, which is an on-site treatment system, is waste disposal from inadequately designed or maintained septic tanks can lead to the contamination of the shallow groundwater.. Unfortunately, the shallow groundwater is being used as a potable water resource by a significant fraction of the urban population due to inadequate coverage of reticulated water supply, which can negatively affect the human health. This research study intended to investigate the impact of on-site sanitation systems on groundwater quality of dug wells, which was carried out in three villages in Tembalang sub-district of Semarang.

Methodology / Approach - Water samples from 22 selected shallow wells (at least 7 each village) were analysed for biological (total coliforms and E. coli), chemical (Nitrate, Chloride, COD, pH) and physical (Total Dissolved Solids and Temperatur) parameters of water according to Indonesian National Standard (SNI). Open space ratio, septic tank density, drainage density, soil permeability were also determined for incorporation into the envisaged analysis. House owners and septic tank builders were also interviewed using a structured interview.

Results - It was found that most of the septic tanks were constructed without lined bottoms as pit latrines and no additional leach field was provided. Generally, the septic tank was located in the back yard, while shallow well was in the front yard. This condition did not only make the sludge removal problem, but also difficulty in maintain safe distance between the septic system and the well. The groundwater quality during dry season was considerably better than that during rainy season. The study also revealed that 55%, 30% and 50% of water samples contained Nitrate, COD and E. coli, respectively, which exceeded the Indonesia Health Ministry Standard for drinking water.
Key Findings / Implications – The study results presented that even though the distance between septic tank to shallow well could be more than 10 m, the groundwater was still found to be microbiologically polluted. A communal sanitation system such as Small Bore Sewerage could be one of the options to be considered for minimizing the potential groundwater pollution.

Keywords - septic tank, groundwater pollution, shallow wells, on-site sanitation, *E. coli*

1. Introduction

1.1 Water quality and domestic waste water treatment

Despite global reduction in under-five mortality rate – UFMR from 90 in 1990, 76 in 2000 to 46 in 2013, it is estimated that 6.3 million children under age five still died in 2013. The government of Indonesia, in fact, also succeeded to decrease the UFMR, that is from 84 (1990), 52 (2000) to 29 (2013). However, in 2013 the amount of children under age five died, i.e 136 thousand, is still high (You et al., 2011). The main cause of death of children under five and infant in Indonesia were diarrhea, by 25.2 % and 31.4%, respectively (Departemen Kesehatan, 2008). For all ages, diarrhea was ranked as the 3rd leading cause of death due to infectious diseases (Agtini & Soenarto, 2011). Those high mortality rate attributable to diarrhea was related closely to sanitary condition in Indonesia.

Although water services have been improved since in 1990, 2000, 2012, with total improved 70 %, 78 %, 85 %, respectively, about 37 million people still live with no access to improved water source (Supply et al., 2014). This community groups might rely mainly on shallow wells, rivers, stream and ponds for their daily water needs. In most cases water from unimproved water source may be faecally polluted (Dzwairo et al., 2006; Zingoni et al., 2005). Water sources which categorized as improved source are piped water, public tap / standpost, borehole, protected dug well (Supply et al., 2014).

Sanitation or domestic wastewater service also have been improved. In 1990, 2000 and 2012, proportion of household who have an acces to improved sanitation facilities increased become 35%, 47% and 59%, respectively. However, 10%, 9% and 22 % of the Indonesian households still have no the unimproved shared usage, other unimproved sanitation facilities and are practice open defecation (Supply et al., 2014). Only eleven ten cities in Indonesia operate a sewerage network, amounting to 1% of the Indonesia population who was covered by the network (Colin et al., 2009). Although most households have a private toilet, however in many cases the wastewater is discharged untreated or partially treated into open drains, canals, rivers and ponds. Consequently, fecal contamination of urban ground water resources is widespread. Due to limited choices many people remain relying on wells for their drinking water (Colin et al., 2009). Even if the toilets are connected to septic tanks, these septic tanks are often poorly constructed, rarely emptied. According to Supply et al., (2014) about two-thirds of toilet is connected into septic tank.

The simple septic tank system is the most commonly known primary treatment method for on-site wastewater treatment because of its considerable advantages (Dawes & Goonetilleke, 2003). Even in developed country such as United States and Australia, septic tank is still applied. In the United States, about 60 million people use some form of on-site wastewater treatment systems of which about 20 million use the conventional septic tank system (Bradley et al., 2002). Australia is no difference, where about 12 percent of the population uses septic tank systems to get rid of its wastewater (Ahmed et al., 2005).

The septic tank is a settlement tank to provide anaerobic condition for settlement of blackwater and decomposition of its organic matter (Butler & Payne, 1995; Dawes & Goonetilleke, 2003). Black water is fed to the tank, and settled, whereas effluent is discharged
Sanitation infrastructure and their potential impacts on human health: a case study of Tembalang sub-district in Samarang City, Indonesia

Sudarno, S

HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.

Periodically, accumulated sludge at the bottom of the tank has to be discharged (Butler & Payne, 1995; Withers et al., 2011). However, the biggest drawback is the well-recognized potential to pollute groundwater resources (Dzwairo et al., 2006; Withers et al., 2012; ARGOSS, 2001; Lewis et al., 1980). Indeed, if a septic tank is correctly designed, built accordingly, properly operated and regularly emptied, it is an effective device to treat wastewater (Roomratanapun, 2001). Many reported problems are caused by failure to desludge septic tanks. The most common reason for not desludging was ignorance or negligence on the part of the owners that their properties are served by septic tanks resulting in un awareness of any desludging as required (Butler & Payne, 1995). Furthermore, their main cause of failure was the unsuitability of the soil and the site characteristics (Massoud et al., 2009). According to Dzwairo et al., 2006, failure of on-site sanitation systems such as septic tank might result in serious pollution of groundwater.

The hand dug shallow wells are a traditional source of water for communities (Liddle et al., 2015) and often offer the only means of groundwater exploitation. Dug wells are dug down below the water table and lined with a material, like stone or brick (Bakundukize et al., 2016). Commonly in Indonesia, the dug wells have a diameter of around 1 m, providing working space for digging the well. Dug wells are highly vulnerable to contamination, caused by their proximity of water table to the surface. The contamination could be a result of overland flow, subsurface contamination, or atmospheric contaminants (Fallis, 2003). Therefore the quality of groundwater must be carefully assessed in order to prevent contamination and reduce the health and environmental risks. (Dzwairo et al., 2006)

Over the past century there has been some researches focusing on correlation between groundwater quality and on-site sanitation. Mkandawire, 2008 reported that groundwater in boreholes is high contaminated by faecal matter during dry and wet season. Whereas, Liddle et al., 2015 studied the suitability of shallow wells for providing safe drinking water in Ndola, Zambia.

If groundwater used as drinking water is contaminated with waste water, there is a greater risk of transmitting bacteria and viruses that cause disease such as diarrhea. According to Environmental Health and Risk Assessment (EHRA) study, about 14% (in the last 6 six month) and 12 % (before six month ago) people in Tembalang sub-district was recorded suffer from diarrhea.

In Indonesia, most research on water resource has focused solely on water system or wastewater system separately. Very limited research has been focused on relationship between water quality of shallow well and sanitation system. Therefore this study was focused on impacts of sanitation system on groundwater quality in different seasons, taking levels of TSS, nitrate, chloride, COD, E. coli and total coliforms as impact indicators. The parameters were chosen because a wide range of studies internationally have demonstrated that they were problematic with regards to on-site sanitation.

1.2 Study area

Tembalang sub-district is in Semarang City - Central Java, with geographical location is shown in Figure 1. Topographically Semarang consists of hilly areas in the south parts, lowland and coastal areas in the north parts, in which Tembalang lies in hilly areas, range 90 to 300 m above the sea level.

The city is situated in a tropical region and has a tropical climate with two seasons: rainy and dry seasons. The annual rainfall is about 2065–2460 mm with maximum rainfall in the month of December and January (Marfai and King, 2008a). The mean dry season rainfall in Semarang 104 mm/month, and rainfall wet season is 334 mm/month (Gemowo & Ina, 2008).
Tembalang sub-district had been planned as an urban residential and education area. A large influx of people, most of them is student, occurred during early 2010, when almost academic activities of Diponegoro University were moved from old campus, Pleburan sub district, to Tembalang Campus. In 2007, 2010 and 2014, the population in this subdistrict was 120,000, 133,000 and 154,000, respectively. The population density in 2014 was 3500 people/km² (Badan Pusat Statistik, 2015). Unfortunately, this rapid increase in population was not accompanied with increase of infrastructure facility such as water supply, sanitation and transportation facilities. According to EHRA report, in Tembalang, the predominant form of sanitation was septic tank 95%, while the main source of domestic water was shallow wells 45%.

2. Materials and methods

2.1 Study design

The groundwater quality in three villages of Tembalang sub-district (Figure 2) was investigated in this study. Water samples for water quality analysis were collected from at least 7 dug wells across the settlement. Sampling was carried out at three different times in February representing wet season and Juni for dry season. Dug wells were labelled in such a way that Baskoro One (B1), B2 – B7 were dug wells located in Baskoro Villages. Kramas One (K1), K2 – K8 and Tunjungsari One (T1), T2 – T7) were dug wells in Kramas and Tunjungasari village, respectively. Open dug well samples were collected using the in situ bucket and rope systems within each well. Samples were collected in plastic containers, which were rinsed three times with sample water prior to used. For covered dug wells, the samples were collected from faucets. Water were kept running for five minute before samples were collected in plastic containers. Water samples were stored in cool boxes with ice and transported and processed in Environmental Engineering Laboratory – Diponegoro University within 2 hours after collection.

In addition, for E. coli and total coliforms analysis, all equipments including fauced were sterilized before samples were collected. Samples were examined for total and E. coli counts using the Most Probable Number (MPN) method.

2.2 Sampling and analysis methods

For E. coli and total coliforms microbiological tests were performed using duplication procedure as method number APHA 9221, 2005. Temperature, pH and Total Dissolved Solid were determined in-situ using a calibrated water quality probe (Horriba U 52 Japan). The
samples were tested for chemical oxygen demand (Standard Nasional Indonesia - SNI 06-6989.2:2004), nitrate (SNI 01-3554-2006 Point 2.8), chloride (SNI 6989.19:2009). All other chemicals used were of analytical grade or purest quality purchased from Merck, Fluka. Undisturbed soil samples were taken from sites and percolation test was conducted in Civil Engineering Laboratory – Diponegoro University according to SNI 2435:2008.

3. Results and discussion

3.1 Site characteristics

The study discovered that built to total area ratio and septic tank density in Baskoro were the highest compared to the other villages (Table 1 and Figure 1). Baskoro was located the closest to University Diponegoro, therefore many student boarding houses, small stores, stalls were built up in Baskoro, leaving almost no open space. Compared with other locations, boarding houses in Baskoro was relative bigger and have at least 2 septic tanks.

Most of the septic tanks were built up on back yard and receive only black water from toilet. According to interviewer with house owners and construction workers, septic tank design was commonly built based on available space and not to a standard specification regulated in Indonesian National Standard (SNI). The septic tanks was mostly designed bigger than SNI, indeed many
septic tanks with size more three times than SNI could be found in study location. Effluent of the septic tank was directly discharged via a waste pipe into open drains and not to leach field. Although businesses of septic tank emptying were common in Semarang, the septic tanks in Tembalang were rarely or never emptied, due to the lack of knowledge of house owner or technically constraints considerations such as, difficulty for emptying the septic tank located in back yard.

In Tembalang, combined drain system was applied to discharge communal wastewater and also rain water. Most drains were already lined with stone or brick. However, several spots of the drains were broken, enabling the water to infiltrate into soil below. In front of property, the drain was natural soil without lined or coated. Tembalang is a hilly area with varied slopes and directions (Table 1). Land slope in Baskoro is the sharpest i.e almost 20%. Cardona (Cardona, 1998) reported that groundwater follows the topographic gradient, therefore it was assumed that groundwater in Baskoro and Kramas flowed to southeast; while in Tunjungsari it flowed to south-west. Results of soil characterization showed that the soils were silt – clay, in which composition silt about 42%, Clay about 55%, and the rest was sand. Soil permeability ranged from \(2.9 \times 10^{-7}\) to \(8.6 \times 10^{-7}\) cm/s, in which Baskoro’s soil permeability was the highest (Table 1).

<table>
<thead>
<tr>
<th>Table 1: Site characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1</td>
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<td>2</td>
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<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

The dug wells depth average varied between 10.8; 9.5 and 6.8 m in Baskoro, Kramas and Tunjungsari, respectively. The wells, lined with concrete rings, have a diameter of around 0.9 m. The extended well wall, which was called as head wall, was constructed above the ground surface varying 0.1 – 1.3 m, to prevent contamination of surface water run-off and to meet safety reason. In term of head wall height, more than three-quarter of dug well fulfill SNI, i.e 0.8 meter. Dug well with under 50 cm head wall, commonly permanent or semi permanent lining covered and electrical pump was installed to draw water. Whereas, water in relative high head wall wells was pulled either by electrical pump or by manual using rope and bucket.

Distance of dug well to possible pollution sources, i.e septic tank and drain was also measured (Table 2). There was no significant different in distance average of dug well to septic tank between villages. The distance average of distance of dug well to drain in Baskoro was almost twice and four times longer than that in Kramas and Tunjungsari, respectively. Other potential pollution source was chicken rearing activities surrounding B6, T1, T2 and T7, where the animal waste spread over the area.

3.2 Water quality

3.2.1 Total dissolved solid (TDS)

Results of the study parameters from TDS, nitrate, chloride, COD, *E. coli* and total coliforms, are presented for all of the 22 sampling points in Figure 3. In all villages, all dug wells in both seasons had TDS values less than the WHO DWS (WHO 2003) and INA DWS (Endang, 2010) guideline values of 500 mg/l (Figure 3A). The only well with TDS concentration slightly under DWS limit was B4 dug well. This outdoor open well was located on back yard of a house in Baskoro and was equipped with electrical pump and bucket to draw water. In term of season affects, no significant difference of TDS concentration was found at all wells in both seasons. About 45% dug well, how-
ever, had lower TDS concentration in the dry season than that of the wet season. It was found that the highest average concentration of TDS occurred in Baskoro, whereas the lowest was in Kramas.

3.2.2 Nitrate
Nitrate concentration in all the wells in Baskoro villages in both seasons exceeded WHO DWS and INA DWS, while in Kramas, nitrate values were less than those standards, except K1 in wet season, (Figure 3B). It was revealed that average of nitrate concentration in Baskoro in both seasons was much higher than those in the other villages. Nitrate concentration in Baskoro was, even, three fold of that in Kramas. About 80% of dug wells had nitrate concentration during wet season higher than that of in dry season. In Kramas village, all nitrate concentrations of wells increased during wet season. The highest nitrate concentration was found in B4 dug wells, the same dug well that had the highest TDS concentration as mentioned before. The lowest nitrate concentration was found in K6 in dry season. In K6, the lowest TDS was also observed.

Table 2: Characteristics of dug well and distance of dug well to pollution sources

<table>
<thead>
<tr>
<th>Characteristics of dug well</th>
<th>Distance of dug well to (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (m)</td>
<td>Head Wall (m)</td>
</tr>
<tr>
<td>B1 0,8</td>
<td>0,4</td>
</tr>
<tr>
<td>B2 0,8</td>
<td>0,1</td>
</tr>
<tr>
<td>B3 0,8</td>
<td>-</td>
</tr>
<tr>
<td>B4 0,9</td>
<td>0,9</td>
</tr>
<tr>
<td>B5 0,8</td>
<td>0,1</td>
</tr>
<tr>
<td>B6 1,0</td>
<td>0,1</td>
</tr>
<tr>
<td>B7 0,8</td>
<td>0,2</td>
</tr>
<tr>
<td>Average</td>
<td>10,8</td>
</tr>
<tr>
<td>K1 0,7</td>
<td>0,7</td>
</tr>
<tr>
<td>K2 0,9</td>
<td>0,9</td>
</tr>
<tr>
<td>K3 0,7</td>
<td>0,5</td>
</tr>
<tr>
<td>K4 0,9</td>
<td>0,1</td>
</tr>
<tr>
<td>K5 0,7</td>
<td>0,7</td>
</tr>
<tr>
<td>K6 1,3</td>
<td>1,3</td>
</tr>
<tr>
<td>K7 0,9</td>
<td>0,9</td>
</tr>
<tr>
<td>K8 0,8</td>
<td>0,1</td>
</tr>
<tr>
<td>Average</td>
<td>9,5</td>
</tr>
<tr>
<td>T1 0,8</td>
<td>0,8</td>
</tr>
<tr>
<td>T2 0,9</td>
<td>0,7</td>
</tr>
<tr>
<td>T3 0,8</td>
<td>0,6</td>
</tr>
<tr>
<td>T4 0,9</td>
<td>0,7</td>
</tr>
<tr>
<td>T5 0,7</td>
<td>0,1</td>
</tr>
<tr>
<td>T6 0,8</td>
<td>0,5</td>
</tr>
<tr>
<td>T7 1,0</td>
<td>0,5</td>
</tr>
<tr>
<td>Average</td>
<td>6,8</td>
</tr>
</tbody>
</table>
Sudarno, S
Sanitation infrastructure and their potential impacts on human health: a case study of Tembalang sub-district in Samarang City, Indonesia

HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.

Figure 3 Seasonal variation of (A) Total Dissolved Solid (TDS), (B) Nitrate, (C) Chloride, (D) COD, (E) E. coli and (F) total coliforms in dug well water

3.2.3 Chloride
Similar to TDS and Nitrate parameter, the highest chloride in both season was also found in the B4 well, with concentration averate of 262.5 mg/l (Figure 3C). It was the only well that chloride concentration exceeded the WHO and INA DWS. In the K6 wells, Chloride concentration was relatively low compare the others (the second lowest – of nitrate concentration in dry season). Location study with the highest to the lowest of nitrate concentration average was Baskoro, Tunjungasari and Kramas, respectively. The was no trend, whether the chloride in dug well would increase or decrease in wet season. It was found that nitrate concentration from about 50 % of dug wells would increase during the changing season.

Consistent results were found on the B1, B3, B4 and B7 well, in which for three parameter, i.e TDS, nitrate and chloride, their concentrations increased in wet season. In contrast, in B2, K1, K2, T3 and T6 well those parameters constantly decreased in wet season.

3.2.4 COD
Either dry or wet season, in all wells COD concentration exceeded the WHO and INA DWS (Figure 3D). It also showed that the COD concentration in wet season from about 85 % of dug
wells was higher than that of in dry season. The significant increasing of COD concentration at rain season compared with dry season was found in Kramas’s wells, in which the increasing average were almost twice. Even in K2, COD concentration in wet season was four times compared with that of in dry season. The highest to the lowest COD concentration orders in wells were similar to the other chemical parameter, in which Baskoro’s concentration was the highest and Kramas’s concentration was the lowest.

3.2.5 Total coliforms
In dry season, about 39%, 60% and 85% of dug wells in Baskoro, Kramas and Tunjungasari, respectively was polluted by E. coli (Figure 3E). The amount of the polluted wells increased during wet season, in which 60% and 85% of dug wells in Baskoro and Kramas, respectively, was contaminated E. coli. Although E. coli concentration was much lower in wet season that that of in dry season, E. coli contaminated wells increased in wet season.

Interestingly, E. coli was also found in water sample of B2, B5, K2, K8 and T6 wells during wet season, of which those wells were not polluted by E. coli in dry season. As presented in the detailed examinations of Baskoro’s wells, a trend of biological parameter concentration was rather contrary with that of physic-chemical parameter concentration. B4 well, containing the highest TDS, nitrate, chloride concentration, which was contaminated with the least E. coli number.

Rather similar phenomena was also examined in Kramas’s well, in which shallower wells and closer distance between septic tank and well, such as K2 and K8, was polluted with relatively low E. coli amount. In comparison to the other village wells, in Baskoro’s well is the lowest, in contrast to the trend or phenomena of physic chemically parameter measured at those different village wells.

3.2.6 Total coliforms
During dry season, all wells were polluted by the total coliforms (Figure 3F). The concentration of total coliforms reduce significantly in wet season. Even, K3 well, located relatively far away from the other houses, was not contaminated by the total coliforms, as shown by Figure 2b and table 3. In Baskoro, total coliforms concentration that polluted the wells, is half of that in Kramas and Tunjung sari.

4. Conclusion
The water quality of more than 60% and 70% of dug wells in Tembalang was contaminated by E. coli and total coliforms. The pathways of TDS, Nitrate, Chloride and COD in move in soils were in the contrary with those of E. coli and total coliforms. TDS, Nitrate, Chloride and COD parameters of the shallow wells water did not show significant variation between seasons, but varied partially. Total coliforms and E. coli were found to be impacting negatively on groundwater quality.

5. Acknowledgement
The works are financially supported by DIPA Diponegoro University for International Scientific Publication Grant, Number 042.01.2.400898/2016

6. Reference
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Automatic Estimation of the Number of People Remaining in a Room by using a Micro Computer and Environmental Sensors

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Abstract

Purpose / Context - It is important to estimate the number of people remaining in a room to allow for modification of the room environment and effective energy use.

Methodology / Approach - A prototype of an automatic estimation system consisting of a general-purpose microcomputer and environmental sensors (e.g., a thermometer, hygrometer, and CO₂ concentration sensor) was fabricated. We applied "Arduino 2009" as a root device and "XBee" as an extension.

Results – According to experiments performed with this system, correct estimation was obtained once per eight tests.

Key Findings / Implications – Although sufficient precision has not yet been demonstrated, our preliminary experiments led us to recognize that the system would be capable of error-free operation. We aim to achieve usable precision results by discarding the factors leading to incorrect estimations.

Originality - This paper proposes a method to estimate the number of people remaining in a room of a house based on both CO₂ concentration and humidity changes.

Keywords - Remaining, Expiration, Arduino, XBee
1. Introduction

The outdoor climate, especially the sun, wind, and air temperature, affects the indoor climate in low-energy houses. Further, it is important to estimate the number of people remaining in a room to enable appropriate modification of the room environment and to ensure effective energy use. In the past, the manual maintenance of a daily logbook by inhabitants was an orthodox measurement method to track the daily number of people remaining in a room. However, this type of measurement has externalization defects and places a mental load on inhabitants. In the future, a simple measurement technique is needed that would not constitute a breach in privacy. This paper proposes a method to estimate the number of people in a room of a house based on both CO₂ concentration and humidity changes. Application of this method led to the fabrication of a prototype of an automatic estimation system consisting of a general-purpose microcomputer and environmental sensors.

2. Proposed Estimation Method

The number of people remaining in a room is estimated based on measurements recorded by the sensors (e.g., a thermometer, hygrometer, and CO₂ concentration sensor) located indoors/outdoors and using the following equations:

\[ C(t) = C_o + \frac{k}{Q} + \left( C(0) - C_o - \frac{k}{Q} \right) e^{-\frac{Q}{V}} \]  
\[ k = mk^3 = mMP \]  
\[ \sigma(t) = \sigma_o + \frac{h}{Q} + \left( \sigma(0) - \sigma_o - \frac{h}{Q} \right) e^{-\frac{Q}{V}} \]  
\[ h = mh' + h'' = mh' + \beta \frac{\sigma(t) - \sigma(0)}{100} \]  
\[ h' = L + B = L + \gamma(h'' - L) \]  
\[ L = \left( 2.1613 \times 10^{-5} M^2 + 9.6943 \times 10^{-7} M \right) \left( \sigma_o - \frac{\sigma(0)}{2} \right) \]  
\[ h'' = -1.3697 \times 10^{-4} \left( \theta - 0.1818 \right) \left( M - 58.939 \right) \left( M - 1444.9 \right) \]

The coefficients of eq. 6 & 7 were calculated from values indicated by Shiotsu et al. (1998) and Carrier Air-Con. Comp. (1966). The metabolic rate per person (\( \dot{M} \)) is assumed to be 87.3 W as a module (1 met), as the surface area of the human body is 1.5 m², and the range is set between a minimum value of 61.1 W (0.7 met) and a maximum value of 305.6 W (3.5 met). It is important, but difficult, to measure room ventilation as a definite quantity, as this would require the room to be airtight and ventilated only by mechanical fans, as a precondition.
3. Automatic Estimation System

The system consists of "Arduino" as the root device and "XBee" as an extension. The functions of the root device are measuring the room environment, performing calculations for estimation, and wireless connection with the extension device that measures the outdoor environment. We used a unit of code that is uploaded to and run on an "Arduino" board (i.e., a sketch) as a program for the estimation process (see Figure 1). "Arduino" possesses both multiplicity of functions in an easy-to-use design and performs economically in electric power consumption, while there are limits of procedures (e.g., in case of Arduino2009, seven significant digits, clock speed of 16 MHz, and memory of 30,720 bytes). "XBee" is a radio communication module with an available distance of 40 m.

4. Results from Experimentation with the System and Discussion

The actuation of the system as well as the precision of estimation were determined by performing an experiment in a room (6.0 m depth × 3.3 m width × 2.4 m height, 2 people inside) on the fourth floor of a building on Feb. 6, 2015. $Q$ was controlled at a constant value of 0.105 m$^3$/s by an annexed ventilation fan. $C(t)$ was increased to more than twice the outdoor concentration prior to the examination and was uniformly distributed by blowing the room air. $\beta$ and $\gamma$ were set to 0.68 g/s and 0.35339, respectively, from legitimate data (Sugawara, 2009). According to the results listed in

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**Figure 1 Flow chart of the estimation process**

---

4.244mM3.183
2.122mM1.61<≦
3.183mM2.122<≦
183.3 ≤ mM < 244.4
122.2 ≤ mM < 183.3
61.1 ≤ mM < 122.2
m =1

Indicate the estimated value.

Calculate metabolic rates per person ($M_s$) in terms of $m = 1, 2$.

Choose the route depending on $mM$.

Calculate moisture emissions from materials in the room ($h_s$) using eq. (7) with couples of $m$ and $M_s$.

Calculate moisture emissions from nude human body per person excluding expiration ($h^\text{**}$) using eq. (5) with couples of $L$ and $h^\text{**}$.

Calculate moisture emissions per person ($h^*$) using eq. (6) with couples of $m$ and $M$.

Calculate the total metabolic rate in the room $mM$ by using eq. (2) with $k$.

Calculate a CO$_2$ emission speed ($k$) and a moisture emission from human beings and materials in the room ($h$) using eq. (1) & (3).

Measure an indoor/outdoor environment.

Indicate the estimated value.
Table 1, correct estimation was obtained once per eight tests. Although sufficient precision has not yet been demonstrated, it is recognized that the system could run without error.

Table 1: Measured value and estimated number of people

<table>
<thead>
<tr>
<th>Time [min]</th>
<th>5 min before (Indoor Temperature, Relative Humidity, CO₂ Concentration)</th>
<th>Present (Indoor Temperature, Relative Humidity, CO₂ Concentration)</th>
<th>Present (Outdoor Temperature, Relative Humidity, CO₂ Concentration)</th>
<th>k [mg/s]</th>
<th>mM [W]</th>
<th>h [mg/s]</th>
<th>Estimate [people]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>32.8 °C, 25.5 %, 1726 ppm</td>
<td>25.9 °C, 25.8 %, 1091 ppm</td>
<td>18.7 °C, 22.0 %, 513 ppm</td>
<td>-7.97</td>
<td>-93.7</td>
<td>-0.0043</td>
<td>Failure</td>
</tr>
<tr>
<td>1</td>
<td>26.4 °C, 26.0 %, 1418 ppm</td>
<td>25.4 °C, 25.4 %, 1044 ppm</td>
<td>18.4 °C, 22.4 %, 513 ppm</td>
<td>27.46</td>
<td>323.0</td>
<td>0.2124</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>26.4 °C, 25.0 %, 1301 ppm</td>
<td>24.9 °C, 31.0 %, 971 ppm</td>
<td>29.7 °C, 31.0 %, 736 ppm</td>
<td>-16.11</td>
<td>-189.6</td>
<td>-0.1307</td>
<td>Failure</td>
</tr>
<tr>
<td>3</td>
<td>25.9 °C, 25.2 %, 1225 ppm</td>
<td>24.9 °C, 25.7 %, 932 ppm</td>
<td>19.4 °C, 22.6 %, 523 ppm</td>
<td>20.44</td>
<td>240.4</td>
<td>0.2082</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>25.9 °C, 25.4 %, 1157 ppm</td>
<td>24.9 °C, 26.1 %, 891 ppm</td>
<td>18.7 °C, 22.0 %, 509 ppm</td>
<td>20.41</td>
<td>240.1</td>
<td>0.2436</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>25.9 °C, 25.8 %, 1091 ppm</td>
<td>24.9 °C, 26.4 %, 866 ppm</td>
<td>18.7 °C, 21.9 %, 509 ppm</td>
<td>24.22</td>
<td>284.9</td>
<td>0.2539</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>25.4 °C, 25.4 %, 1044 ppm</td>
<td>24.4 °C, 25.9 %, 834 ppm</td>
<td>18.7 °C, 21.9 %, 509 ppm</td>
<td>21.07</td>
<td>247.9</td>
<td>0.2208</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>24.9 °C, 31.0 %, 971 ppm</td>
<td>24.4 °C, 25.9 %, 810 ppm</td>
<td>19.4 °C, 22.5 %, 528 ppm</td>
<td>22.04</td>
<td>259.3</td>
<td>0.2040</td>
<td>1</td>
</tr>
</tbody>
</table>

5. Conclusion

In this study, we proposed a method to estimate the number of people remaining in a room of a house based on both CO₂ concentration and humidity changes. We applied the system consisting of "Arduino 2009" as the root device and "XBee" as an extension. Although sufficient precision has not yet been demonstrated, it is recognized that the system could run without error. We aim to achieve usable precision results for the system by discarding factors leading to incorrect estimations.

6. References

7. Nomenclatures

- $B$: Moisture emission from human beings per person excluding expiration [g/s]
- $C(t)$: CO₂ concentration at $t$ [mg/m³]
- $C_o$: Outdoor CO₂ concentration [mg/m³]
- $h$: Moisture emission from human beings and materials in the room [g/s]
- $h'$: Moisture emission per person [g/s]
- $h''$: Moisture emission from materials in the room [g/s]
- $h^*$: Moisture emission from nude human body per person excluding expiration [g/s]
- $k$: CO₂ emission speed [mg/s]
- $k'$: CO₂ emission speed per person [mg/s]
- $L$: Moisture emission from human expiration per person [g/s]
- $m$: Number of people in the room [person]
- $P$: CO₂ emission quantity for metabolic energy consumption (=0.085) [mg/J]
- $Q$: Ventilation quantity of the room [m³/s]
- $t$: Time after the experiment starts [s]
- $V$: Volume of the room [m³]
- $M$: Metabolic rate per person [W]
- $\beta$: Proportional coefficient [g/s]
- $\gamma$: Proportional coefficient [n.d.]
- $\varphi(t)$: Relative humidity at $t$ [%]
- $\theta$: Air temperature [°C]
- $\sigma(t)$: Absolute humidity at $t$ [g/m³]
- $\sigma_o$: Outdoor absolute humidity [g/m³]
- $\sigma_i$: Absolute humidity inside human body (= 43.774) [g/m³]
Impact of Regional Differences in Residential Environment on Healthy Life Expectancy in 1,300 Japanese Municipalities

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Abstract

Purpose / Context – We clarify how regional differences in residential environment impact healthy life expectancy.

Methodology / Approach – We defined healthy life expectancy and considered how to measure and calculate it. We prepared the data for calculating healthy life expectancy from various Bureau of Statistics data, and applied the method to calculating healthy life expectancy for 1,750 municipalities in Japan in 2005 and 2010.

Results –
(1) The healthy life expectancy of men had increased by 0.38 years, and that of women decreased by 0.20 years on average in every municipality in Japan from 2005 to 2010.
(2) It was confirmed that 1% of the decrease of proportion of housing constructed before 1970 in each municipality contributed to increasing healthy life expectancy by 4.84 years for men and 4.09 years for women.

Key Findings / Implications – Regional difference in healthy life expectancy was seen strongly relevant to the lifestyle and revenue and found a certain degree of relevance with regional differences in living environment.

Originality – This work could quantify the impacts of not only the life habit known in the previous studies but also the residential environment on the extension of healthy life expectancy.

Keywords – Housing and Land Survey, Vital Statistics, Healthy Life Expectancy, Multiple Regression Analysis, Japanese Municipalities

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1. Introduction

In light of Japan’s super-aging society, the Japanese Ministry of Health, Labour and Welfare has set two key targets for the next 10 years. The first is to extend healthy life expectancy, defined as the period in which a person can live in a healthy state with no limitations to their daily activities. The second is to reduce health disparities due to regional and socioeconomic differences. To achieve these targets in the next 10 years, it is important to recognize how healthy life expectancy has changed. Therefore, in this study, we clarify how much healthy life expectancy has been extended or shortened and how much health disparities have increased or decreased.

The WHO report provides a conceptual framework for measures of social determinants of health. Socioeconomic status, such as gender, ethnicity, education, occupation, and revenue, decides the social determinants of health, which results in health disparities. The social determinants of health include the effect of residential environment. Therefore, verifying the effect of residential environment on human health has attracted great interest. In this study, we use healthy life expectancy as a health indicator, and elucidate how regional differences in residential environment impact healthy life expectancy.

2. Changes in healthy life expectancy

2.1 Definition and calculation of healthy life expectancy

Healthy life expectancy statistically refers to the average number of years that healthy people of a certain age will live in full health. The following three points are important: (1) the definition of people’s health status; (2) measurement of peoples’ health condition; and (3) calculation of an index value from the measurements. Health status is defined as the condition in which they can live a self-sufficient day-to-day lifestyle. In Japan, the Long-term Care Insurance System helps those who need long-term support or care depending on their health (Table 1). In particular, people aged 65 or older can use this service freely if they are judged to need support or care in daily life. Therefore, healthy life expectancy is defined in this study as the period in which people aged 65 or older can live with no limitations.

Table 1: Levels of need for support or care

<table>
<thead>
<tr>
<th>Support Required Level</th>
<th>Support required for daily living activities to help prevent progression to requiring care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Care Level 1</td>
<td>Ability to perform routine operations is lower than that for the Support Required Level, and partial care is necessary</td>
</tr>
<tr>
<td>Care Level 2</td>
<td>In addition to Care Level 1, partial help with daily activities is necessary</td>
</tr>
<tr>
<td>Care Level 3</td>
<td>In addition to Care Level 2, the ability to perform daily activities is poor, and care is essential</td>
</tr>
<tr>
<td>Care Level 4</td>
<td>In addition to Care Level 3, the ability to perform daily activities is lower, and it is difficult to engage in daily life without care</td>
</tr>
<tr>
<td>Care Level 5</td>
<td>The ability to perform daily activities is lower than that for Care Level 4, and it is almost impossible to engage in the daily life without care</td>
</tr>
</tbody>
</table>

To calculate the healthy life expectancy as a health indicator, the population and the number of deaths and unhealthy people classified by sex and age are considered (Table 2). Age groups are 65–69, 70–74, 75–79, 80–84, and >85. People certified as meeting any of the support or care levels in Table 1 are defined as unhealthy in this study. The proportion of unhealthy people is obtained by dividing these values by the total number of people in each age group.
Table 2: Database list for calculating healthy life expectancy

<table>
<thead>
<tr>
<th>Database</th>
<th>Data unit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population aged 65 and older (classification sex/five-year age groups)</td>
<td>Country, municipality</td>
<td>Statistics Bureau, Ministry of Internal Affairs and Communications &quot;National Census&quot;</td>
</tr>
<tr>
<td>Number of deaths aged 65 and older (classification sex/five-year age groups)</td>
<td>Municipality</td>
<td>Ministry of Health, Labour and Welfare &quot;Vital Statistics of Population&quot;</td>
</tr>
<tr>
<td>Number of people requiring long-term support or care (classification sex/five-year age groups)</td>
<td>Country</td>
<td>Ministry of Health, Labour and Welfare &quot;Comprehensive Survey of Living Conditions&quot;</td>
</tr>
<tr>
<td>Number of survivors aged 65–85, stationary population (classification sex/five-year age groups)</td>
<td>Country</td>
<td>Ministry of Health, Labour and Welfare &quot;Life Tables&quot;</td>
</tr>
</tbody>
</table>

Healthy life expectancy is calculated based on the database shown in Table 2. Average life expectancy is calculated by using Chiang’s life table method. Average life expectancy $\hat{e}_x$, defined as the number of subsequent years that a person $x$ years old will live, is given by $T_x / l_x$, where $T_x$ is the stationary population aged $x$ years old and older and $l_x$ is the number of survivors. The average life expectancy at 65 years old is calculated statistically with this method (Figure 1).

![Figure 1 Calculation method for the average life expectancy at 65 years old (Chiang’s method)](image)

To determine the unhealthy stationary population, the stationary population and the proportion of unhealthy people for each age group are multiplied by using Sullivan’s method. The independent stationary population without care aged $x$ years old and older, $T_x'$, and the healthy life expectancy, $\hat{e}_x'$, are related by Equation (1).

\[
\hat{e}_x' = T_x' / l_x
\]  

In addition, $T_x'$ can be expressed as Equation (2), where $l_x$ is the independence ratio ($1 -$ proportion of unhealthy people).

\[
T_x' = (T_x - T_{x+1}) \cdot l_x + (T_{x+1} - T_{x+2}) \cdot l_{x+1} + \cdots + (T_{\infty} - T_{\infty+1}) \cdot l_{\infty}
\]

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Here, subscript $\infty$ in $T_{\infty}$ and $I_{\infty}$ denotes the maximum age of local residents. Furthermore, by substituting Equation (2) into Equation (1), healthy life expectancy at $x$ years old $\tilde{e}_x$ can be expressed as Equation (3).

\[
\tilde{e}_x = \left\{ (T_x - T_{x+1}) \cdot l_x + (T_{x+1} - T_{x+2}) \cdot l_{x+1} + \cdots + (T_{\infty} - T_{\infty+1}) \cdot l_{\infty} \right\} / l_x
\]  

(3)

Because the value of $T_x$ and $l_x$ are derived from life tables, $\tilde{e}_x$ can be obtained from $l_x$, based on the number of people certified as Support Required Level or Care Level 1-5. The healthy life expectancy at 65 years old is statistically calculated as the expected value of the period that healthy people aged 65 will survive without health limitations (Figure 2).

We apply the abovementioned method to the municipalities because municipalities provide medical care, insurance, and welfare services directly to people. For each of the 1,750 municipalities in Japan, the input information “population”, “number of deaths”, and “number of people requiring long-term support or care” is used to obtain the healthy life expectancy at 65 years old as output information.

2.2 Healthy life expectancy in every municipality in Japan

For healthy life expectancy in each municipality at 65 years old, we consider (1) the calculation results for 2005 and 2010 and (2) the transition from 2005 to 2010.

(1) Calculation results for 2005 and 2010

The healthy life expectancy at 65 years old in every municipality in 2005 and 2010 is shown in Figures 3 and 4, respectively. In Japan, altitude increases from the coast toward inland regions, and high altitude areas have rich nature. Male and female healthy life expectancy tends to be longer in inland areas such as Yamanashi, Nagano, Shizuoka and Aichi prefectures. Hence, environments with clean water and air in high altitude areas could improve the quality of life. In contrast, healthy life expectancy in the northern areas of Honshu (the main island), such as Aomori and Akita prefectures, is relatively shorter. For most municipalities, female healthy life expectancy is longer than male life expectancy.
Figure 3 Healthy life expectancy at 65 years old in every Japanese municipality in 2005

Figure 4 Healthy life expectancy at 65 years old in every Japanese municipality in 2010
(2) Transition from 2005 to 2010

The change in healthy life expectancy at 65 years old in every municipality from 2005 to 2010 for men and women is shown in Figures 5 and 6, respectively. Male healthy life expectancy has increased by 0.38 years, and female healthy life expectancy has decreased by 0.20 year on average in every municipality in Japan. In some areas, such as Shizuoka Prefecture, where the healthy life expectancy in Figures 3 and 4 is long, the healthy life expectancy decreased from 2005 to 2010. However, even though healthy life expectancy in some areas, such as Akita and Yamagata Prefectures, remained low, the healthy life expectancy decreased over five years. Thus, healthy life expectancy decreased regardless of the original healthy life expectancy. In contrast, healthy life expectancy in Hokkaido and mountainous areas around Japan tended to increase.

![Map showing change in healthy life expectancy](image)

Figure 6 Change in the healthy life expectancy at 65 years old in every municipality from 2005 to 2010 (female)
3. Multivariate analysis of residential environment factors that affect the length of healthy life expectancy

To clarify the factors that affect the length of healthy life expectancy, the multiple regression analysis with objective variables of healthy life expectancy in 2005 and 2010 was performed. The socioeconomic health determinants, “ratio of aging” and “revenue” from the socioeconomic status, and the social health determinants “residential environment” and “lifestyle behaviour” affect health, and we collected these data. Table 3 shows the typical indicators that were considered for the explanatory variables of the multiple regression equation.

Table 4 shows the results of multiple regression analysis for the objective variable of healthy life expectancy separated by gender in 2005. The value of the standardized partial regression coeffi-
cient, "ratio of aging" has the greatest effect compared with the other explanatory variables of each regression equation. In addition, "average annual income" has effect on the objective variable, thus a certain level of the economic affluence is required to improve the human health. Furthermore, "average salt intake" also has negative effect on the objective variable, thus hostile life habits can shorten healthy life expectancy.

### Table 3: Typical indicators considered for the explanatory variables

<table>
<thead>
<tr>
<th>Name of indicator</th>
<th>Classification</th>
<th>Year</th>
<th>Data unit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average vegetable intake [g/day]</td>
<td>Average of people aged 20 or over</td>
<td>2006–2010</td>
<td>Ministry of Health, Labour and Welfare</td>
<td></td>
</tr>
<tr>
<td>Average salt intake [g/day]</td>
<td></td>
<td></td>
<td>&quot;National Health and Nutrition Survey&quot;</td>
<td></td>
</tr>
<tr>
<td>Proportion of people who drink alcohol [%]</td>
<td>Average of men aged 20 or over</td>
<td>2008</td>
<td>Ministry of Land, Infrastructure and Transport</td>
<td></td>
</tr>
<tr>
<td>Number of cars per capita [vehicles / people]</td>
<td></td>
<td>2008</td>
<td>&quot;Number of Vehicles&quot;</td>
<td></td>
</tr>
<tr>
<td>Ratio of aging [%]</td>
<td>Men or women</td>
<td>2005</td>
<td>Statistics Bureau, Ministry of Internal Affairs and Communications</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2010</td>
<td>&quot;National Census&quot;</td>
<td></td>
</tr>
<tr>
<td>Average annual income [million yen / household]</td>
<td></td>
<td></td>
<td>Data unit</td>
<td>Source</td>
</tr>
<tr>
<td>Housing classified by age of building [%]</td>
<td>Before 1970</td>
<td></td>
<td>Municipality</td>
<td>Statistics Bureau, Ministry of Internal Affairs and Communications</td>
</tr>
<tr>
<td></td>
<td>After 2001</td>
<td></td>
<td>&quot;Housing and Land Survey&quot;</td>
<td></td>
</tr>
<tr>
<td>Proportion of housing with a flushing toilet [%]</td>
<td></td>
<td>2003</td>
<td>Municipality</td>
<td>Statistics Bureau, Ministry of Internal Affairs and Communications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2008</td>
<td>&quot;Housing and Land Survey&quot;</td>
<td></td>
</tr>
<tr>
<td>Proportion of vacant housing [%]</td>
<td></td>
<td>Less than 500 m</td>
<td>Municipality</td>
<td>Statistics Bureau, Ministry of Internal Affairs and Communications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Less than 1 km</td>
<td>&quot;Housing and Land Survey&quot;</td>
<td></td>
</tr>
<tr>
<td>Housing classified by distance to the nearest medical institution [%]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4: Results of multiple regression analysis (objective variable: healthy life expectancy by gender in 2005)

<table>
<thead>
<tr>
<th>Objective variable</th>
<th>Healthy life expectancy in 2003 (male)</th>
<th>Healthy life expectancy in 2003 (female)</th>
<th>Healthy life expectancy in 2005 (male)</th>
<th>Healthy life expectancy in 2005 (female)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²=0.414 Partial regression coefficient</td>
<td>Standardised partial regression coefficient</td>
<td>R²=0.196 Partial regression coefficient</td>
<td>Standardised partial regression coefficient</td>
</tr>
<tr>
<td>Ratio of aging</td>
<td>20.3</td>
<td>0.872***</td>
<td>9.80</td>
<td>0.384***</td>
</tr>
<tr>
<td>Average annual income</td>
<td>0.01</td>
<td>0.528***</td>
<td>0.01</td>
<td>0.297***</td>
</tr>
<tr>
<td>Average salt intake</td>
<td>-0.998</td>
<td>-0.432***</td>
<td>-0.792</td>
<td>-0.239***</td>
</tr>
<tr>
<td>Number of cars per capita</td>
<td>3.77</td>
<td>0.280***</td>
<td>4.81</td>
<td>0.248***</td>
</tr>
<tr>
<td>Average vegetable intake</td>
<td>1.30×10⁻²</td>
<td>0.264***</td>
<td>1.17×10⁻²</td>
<td>0.164***</td>
</tr>
<tr>
<td>Proportion of housing constructed before 1970</td>
<td>-6.46</td>
<td>-0.388**</td>
<td>7.15</td>
<td>0.075**</td>
</tr>
<tr>
<td>Proportion of vacant housing</td>
<td>-7.82</td>
<td>-0.167***</td>
<td>-6.29</td>
<td>-0.094*</td>
</tr>
<tr>
<td>Proportion of housing with a flushing toilet</td>
<td>1.33</td>
<td>0.137***</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Proportion of housing constructed after 2001</td>
<td>5.73</td>
<td>0.086**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Proportion of housing within 1 km of transportation</td>
<td>-</td>
<td>-</td>
<td>-1.363</td>
<td>-0.142***</td>
</tr>
</tbody>
</table>

Considering the effects of lifestyle and ratio of aging in each municipality, the indicators for residential environment were selected. The results show that healthy life expectancy decreased for both men and women when the "proportion of housing constructed before 1970" is high. The proportion of houses in poor condition increases as the rate of aging increases; therefore, exposure to old and poor indoor environments for many years shortens healthy life expectancy.
A high "proportion of vacant housing" has a negative impact on the mental health of residents through the deterioration of the regional environment. In addition, healthy life expectancy tends to be longer for areas with a higher "proportion of housing with a flushing toilet". When the thermal environment of the toilet is cold, it is assumed that the temperature difference between the living room and the toilet can cause heat shock. Furthermore, healthy life expectancy tends to be longer in regions where the "proportion of housing constructed after 2001" is higher. Houses built 2001 should meet the latest insulation standards in Japan; therefore, healthy life expectancy increases in regions where these houses are common.

Table 5: Results of multiple regression analysis (objective variable: healthy life expectancy by gender in 2010)

<table>
<thead>
<tr>
<th>Objective variable</th>
<th>Healthy life expectancy in 2010 (male)</th>
<th>Healthy life expectancy in 2010 (female)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²=0.438</td>
<td>R²=0.366</td>
</tr>
<tr>
<td></td>
<td>Partial regression coefficient</td>
<td>Standardised partial regression coefficient</td>
</tr>
<tr>
<td>Ratio of aging</td>
<td>12.2</td>
<td>0.706***</td>
</tr>
<tr>
<td>Average annual income</td>
<td>0.01</td>
<td>0.481***</td>
</tr>
<tr>
<td>Average salt intake</td>
<td>-0.649</td>
<td>-0.385***</td>
</tr>
<tr>
<td>Average vegetable intake</td>
<td>1.11×10⁻²</td>
<td>0.308***</td>
</tr>
<tr>
<td>Proportion of people who drink alcohol</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Proportion of housing constructed before 1970</td>
<td>-4.84</td>
<td>-0.409***</td>
</tr>
<tr>
<td>Proportion of housing with a flushing toilet</td>
<td>1.22</td>
<td>0.141***</td>
</tr>
<tr>
<td>Proportion of housing constructed after 2001</td>
<td>-3.36</td>
<td>-0.138***</td>
</tr>
<tr>
<td>Proportion of housing within 500 m of transportation</td>
<td>-2.01</td>
<td>-0.245***</td>
</tr>
<tr>
<td>Proportion of housing within 500 m of medical institution</td>
<td>-0.503</td>
<td>-0.116***</td>
</tr>
</tbody>
</table>

Table 5 shows the results of multiple regression analysis where the objective variable is healthy life expectancy separated by gender in 2010. Although the healthy life expectancy in 2010 is the target variable, some indicators of the residential environment are also selected to take the lifestyle and aging background of the residents in each municipality into account. The municipalities where the value of the "Proportion of housing constructed before 1970" is high have a shorter healthy life expectancy compared with the national average. In particular, the value of the partial regression coefficient confirmed that 1% of the decrease of this indicator in each municipality contributed to increasing the healthy life expectancy by 4.84 years for men and 4.09 years for women. Furthermore, Healthy life expectancy is shorter in municipalities where a lot of housing is close to the nearest transportation and medical institutions; easy access to these facilities could reduce peoples’ activity and increase the number of unhealthy people.
4. Conclusion

4.1 Key contributions

In this study, we evaluated healthy life expectancy at 65 years old as an indicator to assess the health of whole municipalities in Japan. We defined healthy life expectancy and considered how to measure and calculate it at municipality level. We prepared the data necessary for calculating healthy life expectancy from Bureau of Statistics data, and used our method to calculate healthy life expectancy for 1,750 municipalities in Japan in 2005 and 2010. The results clarify the increase in healthy life expectancy and the differences. To analyse the factors that affect healthy life expectancy, multiple regression analysis captured the elements such as “ratio of aging”, “revenue”, “lifestyle-related behaviour”, and “residential environment”. The residential environment could extend healthy life expectancy.

4.2 Limitation of the study and future challenges

In this study, there is a room for improvement in the R-squared value of the multiple regression analysis. In addition, it has yet to verify the cause and effect relationship in this analysis. We will expand the index to consider and aim to elucidate the causal structure in more detail using the structural equation modelling in the future.

5. Acknowledgement

This study was supported in part by the Japan Science and Technology Agency project “Housing and Healthy Aging” (Principal Researcher: Prof. Toshiharu Ikaga), and by a Grant-in-Aid for Scientific Research (A) (No. 23246102; Principal Investigator: Prof. Toshiharu Ikaga).

6. References

Decrease in the number of bacteria for nucleic acid extraction and sampling of microbiome from the environment

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Abstract

Purpose / Context - Public facilities such as homes for aged individuals and schools are considered at an increased risk for the spread of infections. To our knowledge, there has been no research on the relationship between the microbiome and human activity at such places. Therefore, we investigated the microbiome of locations housing individuals with weakened immune systems due to the spread of infection, to reveal its characteristics. We attempted to establish a method to sample microbiomes from these environments.

Methodology - For ease of sampling, we used Lactobacillus instead of the microbiome directly. We dropped the diluted Lactobacillus onto a plate and swabbed it. After DNA extraction from these bacteria, we calculated the number of bacteria by real-time PCR analysis.

Results - Results showed that approximately 50% of bacteria were lost during sampling and nucleic acid extraction. In this experiment, we found a faint band for the negative control by gel electrophoresis. Prevention and control of microbial contamination are required in the future.

Key Findings - Slightly fewer than 50% of initial bacteria were scattered in the air or deposited on the plate, even considering the number of bacteria after wiping.

Originality - Identification of bacteria directly and rapid analysis.

Keywords - Microbiome; real time PCR; Lactobacillus; 16S rRNA
1. Introduction

Public facilities such as homes for aged individuals and schools are considered at high risk for spreading of infections (Rintala et al., 2008). Conventionally, transmission has been controlled by identification of the bacteria or virus from the pathogenic substance and isolation of the source of infection. To identify bacteria, colonies from cultured samples are used. However, some bacteria cannot be identified owing to culturing difficulties. Moreover, viruses cannot be cultured; therefore, we must analyze cells infected with the virus. Therefore, we cannot directly and rapidly identify and analyze viruses. However, identification and analysis speed has been recently improved with developments in gene analysis technology. (Hattori et al., 2009; Shokralla et al., 2012)

This experiment was performed to establish a microbiome sampling method based on genome analysis for fungi, bacteria, and viruses to evaluate infection risk. We could not clarify the variables for each condition (such as exposure time of sample, number of times of wiping, type of swab); therefore, we used fermented milk in this study, since one reason for the low success rate during collection was the presence of spore-forming *Lactobacillus*.

2. Methodology

First, coated wood plates of 10 cm² were vertically and horizontally wiped twice with 70 % alcohol-impregnated degreased cotton. Subsequently, the plate was irradiated with ultraviolet rays for 10 minutes in a safety cabinet. At this time, the researcher wiped the plate to confirm the absence of bacteria.

Fermented milk drink was diluted 100-fold, and the researcher dropped the diluted sample (0.5 μL) onto the plate at regular intervals for a total of 10 μL. The sample was then spread uniformly over the entire plate with a bacterial spreader.

Two types of swabs were used: wet and dry. The researcher pressed the swab against the wood plate with a force of 0.15 kgf and subsequently wiped the plate. Wiping proceeded vertically and horizontally 33 times, as the width of the swab was 3.0 mm. This process was repeated three times. Subsequently, we extracted DNA from 10 μl of diluted fermented milk to confirm the initial inoculum of *Lactobacillus*. Furthermore, we added 10 μl of diluted fermented milk to the swab to determine the number of *Lactobacillus* that remained on the swab.

We analyzed all samples by real-time PCR.

<table>
<thead>
<tr>
<th>Table 1: Real-time PCR reaction composition (20 μl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYBR Fast qPCR MIX</td>
</tr>
<tr>
<td>Forward Primer</td>
</tr>
<tr>
<td>Reverse Primer</td>
</tr>
<tr>
<td>Sterile Water</td>
</tr>
<tr>
<td>Sample</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: PCR protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Step PCR (Cycles: 30)</td>
</tr>
<tr>
<td>1 94 °C 3 min</td>
</tr>
<tr>
<td>2 94 °C 5 sec</td>
</tr>
<tr>
<td>3 55 °C 1 sec</td>
</tr>
<tr>
<td>4 68 °C 4 sec</td>
</tr>
<tr>
<td>5 GOTO 2, 29 times</td>
</tr>
</tbody>
</table>

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3. Results and discussion

Figure 1 shows the standard curve from real-time PCR analysis. Correlation coefficients and amplification efficiency were within the proper range.

Table 3 shows the number of Lactobacillus in each sample.

Comparing Exp 1 and 2, the number of Lactobacillus decreased in the latter because the contact load was unstable. The proportion of Lactobacillus that remained in the swab was approximately 13% and the proportion that attached to the bacterial spreader was approximately 5%. Based on these results, we calculated the rate of bacteria collection.

Figure 2 shows that slightly fewer than 50% of bacteria were scattered in the air or deposited on the plate, even considering the number of bacteria after wiping.

We will next study the actual phenomenon of movement of bacteria or viruses within oral, hand, desk, and air samples.

**Table 3: Number of Lactobacillus**

<table>
<thead>
<tr>
<th>(SQ/1 μl)</th>
<th>First</th>
<th>Second</th>
<th>Third</th>
<th>Standard</th>
<th>Dropped Swab</th>
<th>Bacterial Spreader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp 1</td>
<td>45,175</td>
<td>11,250</td>
<td>4,493</td>
<td>155,950</td>
<td>141,200</td>
<td>5,145</td>
</tr>
<tr>
<td>Exp 2</td>
<td>20,180</td>
<td>13,490</td>
<td>6,851</td>
<td>149,400</td>
<td>124,000</td>
<td>9,448</td>
</tr>
</tbody>
</table>

**Table 4: Sample details**

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>First-time wiping</td>
</tr>
<tr>
<td>Second</td>
<td>Second-time wiping</td>
</tr>
<tr>
<td>Third</td>
<td>Third-time wiping</td>
</tr>
<tr>
<td>Standard</td>
<td>Initial number in 10 μl of diluted fermented milk</td>
</tr>
<tr>
<td>Dropped Swab</td>
<td>10 μl of diluted fermented milk added directly to swab</td>
</tr>
<tr>
<td>Bacterial Spreader</td>
<td>Lactobacillus attached to bacterial spreader</td>
</tr>
</tbody>
</table>
4. Conclusion

This experiment was performed to establish a sampling method based on genome analysis for microbiomes that are composed of fungi, bacteria, and viruses, to evaluate the risk of infection. The results indicate the following:

1. Slightly fewer than 50% of the bacteria were scattered in the air or deposited on the plate, even when considering the number of bacteria after wiping.
2. If the number of bacteria obtained after wiping three times was the total number of bacteria adhering to the plate, we can obtain more than 80% of bacteria by wiping two times.

In addition, future tasks are needed as follows:

1. To determine the cause of contamination and to reliably prevent contamination during the experiment. Due to contamination, this method would not be able to sample a small number of bacteria, as it was not possible to obtain accurate data.
2. To perform this experiment with simultaneous air sampling to assess the number of bacteria scattered in the air. This is based on the possibility that bacteria were scattered in the air with drying and upon dropping *Lactobacillus* on the plate.
3. To consider differences in number of bacteria collected due to the contact load. This is based on the possibility that the contact load led to a reduction in the number of bacteria harvested, because it was not constant.

5. References


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Indoor air condition in narrow living spaces (Part 2)

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Abstract

Purpose - It is rather easy to control thermal air conditions in narrow-air tight living spaces. However, it is not so easy to keep good air quality in the spaces. Indoor air condition is especially important to keep the health condition of the people. We researched the environmental condition of the temporary houses.

Methodology - We carried out a survey regarding housing conditions, families and so on, measuring indoor air conditions, room air temperature, humidity in summer and winter, and carbon dioxide (CO2) in winter.

Results - In August, average air temperatures were near 28°C in living rooms and in bed room. Humidity was near 70% in both rooms. Discomfort index was about 78 in both rooms. In January, average air temperature was 14.3°C. Humidity was near 60% and Wind-chill index was about 320kcal/m²/hr. Mean of average CO2 concentration was 1240ppm. Max CO2 concentration was 2182ppm.

Key Findings - The thermal condition in indoor housing is hot and humid: not so comfortable in summer. Wind-chill index 300 ~500kcal/m²/hr. is cool and wind-chill index 150 ~300 kcal/m²/hr. is comfortable according to the evaluation of thermal conditions. Inside the housing is not so uncomfortable for the activities and daily life of people. CO2 levels became to be high. Poor air quality occurs frequently inside air tight and narrow spaces. Therefore, adequate ventilation in rooms is needed to keep good air quality.

Originality - In practice, carbon dioxide (CO2) is an easy index of air quality in living spaces. Discomfort index (DI) in hot and humid environments and, wind-chill index (WCI) in cold environments are better indices.

Keywords - narrow living spaces, carbon dioxide, thermal air conditions, summer, winter
1. Introduction

It is rather easy to control thermal air conditions in narrow-air tight living spaces. However it is not so easy to keep good air quality in the spaces. Carbon dioxide (CO₂) is an easy index of air quality in living spaces. On the Japanese standard levels of CO₂, a concentration of less than 700 ppm is excellent, 1000 ppm is generally permitted, 1500 ppm is permitted in the space with a ventilator, 2000~5000 ppm is not so good, and a level of over 5000 ppm is considered to be bad for daily life.

After the earthquake on 11th March 2011 in North-East area of Japan, temporary houses were built in the area. In Fukushima, temporary houses were built further inland especially due to the nuclear evacuation zones, and evacuees are living in them. There are many elderly people in the housing. Indoor air condition is especially important to keep the health condition of the people. We researched the environmental condition of the housing.

2. Methods

We carried out a survey regarding housing conditions, families and so on, measuring indoor air conditions; room air temperature, humidity in summer and winter, and Carbon dioxide (CO₂) in winter. We researched some temporary housing estates in Fukushima city. 10 houses were selected as the housing for this research at each estate, totaling 30 houses.

Room air temperature and humidity were measured and recorded in the living room and bedroom at 30 minute intervals. Thermal recorders were set up at a height of 0.5~1.5m from the floor for each room. In winter, the CO₂ was measured and recorded in the kitchen at 10 minute intervals also.

The measuring devices were a Thermo-Recorder and CO₂ Recorder, with automatic recording system (T&D Corporation, Japan).

3. Results

3.1 In summer

Summer season is from June to August in Japan. August is the hottest month. The basic material of the structure of the temporary housing is light-weight steel. Room air temperatures using air conditioners in each housing were set up from 19 to 32°C. Setting room air temperature at 28°C comprised the highest frequency at 45%, and the next setting of room air temperature at 25°C was 15%. Rooms were comfortable with the use of the air conditioner, but uncomfortable with no use. Natural ventilation was not satisfactory.

As an example, in the living room of temporary housing with air conditioner in August, the air temperature level was 24~25°C and humidity was rather high at night. During the daytime, the air temperature level was 26~27°C. Humidity level was 40~50% and Discomfort index (DI) was 70~75 level.
Table 1: Room air temperature, humidity, and Discomfort Index (ID) in living room and bed room

<table>
<thead>
<tr>
<th></th>
<th>Average air temp. (℃)</th>
<th>Average humidity (%)</th>
<th>Discomfort index (DI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>living room</td>
<td>bed room</td>
<td>living room</td>
</tr>
<tr>
<td>Mean</td>
<td>27.8</td>
<td>28.1</td>
<td>69.5</td>
</tr>
<tr>
<td>SD</td>
<td>0.94</td>
<td>0.70</td>
<td>3.17</td>
</tr>
<tr>
<td>Max</td>
<td>29.6</td>
<td>30.3</td>
<td>74.5</td>
</tr>
<tr>
<td>Min</td>
<td>24.6</td>
<td>25.7</td>
<td>59.8</td>
</tr>
</tbody>
</table>

Table 1 shows average values of room air temperature, humidity, and Discomfort index in living rooms and bed rooms of the temporary housing in August. Average air temperature were 27.8℃ in living rooms and 28.1 ℃ in bed room. Humidity was near 70% in both rooms. Discomfort index was about 78 in both rooms.

3.2 In winter

Winter season is from December to February. January is the coldest month. In many temporary houses, air conditioners and double windows were added to prevent coldness in winter.

Room air temperatures using air conditioners in the housing were set up from 14 to 30℃. Setting room air temperature at 25℃ comprised the highest frequency at 35%.

Figure 1 shows CO₂ concentration, air temperature and humidity using an oil heater in the kitchen of one house in January as an example. At night, the CO₂ level was 600 ppm. During the daytime the CO₂ was sometimes high; over 2000ppm. The air temperature level was 18~20℃ at night, and the air temperature level was 20~25℃ during the daytime. Humidity level was 40~50%.

![Figure 1 CO₂ concentration, air temperature, humidity in the kitchen of one house in January](image)

CO₂ concentration in the kitchen of each was was measured for one week in winter season. Mean average CO₂ concentration was 1240ppm and standard deviation (SD) was 663ppm. Max CO₂ concentration (±SD) was 2182±653ppm.
Table 2 shows the average mean values of room air temperature, humidity, and Wind-chill index in living rooms of the temporary housing in January. Average air temperature was 14.3°C. Humidity was near 60% and Wind-chill index was about 320kcal/m2/hr.

4. Conclusion

In summer, room air temperatures in living rooms and bed rooms were similar; max average temperature over 29°C. Humidity was rather high; about 75%. Discomfort index (DI) was about 80. Therefore the thermal condition in indoor housing is hot and humid: not so comfortable in summer.

In winter, wind-chill index was 320kcal/m²/hr. Wind-chill index 300 ~500kcal/m²/hr. is cool and wind-chill index 150 ~300 kcal/m²/hr. is comfortable according to the evaluation of thermal conditions. Inside the housing are not so uncomfortable for the activity and daily life of people.

But CO₂ levels became to be high. Poor air quality occurs frequently inside air tight and narrow spaces; therefore adequate ventilation in the room is needed to keep good air quality. The thermal condition of living spaces and healthy air must be seriously considered.

5. References

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Tanaka, M (2015) Indoor air quality, air temperature and humidity in narrow /air tight space Proceedings of the 4th International Conference on Climate, Tourism and Recreation–CCTR2015, Istanbul, Turkey, 17~ 19 September
Statistical Analysis of Residential Energy Consumption except Heating in Beijing of China

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Abstract

**Purpose / Context** - Residential energy consumption except heating (RECEH) plays an important role in China. The purposes of this study were to analyze RECEH in Beijing and find out the influence factors of RECEH.

**Methodology / Approach** - A survey of 2024 households in Beijing was undertaken. The investigated residences were located in 23 residential communities and two farmers markets. Questionnaire contents included six aspects: building information, building envelope, living style, auxiliary household appliance, electricity consumption and other energy consumption. While electricity consumption in 8571 families, gas consumption in 189 families, and water consumption in 414 families have been measured by the meter readings last for four months and a year. This paper obtained the results by a method combining data statistics with grey correlation analysis.

**Results** – The results showed that the annual average consumption of electricity and air conditioner electricity in each household was 1689 and 160.4 kWh separately. In addition, the quantity of annual average gas usage was 140 m³/household and the water consumption was 80 m³/household. The analysis of influence factor showed that usable floor area and number of household members was the most profound impact on the entire electricity and gas consumption respectively. The most important influence factor of high, middle, low level electricity consumption families was the number of glass layers, number of household members and temperature setting of air conditioner separately. While construction year, number of household members and construction year became the most important influence factor of high, middle, low level gas consumption families separately.

**Key Findings / Implications** –
- Residential energy consumption except heating in Beijing has been investigated.
- Influence factor was analyzed by grey correlation analysis.
- The effect of usable floor area and number of household members was the strongest contribution to the entire electricity and gas consumption respectively.
Originality - This paper analyzed residential energy consumption except heating in Beijing and obtained the influence factor by a method combining data statistics with grey correlation analysis.

Keywords - Residential buildings, Energy consumption except heating, Influence factors, Grey correlation analysis.

1. Introduction

With the rapid development of economy, building energy consumption has become a significant issue affecting the development strategy of the whole country. It's reported that the proportion of China building energy consumption to total energy consumption increased from 10% in 1970s to 27.5% in 2014, and the proportion is expected to rise to 35% in 2020 (Wang, 2014). By 2009, the average area of Beijing residential energy consumption is 28.73 kgce/(m² ∙ a), and the energy consumption except heating which accounts for 42.6% of the total is 12.24 kgce/(m² ∙ a) (Beijing Municipal Bureau Statistics [BMBS], 2010).

Some researchers made investigations to analyze the residential energy consumption in China. Chen, Yoshino, and Li made analyses on summer energy consumption of residential buildings and their influence factors in seven cities (Chen, Yoshino, & Li, 2010). Wang developed a model to estimate the residential heating energy consumption and sensitivity analysis shows that residential heating energy consumption is significantly influenced by heating set-point temperature (Wang, Zhao, Lin, Zhu, & Ouyang, 2015). Tianchi Hu made the research in three cities and the influence factor analyses showed that the important influence factors were city location, floor area, CDD and the type of water heater (Hu, Yoshino, & Jiang, 2013). Zhao use the LMDI approach in its additive form to explore the driving factors behind the rapid growth of China's urban residential energy consumption (Zhao, Li, & Ma, 2013). Qiaoxia Yang adopts a bottom-up typical method to establish a model and the model can be used to analyse the development trend of the related factors (Yang, Liu, Huang, Min, & Zhong, 2015). In addition, Li and Jiang analyzed the residential energy consumption except heating in Beijing. But it is regrettable that detailed analysis of other influence factors is lacking (Li & Jiang, 2006).

This paper focused on the research of energy consumption in Beijing residential except heating, and analyzed the correlation between RECEH in Beijing and its influence factors by collecting questionnaire data. It is essential for decision makers and the public to keep gaining insight into the energy consumption in Beijing residential except heating and to figure out the influence factors, so as to put forward the corresponding energy saving measures.

2. Methodology

2.1 Investigation and Measurement

The questionnaire survey lasts for one year and four months. The distribution of respondents ranges widely which included 23 communities and 2 markets (defined as A, B in all figures). The total number of questionnaires is 3000, while 2024 of them are valid. The distribution of questionnaire are as follows: 251 in Fengtai district, 725 in Chaoyang district, 335 in Xicheng district, 186 in Dongcheng district, 45 in Shijingshan district, 482 in Haidian district. Table 1 lists the questionnaire contents which covered 26 questions in total: building information, building envelope, living style, auxiliary household appliance, electricity consumption and other energy consumption. In addition, electricity consumption of 8571 families and water consumption of 414 families were collected by the meter readings once a month, in addition, gas consumption of 189 families were recorded every three months.
Table 1: Contents of questionnaire

<table>
<thead>
<tr>
<th>Items</th>
<th>Specific content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building information</td>
<td>Construction year, structure, usable floor area, number of household members</td>
</tr>
<tr>
<td>Building envelope</td>
<td>Material of window frame, number of glass layers, ways of shading</td>
</tr>
<tr>
<td>Auxiliary household appliance</td>
<td>Number of air conditioner, temperature setting of air conditioner, use frequency of room auxiliary heater, types of water heater</td>
</tr>
<tr>
<td>Living style</td>
<td>Cooling pattern, energy saving habits</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>Annual household electricity consumption</td>
</tr>
<tr>
<td>Other energy consumption</td>
<td>Energy consumption of gas and water</td>
</tr>
</tbody>
</table>

2.2 Grey correlation analysis method

Grey correlation analysis method is a multi-variable statistical analysis method which based on sample data of various factors and described the degree and sequence of correlation among all factors by using the grey association degree. The basic concepts are as follows (Li, 2012):

(1) Grey correlation coefficient

Let $X_0 = \{X_0(k) \mid k = 1, 2, \ldots, n\}$ be the reference sequence,

$X_i = \{X_i(k) \mid k = 1, 2, \ldots, n\} (i = 1, 2, \ldots, n)$ be the relative sequence,

Thus

$$\xi_i(k) = \frac{\text{Min} \text{Min} \Delta_i(k) + \rho \text{Max} \text{Max} \Delta_i(k)}{\Delta_i(k) + \rho \text{Max} \text{Max} \Delta_i(k)} \tag{1}$$

Where $\rho$ is the resolution, the value is in the range from 0 to 1. In general, the value of $\rho$ should be 0.5. $\Delta_i(k) = |X_0(k) - X_i(k)|$, which is the absolute differences between $X_0$ and $X_i$ of $k^{th}$.

$\text{Min} \text{Min} \Delta_i(k)$ is the minimum difference between the reference sequence and all relative sequences. $\text{Max} \text{Max} \Delta_i(k)$ is the maximum difference between the reference sequence and all relative sequences.

(2) Grey correlation degree

The grey coefficients of each point are integrated to get the relevancy $\gamma_i$ between the whole and references:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \tag{2}$$
(3) Data processing

When the series whose units and initial values are different are analyzed with the relevance, they are processed usually with non-dimensional.

\[
X_i^*(k) = \frac{X_i(1) - \min X_i(k)}{\max X_i(k) - \min X_i(k)} \quad (i = 1, 2, \ldots, m, k = 1, 2, \ldots, n) \quad (3)
\]

3. Results and Discussion

3.1 Questionaire results

As is shown in Table 2 and Table 3, most of the investigated buildings were built during the period of 2000-2004, while most buildings were constructed between 1990 and 2004 which accounted for 82%. In addition, nearly half of the investigated buildings in Beijing were board structure which is more than the structure of tower and mixed.

Table 2: Building structure

<table>
<thead>
<tr>
<th>Building Structure</th>
<th>Tower</th>
<th>Board</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td>1,2,12,18,19,23</td>
<td>5,7,10,13,15,16,17,20,21,22</td>
<td>3,4,6,8,9,11,14</td>
</tr>
</tbody>
</table>

Table 3: Construction year

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td>10, 5,6,9,13,20,22,23</td>
<td>1,2,3,4,8,11,12,14,15,17,19,21</td>
<td>7,16,18</td>
<td></td>
</tr>
</tbody>
</table>

Fig.1 shows the number of household members in the investigated buildings. It is found that families of three people are dominant which occupied 41%, while 17% of the investigated families have more than four persons. In general, the families have more members tend to be more energy consumption. Regarding to usable floor area, Fig.2 illustrates that more than 70 percent of the investigated inhabitants live in apartments with less than 90 m².
As we all known, around 50% are lost through doors and windows in the energy cost of the whole building. Fig. 3 lists the material of window frames used in investigated buildings. More than 80% of the families used plastic steel windows with smaller heat transfer coefficients. And we can see from Fig. 4 that installing double glazing is the best choice for most people, which can give a great help for cutting down the energy consumption of the external window.

Regarding the types of shading, more than 90% of households in Beijing had curtain as shown in Fig. 5. Fig. 6 shows the household percentage of cooling mode. It is concluded from the figure that the most are all accustomed to use the air conditioner and electric fan in summer, while around 20% of people choose to cool down by opening window.

Air conditioner has become an indispensable home appliance of our life. It is evident from Figure 7 that nearly 90% of households had one or more air conditioners. According to Fig. 8, most people have a strong sense of energy saving that refrigerating temperature could be maintained in the range of 25-28°C, but still about 40 percent of residents are still setting temperature too low. The average energy consumption of air conditioner in Beijing was reduced by 1.4 KWh/㎡ when the temperature of air-conditioned room was raised by 1°C (Li & Jiang, 2006).

HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.
As we can see from Fig. 9, the majority of residents won't use auxiliary heater in winter for that central heating system can meet the requirement of indoor temperature. Some residential buildings built in earlier times use heating for the aging radiator has little effect. Figure 10 shows that most investigated residences were equipped with individual water heater. The piping gas water heater was the most popular type. In addition, only very few people adopted a system of solar energy water heater for lack of promote and publicize in early time.

According to Fig. 11, the implementation rate of energy-saving measurement are lower than 60% because these energy saving habits haven't yet caused much attention. Implementation of "open fewer lights" is the best, meanwhile, "recommend energy-saving equipment for others" and "regular
maintenance of home appliance” are enforced poorly. Therefore, the government should formulate relevant preferential policy and strengthen the promotion efforts of energy-efficient appliances.

3.2 Measured results of energy consumption

Fig. 12 Annual household electricity consumption

Fig.12 illustrates annual electricity consumption distribution in the investigated household. All investigated families were divided into three categories: high level electricity consumption families accounted for top 30% of the total energy consumption and low level electricity consumption families accounted for bottom 20% of the total energy consumption, what’s more, the remaining of families belongs to middle level electricity consumption. The annual mean electricity consumption was 1689 kWh. Furthermore, the annual average electricity consumption in high level electricity consumption families was 3460.0 kWh, which was 1.9 times as much as that in the middle level families (1859 kWh) and 4.1 times as the low level families(851.7 kWh). It may easily to get into this situation that electricity consumption were distributed unevenly.

Fig. 13 Quarterly mean gas use amounts

Fig. 14 Monthly mean water use amounts
Fig. 13 shows the average value of gas use during different quarters. The household gas use was 35 m³ in a quarter and around 140 m³ in a whole year. It is found from Fig. 13 that the largest mean gas value of 38 m³/household occurs in winter while the lowest gas value of 32 m³/household occurred in autumn. Monthly measurement data of water consumption in a year were obtained and shown in Fig. 14. The months of peak water usage were November and December while the lowest water consumption occurred in March and April. The annual total amount of water consumption was 80 m³/household, which was close to that in England (Zhang, Zhang, & Yue, 2004).

### 3.3 Influence factor analysis

When choosing the influence factors, we can firstly conduct a preliminary screening and then do the second step screening by calculating correlation and contribution.

(1) Calculate the correlation and contribution of influence factors

Gas is generally used to cooking and heating water, therefore we can choose 6 influence factors subjectively. Then we can get the correlation coefficients among them by using statistical products and service solutions (SPSS) software. The correlation coefficient showed in Table 5 and each influence factor’s contribution to gas consumption showed in Table 6.

#### Table 5 The correlation coefficients between the 6 influence factor

<table>
<thead>
<tr>
<th>Number</th>
<th>NO.1</th>
<th>NO.2</th>
<th>NO.3</th>
<th>NO.4</th>
<th>NO.5</th>
<th>NO.6</th>
<th>Gas consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO.1</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>NO.2</td>
<td>0.396</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO.3</td>
<td>0.201</td>
<td>0.138</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO.4</td>
<td>-0.225</td>
<td>-0.151</td>
<td>-0.217</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO.5</td>
<td>0.105</td>
<td>0.104</td>
<td>0.070</td>
<td>0.022</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO.6</td>
<td>0.088</td>
<td>0.231</td>
<td>0.030</td>
<td>-0.067</td>
<td>0.009</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

| Gas consumption | -0.025| 0.092| -0.024| -0.028| -0.124| 0.107| 1 |

NO.1—construction year; NO.2—usable floor area; NO.3—building structure; NO.4—top floor or not; NO.5—type of water heater; NO.6—number of household members.

#### Table 6 Influence factor’s contribution to gas consumption

<table>
<thead>
<tr>
<th>Number</th>
<th>NO.1</th>
<th>NO.2</th>
<th>NO.3</th>
<th>NO.4</th>
<th>NO.5</th>
<th>NO.6</th>
</tr>
</thead>
</table>

(The meaning of Number is as the same as Table 5)
In Fig.15, the abscissa and ordinate are the absolute value of correlation coefficient to electricity consumption and contribution respectively. Then we divide the whole area into four parts: area Ⅰ, Ⅱ, Ⅲ, Ⅳ, and the influence factors in area Ⅳ should be deleted for the reason that the correlation and contribution are both in a low level. Finally there are four influence factors left, which are construction year, usable floor area, type of water heater, number of household members.

![Figure 15 correlation and contribution of gas consumption](image)

(2) Calculate grey correlative degree

Liking the classification standard of electricity consumption, we divide the gas consumption into three levels: high, middle, low level. As is showed in Table.7, we can obtain influence factors’ grey correlative degree to gas consumption by grey correlative analysis theory. Similar to the previous approaches, Influence factors’ grey correlative degree of electricity consumption could be calculated and showed in Table. 8. In order to better explain the usage of air conditioner, we draw out the factor: the usage number of air conditioner, which is obtained by the number of air conditioner times the usage frequency. The value of non use, rarely use, occasional use and frequently use is 0.25, 0.5, 0.75 and 1 respectively.

<table>
<thead>
<tr>
<th>Number</th>
<th>construction year</th>
<th>usable floor area</th>
<th>type of water heater</th>
<th>number of household members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.540</td>
<td>0.732</td>
<td>0.621</td>
<td>0.759</td>
</tr>
<tr>
<td>High level</td>
<td>0.720</td>
<td>0.499</td>
<td>0.693</td>
<td>0.634</td>
</tr>
<tr>
<td>Middle level</td>
<td>0.604</td>
<td>0.740</td>
<td>0.576</td>
<td>0.737</td>
</tr>
<tr>
<td>Low level</td>
<td>0.704</td>
<td>0.591</td>
<td>0.541</td>
<td>0.616</td>
</tr>
</tbody>
</table>
Table 8: Grey correlative degree of influence factors to electricity consumption

<table>
<thead>
<tr>
<th>Number</th>
<th>NO.1</th>
<th>NO.2</th>
<th>NO.3</th>
<th>NO.4</th>
<th>NO.5</th>
<th>NO.6</th>
<th>NO.7</th>
<th>NO.8</th>
<th>NO.9</th>
<th>NO.10</th>
<th>NO.11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.549</td>
<td>0.545</td>
<td>0.776</td>
<td>0.476</td>
<td>0.504</td>
<td>0.651</td>
<td>0.754</td>
<td>0.572</td>
<td>0.681</td>
<td>0.624</td>
<td>0.775</td>
</tr>
<tr>
<td>High level</td>
<td>0.438</td>
<td>0.852</td>
<td>0.602</td>
<td>0.842</td>
<td>0.881</td>
<td>0.466</td>
<td>0.472</td>
<td>0.723</td>
<td>0.426</td>
<td>0.543</td>
<td>0.626</td>
</tr>
<tr>
<td>Middle level</td>
<td>0.552</td>
<td>0.540</td>
<td>0.699</td>
<td>0.452</td>
<td>0.460</td>
<td>0.693</td>
<td>0.716</td>
<td>0.598</td>
<td>0.671</td>
<td>0.624</td>
<td>0.735</td>
</tr>
<tr>
<td>Low level</td>
<td>0.712</td>
<td>0.709</td>
<td>0.591</td>
<td>0.583</td>
<td>0.567</td>
<td>0.532</td>
<td>0.622</td>
<td>0.783</td>
<td>0.597</td>
<td>0.700</td>
<td>0.662</td>
</tr>
</tbody>
</table>

NO.1—construction year; NO.2—building structure; NO.3—usable floor area; NO.4—top floor or not; NO.5—number of glass layers; NO.6—type of water heater; NO.7—the usage number of air conditioner; NO.8—the setting temperature of air conditioner; NO.9—cooling method; NO.10—family size; NO.11—energy saving habit.

From Table 9, we can see that the usable floor area is the biggest influence factor, number of household members ranks the second, the usage number of air conditioner is the third in total electricity consumption. Larger usable floor area means that the family is very likely to use more or higher power appliances. And families with larger population can lead to increase the frequency of household appliances. In addition, even though the variable frequency air conditioner enter into the market, but larger use rate of air conditioner leads to higher electricity consumption. In high level electricity consumption families, the number of glass layers has the strongest effect on electricity consumption, building structure and top floor or not rank the second and third respectively. What’s more, these factors can be attributed to the performance of building envelope. As for middle level electricity consumption families, number of household members is the most important factor. Higher temperature setting of air conditioner can reduce the electricity consumption effectively for low level electricity consumption family, however it don’t have remarkable influence on high and middle level electricity consumption families. As we all know, gas in residential is generally used to cooking and heating water, larger population means that the demand to meet daily life is larger. Therefore, no matter which level of gas consumption, the number of household members is always a big influence factor.
Table 9 Influence factors rank

<table>
<thead>
<tr>
<th>Influence Factor Rank</th>
<th>Electricity Consumption</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>High level</td>
<td>Middle level</td>
<td>Low level</td>
</tr>
<tr>
<td>1</td>
<td>NO.3</td>
<td>NO.5</td>
<td>NO.11</td>
<td>NO.8</td>
</tr>
<tr>
<td>2</td>
<td>NO.11</td>
<td>NO.2</td>
<td>NO.7</td>
<td>NO.1</td>
</tr>
<tr>
<td>3</td>
<td>NO.7</td>
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<td>NO.3</td>
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<td>4</td>
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<table>
<thead>
<tr>
<th>Influence Factor Rank</th>
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</thead>
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<td></td>
<td>Total</td>
<td>High level</td>
<td>Middle level</td>
<td>Low level</td>
</tr>
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<td>NO.4</td>
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<td>NO.2</td>
<td>NO.1</td>
</tr>
<tr>
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<td>NO.2</td>
<td>NO.3</td>
<td>NO.4</td>
<td>NO.4</td>
</tr>
<tr>
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<td>NO.3</td>
<td>NO.4</td>
<td>NO.1</td>
<td>NO.2</td>
</tr>
<tr>
<td>4</td>
<td>NO.1</td>
<td>NO.2</td>
<td>NO.3</td>
<td>NO.3</td>
</tr>
</tbody>
</table>

Electricity consumption: NO.1—construction year; NO.2—building structure; NO.3—usable floor area; NO.4—top floor or not; NO.5—number of glass layers; NO.6—type of water heater; NO.7—the usage number of air conditioner; NO.8—temperature setting of air conditioner; NO.9—cooling method; NO.10—thermal comfort; NO.11—number of household members

Gas consumption: NO.1—construction year; NO.2—usable floor area; NO.3—type of water heater; NO.4—number of household members

4. Conclusion

In this paper, we investigated energy consumption in Beijing residential buildings except heating and analyzed the influence factors by statistical method and grey correlation analyses. Some conclusions are summarized as follows:

- There exists energy consumption distribution unevenness in most investigated households. The average annual electricity consumption was 1689 kWh/household with a maximum reaching 17047 kWh/household. In addition, the high level electricity consumption families consumed 30% of the total electricity consumption annually and 40% of the total electricity consumptions could be enough to supply daily life of the low level electricity consumption families.

- The quantity of average annual gas usage was 140m³/household.

- The annual average water consumption was around 80m³/household, including 14m³ hot water, 19m³ reclaimed water and 47m³ cold water.
• Among the entire influence factors of electricity and gas consumption, usable floor area and number of household members rank the first position respectively.

• The most important influence factor of high, middle, low level electricity consumption families is the number of glass layers, number of household members and temperature setting of air conditioner respectively.

• Construction year has the strongest effect on high and low level gas consumption families while number of household members is the most important influence factor for middle level gas consumption families.

5. Reference


Pilot Monitoring of Ultrafine Particle Number Concentrations in some Households in Hanoi

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Abstract

Purpose / Context - Epidemiological studies have consistently shown that fine and course airborne particles (PM$_{2.5}$ and PM$_{10}$), as well as ultrafine (UF) particles measured in terms of particle number (PN) concentrations, are toxic to human health. A number of studies on particle concentrations in households were conducted worldwide; however, no such studies have so far been conducted in Vietnam.

Methodology / Approach - Using two Nano-Tracers, the authors have simultaneously and continuously measured both indoor and outdoor number concentrations of UF particles at one low rise residential house and one apartment at a high rise building in Hanoi in order to quantify the concentrations and develop an understanding of factors driving them.

Results - Daily average indoor and outdoor PN concentrations ranged from 14.5 to 19.8 x 10$^3$ p/cm$^3$ and from 33.4 to 35.5 x 10$^3$ p/cm$^3$, respectively. However, mean concentrations of indoor and outdoor PN during rush-hours were higher and increased up to the maximum of 23.1 and to 57.8 x 10$^3$ p/cm$^3$, respectively.
Key findings / Implications - Inspection of time series of particle concentration and subsequent statistical analysis showed that outdoor PN concentrations were strongly influenced by the outdoor vehicle emissions, while indoor PN concentrations were contributed by both indoor and outdoor sources.

Originality – It is the first time, UF particle number concentrations outside and inside the residential houses in Hanoi were quantified. Outdoor particle concentrations were found strongly influenced by vehicle emissions, while indoor particle levels affected by both indoor and outdoor sources.

Keywords – ultrafine particle, household, traffic, indoor activities.

1. Introduction

Air pollution is considered to be one of the major environmental risks to human health and can cause numerous kinds of diseases, especially respiratory diseases such as asthma, sinusitis, bronchitis, pneumonia, lung cancer and others related to the heart, as well as the nervous, circulatory and digestive system. Epidemiological research has consistently shown an association between fine (<2.5 μm; PM_{2.5}) particle concentrations and increases in both respiratory and cardiovascular morbidity and mortality (Pope 2000, Schwartz and Neas 2000, Davidson, Phalen et al. 2005). The health effects of ultrafine (<0.1 μm) particles are less well known, however research to date indicates that they may be equally or more detrimental than those of PM_{2.5} and PM_{10} (Oberdorster 2000, Franck, Odeh et al. 2011).

The amount of fine and ultrafine particles in the urban atmosphere is mainly influenced by vehicle exhaust emissions during the traffic peak hours (Pey, Rodriguez et al. 2008, Perez, Pey et al. 2010, Quang, He et al. 2012). High outdoor particle concentration can reach the interior of buildings via penetration through their envelopes (Thornburg, Ensor et al. 2001). At the same time, indoor activities, such as movement of building occupants, cooking can also affect and increase indoor particle concentrations (Abt, Suh et al. 2000, Long, Suh et al. 2000, He, Morawska et al. 2004, Mazaheri, Clifford et al. 2013, Mazaheri, Reche et al. 2016). The high indoor particle level may impose adverse health effects on the building occupants, especially for households where retired people spend almost all their time inside home. Several studies related to particle mass concentration have been conducted in Hanoi (Hien, Bac et al. 2002, Kim Oanh, Upadhyyay et al. 2006, Saksena, Quang et al. 2008, Cohen, Crawford et al. 2010) but so far no study on ultrafine particle number monitoring in Hanoi have been published.

To help addressing the gap in knowledge about ultrafine particle concentrations in developing countries and Hanoi, Vietnam in particular, this pilot study was set up with the aim to: (1) quantify the indoor and outdoor UF particle number concentration in one low rise residential house and one apartment at a high rise building in Hanoi; and (2) initially evaluate factors influenced UF particle concentrations at these residential houses.

2. Methods

2.1. Study area and measured locations

Hanoi is located in Red River Delta in North Vietnam (21.02°N, 105.85°E), about 100 km west of the East Sea of Vietnam. Hanoi has 30 urban and sub-urban districts with the area of 3345 km² and the population of 7.2 million (Vietnamese statistic book, 2015). Central of Hanoi is boundary by the ring-road No3, where various new urban areas are being constructed.
The climate in Hanoi is representative for northern climate in Vietnam. The characteristics of the tropical monsoon climate are warm, hot and rainy summers (May to August), cold and dry winters (November to January). Located in the tropical site, Hanoi receives an abundant solar radiation and high temperature. The average amount of radiation in Hanoi is 122.8 kcal/cm² and average temperature is 23.6ºC. Due to the influence of the sea, Hanoi humidity and rainfall is quite large. The annual humidity is 79%. Average annual rainfall is 1.800mm and every year, there are approximately 114 days of rain. It is obvious to see the change between seasons in Hanoi.

In Hanoi, motorbikes are the main transport mode that people use for travelling. In the beginning of 2016, the total number of registered motorbikes and cars reached 5 million and 1 million units, respectively. The number of motorbikes and cars in Hanoi has increased rapidly in recent years, surpassing the growth rates of population, GDP, and the growth of automobiles will continue to grow for years ahead.

We selected one low rise residential house and one apartment at a high rise building to measure, and named them as site S1 and S2, respectively. Two selected sites have retired grandparents living in, especially, they were at home during the measurement.

Sites S1 is a four storey residential houses, locate in the new urban area in the southern of Hanoi. They are about 20 m from the city ring-road and 50 m from the elevation free way No3 with a total daily traffic volume of about 83 000, consisting of 52 000 motorcycles.

Site S2 is an apartment at high rise buildings. It locates in the eight floor and its main elevation faces to a national express way with only four wheel vehicle volume per day of about 74 000. The distances from site S2 to the main road are about 50 m wide and 30 m high.

2.2. Instrumentation and quality assurance

Two Philips Aerasense NanoTracers (NTs) were used to measure UF particles continuously and simultaneously indoor and outdoor of each households for at least 48 h. In brief, NT measures particle number (PN) concentrations up to 1 x 10⁶ p/cm³ in the size range of 10 to 300 nm and it also provides an indication of mean particle diameter. If operated in Advanced mode, it measures both UF particle number concentration and average particle diameter at a fixed sampling interval of 16 s. Details of design and operational procedures for the NT are available elsewhere (Marra, Voetz et al. 2010)

The NT’s time stamp was synchronised to the local time using the Nano Reporter software prior to each measurement. The NTs were tested at the International Laboratory for Air Quality and Health, Queensland University of Technology, Brisbane, Australia prior to their shipment to Hanoi, Vietnam. The two NTs (n = 1,2) used in this study were run side by side with a TSI model 3787 condensation particle counter (CPC) in order to calibrate the instruments the same way, and ensure the readings from each NT were directly comparable. The correction factors were derived using the following equation: where, \( C_{\text{CPC}} \) and \( C_{\text{NTs}} \) refer to the concurrent total particle number concentrations in the ambient air, as measured by the CPC and the NTs.

2.3. Sample sites and measurement procedures

Two NTs were used to measured UF particle number concentrations. One measured continuously at the outside of each household. The second measured simultaneously inside the rooms of this house. At the same time, a data logging sheet was supplied to a house member; and requested him/her to fill the sheet when any inside activity occurred. The logging sheet then was collected for data interpretation.
Site 1
One NT continuously measured at level 4 for catching up outdoor concentration. The other measured simultaneously inside a tightly closed and un-occupancy bedroom at level 3 from 16:30, 7 Jan to 16:30, 8 Jan 2016; then in dining combined with kitchen room at ground floor from 17:00, 8 Jan to 17:30, 9 Jan 2016.

Site 2
One NT continuously measured at a balcony of level 8, about 30m high catching up outdoor UF particle number concentration. The other measured simultaneously at the same level inside a combined living and dining room from 21:30, 9 Jan to 18:30, 13 Jan 2016.

2.4. Ambient PM$_{2.5}$ concentrations

Hanoi has seven automatic air quality monitoring (AAQM) stations. However, only one in Gia Lam District is still working, but its data during our site campaign was unable to access. Therefore, we obtained average hourly PM$_{2.5}$ concentrations, which monitored at and by US embassy in the centre of Hanoi, and about 5 - 7 km from the survey sites for reference ambient PM$_{2.5}$ concentration.

2.5. Data preparation and analysis

Data from the NTs were downloaded after each measurement and multiplied by the corresponding NT correction factors. The corrected data were grouped according to their location and time period.

2.6. Statistical techniques

All statistical analyses were performed with SPSS version 20 (SPSS Inc.), with a 5% level of significance (p < 0.05).

3. Results and discussion

3.1. Referenced ambient PM$_{2.5}$ concentrations in Hanoi

A summary of the descriptive statistics for relevant Hanoi ambient PM$_{2.5}$ concentrations during the each site survey and whole period from 7 Jan 2016 to 13 Jan 2016 is are presented in Table 1. Average concentration is 59.2 ± 12.1 μg/m$^3$, which is higher than annual mean concentration of (36.1 ± 1.3) μg/m$^3$ reported by Hien at al. (2002). Actually, our measure period is during dry season, when Hanoi recorded high PM levels due to climate and atmospheric conditions both do not support the vertical dispersion there (Hien, Bac et al. 2002). However, the ambient PM$_{2.5}$ concentration was significant lower than those measured at residential site, 200 μg/m$^3$ (Kim Oanh, Upadhyay et al. 2006).

Table 1: Statistic description of PM$_{2.5}$ ambient concentrations (μg/m$^3$)

<table>
<thead>
<tr>
<th>Measured site</th>
<th>S1</th>
<th>S2</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period</td>
<td>7-9 Jan</td>
<td>9-13 Jan</td>
<td>7-13 Jan</td>
</tr>
<tr>
<td>Mean</td>
<td>64.8</td>
<td>57.2</td>
<td>59.5</td>
</tr>
<tr>
<td>SD</td>
<td>7.3</td>
<td>13.2</td>
<td>12.1</td>
</tr>
<tr>
<td>Max</td>
<td>77.5</td>
<td>82.1</td>
<td>117.2</td>
</tr>
<tr>
<td>Min</td>
<td>52.7</td>
<td>42.1</td>
<td>28.1</td>
</tr>
</tbody>
</table>
3.2. Quantification and assessment of factors influenced UF particle number concentrations in Hanoi

A summary of the descriptive statistics for outdoor and indoor UF particle number concentrations and their I/O ratio at each site for whole period as well as during rush-hour and non-rush-hour are presented Table 2. Time series variations of outdoor and indoor UF particle number concentrations at each site are showed in Figures 1 and 2.

In general, average outdoor UF particle number concentrations measured in two sites Hanoi were from \((33.4 - 35.5) \times 10^3 \, \text{p/cm}^3\), which were significantly higher than those measured at the outside of three office buildings closed to busy streets in Brisbane, Australia (Quang, He et al. 2013). Outdoor PN levels during rush-hour periods were significantly higher than other periods at both sites \((p < 0.05)\). The higher PN concentrations at both sites in Hanoi compared to those in Brisbane could be explained by the close distance of the measured site to the busy ring-road and national express way. On the other hand, farming crop burnings occurred around the high rise building, where site 2 located contributed to outdoor PN concentration there.

Comparing indoor and outdoor PN concentrations, overall 24-h average outdoor particle concentrations were significantly higher than indoor concentrations for both sites \((p < 0.01)\). I/O ratios of PN concentrations at all sites were significantly lower than 1 \((p < 0.01)\).

Two special events related to indoor particle emissions were reported by house owners. Firstly, measured PN levels rose exponentially at site 1 and during cooking activities, including roasting peanuts using micro-oven, when the indoor NT was moved from the bedroom to the kitchen. Secondly, at site 2, during midnight at 1:30 am on 13rd Jan, indoor particle concentration in the dining room suddenly increased. The house owner was inquired about that, and he did remember that he got up early to watch a European Champion League football match. Feeling hungry, he operated the micro-oven to cook instant noodle.

At site S1, indoor NT was used to monitored UF particle level in a tight, un-occupancy bedroom from 16:30, Jan 7th 2016 to 16:30, Jan 8th 2016. Results showed that I/O ratios of PN concentrations at this room was \(0.31 \pm 0.08\) and significant lower than other room. It implied that tighter room or low infiltration ventilation concentration can significant reduced the influence of outdoor particles indoor.

### Table 2: Summary of UF particle number concentrations at measured sites S1 and S2

<table>
<thead>
<tr>
<th></th>
<th>Whole period</th>
<th>Rush-hour</th>
<th>Non Rush-hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indoor</td>
<td>Outdoor</td>
<td>I/O ratio</td>
</tr>
<tr>
<td><strong>Site S1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>14479</td>
<td>33338</td>
<td>0.45</td>
</tr>
<tr>
<td>SD</td>
<td>7567</td>
<td>9570</td>
<td>0.20</td>
</tr>
<tr>
<td>Max</td>
<td>68384</td>
<td>91167</td>
<td>1.79</td>
</tr>
<tr>
<td>Min</td>
<td>7744</td>
<td>17100</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Site S2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>19863</td>
<td>35514</td>
<td>0.87</td>
</tr>
<tr>
<td>SD</td>
<td>8727</td>
<td>57471</td>
<td>0.35</td>
</tr>
<tr>
<td>Max</td>
<td>93441</td>
<td>1016967</td>
<td>2.35</td>
</tr>
<tr>
<td>Min</td>
<td>6399</td>
<td>7128</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Figure 1: Time-series of indoor and outdoor UF particle number concentrations at the site S1.

Figure 2: Time-series of indoor and outdoor UF particle number concentrations at the site S2.
4. Conclusions

The first time, UF particle number concentrations were measured at the residential houses in Hanoi. Both indoor and outdoor particle concentrations were quantified and compared with other published results. This preliminary research indicated that vehicle emissions strongly influenced outdoor particle concentrations. At the same time, both outdoor and indoor sources contribute to the concentrations of indoor particles.

References


Effectiveness and Impact of the National Healthy Homes Partnership on Occupant Health

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Abstract:
It is important to translate healthy housing research into real-time action steps that people can take to improve their indoor environment. The Healthy Homes Partnership does this by uniting the efforts of Cooperative Extension professionals at eight universities in the United States. Cooperative Extension is an outreach arm of land-grant universities to provide the public with evidence-based information that can help them make informed decisions.

For the last fifteen years the Healthy Homes Partnership has assisted individuals, families, and professionals using a variety of tools, including publications and curricula that addressed mold, safe drinking water, lead poisoning, pests, pesticides and chemicals, carbon monoxide poisoning, radon, and other toxins. The educational toolkit incorporates eight principles of healthy housing (dry, clean, maintained, safe, ventilated, pest-free, contaminant-free, and green) that are widely recognized across federal agencies and national organizations.

Using a variety of outreach methods, including programs, exhibits, and media (broadcast, print and social), between September 1, 2014 and November 30, 2015 we had 9,617 direct contacts and 2,000,838 indirect contacts. Effective programming requires an understanding of the audiences, potential barriers, and different tools that can be used to reach them. Increasingly, people are going online for information. With so much information online, it is critical that we provide sources for trustworthy information on healthy housing.

In this paper the authors discuss the effectiveness of this comprehensive approach, the different methods of relaying healthy housing research, and provide short, intermediate, and long-term impacts.

Keywords: Healthy housing, indoor environment, occupant health
1. Introduction / Purpose

The place we call home and the type of house we live in affects our health and well-being. A house impacts health on three levels - affordability, neighbourhood conditions, and the physical condition of the house (Braveman, et al., 2011). The linkage between health and housing is not new. In the mid-19th century, physicians were advocating for decent housing as a way to reduce death and illness among the poor (Krieger and Higgins, 2002; Garb, 2003). Research supports the link between stable, decent and affordable housing and positive health outcomes (Maqbool, Viveiros & Ault, 2015). A recent study examined the health effects of housing quality, stability, affordability, ownership and subsidy receipt (Coley, Leventhal, Lynch & Kull, 2013). The researchers reported that poor housing quality was a strong predictor of emotional and behavioural problems in low-income children and youth.

When affordable housing options are limited, households can end up living in a substandard or poorly maintained housing. They may also live in older houses with lead-based paint and lead in the plumbing (Maqbool, Viveiros & Ault, 2015). In these houses, occupants are more likely to be exposed to health hazards such as lead poisoning, mould, and pests. Lead poisoning is a concern for people of all ages, but especially young children. The U.S. Centers for Disease Control and Prevention (CDC) estimates that in the U.S. over 500,000 children between one and five years of age have elevated blood lead levels (CDC, 2016). Exposure to household environmental contaminants like indoor dampness, mould and cockroaches is associated with asthma in children (Kanchongkittiphon, et al., 2015). In the U.S., asthma affects over 20 million adults (7.4%) and children (8.6%), and is the most common chronic disease among children (U.S. Department of Health and Human Services, 2016a & 2016b).

In 2009, the U.S. Surgeon General issued a call to action to promote healthy homes (U.S. Department of Health and Human Services, 2009). The definition of a healthy home is one that “...is sited, designed, built, renovated and maintained in ways that support the health of residents” (US Department of Health and Human Services, p. 3, 2009). The call to action outlines a comprehensive and coordinated approach to addressing health and housing that will result in the greatest impact. Four goals were put forth.

Goal 1: Ensure healthy, safe, affordable, and accessible homes
Goal 2: Increase public awareness and promote health literacy
Goal 3: Conduct healthy homes research
Goal 4: Translate research into practice and policy

The Healthy Homes Partnership (HHP) is an excellent resource to use to help reach these goals. It is a public outreach education program that addresses housing deficiencies and risks associated with indoor environmental issues related to occupant health. This unique partnership takes a holistic approach to healthy housing, addressing health and safety issues such as indoor air quality, lead poisoning, home maintenance, mould, water quality, household pests, radon, and home energy. The HHP was formed in 1999 through an interagency agreement between the U.S. Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA) and the U.S. Department of Housing and Urban Development (HUD) (Booth & Peek, 2013). The goal of the HHP is to provide information and education to the public on reducing housing deficiencies and risks associated with childhood diseases and injuries (USDA-NIFA, 2016). The outreach activities of Extension assist with implementation of Goal four – Educate the public about healthy homes – of the federal strategy for action on healthy housing that was put forth in 2003 (U.S. Department of Housing & Urban Development, 2013).

In this paper the authors evaluate the effectiveness of the HHP’s approach to providing healthy housing research and information to the public, and discuss some of the short, intermediate, and long-term impacts.
2. Methodology / Approach

2.1 Extension and the National HHP

Participation in the HHP is limited to the 107 land-grant colleges and universities that engage in research, teaching, and extension or outreach (Booth & Peek, 2013). The outreach mission is met through the Cooperative Extension System (Extension), which delivers research-based information to the public. Extension has provided non-formal education and learning opportunities since 1914. Extension is found in each of the land grant universities or colleges in the 50 states, the District of Columbia, 6 territories, 19 historically Black institutions, and 31 tribal colleges (Association of Public and Land Grant Universities, 2012). The outreach structure varies in each state or territory, but generally there are regional or county Extension educators who translate science into practical application, so people can make informed decisions.

Extension was selected as the outreach mechanism because of the long-standing history of effectively delivering healthy housing programs for low-resource audiences (Booth & Peek, 2013). From the beginning, the HHP maintained a holistic approach to healthy housing programming. Over the past 16 years, HHP has worked through the Extension delivery system, reaching over 17.5 million consumers, training more than 25,000 professionals, and developing hundreds of resources for the public. In addition to increasing knowledge, changes in behaviour have occurred. In 2010 over 16,000 homes were tested for radon and 1,164 households reduced the level of radon in their home (Booth & Peek, 2013). In addition, over 14,000 people reduced their exposure to lead in their home, about 9,000 households installed carbon monoxide alarms, 719 households “poison-proofed” their homes, and 619 households added smoke detectors. Since 2010, the HHP has developed a more unified approach to demonstrating impact that includes an educational curriculum for all of the partners to use.

2.2 The National HHP Curriculum

The educational curriculum – Healthy Home Solutions – was developed around the principles of a healthy home. There are seven widely recognized principles of keeping a home healthy that were set forth by the National Center for Healthy Housing (NCHH) and an eighth principle that was added in recent years by the U.S. Department of Housing and Urban Development (HUD) (NCHH, 2008; HUD, 2016). The eight ways to keep a home healthy are to keep it:

- **Dry** – Control moisture to reduce mould, dust mites, cockroaches and rodents, which are associated with asthma.
- **Clean** – Eliminate clutter and clean regularly to help reduce pest infestations and exposure to contaminants.
- **Pest-free** – Keep pests like cockroaches and mice out of the house.
- **Safe** – Protect adults and children from falls and accidental poisoning.
- **Contaminant-free** – Reduce exposure by smoking outside, testing for radon gas, installing a carbon monoxide detector, safely removing lead paint, and selecting low-toxicity household pesticides and cleaning products.
- **Ventilated** – Increase the fresh air supply and change air filters regularly.
- **Maintained** – Regularly monitor the condition of the house and make repairs.
- **Thermally Controlled** – Maintain comfortable or adequate temperatures to reduce risk from exposure to extreme cold or heat.

The eighth principle encompasses energy efficiency, which is an important component of healthy housing for low-resource audiences. Findings from a recent study, indicate that low-income households (income at or below 80 percent of area median income) who lived in older houses with poor ventilation, and aging appliances and heating systems, spent 7.2 percent of their income on utility bills, which is more than three times the 2.3 percent paid by higher income households.
Effectiveness and Impact of the National Healthy Homes Partnership on Occupant Health

(Drehobl, A. & Ross, L., 2016). Energy efficiency and healthy housing principles are key factors in green building strategies. A tighter building envelope with adequate ventilation reduces energy use and exposure to indoor contaminants (Beatley, 2011).

2.3 Method of Program Delivery

The Healthy Home Solutions curriculum includes educational presentations, speaker notes, lesson plans and evaluations. State partners use this curriculum as a foundation for conducting healthy housing programs and outreach activities. Effective programming requires an understanding of the audiences, potential barriers, and different tools that can be used to reach them. Extension has a history of providing programs for both rural and urban audiences. Historically face-to-face Extension programs have been used to disseminate information to the public in both urban and rural communities. It was, and still is, an effective way to deliver findings from research at the universities to the public.

Healthy housing information is also delivered through broadcast, print and social media outlets. As personal time constraints increase and technology continues to improve, more people have access to online sources of information. As of July 2015, 67-percent of adults in the U.S. had broadband internet access at home and 8-percent of adults owned a Smartphone (Pew Research Center, 2016). The use of social media by adults has grown from 10-percent of internet users in 2005 to 76-percent in 2015 (Perrin, 2015). It is more widely used by adults under the age of 50, with 90-percent of all 18 to 29 year olds using social media and 77-percent of 30 to 49 year olds (Perrin, 2015). Slightly over half (51%) of all adults 50 to 64 years of age use social media. Facebook remains the most popular social media site. As of September 2014, 71-percent of online adults reported using Facebook (Duggan, Ellison, Lampe, Lenhart & Madden, 2015). Around one-fourth of online adults reported using Twitter (23%), Instagram (26%), Pinterest (28%) and LinkedIn (28%). The HHP uses social media sites to provide reliable and consumer-friendly sources of information.

2.4 State and Regional HHP Leadership

The states participating in the HHP are affiliated with Extension at eight universities – University of Alaska, University of Connecticut, University of Georgia, Louisiana State University, University of Missouri, Montana State University, Oklahoma State University and University of Tennessee. Each of the universities has an Extension education and outreach delivery system in place that reaches rural and urban populations throughout the state. The HHP participating states vary in population and demographics. Three of the states are in the southeast, two in the northwest, one in the northeast, one in the Midwest and one in the Great Plains. Table 1 provides state populations, and racial and ethnic composition of the population.
Table 1: Demographics of HHP States

<table>
<thead>
<tr>
<th>State</th>
<th>Population</th>
<th>White</th>
<th>Black</th>
<th>Native American &amp; Alaska Native</th>
<th>Hispanic</th>
<th>Region of U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska (AK)</td>
<td>736,732</td>
<td>66.9%</td>
<td>3.9%</td>
<td>14.8%</td>
<td>6.8%</td>
<td>Northwest</td>
</tr>
<tr>
<td>Connecticut (CT)</td>
<td>3,596,677</td>
<td>81.2%</td>
<td>11.5%</td>
<td>0.5%</td>
<td>15.0%</td>
<td>Northeast</td>
</tr>
<tr>
<td>Georgia (GA)</td>
<td>10,097,343</td>
<td>62.1%</td>
<td>31.5%</td>
<td>0.5%</td>
<td>9.3%</td>
<td>Southeast</td>
</tr>
<tr>
<td>Louisiana (LA)</td>
<td>4,649,676</td>
<td>63.4%</td>
<td>32.5%</td>
<td>0.8%</td>
<td>4.8%</td>
<td>Southeast</td>
</tr>
<tr>
<td>Missouri (MO)</td>
<td>6,063,589</td>
<td>83.5%</td>
<td>11.8%</td>
<td>0.5%</td>
<td>4.0%</td>
<td>Midwest</td>
</tr>
<tr>
<td>Montana (MT)</td>
<td>1,023,579</td>
<td>89.4%</td>
<td>0.6%</td>
<td>6.6%</td>
<td>3.5%</td>
<td>Northwest</td>
</tr>
<tr>
<td>Oklahoma (OK)</td>
<td>3,878,051</td>
<td>75.1%</td>
<td>7.7%</td>
<td>9.0%</td>
<td>9.8%</td>
<td>Great Plains</td>
</tr>
<tr>
<td>Tennessee (TN)</td>
<td>6,549,352</td>
<td>78.9%</td>
<td>17.1%</td>
<td>0.4%</td>
<td>5.0%</td>
<td>Southeast</td>
</tr>
</tbody>
</table>

1 U.S. Census Bureau, 2015

The eight states participating in the HHP receive a small grant to help fund healthy housing activities. To increase healthy housing activities, states leverage funds from other sources. For example, funds from the State Indoor Radon Grant help to support healthy housing activities related to radon in Alaska and Georgia.

Two of the HHP deliverables for each partner state were to: (1) develop a state wide healthy housing advisory board to bring together community partners to identify and collaborate on healthy housing issues within the state; and (2) deliver healthy housing programs and other outreach activities. In addition, each state partner worked on a national deliverable for the HHP. Table 2 lists these national deliverables.
Table 2: National HHP Deliverables

<table>
<thead>
<tr>
<th>State/University</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Fairbanks – Alaska (AK)</td>
<td>Develop 3 two-hour healthy housing webinars</td>
</tr>
<tr>
<td>University of Connecticut (CT)</td>
<td>Develop, launch and maintain social media in cooperation with the University of Georgia</td>
</tr>
<tr>
<td>University of Georgia (GA)</td>
<td>Develop, launch and maintain social media in cooperation with the University of Connecticut</td>
</tr>
<tr>
<td></td>
<td>Work with Oklahoma and Missouri to create a consumer guide to accompany the <em>Help Yourself to a Healthy Home</em> publication</td>
</tr>
<tr>
<td>Louisiana State University (LA)</td>
<td>Establish a communication network among sub-grantees through a monthly e-newsletter</td>
</tr>
<tr>
<td>University of Missouri (MO)</td>
<td>Develop a series of healthy housing educational displays or posters to support the Healthy Home Solutions toolkit</td>
</tr>
<tr>
<td></td>
<td>Maintain in cooperation with Montana State University, the national HHP website (<a href="http://www.extensionhealthyhomes.org">www.extensionhealthyhomes.org</a>)</td>
</tr>
<tr>
<td></td>
<td>Work with Georgia and Oklahoma to create a consumer guide to accompany the <em>Help Yourself to a Healthy Home</em> publication</td>
</tr>
<tr>
<td>Montana State University (MT)</td>
<td>Provide oversight and guidance involving the HHP online program tracking system/database</td>
</tr>
<tr>
<td></td>
<td>Work with the University of Missouri to develop, launch and maintain the national HHP website</td>
</tr>
<tr>
<td>Oklahoma State University (OK)</td>
<td>Develop an App to serve as a tool to reduce housing deficiencies and risks associate with childhood diseases and injuries</td>
</tr>
<tr>
<td></td>
<td>Work with Georgia and Missouri to create a consumer guide to accompany the <em>Help Yourself to a Healthy Home</em> publication</td>
</tr>
<tr>
<td>Tennessee (TN)</td>
<td>Develop 4 two-hour webinars on comprehensive approaches to healthy homes using the Healthy Home Solutions Toolkit resources</td>
</tr>
</tbody>
</table>

Accomplishment of the national deliverables and individual state outreach activities were reported to the national HHP office at the University of Missouri where they were compiled into a report for USDA-NIFA. The outcomes are discussed in the following section.
3. Results and Discussion

3.1 National HHP Deliverables

The majority of the national deliverables were completed by the end of the reporting period (November 30, 2015). The outcomes of these projects are discussed below.

A total of six healthy housing webinars were developed by Alaska and Tennessee. The webinars were designed for professionals in Extension, public health, environmental health, non-profits, and local, state and federal government. The three webinars developed by Alaska covered home safety; allergies/asthma and hazardous household waste; and indoor air quality. These webinars examined the issues from a cold climate perspective. Tennessee combined two issues and created three webinars instead of four. These webinars examined issues from a hot climate perspective, covering mould and moisture; pests and pesticides; and lead poisoning prevention and energy efficiency. There were 95 participants from 11 different states. To provide ongoing access to past participants and as an ongoing resource, Tennessee posted the webinars they created on the HHP website (http://extensionhealthyhomes.org/) and YouTube.

Connecticut and Georgia worked together to develop an online presence for the HHP. The Facebook, Twitter and Pinterest sites were created in the spring of 2015. As of November 30, 2015, there were 201 likes on Facebook, 144 tweets and 24 Twitter followers, and 19 Pinterest boards with 503 pins and 23 followers.

Louisiana designed, wrote and distributed electronically six Healthy Homes Highlights newsletters to partners, state advisory boards, and other professionals interested in healthy housing. The purpose of the newsletters was to provide a communication network for HHP partners and state advisory boards. To provide a reference and increase reach, the newsletters were posted on the national HHP website (http://extensionhealthyhomes.org/).

Missouri created nine educational posters that were distributed to all of the state partners. The posters were designed so they can be personalized by each of the state partners. Figure 1 shows examples of two of the posters. The poster on the right has been personalized by Georgia with their logo and website.

![Educational Posters designed by Missouri and personalized by Georgia](image)

Missouri and Montana worked together to update the national healthy homes website and incorporate links for consumers and educators (www.extensionhealthhomes.org). The website provides educators access to the Healthy Home Solutions toolkit. Montana is still working on developing a database for HHP educators to track educational outreach activities.
Oklahoma worked with Georgia and Missouri to create a four-page consumer guide to accompany the widely used practitioner publication *Help Yourself to a Healthy Home*. The consumer guide and practitioner publication are under review and should be available before the end of 2016 under the name of *Everyone Deserves a Healthy Home*. Oklahoma continues to work on the development of the Smartphone App.

### 3.2 Other Healthy Housing Activities

Each state established, or strengthened, their healthy homes advisory group. Activities of the advisory groups varied among the states. The healthy homes advisory groups provided an opportunity to increase the exchange of healthy housing resources and information.

To assess the impacts and health improvements from the implementation of this comprehensive healthy housing program, partner states collected data from healthy housing programs, workshops, exhibits, media, websites, telephone calls, emails, and individual questions. Table 3 shows a breakdown by state of healthy housing trainings, workshops, exhibits, media (print, broadcast and social), state web pages, and direct consumer contacts.

States reported healthy housing activities that reflect one or more of the eight principles of healthy home. Examples of some of the outreach activities and the healthy homes principle they relate to are listed below.

- **Keep your home contaminant-free**
  - Alaska radon trainings for 52 professionals at two different international symposiums, and distributed radon test kits throughout the state.
  - Georgia trained 29 professionals about radon in water, and distributed about 900 radon test kits in the state. Around 65-percent of those who purchased a radon test kit tested their homes.
  - Georgia developed a four-page consumer publication on testing for radon in water.

- **Keep your home clean**
  - Connecticut produced a 16-page consumer publication on managing clutter.
  - Georgia conducted programs on green cleaning, reaching 83 people who learned more about the links between a clean house and health.

- **Keep your home pest-free**
  - Oklahoma created a consumer publication on reducing the risk of bed bugs when thrift shopping.

- **Keep your home safe**
  - Oklahoma developed two consumer publications for older adults. One on medication safety and the other on reducing falls in the home.

- **All eight principles**
  - Connecticut conducted a program for 248 youth and adults.
  - Georgia posted healthy housing information on the UGA GreenWay social media sites, which have 559 likes on Facebook; 665 Twitter followers; 45 Pinterest boards with 871 followers; 17 videos with 2,057 YouTube views; and 1,922 visitors to the blog.
  - Louisiana trained 100 Extension educators and collaborators in Louisiana and Mississippi on using the HHP *Healthy Home Solutions* curriculum.
  - Missouri conducted *Rent Smart* programs for 750 adult renters who faced challenges finding rental housing.
  - Missouri worked with university police to provide healthy housing and renting information for an App.
  - Montana conducted trainings for asthma control group community partners who conduct home visits.
  - Oklahoma modified the *Healthy Home Solutions* curriculum to meet the needs of their residents.
  - Tennessee was invited to present information on healthy housing at the Governor’s Housing Summit on affordable housing.
Table 3: Healthy Homes Partnership Activities by State Partners  
(September 1, 2014 to November 30, 2015)

<table>
<thead>
<tr>
<th>Outputs</th>
<th>AK</th>
<th>CT</th>
<th>GA</th>
<th>LA</th>
<th>MO</th>
<th>MT</th>
<th>OK</th>
<th>TN</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trainings, Workshops, Presentations</td>
<td>72</td>
<td>12</td>
<td>1,052</td>
<td>546</td>
<td>4,339</td>
<td>110</td>
<td>65</td>
<td>724</td>
<td>6,920</td>
</tr>
<tr>
<td>Displays, Exhibits</td>
<td>36</td>
<td>185</td>
<td>8,275</td>
<td>2,093</td>
<td>9,762</td>
<td></td>
<td></td>
<td>1817</td>
<td>22,168</td>
</tr>
<tr>
<td>Broadcast Media (radio &amp; television)</td>
<td>200</td>
<td></td>
<td>660,000</td>
<td></td>
<td>874,793</td>
<td></td>
<td></td>
<td></td>
<td>1,534,993</td>
</tr>
<tr>
<td>Print media (newspapers &amp; newsletters)</td>
<td>2</td>
<td></td>
<td>201,661</td>
<td>3</td>
<td>923</td>
<td></td>
<td></td>
<td>200</td>
<td>202,789</td>
</tr>
<tr>
<td>Social media *</td>
<td>575</td>
<td></td>
<td>10,904</td>
<td>5,907</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17,386</td>
</tr>
<tr>
<td>Website activity</td>
<td>4</td>
<td></td>
<td>6,771</td>
<td>200,000</td>
<td>11</td>
<td>12,500</td>
<td>1</td>
<td></td>
<td>219,287</td>
</tr>
<tr>
<td>Telephone calls</td>
<td>61</td>
<td>20</td>
<td>350</td>
<td>308</td>
<td>43</td>
<td>27</td>
<td>15</td>
<td></td>
<td>824</td>
</tr>
<tr>
<td>Direct Mail</td>
<td></td>
<td></td>
<td>150</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>180</td>
</tr>
<tr>
<td>Home visits</td>
<td></td>
<td></td>
<td></td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td>1,248</td>
<td>1,060</td>
<td>903</td>
<td></td>
<td></td>
<td></td>
<td>3,211</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>1,248</td>
<td>1,060</td>
<td>903</td>
<td></td>
<td></td>
<td></td>
<td>3,211</td>
</tr>
</tbody>
</table>

* Social Media numbers reflect total numbers of likes, followers, tweets, boards, pins, views, and subscribers.
4. Conclusion

Working in a partnership provided opportunities for meeting broad overall healthy housing goals. State partners used a broad array of outreach methods, including face-to-face programs, webinars, exhibits, publications, and media (broadcast, print and social) to increase awareness about healthy housing. This analysis of the HHP provides valuable insights into the effectiveness of an integrated approach to healthy housing programming from an established entity. The HHP reaches large numbers of people; however, it could be more effective by increasing assessments of intermediate- and long-term impacts.

The HHP reported several short-term impacts from outreach activities. The main impact was an increase in healthy housing knowledge among consumers and professionals from programs, trainings and webinars. Residents in Alaska and Georgia tested their homes for radon. In the online community, the HHP increased access to healthy housing information. Additionally, several new healthy housing partnerships and collaborations were developed. Fewer intermediate- and long-term impacts were reported. In Missouri 80-percent of the households in Eastern Jackson County who attended a Rent Smart workshop were able to avoid an early lease termination that would have resulted in financial losses of $2,500 or more. Studies in Missouri show long-term success of participants in Rent Smart as well as improvements in cooperation between students and landlords. Assessing intermediate- and long-term impacts requires time and funding to follow-up with participants in programs and trainings. This can be a major challenge for universities with limited staff and finances.

The challenges for the future are to develop new ways to assess outcomes from programs and trainings, and to measure the effectiveness of social media as a means of disseminating information. Key to the ongoing success of the HHP is to maintain a mindset of change.

Extension is a great tool to use across states in the U.S. to provide a consistent healthy housing message. The organization is nationwide, provides unbiased research-based information, and offers free or low-cost access to information. Face-to-face programs will remain an important delivery method, but we expect to continue to see decreases in program attendance and increased use of online tools and networks. It is important to be at the forefront of change and explore ways to expand our reach to the online generation. The HHP should continue to experiment with new ideas to expand knowledge about healthy housing.

Acknowledgements

The Healthy Homes Partnership project is supported by funding from the U.S. Department of Agriculture, National Institute of Food and Agriculture and the U.S. Department of Housing and Urban Development’s Office of Lead Hazard Control and Healthy Homes. The authors acknowledge and thank other Cooperative Extension professionals who provided data to the Healthy Homes Partnership. These individuals include Barbara Allen (Montana State University), Dr. Martha Keel (University of Tennessee), Art Nash (University of Alaska), Dr. Gina Peek (Oklahoma State University), Dr. Claudette Reichel (Louisiana State University), and Mary Ellen Welch (University of Connecticut).
5. References


Effect of Indoor Thermal Environment on Children’s Physical Activity and Body Temperature

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Abstract

Introduction: There have been several studies on the effect of housing environment on children’s health. In particular, health concerns stemming from children’s lack of physical activity and lower body temperature are becoming an issue in Japan. Because children have a larger body surface area-to-weight ratio than adults, the body temperature of children is more strongly affected by the thermal environment in houses. In this work, we examined the effect of the indoor thermal environment on children’s body temperature.

Methods: We conducted a questionnaire survey among 143 parents of children who attended a kindergarten. The questionnaire asked respondents to evaluate the indoor thermal environment in winter (living room, bedroom, dressing room) and the children’s lifestyle. In addition, we measured room temperature at kindergarten, physical activity and body temperature of the children.

Results: Children who live in warmer houses, meaning that they seldom or never feel cold, have a higher body temperature. Children who attend warmer kindergartens, such as those with no difference in temperature between rooms, have higher intensity of physical activity. Multiple regression analysis shows that improving the thermal environment in the bedroom increases body temperature by 0.07 °C.

Conclusion: The thermal environment in the home, particularly in the lavatory, affects children’s body temperature. The children whose body temperatures were low undertook less physical activity at the kindergarten than the normal body temperature group.

Keywords - Child, House, Body temperature, Physical activity, Multiple regression analysis
1. Introduction

There have been several studies on the effect of housing environment on children’s health. Many studies have examined the relationship between respiratory disease in children and indoor air quality, or between allergies and humidity. The relationship between indoor room temperature and children’s health has been shown. However, the indoor environment in kindergartens has not been thoroughly studied.

In Japan, the lack of physical activity in children and consequent low body temperature is a growing problem (MEXT, 2012). In the United States, government guidance on children’s physical activity recommends that all children from birth to age 5 years should engage daily in physical activities to promote movement, improve motor skills, and build the foundations of health-related fitness. Low body temperature in children can also reduce physical activity, which is an increasing concern in Japan (Maebashi, 2004).

Children’s body temperature is more strongly affected by the thermal environment in houses than adults, because children have a larger body surface area-to-weight ratio than adults (Fukazawa, 2008). Hot and cold heat stress decreases the ability to move (Iwashita, 2014).

In this work, we conducted a measurement survey at kindergartens and at home. We examined the effect of the indoor thermal environment on children’s physical activity and body temperature.

2. Method

2.1 Participants and kindergartens

A total of 143 children and their parents were recruited from five kindergartens in Kumamoto and Kochi prefecture in Japan. All children were 5 years old, and we obtained the parent's consent for participation in the survey. The study was conducted for 2 weeks from the middle of January to the beginning of February in 2016. We used data of 134 parents who recorded measurements for more than 5 days in the research period.

Table 1 shows the characteristics of the kindergartens. The thermal insulation performance was based on the structure and building age, and kindergartens A and D had better insulation than B, C, and E.

Table 1. Kindergarten characteristics

<table>
<thead>
<tr>
<th>ID</th>
<th>Structure</th>
<th>Building age (years)</th>
<th>Number of floors</th>
<th>Prefecture</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Reinforced concrete</td>
<td>1</td>
<td>2</td>
<td>Kumamoto</td>
<td>26</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
<td>2</td>
<td></td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>C</td>
<td>22</td>
<td>2</td>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>D</td>
<td>Wood</td>
<td>25(^a)</td>
<td>1</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>E</td>
<td>Reinforced concrete</td>
<td>30</td>
<td>2</td>
<td>Kochi</td>
<td>20</td>
</tr>
</tbody>
</table>

\(^a\)Underwent thermal insulation repairs in December 2012

2.2 Children’s health index

Physical activity. Physical activity was measured by using a triaxial accelerometer (Active Style Pro 750C, OMRON Corporation) for 10 days on weekdays at the kindergartens. We asked teachers to attach the accelerometers to the children’s waists while they were at kindergarten. The intensity of physical activity was recorded at 10 min intervals. We classified the intensity of the physical activity into four levels based on a previous study of 5-year-old children (Tanaka, 2009). Sedentary: lower than 1.0 MET; light: 1.0–2.7 MET; moderate: 2.7–4.4 MET; vigorous: higher than 4.4 MET.

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*HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.*
Body temperature. Body temperature was measured four times a day for 2 weeks with an ear thermometer (MC-510, OMRON Corporation). Measurement times were at waking, attending and leaving the kindergarten, and at bedtime. Parents took the measurements at waking and bedtime, and teachers took the measurements at the kindergarten. We requested the normal axillary temperature on the questionnaire.

2.3 Indoor environmental index

At Kindergarten. We measured the air temperature by using data loggers (TR72Ui, T&D Corporation). Temperatures were measured at 10 min intervals 0.1 and 1.1 m above the floor in the class rooms, and 1.1 m above the floor in the lavatories. The outdoor temperature data recorded at 10 min intervals was obtained from the local meteorological office in each study area.

At Children’s home. We asked about the frequency of feeling cold at each room in winter, and the insulation performance. We asked about the characteristics of the housing and housing environment in winter in the questionnaire. Thermal insulation performance was classified as pre-1980 standards, 1980 standards, 1992 standards, and 1999 standards (Standards of Judgment for Residential Construction Clients Based on the Law of Ministry of Land, Infrastructure and Transport in Japan) based on building age and the presence or absence of insulation, window glazing, and window frames (Takayanagi, 2011).

2.4 Statistical analyses

All statistical analyses were conducted with IBM SPSS Statistics version 22. A t-test was used to compare the physical activity and body temperature of boys and girls and the cold and warm group. One-way ANOVA and Tukey’s test were used to compare the room temperature and humidity of the kindergartens. We used multiple regression analysis to examine the effect of the environmental index on the children’s physical activity and body temperature. All data were checked for normality and equality of distribution before analysis was performed.

3. Results

3.1 Children’s Attributes and Health index

We show the children’s attributes and Health index at Table 2. Also, Physical activity and body temperature of each kindergarten are showed at Table 3. There were not significant difference between boys and girls with attributes, sleeping habit and body temperature. On the other hand, there was significant difference with physical activity. Length of sedentary or light activity of girls was longer than boys; also length of moderate or vigorous activity is reversed. These results suggest the boys are more active than girls. Next, we discuss body temperature. Body temperature was slightly higher for girls than for boys. The change in body temperature over a day showed an increase from morning through the daytime and a decrease in the evening. This is consistent with circadian rhythm.

3.2 Indoor thermal environment

At Kindergarten. Table 4 shows the thermal environment in the kindergarten. Room temperature in the class room 1.1 m above the floor was almost 15 °C. There was a significant difference in the temperature at 0.1 m between kindergartens. Room temperature 0.1 m above the floor in kindergartens B and C was lower than in kindergartens A, D, and E. In addition, the lavatory in kindergartens B, C, and E were significantly colder than those in A and D.

At Children’s home. Tables 5 and 6 show the housing characteristics. Half of the houses were built within 10 years, although the most common thermal insulation performance was 1980 stand-
ards, meaning that that thermal environment in winter may be poor. Table 6 shows the frequency of feeling cold in winter. Many people felt cold in the hall or dressing room, which were generally not heated.

### 3.3 Relationship between Children’s Physical Activity and Body Temperature

Figure 1 shows that the change in body temperature over a day. There was not significant difference between the length of moderate / vigorous activity. Generally, active children have higher body temperature, but in this research, a reverse tendency was seen. And we categorized body temperature group based on temperature at waking as the following 3 groups. Low: < 36°C; Normal; 36°C ~37°C, High; > 37°C. Low group’s body temperature is lower than Normal group at any time.

#### Table 2. Children’s Attribute, Physical activity and Body temperature

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Boys (n=65)</th>
<th>Girls (n=69)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, cm</td>
<td>108.6 ± 20.0</td>
<td>110.1 ± 14.3</td>
<td>-</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>19.1 ± 3.5</td>
<td>19.1 ± 2.3</td>
<td>-</td>
</tr>
<tr>
<td>Kaup index, -</td>
<td>15.3 ± 1.4</td>
<td>15.4 ± 1.8</td>
<td>-</td>
</tr>
<tr>
<td>Sleep habit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time of waking up</td>
<td>7.22 ± 0.32</td>
<td>7.33 ± 0.29</td>
<td>-</td>
</tr>
<tr>
<td>Time of going to sleep</td>
<td>20.58 ± 0.38</td>
<td>21.00 ± 0.33</td>
<td>-</td>
</tr>
<tr>
<td>Length of sleep</td>
<td>10:47 ± 1:28</td>
<td>10:51 ± 1:12</td>
<td>-</td>
</tr>
<tr>
<td>Physical Activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of sedentary activity, min</td>
<td>74.4 ± 69.0</td>
<td>80.6 ± 69.4</td>
<td>-</td>
</tr>
<tr>
<td>Length of light activity, min</td>
<td>167.0 ± 22.7</td>
<td>179.1 ± 18.3</td>
<td>**</td>
</tr>
<tr>
<td>Length of moderate activity, min</td>
<td>58.7 ± 14.4</td>
<td>53.1 ± 13.6</td>
<td>*</td>
</tr>
<tr>
<td>Length of vigorous activity, min</td>
<td>29.3 ± 13.4</td>
<td>20.6 ± 10.7</td>
<td>**</td>
</tr>
<tr>
<td>Body temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waking, °C</td>
<td>36.2 ± 0.3</td>
<td>36.3 ± 0.4</td>
<td>-</td>
</tr>
<tr>
<td>Attending kindergarten, °C</td>
<td>36.3 ± 0.4</td>
<td>36.4 ± 0.4</td>
<td>-</td>
</tr>
<tr>
<td>Leaving kindergarten, °C</td>
<td>36.3 ± 0.4</td>
<td>36.4 ± 0.5</td>
<td>-</td>
</tr>
<tr>
<td>Bedtime, °C</td>
<td>36.3 ± 0.4</td>
<td>36.3 ± 0.4</td>
<td>-</td>
</tr>
</tbody>
</table>

-: not significant, **: p<0.01 *: p<0.05

#### Table 3. Physical Activity (extract) and Body temperature of each kindergarten

<table>
<thead>
<tr>
<th></th>
<th>A (n=26)</th>
<th>B (n=33)</th>
<th>C (n=40)</th>
<th>D (n=15)</th>
<th>E (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of moderate activity, min</td>
<td>59.0 ± 12.3</td>
<td>49.0 ± 10.7</td>
<td>50.7 ± 12.2</td>
<td>57.2 ± 10.0</td>
<td>71.6 ± 13.9</td>
</tr>
<tr>
<td>Length of vigorous activity, min</td>
<td>35.7 ± 8.9</td>
<td>18.2 ± 5.5</td>
<td>17.5 ± 9.2</td>
<td>21.2 ± 7.1</td>
<td>38.4 ± 14.0</td>
</tr>
<tr>
<td>Waking, °C</td>
<td>36.1 ± 0.3</td>
<td>36.3 ± 0.4</td>
<td>36.3 ± 0.3</td>
<td>36.2 ± 0.3</td>
<td>36.1 ± 0.3</td>
</tr>
<tr>
<td>Attending kindergarten, °C</td>
<td>36.1 ± 0.4</td>
<td>36.7 ± 0.6</td>
<td>36.3 ± 0.3</td>
<td>36.2 ± 0.3</td>
<td>36.4 ± 0.2</td>
</tr>
<tr>
<td>Leaving kindergarten, °C</td>
<td>35.7 ± 0.4</td>
<td>36.6 ± 0.6</td>
<td>36.3 ± 0.3</td>
<td>36.1 ± 0.3</td>
<td>36.5 ± 0.2</td>
</tr>
<tr>
<td>Bedtime, °C</td>
<td>36.2 ± 0.4</td>
<td>36.3 ± 0.3</td>
<td>36.4 ± 0.4</td>
<td>36.3 ± 0.3</td>
<td>36.3 ± 0.3</td>
</tr>
</tbody>
</table>
Table 4. Thermal environment at kindergarten (Average of research period)

<table>
<thead>
<tr>
<th>Room</th>
<th>ID</th>
<th>Temperature, °C</th>
<th>p value</th>
<th>Humidity, %</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class room 0.1 m above the floor</td>
<td>A</td>
<td>16.6 ± 1.8</td>
<td>*</td>
<td>47 ± 6</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>12.8 ± 1.2</td>
<td></td>
<td>54 ± 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>9.3 ± 0.3</td>
<td></td>
<td>63 ± 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>15.0 ± 1.0</td>
<td></td>
<td>55 ± 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>15.1 ± 0.7</td>
<td></td>
<td>49 ± 3</td>
<td></td>
</tr>
<tr>
<td>Class room 1.1 m above the floor</td>
<td>A</td>
<td>17.0 ± 1.8</td>
<td></td>
<td>47 ± 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>15.6 ± 1.7</td>
<td></td>
<td>44 ± 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>14.7 ± 1.9</td>
<td></td>
<td>54 ± 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>15.6 ± 1.6</td>
<td></td>
<td>55 ± 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>14.5 ± 1.2</td>
<td></td>
<td>43 ± 3</td>
<td></td>
</tr>
<tr>
<td>Lavatory 1.1 m above the floor</td>
<td>A</td>
<td>17.6 ± 1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>9.4 ± 0.7</td>
<td>n.s.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>8.9 ± 0.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>15.2 ± 1.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>7.8 ± 0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: * represents significance at the 0.05 level and ** represents significance at the 0.01 level.

Table 5. Housing characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Answer</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building age</td>
<td>&lt;10 years</td>
<td>76 (53.1%)</td>
</tr>
<tr>
<td></td>
<td>10–19 years</td>
<td>27 (18.9%)</td>
</tr>
<tr>
<td></td>
<td>20–29 years</td>
<td>15 (10.5%)</td>
</tr>
<tr>
<td></td>
<td>&gt;30 years</td>
<td>25 (17.5%)</td>
</tr>
<tr>
<td>Thermal insulation performance</td>
<td>Pre-1980 standards</td>
<td>9 (6.6%)</td>
</tr>
<tr>
<td></td>
<td>1980 standards</td>
<td>90 (66.2%)</td>
</tr>
<tr>
<td></td>
<td>1992 standards</td>
<td>17 (12.5%)</td>
</tr>
<tr>
<td></td>
<td>1999 standards</td>
<td>20 (14.7%)</td>
</tr>
</tbody>
</table>

Table 6. Frequency of feeling cold in winter

<table>
<thead>
<tr>
<th>Room</th>
<th>Frequency of feeling cold</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>Never</td>
<td>16 (11.5%)</td>
</tr>
<tr>
<td></td>
<td>1) Seldom</td>
<td>59 (42.4%)</td>
</tr>
<tr>
<td></td>
<td>2) Often</td>
<td>48 (34.5%)</td>
</tr>
<tr>
<td></td>
<td>3) Very often</td>
<td>16 (11.5%)</td>
</tr>
<tr>
<td>Bedroom</td>
<td>0) Never</td>
<td>6 (4.3%)</td>
</tr>
<tr>
<td></td>
<td>1) Seldom</td>
<td>38 (27.3%)</td>
</tr>
<tr>
<td></td>
<td>2) Often</td>
<td>61 (43.9%)</td>
</tr>
<tr>
<td></td>
<td>3) Very often</td>
<td>34 (24.5%)</td>
</tr>
<tr>
<td>Dressing room</td>
<td>0) Never</td>
<td>60 (43.2%)</td>
</tr>
<tr>
<td></td>
<td>1) Seldom</td>
<td>60 (43.2%)</td>
</tr>
<tr>
<td></td>
<td>2) Often</td>
<td>16 (11.5%)</td>
</tr>
<tr>
<td></td>
<td>3) Very often</td>
<td>3 (2.2%)</td>
</tr>
</tbody>
</table>
of indoor thermal environment on children’s physical activity and body temperature

3.4 Relationship between Room temperature at kindergarten and Physical Activity

Next, we discuss the relationship between the thermal environment at kindergarten and physical activity. There was significant difference between boys and girls, so the results are shown separately. We classified kindergartens based on room temperature (Table 3) into the cold group (B, C, and E) and the warm group (A and D). Figure 2 shows that as the difference between the temperatures at 0.1 and 1.1 m decreases, the intensity of the children’s physical activity increases.

3.5 Relationship between Thermal environment at home and Body Temperature

The frequency of feeling cold for each type of insulation performance is shown in Table 7. In the bedroom, almost 40% reported feeling cold very often or often in houses with 1980 standard insulation, whereas most people answered seldom or never in houses of 1992 or 1999 standards. In the dressing room, most people felt cold very often or often; the percentage was 90% in the 1980 standard houses. From these results, frequency of feeling cold in a heated bedroom was low. However, the frequency of feeling cold in the dressing room, where there was also often no heating, was high. Houses with low insulation performance were more strongly affected by the outside temperature, resulting in a cold environment.
Table 7. Relationship between housing insulation performance and frequency of feeling cold

<table>
<thead>
<tr>
<th>Insulation performance</th>
<th>Coldness in winter in the bedroom</th>
<th>Coldness in winter in the dressing room</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>n (%)</td>
</tr>
<tr>
<td>Pre-1980/1980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0) Very often/often</td>
<td>29 (37.2%)</td>
<td>69 (88.5%)</td>
</tr>
<tr>
<td>1) Seldom/never</td>
<td>49 (62.8%)</td>
<td>9 (11.5%)</td>
</tr>
<tr>
<td>1992</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0) Very often/often</td>
<td>3 (17.6%)</td>
<td>13 (76.5%)</td>
</tr>
<tr>
<td>1) Seldom/never</td>
<td>14 (82.4%)</td>
<td>4 (23.5%)</td>
</tr>
<tr>
<td>1999</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0) Very often/often</td>
<td>4 (19.0%)</td>
<td>13 (62.0%)</td>
</tr>
<tr>
<td>1) Seldom/never</td>
<td>17 (81.0%)</td>
<td>8 (38.1%)</td>
</tr>
</tbody>
</table>

Next, we show the relationship between body temperature at waking and frequency of feeling cold in the dressing room (Figure 3). The frequency of feeling cold was lower for children with higher body temperature.

3.6 Effect of indoor thermal environment on physical activity and body temperature

We performed multiple regression analysis (forced injection) to examine the relationship between physical activity and the thermal environment in kindergartens. The dependent variable was the intensity of physical activity, and the independent variable was room temperature 0.1 m above the floor (Table 8). Table 9 shows the results.

We performed multiple regression analysis (forced injection) to examine the relationship between children’s body temperature and thermal environment at home (Table 10). The dependent variable was body temperature at waking, and the independent variable was frequency of feeling cold in the dressing room. The analysis targets were children who were not categorized as having an extremely low or high body temperature which over mean ± 2SD. Table 11 show the results.

Table 8. Multiple regression analysis

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Physical activity intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent variable</td>
<td>Difference of temperature between lavatories and class rooms</td>
</tr>
<tr>
<td>Independent variable</td>
<td>Sex 1) Boy, 2) Girl</td>
</tr>
<tr>
<td>Independent variable</td>
<td>Kaup index</td>
</tr>
</tbody>
</table>
Table 9. Partial regression coefficients for body temperature

<table>
<thead>
<tr>
<th>Partial regression coefficient (95% CI)</th>
<th>Standardized partial regression coefficient</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>-0.112 (-0.247 to -0.024)</td>
<td>-0.235</td>
</tr>
<tr>
<td>Kaup index</td>
<td>0.005 (-0.028 to 0.039)</td>
<td>0.029</td>
</tr>
<tr>
<td>Room temperature 0.1 m above the floor</td>
<td>0.065 (0.040 to 0.090)</td>
<td>0.433</td>
</tr>
</tbody>
</table>

Adjusted R-square: 0.527, n = 97  *: p < 0.1, **: p < 0.05

Table 10. Multiple regression analysis

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Body temperature (at waking)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent variable</td>
<td>Frequency of feeling cold in the dressing room</td>
</tr>
<tr>
<td></td>
<td>1) Very often, 2) Often, 3) Seldom, 4) Never</td>
</tr>
<tr>
<td>Independent variable (input in all models for adjustment of individual attributes)</td>
<td>Sex 1) Boys, 2) Girls</td>
</tr>
<tr>
<td></td>
<td>Kaup index</td>
</tr>
<tr>
<td></td>
<td>Physical activity 1) Under mean, 2) Over mean</td>
</tr>
<tr>
<td></td>
<td>Hours of sleep 1) Under mean, 2) Over mean</td>
</tr>
</tbody>
</table>

*Because there were significant differences between kindergartens, we used each kindergarten’s mean

Table 11. Partial regression coefficients for body temperature

<table>
<thead>
<tr>
<th>Partial regression coefficient (95% CI)</th>
<th>Standardized partial regression coefficient</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>35.78</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>.089 (-.018--.195)</td>
<td>.054</td>
</tr>
<tr>
<td>Kaup</td>
<td>-.002 (.131-.896)</td>
<td>-.013</td>
</tr>
<tr>
<td>Physical activity</td>
<td>.094 (-.012--.199)</td>
<td>-.053</td>
</tr>
<tr>
<td>Hours of sleep</td>
<td>.111 (.016--.239)</td>
<td>.064</td>
</tr>
<tr>
<td>Frequency of feeling cold in the dressing room</td>
<td>.067 (.005-.130)</td>
<td>.031</td>
</tr>
</tbody>
</table>

Adjusted R-square: 0.052, n = 101  n.s.: not significant, †: p < 0.2, *: p < 0.1, **: p < 0.05

4. Discussion

In this study, we conducted a field survey to examine the effect of the indoor thermal environment and physical activity on children’s body temperature. To our knowledge, this is the first study to evaluate the relationship between the thermal environment and children’s physical activity or body temperature. Our major finding was that the children who live in warmer houses, meaning that they seldom or never feel cold, have a higher body temperature. The children who attend warmer kindergartens, meaning that there was no difference in temperature between rooms, have a higher physical activity intensity. Because children play near the floor, it may be important to keep the temperature near the floor warm as well as 1.1 m above the floor.

Multiple regression analysis revealed that the temperature in classrooms had a significant correlation with physical activity. This result indicated that keeping whole class rooms warm was asso-
associated with high intensity of physical activity. In addition, the frequency of feeling cold in the dress-
ing room had a significant correlation with body temperature at waking. Therefore, a warmer envi-
ronment in the dressing room was associated with higher body temperature in children. This result
suggests that the thermal environment in the dressing room has a larger impact on body tempera-
ture than physical activity or hours of sleep.

This study had some limitations. The housing thermal environment was evaluated subjectively by
parents. Ideally, this should be evaluated with an objective measurement survey. The physical
activity data were collected during the daytime, whereas data should be collected throughout the
day.

5. Conclusion

In this field survey, we conducted a questionnaire survey and actual measurements to analyse the
relationship between housing environment and children’s body temperature statistically. The
thermal environment in the home, particularly in the dressing room, affected children’s body tem-
perature at waking. Children with a low body temperature undertook less physical activity at the
kindergarten than the standard group.

6. Acknowledgement

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Occupancy inefficiency of larger detached houses

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Abstract

Purpose / Context - New detached houses have been getting larger in New Zealand for several decades. Large houses require more materials to build, and have greater ongoing energy costs than smaller houses built to the same standard. The purpose of this work was to examine whether larger houses are as efficient at accommodating people as smaller houses.

Methodology / Approach - On-line house schematics from major franchise builders in New Zealand were accessed, and a stratified random sample selected based on dwelling floor-area and developer. These schematics were analysed for number and area of bedrooms (and potential bedrooms), and number of toilets/bathrooms. Schematics for older social housing were also analysed. The potential occupancy was calculated using several methods.

Results – Older social housing had similar potential occupancy to new franchise dwellings of similar size. Larger new franchise dwellings tended to have a lower potential occupancy per square metre than smaller dwellings.

Key Findings / Implications – Large houses are built to satisfy current perceived market demands. The ability of the owners to pay for maintenance, and the occupiers to pay for heating/cooling energy will affect both how long the dwelling will last and occupant health. Inefficiencies designed into dwelling structure will remain unless there is a major renovation. Large dwellings with high building, running and carbon costs, which are unable to safely and healthily accommodate an appropriate number of people, are unsustainable for society.

Originality - This paper provides a critique of the trend of increasing dwelling size.

Keywords - Dwelling; size; occupancy
1. Introduction

New stand-alone houses have been increasing in size in New Zealand for several decades (Telfar Barnard, personal communication, 2015), and in Australia since at least the mid-1980s (Becker, personal communication, 2015), although they may have recently reached a maximum.

Larger dwellings take both more materials to build and more energy to heat or cool, than smaller dwellings built to the same standard. Therefore, they need to accommodate more people if they are to be as efficient on an emissions or energy use per capita basis as smaller dwellings.

There is no firm consensus in evaluating how many people it is appropriate to have living in a house of a given design. However, it is known that there is a relationship between household crowding and increased rates of several infectious diseases (Baker, McDonald, Zhang, & Howden-Chapman, 2013).

New Zealand has an official definition of unacceptable crowding defined in legislation from 1947 ("Housing Improvement Regulations," 1947), although this law is rarely used in practice (Bierre, Bennett, & Howden-Chapman, 2014). Perhaps one of the reasons it is rarely used is because it requires knowledge of the area of all the bedrooms in the dwelling, in addition to the household composition. Britain, through the Housing Act ("Housing Act," 1985), and parts of the United States, which have implemented the International Code Council’s Property Maintenance Code (International Code Council, 2014), have similar definitions of unacceptable crowding. Table 1 summarises the main comparative points, although all three jurisdictions include additional complications (including some combination of: the ages, relationships and genders that may share bedrooms, the age at which children are considered adults, the weighting given to children, the additional area required for more people, privacy restrictions on what can be used as a bedroom, and rules about toilet access).

Table 1: Required Bedroom Area (m²) for given occupancy by jurisdiction

<table>
<thead>
<tr>
<th>Allowed Occupancy</th>
<th>New Zealand</th>
<th>Britain</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.00</td>
<td>6.50</td>
<td>6.50</td>
</tr>
<tr>
<td>2</td>
<td>10.00</td>
<td>10.22</td>
<td>9.20</td>
</tr>
<tr>
<td>3</td>
<td>14.00</td>
<td>--</td>
<td>13.80</td>
</tr>
<tr>
<td>4</td>
<td>20.00</td>
<td>--</td>
<td>18.40</td>
</tr>
</tbody>
</table>

More commonly used is the Canadian National Occupancy Standard (Canada Mortgage and Housing Corporation 1996) (CNOS), which requires knowledge of the number of bedrooms in the dwelling and household composition. This standard allows only one or two people per bedroom regardless of size, but has compositional rules. Other crowding metrics include the Equivalised Crowding Index, and the British Bedroom Standard (Goodyear & Fabian, 2012).

Rules that focus on domestic housing typically require that there is both a bathroom and a separate living room (except for very small dwellings), but do not specify the maximum number of people expected to use a single bathroom. Boarding or dwelling house regulations may specify a maximum number of residents per bathroom or toilet.

The CNOS definition of crowding is used in many Australian documents, although critiques note its lack of correlation with how indigenous Australians view crowding (Memmott, Birdsall-Jones, Go-Sam, Greenop, & Corunna, 2011; Memmott, Birdsall-Jones, & Greenop, 2012 ). The CNOS definition is similarly used in many reports on conditions in New Zealand, as it is amenable to calculation from census data.
Those definitions of crowding which include a firm cut-off between crowded and non-crowded dwellings can also be used to define the maximum number of people who could acceptably live in a dwelling.

2. Aim

The aim of this work is to assess whether larger houses can appropriately accommodate as many people per square metre of floor space as smaller houses.

3. Methodology

3.1 House plans

A random sample of ten of the twenty largest franchise builders in New Zealand in 2012 (Curtis, 2013) was selected after weighting by the proportion of completed 2012 consents. Basic details including floor area of each plan were collected from the developers' websites. This yielded 540 plans, ranging in area from 50 to 484 square meters. The nominal dwelling sizes were broken into ten categories, and one dwelling of each size randomly chosen from each developer. This yielded 62 plans for closer analysis.

A sample of older plans was also consulted. A series of State house plans (plans drawn up by the predominant supplier of Social Housing in New Zealand) at Archives New Zealand were consulted (Archives New Zealand). There were 599 plans from which the number of bedrooms was the main searchable size feature. A stratified sample was drawn to encompass a range of dwelling sizes, while keeping the majority of the dwellings as the most common two- and three-bedroom sized dwellings.

The area of each living or bedroom, and overall building area, was calculated using whatever scaling information was available. Additional information, such as the number and accessibility of bathrooms, whether living rooms were potentially suitable to be bedrooms, and the presence of garages were noted.

3.2 Occupancy metrics

Seven methods of calculating potential maximum occupancy were used.

(i) The New Zealand 1947 regulations applied to every room described as either a bedroom or a study.
(ii) The Canadian National Occupancy Standard applied to every room described as either a bedroom or a study.
(iii) Both the New Zealand 1947 and Canadian National Occupancy Standard applied to every room described as either a bedroom or a study.
(iv) A “cultural aspirational norm” of two people in the largest bedroom and one in every other room designated a bedroom.
(v) Applying the CNOS and the New Zealand 1947 regulations, to every room described as a bedroom or study, along with privacy and a maximum of 7 residents per bathroom/toilet.
(vi) Applying the CNOS and New Zealand 1947 regulations to every room that can be used as a bedroom (except for one living area), with privacy and a maximum of 7 residents per bathroom/toilet. Not using garages as bedrooms.
(vii) Applying the CNOS and New Zealand 1947 regulations to every room that can be used as a bedroom (except for one living area), with privacy and a maximum of 7 residents per bathroom/toilet. Allowing garages to be used as bedrooms.
3.3 Calculations

The potential occupancy of the dwellings was determined under each of the methods. Normalised occupancy levels (people per 100 m² of floor space) were calculated, both including and excluding the area of any garages attached to the dwelling.

4. Results and Discussion

The older social housing plans ("State Houses") were chosen to be representative of the plans and the era. They were, on average, much smaller than the plans for the modern franchisee dwellings. The State house plans examined ranged in area from 59 to 133m², with an average of 90m², in contrast the modern plans ranged from 51 to 478m², with an average of 207m². In comparison, the median surviving dwelling from the 1950s in the mid-2000s was 111m², and the average recent dwelling was 194m² (Telfar Barnard, personal communication, 2015), so the dwelling sizes in the plan database are broadly representative of the eras.

4.1 Permissible occupancies - Comparing major metrics

Table 1 shows the required sizes of bedrooms to accommodate varying numbers of people under the rules of three countries. The bedroom size required for one person varies between 6.0 and 6.5 m², and for two people between 9.2 and 10.22m². These figures are similar; in two of the countries (New Zealand and the United States) further occupants are allowed if the rooms are sufficiently large. The British rules allow a maximum of two people per bedroom. The Canadian rule allows a maximum of two people per bedroom regardless of bedroom size.

Three methods of permissible occupancy are calculated here and capture the breadth of this variation. The New Zealand rule is applied and then the Canadian one, when both are simultaneously applied the result is similar to the British rule.

The graphs in Figure 1 show the maximum number of people who would be allowed to live in the dwelling under the different sets of rules. Figure 1a shows the New Zealand rules, with a strong increase in people permitted with increasing dwelling size. Figure 1b shows the Canadian method, after a strong initial increase with dwelling size, the allowed number of occupants levels off. This is because even very large dwellings do not have more than five rooms designated as bedrooms. Figure 1c shows allowable occupancy when both sets of rules are applied (thus similar to the occupancy allowed under the British rules).

The New Zealand and United States rules, which allow a maximum occupancy dependent only on bedroom size, unsurprisingly allow more people in larger houses, which tend to have larger bedrooms, than the Canadian or British rules. The Canadian, New Zealand and British systems, as well as setting a limit on the maximum number of people per bedroom, also have additional constraints on the sex, ages and relationships of people deemed appropriate to share a bedroom. Indeed, in current Western culture most adults would prefer to only share a bedroom with an intimate partner. Thus, although under the rules the dwellings could accommodate the calculated maximum number of people, it is also very possible that the relationship restrictions mean that a specific family, or household of the maximum number, may actually be unable to be appropriately accommodated by the house. Therefore, even if applying only the 1947 regulations, it may be more valid to use the additional CNOS rules to give an effective actual maximum occupancy for a dwelling.
4.2 Permissible occupancies - Effect on potential occupancy of room repurposing

Figure 2 shows the potential occupancy, normalised to people per 100 square metres, of the dwellings under the four occupancy scenarios of increasing room usage while still remaining inside both the New Zealand 1947 regulations and the CNOS criteria, and in addition requiring that there is at least one toilet and washing facility available for every seven people in the dwelling, without requiring access through a bedroom, which they do not occupy. Figure 2a shows the potential occupancy rate using the cultural aspirational level (with a maximum of two people in the largest bedroom, and one in all other bedrooms), with only rooms annotated as bedrooms used for sleeping. It shows that as the dwellings get larger the potential occupancy per square metre strongly declines. Figure 2b shows the potential occupancy, if there are a maximum of two people per bedroom, and rooms marked as studies can be repurposed for sleeping. It shows a substantial increase in the potential occupancy rate beyond that of the cultural aspirational level. Figure 2c shows the potential occupancy when in addition to two people sleeping in each bedroom or study, rooms marked as living areas can be used for sleeping, so long as the area to be used for sleeping is private, and at least one living area is left as a living space. Figure 2d shows the potential occupancy when in addition to living areas being used for sleeping, garage spaces can also be used.
The increase in potential occupancy when other spaces are repurposed is not as great as the increase in potential occupancy when all bedrooms in the dwellings are expected to accommodate two people.

Except for the cultural aspirational occupancy level, where smaller dwellings had much higher potential occupancy rate than larger dwellings, dwellings of any size could have relatively low potential occupancy rates, but only dwellings of less than about 150sqm had high potential occupancy rates.

Normalising by the footprint of the whole dwelling is appropriate when considering the carbon cost of the building materials and maintenance. Normalising excluding the area of any garages might be appropriate for considering heating costs, but only if the garage is unheated and the wall between the house and garage is insulated to exterior wall standard. Even in uncrowded houses, garages can be turned into games or exercise rooms and may be heated, so excluding the area of the garage when normalising may not always be appropriate.

Figure 3 shows analogous graphs when potential occupancy rates are calculated excluding the areas of any garages. Overall, they look similar to the earlier figures, with only small increases in the potential occupancy rate. Figure 3a showing the cultural aspirational occupancy scheme is
especially similar to Figure 2a. Figure 3b (analogous to Figure 2b) showing the effect of minor room repurposing, shows that when the garage areas are excluded, the dwellings with very low potential occupancy rates show an improvement, but the dwellings with high potential occupancy rates do not show a similar improvement. Figure 3c (analogous to Figure 2c) shows a similar effect for areas designated as living areas that can be repurposed as sleeping areas. There is no figure equivalent to 2d, as if the garage is repurposed for sleeping then the normalisation should not exclude it. Overall excluding the garage area from the dwelling area does not change the relationship between dwelling size and potential occupancy rates.

Although smaller dwellings often had greater potential occupancy rates than the larger dwellings, there was a sharp cut-off point when bedrooms were so small that they were not large enough under the 1947 regulations for two people to sleep there. Two of the smaller dwelling plans analysed had the largest bedroom under the two-person cut-off size.

![Figure 3a: Cultural Aspiration Occupancy](image1)

![Figure 3b: Occupancy if study repurposed](image2)

![Figure 3c: Occupancy if living areas and studies repurposed](image3)

**Figure 3**: Normalised occupancy against dwelling area (excluding garage) for different maximum occupancy calculations

### 4.3 Comparing newer and older designs

Figure 4 shows the occupancy of the smaller dwellings by the design era of the dwelling. It shows that the older State house designs tend to be able to accommodate slightly more people than designs of equivalent size in the modern era. The occupancy here is calculated from the combined
1947 regulations and CNOS, while allowing study repurposing, but no repurposing of other spaces in the dwelling.

The newer designs accommodate an average of 0.9 fewer people (p=0.008). This difference is partially caused by the absence of garages in the older designs, if only the area excluding garages is considered then the difference reduces to an average of 0.5 fewer people (p=0.06) in the modern smaller designs.

![Figure 4: Effect of design era on potential occupancy of smaller dwellings](image)

5. Conclusions

Dwellings currently being built in New Zealand are substantially larger than those of 50 years ago. This in itself need not be a problem, and houses that are built to the specifications of the intended occupiers, may well suit the first occupiers very well. However, these dwellings are also the current era’s legacy to future housing needs, and therefore consideration needs to be given to other future occupiers. Other things being equal, larger dwellings require more embodied energy to build, more materials to maintain, and more energy to heat/cool. As we are moving into an era of constrained resources, where there will be considerable externalities from resource use, it is appropriate for larger dwellings to also be able to adequately accommodate more people.

A number of English-speaking jurisdictions have compiled rules on the maximum number of people who ‘should’ live in a dwelling. Despite being developed at different times - the CNOS criteria were developed in Canada in the 1980s through consultation between provincial housing agencies and the Canadian Mortgage and Housing Corporation (Statistics Canada, 2013), whereas the New Zealand and English rules were developed during the early and mid-twentieth century - they have some similar features. The similar features include similar break-points for allowed occupancy by room size, sometimes a similar maximum allowed occupancy, and similar breakdowns for the age, gender and relationships of people deemed appropriate to share a bedroom.

Applying these rules to New Zealand dwelling plans of different sizes shows that although larger dwellings can accommodate more people than smaller dwellings, and even small dwellings can be designed inefficiently, generally the number of people able to be accommodated per square metre
of floor area decreases as the dwelling size increases. This result remains even if rooms initially not designated as bedrooms (including garages) are repurposed as bedrooms.

That occupancy rules remain in force in diverse countries, strongly suggests that there is some physical, social or biological merit to them, whether to avoid excessive wear and tear on the dwelling which reduces its longevity, or because increased crowding results in increased disease transmission.

Given the increasing pace of climate change, with energy prices likely to rise and growing shortag-es of housing in fast-growing cities, there is an increasing need to build dwellings with low running costs that will remain usable many years into the future. The trend towards large dwellings, which cannot be appropriately occupied at the same density as smaller dwellings, is undesirable.

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Rational or emotional? Failing to attract home owners in Germany to conduct energy-efficient renovation measures from a marketing perspective.

Abstract

Purpose / Context – Energy efficiency measures/ private home-owners/ decision process

Methodology / Approach – Explorative research/ qualitative interviews/ content analysis

Results – Decisions towards energetic renovation measures can be characterized as a strategic consumer decision rather than the often assumed purely investment decision. Emotionally shaped motives seem to displace rational determinants such as financial savings and amortization.

Key Findings / Implications – The argumentation should focus more specifically on the advantages of the measures that are non-financial. This primarily includes the improvement of the indoor climate and the accentuated well-being that goes with it hand in hand. To sustainably activate potential renovators the supply of out-reach consulting through energy advisors and local craftsmen should be enforced.

Originality – The study makes an attempt to reconsider the decision-making process from the perspective of consumer research in order to understand home-owners reluctance to conduct energy efficiency measures to their homes.

Keywords - Energy efficiency measures, private home owners, consumer behavior, qualitative research
1. Introduction

1.1 Research Problem

The energy transition is one of the main challenges Germany currently faces and will be confronted with in the long term. To meet the energy efficiency aims and climate protection goals, there is a strong need for action in the present building stock. To utilize unused energy efficiency potentials, the annual renovation rate of 0.8 per cent has to be at least doubled (Blazejczak, Edler, & Schill, 2014; Kleemann & Hansen, 2005). For the implementation of these aims, a number of funding and financing programs was launched particularly for the owners of private homes to facilitate the carry out of energy-efficient renovation measures as they argue with economic-rational parameters such as the amortisation period. Retrospectively, the success of those measures lag behind all expectations as the renovation rate still stagnates below one per cent per year. It seems that the purely economic-rational parameters do not generate any added value in activating and in motivating home-owners to carry out energy efficiency measures. Further, these parameters seem to be inefficient to diminish barriers towards energetic renovation measures (Claudy & O'Driscoll, 2008). Moreover, it appears to be surprising if it is considered that the funding and financing programs promise short and medium-term amortisation times as well as substantial financial savings in reduced energy consumption (Lübben, 2015).

Besides these economic-financial parameters, other relevant factors which home-owners rely on in their decision-making should exist. The current debate in the scientific literature criticises that the supporting programs suggest that the energetic renovation decision is purely shaped by economic factors alone (Albrecht & Zundel, 2010; Novikova, Vieider, Neuhoff, & Amecke, 2011; Stockburger-Sauer & Hoyer, 2009; Zundel & Stieß, 2011). However, because of the static renovation rate despite evident advantages it is inevitable to reconsider the assumption of the decision to be purely economically driven.

The aim of this study is to obtain a new gain of knowledge about the decision-making processes in the discourse of energy-efficient refurbishments of owner-occupiers of single family-homes. Therefore, the status of the economic-rational factors needs to be explored and thus the importance and status of further potential factors have to be evaluated by comparing them in terms of mental ranking. In this way, hidden and not yet considered emotional factors that shape the energetic renovation decision could be revealed. Against the backdrop of the empirical findings of this study, a more critical appraisal of recent activation measures to attract home-owners to conduct energetic renovation measures can be conducted.

1.2 Literature Review

The motives to conduct energy efficiency measures have been subject to several research streams over the past decades. As a starting point, the energy efficiency gap (Jaffe & Stavins, 1994; Sorell, 2004) or the energy paradox (Gates, 1983) define the most basic assumptions. Both phenomena suggest that an energy efficiency measure will be conducted if the return in investment is sufficiently high enough. From the deciders' perspective, this decision is perceived as a strict investment decision. Because of the prolonged gap between possible and actually conducted measures, the existence of other relevant criteria was supposed. These include information deficits, risk, and uncertainty as well as irreversible costs (Jaffe & Stavins, 1994; Jochem & Gruber, 1990; Zundel & Stieß, 2011). Notably, Hasset and Metcalf (1993) and Awerbuch and Deehan (1995) assume that uncertainty in the decision-making process and the irreversible costs should explain the energy efficiency gap. However, it is criticised that the decision towards an energy efficiency measure like energetic renovation on single family-homes cannot be determined by economic factors alone but by emotional factors. For that reason, the involvement and the emotional bond towards the building as a home seem to have a significant effect on the decision (Gram-Hanssen, Bartiaux, Jensen, & Cantaert, 2007; Jakob, 2007). Thus, a broader understanding of the cost-benefit calculus than before is assumed.
Notwithstanding, this new approach in understanding the paradigm appears to be unsatisfying (Zundel & Stieß, 2011). The scientific debate suggests that psychologic and socio-psychologic factors should be taken into much closer consideration (Yates & Aronson, 1983). Tan (2008) remarks, that the motivation to conduct energy efficiency measures depends on the personal attitude towards the predicted outcome of the measure. The motivation can be perceived as one of the main triggers for measures in this context (Organ, Proverbs, & Squires, 2013). Both the motivation towards and the perception of the measure is closely linked to the deciders socio-cultural background as Aune (2007) suggests. Here, the family household can be considered as a significant peer group (Darby, 2006; Gram-Hanssen et al., 2007). Relevant information that is crucial for the decision-making will be discussed and deliberated within the household or the family (Guy & Shove, 2007). The decider will relate and compare this information with his closest social peers (Bartiaux, 2008; Desmedt, Vekemans, & Maes, 2009). If the social reconciliation is successful, the crucial information will be appreciated and worshiped. Beyond social motivations, several studies found evidence for environmental-related motives that could explain the decision to conduct energy efficiency measures (DCLG, 2011; Herring, Caird, & Roy, 2007). Based on the work of Stieß et al. (Stieß, Birzle-Harder, & Deffner, 2009), Stieß and Dunkel (2013) made an attempt to bring most of the previous findings together and to merge them into one conceptual model. The model especially unites attitudinal components of the deciders like the attitude towards energy efficiency measures and the outcome of those measures. The latter includes motives such as comfort, energy efficiency, and energy savings. Legal and technical restrictions, monetary and non-monetary resources, the socio-demographic situation, and the occasion to conduct energy efficiency measures form the paling framework for the model. This model appears to comprise most of the relevant aspects; however, the status of the non-economic parameters and their relation to the purely economic factors remain unclear.

Numerous conceptual and empirical studies to analyse the decision-making, the motivation as well as drivers and barriers towards energy efficiency measures, especially energetic renovation measures to private homes, can be found. However, the new gain of knowledge did not contribute to the understanding why and how private home-owners seem to be reluctant to conduct energetic renovation measures to their buildings. Furthermore, the initially mentioned energy efficiency gap (Jaffe & Stavins, 1994) remains unexplained. Although very few studies try understand the homeowner as a consumer, a solid and comprehensible transfer of previous findings to the context of consumer behavior is still lacking (Meester, Marique, Herde, & Reiter, 2013; Zundel & Stieß, 2011). That transfer might represent a significant step to fully understand the decision-making process to conduct energy efficiency measures to private homes and to carry-out energetic renovation measures. Additionally it is of special interest to explore why financial and funding programs permanently fail to attract and to motivate home-owners to conduct such measures.

2. Methodology

To gain a thorough understanding of the decision-making process and the motives to conduct energy efficiency measures, we chose a qualitative-explorative research approach as its objective is to understand the experiences and actions of the participants and to identify their underlying reasons (Maxwell, 2005). In detail, we executed two studies. Study 1 serves for the exploration of the decision of owners of single-family homes to carry-out energetic renovation measures. We conducted 14 semi-standardized in-depth interviews to draw conclusions on conscious and unconscious motives (Craig & Douglas, 2001; Lamnek, 2010; Schub von Bossiazyk, 1992). For all interviews we used a guide to guarantee a certain degree of comparability and standardisation. Each interview partner was selected based on a purposeful sampling (Patton, 2009) under the condition that they all executed energetic renovation measures to their homes within the last five years. Our interview partners were selected and acquired personally between October and December 2015 within a suburban area of a large city in western Germany, based on previous field-trips. We continued with the acquisition of new interview partners until no substantially new insights were generated. The interviews in study 1 took 51 minutes in average. Occasionally, the
interviews were carried out as a pair interview with the respective spouse. The participant's age varied between 32 and 71 years. In total, study 1 consists of eleven male and six female participants.

To gain external validity of the results of study 1, we conducted a second study (study 2) and carried-out six semi-standardized in-depth interviews with experts for energy-efficient renovations, particularly energy advisors and architects. We identified and selected the experts based on the criteria of their long-time experience with energy-efficient renovation measures. In these six interviews, we asked the experts to describe occasions and motives of the home-owners based on their day-to-day experience. Here, the interviews took 50 minutes in average. In total, study 2 consists of four male and two female participants.

All interviews of study 1 and study 2 were recorded and transcribed. Subsequently, we used qualitative content analysis (Mayring, 2005) and inductive coding (Kuckartz, 2009) with the software MAXQDA to structure the high complexity and specificity of the individual statements. The empirical work fulfils central validity criteria (Patton, 2002) for qualitative research. As all interviews were semi-standardized, the participants were able to explain all aspects and points relevant to them. Hereby the criterion for comprehensiveness is fulfilled. The empirical method is described in detail (transparency criteria). Finally, the material was reviewed, analysed and interpreted by two researchers and their results compared to arrive at the findings of this study (multipersonal discourse). All participants live in Germany.

3. Results and Discussion

3.1 Overall Results

For comprehensiveness we brought together the results of both our studies as the findings of study 2 do show a great amount of reflection and confirmation on the results of study 1. In total we were able to develop nine categories inductively from the data. Our results reveal two major categories of motives towards the carry-out decision of energy efficiency measures. Those motives can be divided in (1) rational and (2) emotional motives. First we address the rational motives.

The first group of motives depicts the rational motives. Amongst the participants we found broad agreement for the importance of financial and monetary aspects as they seem to be perceived as the factor with the highest priority. The perspective to save energy and thus money is of core interest. Rising prices for energy costs during the past years is a determinant that is mentioned by most of the interviewees: "Well, first of all to curb the energy expenditure and then of course to pay less money for hot water and electricity. At that time, the energy prices didn't bring me into laughing mood". Home-owners possess financial capital that is strictly determined to undergo renovation measures and improvements to their homes as well as accurately calculated beforehand. Infrequently, some of the home-owners decided not to conduct the most efficient measures in terms of monetary savings, if the calculated budget were to have been exceeded. Energetic renovation measures are perceived as an instrument for the long-term maintenance of value of the family-home. The owners do want to hedge the building for the future. In most cases, the interviewees remarked that they would like to increase the building's market value for the case they have to sell it in old age. Other reasons can be found in the strategic planning to hand the house down to the next generation. Consequently, energetic renovation can be grasped as a store of value for the future because the revenue, even if it is noticeable for the next generation, might be higher than leaving the money in the bank: "Actually it was about bringing the house in top condition from an energetic point of view. Maybe for a sell in the future to make sure that my children could get some kind of benefit". All of the interview persons stated that one should invest the financial means that are at the disposal continuously to increase the quality and the value of the building.
In comparison, less consent between the interview persons can be observed when it comes to the amortization of the executed energy saving measures. They agree in principle that a roughly estimated amortization period would be helpful. But it only serves as a broadly shaped guideline for the decision process and is used to estimate the trade-off between particular measures. Despite the inclusion of the amortization period in the energetic renovation decision this, determinant rapidly loose its importance: “I didn’t come up with the idea to calculate things like that or to scrutinize the single measures if they are truly worth it”. Surprisingly, the majority of the interview persons do not monitor the level of amortization attainment nor the return on investment. They mainly rely on their intuition that the measures they carried out are efficient and have a sustainable effect on monetary savings. Only very few interviewees state that they look on their bill of energy costs from time to time. In summary, the amortization period does not represent a weightily determinant within and after an energetic reconstruction decision. The degree of independence towards energy suppliers seems to be more important for the home-owners. This applies most for those of the interview persons that installed photovoltaic and solar arrays on their buildings’ roof. Especially against the backdrop of the increasing development of the local energy prices they aimed to remain mostly autarkic. The combination of autarky and energy cost reduction was the most important aspect for these persons: “For me and my husband it was our main objective to reach independence from the energy suppliers. That was the prime cause why we started to think about it”.

Besides rational motives we found evidence for emotionally shaped motives as well. Improving the living quality and the indoor living environment was one of the driving intentions to undertake energy efficiency measures. All participants of the studies reported that consentaneously. They described this aspect as equally important as the financial and monetary aspects. Justification is given in the insufficient thermal output and the unsatisfactory sense of well-being to decide to conduct renovation measures: “I wanted to make sure that our house is packed up in the way that the warmth has no chance to leak out of the house. So as a result we would have a better indoor climate condition, and that’s what we were looking for.” Whereas this aspect was one of the driving motives, other interviewees only realized an improvement of the thermal output and well-being after the finalization of the renovation process. Especially these persons did not expect such an amount of improvement. For that reason they perceive the success of the measures as even more positive. Another emotionally shaped motive can be found in the aspect of the outward appearance and aesthetics of the building. Here, we can subdivide our sample in two groups. The first group conducted energy efficiency measures, aiming to improve the outward appearance. However, the improvements concerning the aesthetics of the house came first: “If you paste those insulation panels on the wall, the original style of the house is completely ruined”. This relation is shown within the second group vice versa. Here, the aim to execute energy efficiency measures was the primary motivation. During the deliberating process the home-owners decided to combine the renovation measures with aesthetical improvements. Although according to this aspect, we could separate the sample in two groups, the interviewees showed broad consent that they aimed at lifting their social status through these efficiency measures and regarded energetic renovation as a way to express their personal fulfilment and to show their neighbours and peers their prosperity and situation in life: “You know, at a certain point in life you would like to change a few things. For me it was the thing that I wanted everything a little bit better, bigger, and smarter”. Nevertheless, very few of our interview persons stated that they cancel to conduct an efficiency measure in particular because the carry-out would have affected the outward appearance of the house in an undesirable way, like facade insulation for instance. The motive to conduct energy saving measures in order to protect the environment and the reduce greenhouse gas emissions was mentioned by a few interviewees but it was described as an aspect of minor importance.

3.2 Discussion

Our empirical results show evidence for the existence of two particular groups of motives of home-owners. These motives are supposed to shape the decision to conduct energy efficiency measures. Moreover, owners of single-family homes do not align their decision on a single motive...
but more on a whole set of different motives that can be described as rational as well as emotional. We support the assumption that monetary and financial determinants are one of the most important ones in the decision making. But in comparison with other motives, the status as the most important determinant and thus motive has to be relativized. In fact, financially shaped motives are the motives that were stated directly when we asked for the actual reason for the renovation measures. The more we discussed the topic and other reasons, a greater amount of further, non-financial aspects was revealed. With a closer look on the interviewee's chain of argumentation, it becomes obvious that the financial motives are being used to justify the emotionally shaped motives such as the improvement of the outward appearance. Therefore, we conclude that the status of emotional motives (improvement of the well-being, the indoor climate, the social status etc.) seems to be much higher than expected before. Figure 1 shows a first schematic recapitulation of the status of the emotional and rational motives. For a better comprehension we decided to merge the motives into an iceberg-related model.

![Figure 1: Iceberg-model of motives towards energy efficiency measures. (Source: own illustration)](image)

Financial savings and the profitability of the energy efficiency measures form the visible top of the iceberg. These are the most prominent arguments that are stated by the interview persons. If you ask for deeper motivations and reasons, another bunch of motives can be detected. These are the emotionally shaped motives. In most of our interview cases, these emotional motives are being considered as the main decision criteria.

With reference to the existing literature, our results are partially in line with the findings of Stieß and Dunkel (2013), Tan (2008), and Stieß et al. (2009) as we found evidence for attitudinal decision criteria. Further, motives such as comfort, energy efficiency, and energy savings can be confirmed with the results of our studies. However, we need to renounce the assumptions made in previous studies that the decision of private home-owners to conduct energy efficiency to their occupied buildings is a pure investment decision and driven by rational motives alone. Based on our findings, we perceive this decision more as a so-called strategic consumer decision (Bodenstein, Spiller, & Elbers, 1997). A strategic consumer decision is characterized by four components: a long-range planning horizon, specific financial investments, high personal and emotional involvement, and an ongoing usage of the object. Typical examples for a strategic consumer decision are the purchase of a new car or a house. These purchases are limited to only few occasions in the lifetime of a customer and come along with considerable financial efforts. But on the other hand, the consumer shows a strong emotional bond towards this object. More importantly, the consumer actually uses the object, like driving the car or living in the house. This perception of the consumer decision can be transferred to the context of energy efficiency measures and energetic renovation of single-family homes. Here, home-owners commonly only
conduct such measures one or two times in their life and, of course, need to raise a certain amount of financial means. But like in the case of the car purchase, the home-owner has strong emotional feelings and involvement towards his home as a building that he occupies, because the outcome of his decision will have a lasting effect in the outward appearance and energetic performance.

4. Conclusion

In summary, we found empirical evidence for rationally and emotionally shaped motives of home-owners to conduct energy efficiency measures to their occupied single-family homes. Within the decision-making the deciders follow a bundle of rational as well as emotional motives. We proved that emotional motives seem to have a higher level of importance than the rational and thus financial motives. Our findings include implications for practitioners as well as for the elaboration of public policies. As mentioned above, funding and financing programs to support home-owners regard the decision to carry-out energy efficiency measures as a pure investment decision. They are misled to attract home-owners as they ignore emotional motives in the decision-making. Therefore, a strong need to reconsider the activation and argumentation strategy can be detected. To date, the estimated amortization period was the most important argument to activate the home-owners for renovation measures. As the annual renovation rate stagnates as 0.8 per cent, this argument appears as unconvincing and rather unimportant compared to more emotionally shaped motives. At first glance, the argumentation should focus more specifically on the advantages of the measures that are non-financial. This primarily includes the improvement of the indoor climate and the accentuated well-being that goes with it hand in hand. To sustainably activate potential renovators, the supply of out-reach consulting through energy advisors and local craftsmen should be enforced. These experts could give a better understanding of the non-financial benefits and create a lasting awareness for the topic.

Like most studies, our study has several limitations that need to be addressed in further research. Though this qualitative study disposes a sample of 20 interviews and uses analysis triangulation to enhance the depth of the analysis, the findings cannot be generalized. For more detailed insights into the decision making process of home-owners, a quantitative study should be conducted to trace the correlation between attitudinal constructs and the willingness to carry out energetic renovation measures. Furthermore, to gain a better understanding on the further framing aspects of the energetic renovation decision, the focus should be set on the influence of socio-demographic aspects and the social environment.

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Thermal Environment and Thermal Adaptation in Residential Buildings

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Abstract

Purpose / Context - The winter in the severe cold area of China is long and cold, with a long heating period. In recent years, the indoor air temperature during heating in residential buildings kept increasing. In order to study the thermal comfort and adaptation in such an overheated environment, a field study was carried out in Harbin.

Methodology / Approach - A tracking investigation was conducted during the heating period in 2013-2014. 10 apartments were selected from 9 buildings in 5 residential communities, with 20 participants. The indoor and outdoor air temperatures, as well as relative humidity were monitored continuously, while the residents were interviewed on their thermal responses online every week. 308 valid questionnaires were collected. The heating periods were separated into three phases based on the outdoor temperature.

Results - The results show that the mean indoor air temperatures in the early-, mid- and late-heating periods were 23.6°C, 24.3°C and 25.0°C, respectively, which were larger than or close to the upper limit recommended by thermal comfort standards, and slightly higher than the related thermal neutral temperatures. With the heating process, the mean clothing insulation of residents decreased. Opening windows and reducing clothing were mainly taken by the residents to adapt to the overheated environment.

Key Findings / Implications - The neutral temperature rose with the mean air temperature increasing in the heating period. The lower limit of the temperature range in winter is to be suggested in heating design to achieve a sustainable indoor environment.

Originality - It was found that human thermal neutral temperatures in residential buildings changed with the indoor, and many evidences of thermal adaptation were got.

Keywords - Thermal comfort, Thermal adaptation, Thermal environment, Field study, Residential building
1. Introduction

The winter in the severe cold area of China is long and cold. Especially, the heating period lasts for 6 months in Harbin, a representative city in the area. According to outdoor temperatures, the heating period is divided into three phrases: early period, mid period and late period.

During the long heating period, outdoor temperatures fluctuate significantly, while indoor temperatures stay almost constant. On the basis of thermal adaptive theory put forward by de Dear and Brager (1998), the thermal neutral temperature changes with different climatic conditions. So, does the thermal neutral temperature change with different heating periods? Should the indoor design temperature change with different periods? And how do thermal comfort and adaptation perform in the residential buildings?

Based on previous outcomes, Wang (2006) and Wang et al.(2003, 2011, 2014) found that the thermal neutral temperature changed when space heating began in residential buildings, and the thermal neutral temperatures in winter and spring during space heating were different in teaching buildings. The thermal neutral temperature in winter was lower than that in spring. When the indoor air temperature was overly high, people would feel uncomfortable. Cao et al. (2011) found that once people adapt to the warmer environment, they would lose adaptability to cold outdoor climate, which would cause energy wastes and health problems.

Our previous investigations were conducted in different periods or in different kinds of buildings. How do thermal responses change during the whole heating period? These are focused here.

2. Methodology

In the winter of 2013-2014, a continuous tracking measurement was conducted in residential buildings, as well as subjective questionnaires on residents’ thermal responses.

The measurement and questionnaires were processing at the same time. A digital self-recorded thermometer was placed in the main occupied room for continuous measurement. The participants filled in questionnaires online once every week. 308 valid questionnaires were collected.

2.1 Subjects

10 apartments were selected from 9 buildings in 5 residential communities, with 20 participants. The male to female ratio was almost 1:1. The participants in this study ranged in age from 28 to 72, with an average of 48.5. They had lived in Harbin about 40 years in average, completely accustomed to the climate. Table 1 shows the backgrounds of the participants.

<table>
<thead>
<tr>
<th>Number of participants</th>
<th>Age</th>
<th>Years in Harbin</th>
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<td>Mean</td>
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2.2 Measurement

Thermal parameters involved indoor and outdoor air temperatures, as well as relative humidity (RH). The air temperature and RH were measured continuously. A self-recorded thermo-hygrometer was set at about 1.0m above the floor in each occupied room.
2.3 Subjective questionnaire

The subjective survey was conducted through online questionnaires, which were filled in by respondents every week.

The subjective survey included the following:

(1) The thermal responses of subjects, such as thermal sensation, comfort, expectation and acceptability. Vote Scales were shown in Table 2.

Table 2: Vote scales of thermal response

<table>
<thead>
<tr>
<th>Vote</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Sensation</td>
<td>-3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, +3 hot</td>
</tr>
<tr>
<td>Thermal Preference</td>
<td>-1 cooler, 0 no change, +1 warmer</td>
</tr>
<tr>
<td>Thermal Comfort</td>
<td>0 comfortable, 1 slightly uncomfortable, 2 uncomfortable, +3 unbearable</td>
</tr>
<tr>
<td>Thermal Acceptability</td>
<td>acceptable, unacceptable</td>
</tr>
</tbody>
</table>

(2) The adaptive measures taken to improve indoor thermal environment, such as opening or closing windows, changing clothes and activity levels, having hot drink.

2.4 Research phases

The outdoor temperatures during the investigation are given in Figure 1. The whole heating period is divided into 3 phases (early heating period (EH), mid heating period (MH), and late heating period (LH)) according to outdoor temperature in Harbin.

Figure 1 shows that the daily mean outdoor air temperature descended below -10°C on 22 November 2013 and rebounded above -10°C on 2 March 2014. So the two days were termed as the beginning and end of MH respectively. The mean outdoor temperature of EH and LH were 1.4°C and 2.2°C, which were close. The maximums of the two phases were 11°C and 16°C, and the minimums were -8°C and -12°C. The outdoor temperature of MH varied from -26°C to 2°C, with an average of -16°C, which was the lowest in the periods.

3. Results and discussion

3.1 Air temperature and relative humidity (RH)

The mean indoor air temperatures and RH of 10 apartments were shown in Table 3.
Table 3: Mean indoor air temperature and RH in three phases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RH</th>
<th>MH</th>
<th>LH</th>
<th>Whole Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Air Temperature (°C)</td>
<td>23.6</td>
<td>24.3</td>
<td>25.0</td>
<td>24.3</td>
</tr>
<tr>
<td>Mean RH (%)</td>
<td>46.9</td>
<td>34.6</td>
<td>34.7</td>
<td>37.2</td>
</tr>
</tbody>
</table>

As known in Table 3, the mean air temperature during the whole period was 24.3°C. In LH, the mean indoor air temperature was at the maximum, 25.0°C. In the three phases, the mean air temperatures were close to or beyond the limit (24°C) recommended by ASHRAE standard. The mean RH ranged in 30%-50%.

The mean daily air temperatures and RH of 10 apartments is given in Figure 2.

As indicated in Figure 2, the indoor air temperature became stable since the centralized heating was used, ranging in 21.5-26.1°C. The mean daily RH varied in 29.4%-60.5%.

3.2 Clothing insulation

The clothing insulation values of respondents in residential buildings are shown in Figure 3. It shows that the clothing insulation decreased with the heating period processing, when people had gradually adapted to the indoor air temperature. Clothing adjustments suggest that people can adapt to the indoor environment well through behavioral adjustment.
3.3 Thermal sensation

The distribution of thermal sensation vote (TSV) of respondents in the residential buildings is given in Figure 4. The TSV frequency followed a normal distribution in each phase.

With the space heating going on, the TSV gradually shifted to the warm side. In three phases, only few respondents voted for -1, -2 or -3, while more respondents felt warm (vote for +1, +2 or +3). 36.6% of respondents felt warm in MH, so did 21.0%, 24.0% in EH and LH. This is also a valid evidence of overheating in residential buildings.

Figure 5 shows the air temperature distribution and clothing insulation at TSV of 0, +1, +2 and +3, to demonstrate a deep relationship between thermal sensation and air temperature.

As seen in Figure 5, at votes of +1 and +2, 50% of the relative indoor air temperatures were higher than 24°C. At the vote of +3, 95% of the temperatures were higher than 24°C. Meanwhile, there is no obvious discrepancy between clothing insulations at different votes. Metabolic rates were almost constant because respondents were required not to do heavy activity. Generally, people felt warm mainly because of overheating indoors.
3.4 Behavioral adjustment

Figure 6 shows the distribution of behavioral adjustments when respondents felt hot in residential buildings.

![Figure 6 Distribution frequency of adjustments in residential buildings](image)

Through the heating period, residents commonly improved the indoor environment by opening window in warm environment. Before and after the space heating, opening window could enhance natural ventilation and improve thermal comfort. However, in the heating period, opening window would cause energy waste for a hot indoor environment.

As seen in Figure 6, 37.4% of the subjects opened windows when they felt hot in EH, so did 37.4% in MH and moreover 42.0% in LH. Therefore, the over high indoor air temperature led to a waste in winter.

3.5 Thermal neutral temperature

The relationship between respondents’ MTS and indoor air temperature in three phases (EH, MH and LH) are shown in Figure 7. It is seen that the thermal neutral temperatures in different phases were figured out, which are 21.8°C, 22.9°C and 23.0°C, respectively.

![Figure 7 Relationship between respondents’ MTS and indoor air temperature in three phases](image)

Table 4 shows the comparison between thermal neutral temperatures and mean air temperatures of different phases, which suggests a significant discrepancy between the two temperatures.
Wang, Z Thermal environment and thermal adaptation in residential buildings

Table 4: Thermal neutral temperatures and mean air temperatures of different phases

<table>
<thead>
<tr>
<th>Parameter</th>
<th>EH</th>
<th>MH</th>
<th>LH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Air Temperature: $t_a$ (°C)</td>
<td>23.6</td>
<td>24.3</td>
<td>25.0</td>
</tr>
<tr>
<td>Thermal Neutral Temperature: $t_n$ (°C)</td>
<td>21.8</td>
<td>22.9</td>
<td>23.0</td>
</tr>
<tr>
<td>$t_n - t_a$ (°C)</td>
<td>1.8</td>
<td>1.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>

After space heating began, the indoor air temperature increased significantly, so most residents did not adapt to the thermal environment, and felt warm, which resulted in a low thermal neutral temperature, with a difference of 1.8°C.

In MH, the outdoor temperatures decreased, while the mean indoor air temperature rose by 0.7°C. Meanwhile, respondents built up some adaptation to the indoor environment, with the thermal neutral temperature increased by 0.9°C, 1.4°C lower than the mean air temperature.

In LH, the outdoor temperatures rebounded, and the mean indoor air temperature still rose by 0.7°C. The thermal neutral temperature was 2.0°C lower than the mean air temperature.

It is found that the neutral temperature rose with the mean air temperature increasing in the heating period, which indicates that the residents got used to the indoor thermal environment gradually.

On the other hand, the neutral temperatures were always below the mean air temperatures, suggesting overheating in residential buildings, which might cause discomfort and energy wastes.

When residents’ dependence to the indoor warm environment is built up, resistibility to the cold outdoor climate would be weakened. As a result, in addition to energy wastes, overheating would be against health. This finding further confirms conclusions by Cao et al. (2011).

In general, overly high temperatures would weaken residents’ thermal adaptation, and indoor thermal history affects thermal adaptation significantly.

4. Conclusions

In EH, MH and LH, mean indoor air temperatures were 23.6°C, 24.3°C, 25.0°C. This result shows that there did exist overheating in residential buildings.

At MTS vote of +1 and +2, 50% of the relative indoor air temperatures were higher than 24°C. At the vote of +3, 95% of the temperatures were higher than 24°C. Meanwhile, there is no obvious discrepancy between clothing insulations at different votes. Therefore, people felt warm mainly because of overheating indoors.

In the heating period, more than 20% respondents felt warm (vote for +1, +2 or +3) and above 30% respondents opened windows to release overheat. The clothing insulation decreased with the heating period processing.

The neutral temperature rose with the mean air temperature increasing, which indicates that the residents got used to the indoor thermal environment gradually. On the other hand, the neutral temperatures were always below mean air temperatures, suggesting overheating in residential buildings.

Due to high temperatures indoors, residents commonly adapt to the indoor environment by opening window or taking off clothes. However, it would cause energy increase and discomfort. Therefore, the indoor temperature should be kept at the lower limit of the comfort range in winter to keep residents’ adaptation and realize sustainable building designs.

5. Acknowledgement

The work presented in this paper was funded by the National Natural Science Foundation of China (No. 51278142). All the participants are sincerely acknowledged in this research.
6. References


What happened, how, why and what mattered: Three case studies from a low-income residential energy efficiency intervention program

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Abstract

Purpose / Context - In the context of residential retrofit programs as an opportunity for climate change mitigation and health, the mechanisms that lead to unexpected outcomes in indoor temperature and energy consumption are not well understood. Paradoxical and surprising findings have been attributed to householder behaviour. Better knowledge of householder practices is needed for more effective designs of interventions.

Methodology / Approach - This paper draws on a mixed methods study of an energy retrofit program for the homes of low-income, elderly or frail householders in Victoria, Australia. A quantitative exploration was combined with a phenomenological enquiry to explain the outcomes in warmth, heating energy consumption and householder satisfaction through householder practices and experiences.

Results – This paper details three retrofit case studies that illustrated the diversity of outcomes, the take-back, the prebound and the expected effects. These cases highlighted how the interaction of the material quality of the home, householder capabilities and the meaning of heating shaped the changes in warmth and energy consumption. The householders’ evaluations of the intervention program highlighted that ‘what mattered’ was not necessarily the impact of the retrofit.

Key Findings / Implications – While the effects discussed here are not new and the results lack generalisability, these case studies demonstrate that the theoretical predictions and the interpretation of the outcomes should be sensitive to contextual determinants. Interventions should include pre-study safety checks and aim for high thermal performance to be effective. Intervention studies should include a control group to assess confounding variables and bias.

Originality - By identifying some contextual mechanisms that may enhance or hinder benefits in indoor temperatures and energy conservation, this study helps to better understand the effectiveness of residential energy efficiency interventions.

Keywords - Indoor temperature, intervention, prebound, take back, practices
1. Introduction

Residential energy efficiency interventions programs are regarded as an opportunity for climate change mitigation and public health (Wang & Horton, 2015), with better indoor warmth in winter, improved affordability of fuel and householder satisfaction hypothesised as pathways towards better comfort and wellbeing (Gilbertson, Grimsley, & Green, 2012; Willand, Ridley, & Maller, 2015). However, empirical evidence has shown that energy improvements do not automatically lead to adequately warm homes or a reduction in energy use. Surprising findings are mainly attributed to occupant behaviour that differ from the assumptions of the intervention designers (Willand, Ridley, & Maller, 2015). In addition, the ‘unresolved conundrum’ (Green & Gilbertson, 2008, p. 11) of householders being satisfied despite suboptimal outcomes raises the likelihood of cognitive bias.

Unexpected outcomes in energy consumption are often attributed to the take-back and the prebound effects. The take-back effect refers to the choice of householders to compromise the expected energy costs savings in favour of better warmth (Clinch & Healy, 2000). There is agreement that, particularly in low-income households, modelled energy savings are unlikely to be achieved due to the priority given to better thermal comfort by the householder (Clinch & Healy, 2000). The prebound effect refers to the difference between actual and modelled energy consumption for space conditioning before energy efficiency improvements (Sunikka-Blank & Galvin, 2012). Underheating prior to an energy improvement may reduce the expected benefits in terms of energy conservation (Sunikka-Blank & Galvin, 2012). Hence, knowledge of householder heating practices is key in predicting intervention outcomes and for designing more effective measures. However, investigations into the householder experience of energy efficiency interventions are rare (Willand, Ridley, & Maller, 2015).

A recent residential energy efficiency intervention program conducted by the South East Councils Climate Change Alliance (SECCCA), Australia, provided the opportunity to explore the interaction between dwelling quality and householder practices and to illustrate the variability of outcomes of energy retrofits. This paper had three aims: firstly, to present diverse outcomes in indoor temperature and heating energy consumption; secondly, to explain the outcomes through descriptions and interpretations of the householder practices; and thirdly, to portray the householders’ experience of participating in the program.

2. Methodology

This so-called Health Study supplemented the retrofit intervention component of SECCCA’s Energy Saver Study (ESS) (SECCCA, 2016). The ESS was aimed at finding effective ways of helping low income Home and Community Care recipients in Victoria, Australia, to better manage their energy use. Participants were elderly or frail householders living independently near Melbourne, Australia. In this mixed methods quasi-randomised controlled trial, an experimental set-up was combined with a phenomenological enquiry into the householder experience. The study accompanied 13 control and 16 intervention households from May 2014 to September 2015. The intervention households received energy retrofits such as insulation and draught proofing free of charge. Control homes received retrofit measures at the end of the data collection period.

Technical devices and surveys obtained objective and subjective quantitative data, while four waves of householder interviews sought to capture the nature and meaning of householder practices and the participants’ experience with the study. Table 1 provides an overview of the data types, sources and measurement tools relevant to this paper. This study focused on the analysis of the pre- and post-intervention conditions of the winter months June, July and August 2014 and 2015.
Table 1 Overview of the data types, data sources and measurement tools relevant to this paper

<table>
<thead>
<tr>
<th>Data</th>
<th>Data source/ tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling construction characteristics</td>
<td>Dwelling audits and ESS intervention details&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Home energy efficiency star ratings by FirstRate assessment&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Home energy efficiency star rating estimations by AccuRate software package&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Health Study data</td>
<td>Householder surveys on comfort, adequacy of warmth, affordability of fuel etc.</td>
</tr>
<tr>
<td></td>
<td>Semi-structured interviews on householder practices and opinions</td>
</tr>
<tr>
<td>Indoor temperatures</td>
<td>Living room half-hourly temperature measurements using HOBO data loggers&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Electricity and gas usage data</td>
<td>Half-hourly electricity consumption measurements for various subcircuits on the dwellings’ switchboards by Ecofront monitors&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Half-hourly total gas consumption measurements by Ecofront monitors&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Outdoor temperatures</td>
<td>Half-hourly air temperature data by the Australian Bureau of Meteorology at the homes’ nearest weather station that was located in the same climate zone</td>
</tr>
<tr>
<td></td>
<td>&lt;sup&gt;a&lt;/sup&gt; Data provided by SECCCA</td>
</tr>
<tr>
<td></td>
<td>&lt;sup&gt;b&lt;/sup&gt; Estimations by Michael Ambrose, Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
</tbody>
</table>

As the climatic conditions of the two winters and the data collection periods for each dwelling varied, the monitored data were standardised to an ‘average’ winter day to ensure comparability of outcomes. An ‘average’ winter day was defined as a day with a daily mean outdoor temperature between 9° C and 11° C. These values represented a range of 1° C around, rather than the exact value of, the historic mean of about 10° C (Bureau of Meteorology, 2014) in order to have more valid data points in this limited sample. Standardised daily mean living room temperatures were calculated using the statistical software SPSSv23. Mean half-hourly standardised temperatures indices were then used to calculate the duration of the exposure of householders to living room temperatures that may be interpreted as being inadequate if below 18° C, or wasteful if above 24° C, according to common health guidelines (Public Health England, 2014; WHO, 1987). Only the hours between 8.00am – 10.00pm were considered, when it was reasonably assumed that householders were using their living rooms.

Monitored gas and electricity consumption data was used to standardise mean daily consumption indices, taking into account that the dwellings presented various mixes of fuels for heating and hot water appliances. Heating costs were calculated using AU$0.0171/MJ for reticulated natural gas and AU$0.2843/kWh for electricity (that is, typical consumption unit prices for this region (Switch On, 2016)). The effectiveness of the retrofit measures with regards to the adequacy of warmth and energy conservation was explored through the relationship between the percentage changes in mean daily heating energy and the absolute changes in daily mean living room temperatures on ‘average’ winter days. The graphical juxtaposition of diurnal variations in indoor temperature and heating energy facilitated the identification of changes in heating patterns.

Qualitative information was derived from transcribed semi-structured interviews and observations during the home visits. Questions relevant to the topic presented in this paper centred on the

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<sup>1</sup> FirstRate and AccuRate are both accredited rating tools, using the same simulation engine, but differing in the user interface. The simulation engine calculates the transient heat gains and losses taking into consideration the thermal performance of the building envelope, thermal storage, internal gains, hourly weather data and assumed occupant behaviours (NatHERS National Administrator, 2012). The type or efficiency of the heating system is not part of the assessment.

<sup>2</sup> The HOBO UX100-3 Temp/RH data loggers had an accuracy of ±0.21°C and a resolution of 0.024°C at 25°C (Onset Computer Corporation, 2015). The data loggers had been placed by SECCCA staff about 2 metres above the floor, on internal walls and away from heating and cooling devices or outlets.
participants’ heating practices and changes therein, as well as on the householders’ individual experiences of the program. The analysis adopted an interpretative phenomenological approach to gain a better understanding of the participants’ routines and their meaning (Holt, 2008).

3. Results

Valid data for living room temperatures and heating energy was available for 12 homes. This paper details three retrofit case studies that illustrated the take-back, the prebound and the expected effects. All three houses had a poor thermal performance with star ratings below the mandatory 5 star rating that was introduced in Victoria in 2006. All three houses had received an R4 ceiling insulation top-up and various draught proofing measures. However, the outcomes varied due to different changes in heating practices. The descriptions below explain what happened (that is, the outcomes in warmth and heating energy consumption), how it happened (that is, the changes in householder practices), and why (that is, the reasons and the meanings of the changes in practices).

3.1 The take-back effect

House 23 illustrated the take-back effect, the phenomenon of potential savings in energy being traded for more warmth. The star rating of this home with only a gas wall heater in the living room rose by 0.7 to an estimated 4.2 stars. Living temperatures had been adequate before the intervention. After the intervention, on an ‘average’ winter day, the home was warmer with the daily mean living room temperature having risen by 1.1°C. The mean daily heating energy rose by 9 per cent, an increase in daily fuel costs of AU$0.22.

The rise in energy consumption was predominantly due to an earlier start and increased intensity in heating in the mornings, which resulted in 2°C higher living room temperatures at around 9am, a shift that was largely sustained over the rest of the day and night. Due to the positive shift in warmth, the living room reached temperatures above 24°C for four hours in the evenings after the intervention (Figure 1).

![Figure 1 Comparison of diurnal variations in average living room temperatures and heating energy consumption on 'average' winter days – House 23 (take-back effect)](image-url)
The take-back effect and overheating was due to the householders’ technically indifferent use of the wall heater. The heater possessed a thermostat. However, the elderly couple simply switched the heater on or off, and did not know the thermostat setting when asked. Although the householders reported to have used the heater for longer periods during the daytime of the second winter, this was not apparent in the heating profile of an ‘average’ winter day. The householders, who had found paying for fuel ‘neither easy nor difficult’ before but ‘very easy’ after the intervention, reported to have felt “more comfortable” in the follow-up winter. The husband confirmed that he felt “more relaxed, yeah, you don’t have to think about, you know”. This indicated that the couple had been less concerned about the affordability of fuel after the retrofit, and, hence, more generous in their heating, which had inadvertently led to overheating and an increase in their fuel costs.

3.2 The prebound effect

House 14 illustrated the prebound effect, a rise in energy consumption despite energy efficiency measures due to the underheating of the dwelling prior to the retrofit. In this centrally heated house, whose energy efficiency rating increased by 0.9 to an estimated 3.9 stars, the living room had been underheated for six and a half hours prior to the intervention. Post-retrofit, the underheating period was reduced to only two hours. On an ‘average’ winter day, the daily mean living room temperature was higher by 1.5°C. However, the significant improvement in warmth came at a cost: the mean daily heating energy rose by 38 per cent, equivalent to an increase of AUS$1.58 per day.

The rise in energy consumption was due to a longer daily heating period. Pre-intervention, the householders had heated twice a day: briefly in the mornings and then again in the afternoon when the sedentary part of the day started. In the second winter, the heating had become more intense in the mornings and continuous throughout the day and evening. Night-time temperatures returned to pre-intervention levels shortly after the heater was switched off (Figure 2).

Figure 2 Comparison of diurnal variations in average living room temperatures and heating energy consumption on ‘average’ winter days – House 14 (prebound effect)
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The shift in temperature and heating consumption profiles had three reasons. Firstly, during the second winter, the octogenarian husband had contracted pneumonia. Although warmth had been important in the management of the husband’s chronic lung disease prior to the intervention, it was the acute illness that had triggered the increase in heating. Simply "taking the chill out" in the mornings no longer satisfied the health needs of the husband. Continuous heating led to more adequate temperatures throughout the day, with living room temperature reaching the threshold of 18°C already at 10am in the follow-up winter, rather than only at 3pm at the baseline.

Secondly, the thermostat of the central heating system was located in the family room, opposite a door that was kept permanently open by about 50cm to allow the dog access to the garden. The wife explained:

\[\text{Wife: } \text{We have the door open all the time, as a rule ... The back door is always open, day and night, for the little girl ... she rules the house.} \ (\text{House 14})\]

This practice of leaving the door open hindered the thermostat to reach its set point of 22°C, causing the heating system to work at its maximum and causing the living area, in which the data logger was located, to overheat for two hours during the post-intervention winter. The open door also prevented the warmth to be retained during the night after the heater had been switched off, a retrofit benefit that had been apparent in House 23. The householders were aware of the consequences of leaving the door open by attributing occasional draughts to the open door. In addition, the couple had tried a doggy door insert, however the dog turned out to be too old and sick to move over the threshold. The householders’ personification of the dog (that is, the invariant reference to the “little girl”) and the attribution of powers to the animal (as expressed in the term “rule”), highlighted the position of the animal as a full member of the household, the householders’ emotional involvement with the animal and the priority given to the care of the animal in the household’s everyday routines.

While the prebound effect was only observed in this intervention home, increased heating with better warmth as a reaction to feeling colder with advancing age was also found in two control homes with valid pre- and post-retrofit temperature data, suggesting a time trend of increased heating demand among elderly and impaired householders.

3.3 The expected effect

House 4 illustrated the expected effect, a benefit in energy conservation due to the retrofit measures while indoor temperatures remained almost the same. In this centrally heated house, whose energy efficiency rating rose by 1.4 to a rated 2.0 stars, the living room had been underheated for two hours prior to the intervention. Post-retrofit, the underheating period did not change in the living area. On ‘average’ winter days, the daily mean living room and bedroom temperatures in this centrally heated home rose by a mere 0.1°C while the heating energy consumption was reduced by 14 per cent, a daily savings in fuel costs of AU$0.93.

The comparison of the diurnal variations showed a small delay in switching the heater on in the mornings, which would have contributed to the energy savings. In the afternoons of the follow-up year, the heater was switched on a short time earlier, though, making the rooms marginally warmer. Most importantly, though, in the afternoons and evenings, the living room retained the same level while the heating intensity was reduced, an outcome attributed to the improved insulation and draught sealing (Figure 3). The steeper heat loss gradient over night was explained by a higher ventilation rate.
The beneficial outcomes of the retrofit intervention were achieved by the householder actively and continuously managing her heating consumption and indoor temperature. For this impaired woman in her fifties, retaining a minimum level of warmth during the day and night through heating was necessary for the adequate functioning of her muscles and mental health, despite her concerns about fuel costs. However, post-retrofit, the householder reported that she had become “more liberal” in her heating, switching the heater on when the thermostat showed 19°C rather than waiting for it to drop to 18°C, an action that she justified with the potential benefit of the insulation top-up in the roof. The householder described how she experimented with the thermostat setting. During the night she was able to reduce the setting of the thermostat in the hall by 2°C, without having to compromise on warmth.

Woman: I have kept the heater on at 14 degrees, actually. So, it never gets below that in theory, in this place. […] I think last year you said you had it at 16?

Interviewer: Correct. I figured I could just reduce it a bit more. (House 4)

The expected effects were observed in two other intervention homes. Nonetheless, the improved comfort of the home was only one aspect of the intervention that had mattered to the householder.

3.4 What mattered

As part of the final interview, householders were asked ‘What do you think was the best part about participating in this study?’ What had mattered most to the majority of participants in the intervention group had been the retrofit measures, the gains in comfort and the expected benefits in costs. This view was also expressed by the couple in House 23, which had presented the take-back effect:

Wife: Basically, the best part is getting something for nothing, I guess (laughter). To be honest. And it’s helpful as much as it’s definitely going to save on our bills. (House 23)
The quote expressed that the motivation of the householders for participating in the study had been the offer of free retrofit measures. The satisfaction of the couple was based on the expectations of cost savings, rather than on actual evidence. Hence, the perception that paying energy bills had become “very easy” contained some cognitive bias. Ironically, the actual increase in heating energy costs, which was based on the days that the house had been occupied, would not have been noticed by the householders, as they had spent several weeks during the follow-up winter in a warmer region of Australia.

The householder in House 4, who had been able to reduce her heating energy consumption while retaining the same level of warmth, valued the peace of mind that the pre-study safety checks had provided first, and the retrofit measures only second.

Woman: One is peace of mind. I think the checking out by the electrician and the plumber, was fabulous. [...] and, secondly, of course, [...] the insulation is like a blanket over the house and all the draft excluders. It just makes everything more comfortable, and you feel like everything that can be done has been done. (House 4)

The exchange of faulty electrical safety switches had removed an acute health risk for the householder, who was aware of her vulnerability as a physically impaired person living alone. Faulty appliances had been replaced in another four of the 29 households. The metaphor of the blanket expressed the benefits of fewer draughts and, considering the unchanged indoor temperatures, better comfort through decreased radiant asymmetry due to the improved ceiling insulation.

However, a surprising answer was offered in House 14, the prebound case, in which the husband’s pneumonia had resulted in increased heating and better warmth. The increase in fuel bills had not been noticed by the householders. In response to the question ‘What has been the best part of being part of this study?’, the couple answered:

Husband: Meeting you.
Wife: I was just going to say exactly the same. (Laughter) Yes it’s been a pleasure. That’s what I was going to say.
Interviewer: What about the retrofit?
Husband: No it was educational to us.
Wife: Yeah. Now it has been, I think, very good. I think it has made us more conscious of different things you know? And things like that. Yeah. (House 14)

For this couple the social interactions and energy education had mattered more than the prospect or the outcome of better warmth or reduced energy costs. This sentiment was echoed by another intervention household. While these incidental benefits of the study had been appreciated by a large part of the control group, this response in an intervention home seemed symptomatic for the householders’ social isolation and a reflection of the quality of the ESS team and their interaction with the participants.

4. Discussion

The purpose of this paper was to illustrate the diversity of outcomes of a residential energy efficiency intervention. The juxtaposition of changes in heating energy consumption and indoor temperatures served to identify the take-back, prebound and expected effects of the retrofit measures. While the effects described here are not new and the results lack generalisability, this paper has explained why some retrofit interventions did not achieve the desired results. These case studies demonstrated how householder capabilities, such as acute health problems and technical interest, the material quality of the home, such as the location of the thermostat, and the
meaning of householder routines, such as heating as caring and health protection, varied the real life outcomes.

The take-back example implied that to retain adequate warmth and avoid overheating, householders may need to be better equipped to control their indoor temperatures and heating energy use. The prebound case suggested that, to be effective in achieving adequate warmth and energy conservation in homes that are underheated due to financial constraints, retrofit interventions may need to aim at a higher thermal performance than achieved in this example. The case with the expected results highlighted the active role that householders may need to play in monitoring and adjusting technical settings to optimise retrofit outcomes.

In addition, the program evaluation by the householders revealed that they were pleased by the mere likelihood of energy savings and warmth. This finding concurred with the ‘conundrum’ found in the UK of householders being satisfied with interventions and finding their ability to pay energy bills easier despite an actual increase in costs (Gilbertson et al., 2012; Green & Gilbertson, 2008). This study also found that incidental benefits of the research activities, such as safety, social interaction and energy education were highly valued. Hence, intervention studies should include pre-study safety checks and include a control group to assess such confounding variables and bias.

5. Conclusion

The explanations of the diverse results in indoor temperature and energy conservation in this study suggest that retrofit interventions outcomes and their interpretation should be sensitive to the contextual determinants and the dynamic system that characterise heating practices and feeling comfortable at home. The case studies have highlighted that ceiling insulation and draught proofing programs aimed to reduce fuel hardship and greenhouse gas emissions may not automatically achieve a set of predetermined and seemingly predictable benefits. Instead, the provision of building energy efficiency measures should be regarded as representing a range of potential benefits whose realisation depends on the individual context and householder capabilities.

6. Acknowledgements

The author thanks the South East Councils Climate Change Alliance and the Energy Saver Study team, who have so generously accommodated this research.

7. References


Understanding Australian Real Estate Agent Perspectives in Promoting Sustainability Features in the Residential Property Market

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Abstract

Problem - There is little evidence that over the past 20 years real estate agents in Australia are taking initiative in promoting sustainability features in the property purchase selection phase.

Methodology/Approach - Residential real estate agents are selected as they are the conduit of information between sellers and buyers, having an important role in communicating the importance of sustainability features in housing. A questionnaire was distributed through a newsletter alert from the Real Estate Institute of Queensland (REIQ) and an Australia-wide residential real estate company, PRDnationwide. This questionnaire asked agents to rate the relative importance of 50 building information of housing.

Results - Real estate agents considered more on spatial planning category, which focuses on general housing features, as opposed to other categories which are more related to sustainability.

Discussion - This study provides an insight into the agents’ perspectives on sustainability features that will enhance the effectiveness of sustainability “marketing” in the residential property sector.

Implications – The attitude of agents not actively promoting sustainability features may affect potential sellers/buyers not realising the importance of choosing a home with sustainability features.

Originality - The majority of the studies examine the impact of sustainability features on property value, ignoring the role of real estate agents. This study adds to the importance of assessing agents’ perspectives that may assist in the decision making process of purchasing a house.

Keywords - sustainability features, real estate agents, residential property
1. Introduction

The triple bottom line concept argues that sustainability can only be achieved by balancing the environmental, social and economic performance (Carter & Rogers, 2008). Birkeland (2008) argued that a fourth element of ‘governance’ should be included to enhance sustainable development. Different countries such as Germany and Australia have introduced sustainability features into their building codes to ‘improve’ the design, construction and operation of houses (Dong & Wilkinson, 2007). Consumers can view government’s building code in the aspects of effectiveness and cost efficiency (Dumm, Sirmans, & Smersh, 2012). In the review of Australian National Construction Code (NCC), there are numerous issues of non-compliance with the regulated energy performance requirements and lack of best practice in the Australian residential property industry. Responsibility for poor industry performance was not attributed to any particular sector, but to the multiple failures in all sectors, contributing to a culture of poor performance (State of South Australia, 2014).

To ensure that sustainability features are being covered in the property purchase selection phase, real estate agents play an important role in passing on information regarding these features to potential buyers in advertised property descriptions (Ball & Wiley, 2006). Investigations have been carried out on the impact of real estate agents’ negative comments on the selling price (Haag, Rutherford, & Thomson, 2000) and the impact of specific words in the property description on marketing outcomes (Goodwin, Waller, & Weeks, 2014). A main issue is the varying number of features within a residential property, which mean that agents may not have the opportunity to include all features and/or neglect some of these features. There is a need to investigate the perspectives of real estate agents on different pieces of building information of housing to narrow the housing features and create a list that is meaningful to the real estate agents.

Limited research has been carried out with regards to the perspective of real estate agents on different housing features. This paper specifically investigates the perspectives of Australian real estate agents on different sustainability features of residential property. An online questionnaire was distributed to real estate agents. This provides an insight into the agents’ perspectives on sustainability features that will enhance the effectiveness of sustainability “marketing” in the residential property sector.

2. Literature Review

Sustainable housing was labelled with different terms such as “green” (Schmidt, 2008), which may provide an impression that sustainability is only related to environmental issues. However, sustainable housing should encompass at least three components of environment, economics and ecology (Birkeland, 2008). Housing sustainability should highlight a positive concept that enables the occupants to have better quality of life and reduce the consumption cost. Research has shown the positive impact of green values in the residential property (Aroul & Hansz, 2012; Cajias & Piazolo, 2013). However, there is little evidence that over the past 20 years the residential property sector in Australia is taking initiative in promoting sustainability in the property purchase selection phase (Cutting, Cahoon, & Hall, 2012). In the housing market, the most important criteria for choosing a house is location and the value to pay for it (Whipple, 2006). There is less concern about sustainability features although regulations signify the need to take sustainability into consideration for the decision making process (Dent, Patrick, & Ye, 2012).

Incorporating sustainability into the decision making process of purchasing a house requires the help of real estate agents, as they are the conduit of information flow between sellers and buyers to ensure the efficiency and effectiveness of bringing both parties together (Ball & Wiley, 2006; Smith, 2012). Germany’s Sustainable Building Quality Label, informed by research on building performance, property valuation and sustainability, has identified 60 sustainability features, describing buildings in six main topics: economical quality, ecological quality, technical quality, social-cultural and functional quality, location quality, and process quality (Bock, Linner, &
Hartmann, 2010; Lützkendorf & Lorenz, 2011). A research project “Strategies and Solutions for Housing Sustainability” identified approximately 150 building information for residential property. This list was condensed to 45 information that were then classified into the five categories: spatial planning, occupant health and safety, occupant comfort, operation and services, and building durability, by taking into consideration of Germany’s Sustainable Building Quality Label (Miller, Stenton, Worsley, & Wuersching, 2014).

The real estate company LJ Hooker introduced The 17 Things™, which form the basis for a new checklist for sustainable housing design and construction. These 17 elements are climate zone, living locally, orientation, cross-ventilation, zoning, insulation, density of building materials, windows (glazing), shading or sun control, efficient heating and cooling devices, energy efficient lighting, efficient hot water system, solar photovoltaic system, low water garden, water efficiency devices, rainwater tanks, and energy rating. These 17 elements are grouped into five areas, which are location, floor plan and layout, key building structure elements, important energy and water saving inclusions, and energy rating (LJ Hooker, 2014). To get this certification on the property listings, the property needs to achieve six out of seventeen elements.

All of the housing features discussed in both research project “Strategies and solutions for Housing Sustainability” and The 17 Things are important for the development of a list of sustainability features that could be useful for the residential property market. These studies provided an important indication on the sustainability features which can be further explored in residential property. However, there is no established theoretical framework which can help to justify the outcomes of the sustainability features. As potential buyers refer to the advertised property descriptions in making their purchasing decision, the property descriptions listed by real estate agents will affect the buyers’ decision in the property purchase selection phase (Goodwin et al., 2014). Therefore, it is worth investigating real estate agents’ perspectives about different sustainability features to ensure that they can assist in “marketing” sustainability in the property sector and assist in the buyers’ decision making of purchasing a house.

3. Research Methodology

This paper investigates the perspectives of Australian real estate agents in promoting sustainability features in residential property during the property purchase selection phase. Residential real estate agents are selected as they are the conduit of information between sellers and buyers, and communicate the importance of different housing features.

An online questionnaire was created by using an online survey creation tool, Key Survey, with 265 records clicked on the survey link. This survey was distributed to real estate agents, mortgage brokers and property valuers in Australia. This paper will focus on the discussion of real estate agents. This questionnaire was distributed through a newsletter alert from the Real Estate Institute of Queensland (REIQ) and an Australian wide residential real estate company, PRDnationwide, from September to December 2015. As the questionnaire was distributed through the internal newsletter alert to the members of REIQ and PRDnationwide, tracking the number of agents reached by this alert was not possible. By combining the housing features listed in the LJ Hooker The 17 Things and research project “Strategies and Solutions for Housing Sustainability”, this questionnaire created 50 pieces of building information of housing (refer to Table 1).
Table 1: 50 Building information being tested in questionnaire

<table>
<thead>
<tr>
<th>Category</th>
<th>Code</th>
<th>Building information of housing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>S1</td>
<td>Site area</td>
</tr>
<tr>
<td>S2</td>
<td>S2</td>
<td>House size</td>
</tr>
<tr>
<td>S3</td>
<td>S3</td>
<td>Site coverage</td>
</tr>
<tr>
<td>S4</td>
<td>S4</td>
<td>Zoning/land use</td>
</tr>
<tr>
<td>S5</td>
<td>S5</td>
<td>Number of bedrooms/bathrooms</td>
</tr>
<tr>
<td>S6</td>
<td>S6</td>
<td>Size of rooms</td>
</tr>
<tr>
<td>S7</td>
<td>S7</td>
<td>Ceiling height</td>
</tr>
<tr>
<td>S8</td>
<td>S8</td>
<td>Internal room layout and connections</td>
</tr>
<tr>
<td>S9</td>
<td>S9</td>
<td>Access to personal modes of transport</td>
</tr>
<tr>
<td>S10</td>
<td>S10</td>
<td>Access to public modes of transport</td>
</tr>
<tr>
<td>Occupants health and safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1</td>
<td>H1</td>
<td>Indoor air quality</td>
</tr>
<tr>
<td>H2</td>
<td>H2</td>
<td>Accessibility - wide doorway</td>
</tr>
<tr>
<td>H3</td>
<td>H3</td>
<td>Accessibility - accessible ramps</td>
</tr>
<tr>
<td>H4</td>
<td>H4</td>
<td>Durability of building material</td>
</tr>
<tr>
<td>H5</td>
<td>H5</td>
<td>Visual access to neighbours/streets</td>
</tr>
<tr>
<td>H6</td>
<td>H6</td>
<td>Security system</td>
</tr>
<tr>
<td>H7</td>
<td>H7</td>
<td>Smoke alarms</td>
</tr>
<tr>
<td>H8</td>
<td>H8</td>
<td>Pest control measures</td>
</tr>
<tr>
<td>H9</td>
<td>H9</td>
<td>Building materials (e.g. concrete, masonry, brick)</td>
</tr>
<tr>
<td>H10</td>
<td>H10</td>
<td>Hot water temperature regulators</td>
</tr>
<tr>
<td>Occupants' comfort</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>C1</td>
<td>Annual thermal comfort- star rating</td>
</tr>
<tr>
<td>C2</td>
<td>C2</td>
<td>Insulation (wall, floor, roof and ceiling)</td>
</tr>
<tr>
<td>C3</td>
<td>C3</td>
<td>Building orientation</td>
</tr>
<tr>
<td>C4</td>
<td>C4</td>
<td>Cross-flow ventilation</td>
</tr>
<tr>
<td>C5</td>
<td>C5</td>
<td>Location of ceiling fans</td>
</tr>
<tr>
<td>C6</td>
<td>C6</td>
<td>Type of hot water unit</td>
</tr>
<tr>
<td>C7</td>
<td>C7</td>
<td>Sealing on windows and doors</td>
</tr>
<tr>
<td>C8</td>
<td>C8</td>
<td>Shading/sun control</td>
</tr>
<tr>
<td>C9</td>
<td>C9</td>
<td>Acoustic comfort</td>
</tr>
<tr>
<td>C10</td>
<td>C10</td>
<td>Visual comfort/scenic view</td>
</tr>
<tr>
<td>Operation and services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O1</td>
<td>O1</td>
<td>Type of energy services connections (gas/electricity)</td>
</tr>
<tr>
<td>O2</td>
<td>O2</td>
<td>Type of communication/data services connections (fax/phone coverage)</td>
</tr>
<tr>
<td>O3</td>
<td>O3</td>
<td>Water services connections (mains supply/rainwater/recycled water)</td>
</tr>
<tr>
<td>O4</td>
<td>O4</td>
<td>Connection to watertank</td>
</tr>
<tr>
<td>O5</td>
<td>O5</td>
<td>Hot water service storage capacities (litres)</td>
</tr>
<tr>
<td>O6</td>
<td>O6</td>
<td>Alternative power systems</td>
</tr>
<tr>
<td>O7</td>
<td>O7</td>
<td>Size of solar photovoltaic (PV) panel</td>
</tr>
<tr>
<td>O8</td>
<td>O8</td>
<td>Battery storage capacity for solar photovoltaic (PV) panel</td>
</tr>
<tr>
<td>O9</td>
<td>O9</td>
<td>Energy efficient lighting</td>
</tr>
<tr>
<td>O10</td>
<td>O10</td>
<td>Water usage of dishwasher</td>
</tr>
<tr>
<td>Building durability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>B1</td>
<td>Accessible bathroom/toilet</td>
</tr>
<tr>
<td>B2</td>
<td>B2</td>
<td>Flexible layout (i.e. use of rooms for different purposes)</td>
</tr>
<tr>
<td>B3</td>
<td>B3</td>
<td>Ability to adapt to changing needs over time</td>
</tr>
<tr>
<td>B4</td>
<td>B4</td>
<td>Reusable building materials</td>
</tr>
<tr>
<td>B5</td>
<td>B5</td>
<td>Non-toxic building materials</td>
</tr>
<tr>
<td>B6</td>
<td>B6</td>
<td>Recyclable building materials</td>
</tr>
<tr>
<td>B7</td>
<td>B7</td>
<td>Building envelope construction materials - lifespan and durability</td>
</tr>
<tr>
<td>B8</td>
<td>B8</td>
<td>General interior fit out materials – lifespan and durability</td>
</tr>
<tr>
<td>B9</td>
<td>B9</td>
<td>Kitchen/bathroom materials – lifespan and durability</td>
</tr>
<tr>
<td>B10</td>
<td>B10</td>
<td>Ease of access to service wiring, plumbing and data cabling</td>
</tr>
</tbody>
</table>

The questionnaire was comprised of four sections: (1) rating of building information importance, (2) general opinions on sustainable housing, (3) demographic details and (4) further comments. The main questions under “Rating of building information importance” were designed using a five-point Likert scale from “1” (Not at all important) to “5” (Extremely important). The agents were asked to
rate the relative importance of 50 pieces of building information of housing. These 50 features were classified into five categories (with 10 each category): spatial planning, occupants’ health and safety, occupants comfort, operation and services, and building durability.

The validity of the questionnaire response was measured based on the principle that the first and second sections of the questionnaire were being answered. The following questionnaire results will form the basis of on-going research that will develop a model for more effective gathering and distributing of information on sustainability features from real estate agents to potential buyers.

4. Results and Discussions

Forty-seven real estate agents participated in this questionnaire, with 63.8% of respondents having more than 10 years working experience as real estate agents. This questionnaire covered major states in Australia, including New South Wales, South Australia, Victoria, and Queensland.

The level of understanding on the meaning of sustainable housing may affect the respondents’ analysing skill on the interest from potential buyers/sellers on sustainability features in a property. The questionnaire results showed that 65.2% of the respondents believed there is little growing interest from their clients on sustainability features and among these respondents, and more than 50% believed they had quite substantial understanding on the meaning of sustainable housing. This indicated that sustainable housing is starting to gain interest from both the real estate agents and the buyers.

The respondents were asked to rate their opinion on Likert scale statements, from “1” being strongly disagree to “5” being strongly agree. Figure 1 shows the agreeability of the respondents towards the statement – “Apart from location and price, three main housing features sought by home buyers are number of bedrooms, bathrooms and car spaces.”

Figure 1 illustrates that most of the real estate agents agreed and strongly agreed that home buyers are seeking and prioritising features such as: number of bedrooms, bathrooms and car spaces apart from location and price. This indicated that the current residential property market is focusing on the general property features.

The focus of home buyers on the general property features may lead to the lack of focus on sustainability features. Figure 2 shows the agreeability of respondents towards the attitude of home buyers and home renters in relation to sustainability features.
Figure 2: Agreeability of the participants towards sustainability features sought by home buyers and home renters

Figure 2 shows that most of the respondents disagree with the statement that home buyers are not interested in sustainability features. However, the respondents had different opinions about the attitude of home renters, with the majority of the respondents agreeing or strongly agreeing that home renters are not interested in sustainability features. It is believed that home buyers are more interested in sustainability features compared to home renters, as home buyers are holding the property in the long term and are more concerned about the lifespan and thus capital growth of the property. Most home renters are temporary residents of the property, and their main concern is not necessarily the extra features of the house (other than general), but rather the rental price.

In order to have a greater understanding on the perspectives of real estate agents towards different building information of housing in residential property, the respondents were asked to rate their opinion on five categories of building information. Each category consists of 10 pieces of building information (refer to Table 1). The results of the top 3 building information in each category are showed in Table 2. The mean value showed for each category is the average mean value of the 10 pieces of building information. The ranking of the different building information is based on the mean value of all the features listed in Table 2, from highest to lowest. If two building information have the same mean value, the ranking is determined by the standard deviation.
Table 2: Top 3 Building Information in Each Classification

<table>
<thead>
<tr>
<th>Building Information</th>
<th>Mean</th>
<th>Std. Dev</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial planning</td>
<td>3.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1 Site area</td>
<td>4.07</td>
<td>0.68</td>
<td>2</td>
</tr>
<tr>
<td>S4 Zoning/land use</td>
<td>3.98</td>
<td>0.95</td>
<td>4</td>
</tr>
<tr>
<td>S5 Number of bedrooms/bathrooms</td>
<td>3.98</td>
<td>0.68</td>
<td>3</td>
</tr>
<tr>
<td>Occupant health and safety</td>
<td>3.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H7 Smoke alarms</td>
<td>4.23</td>
<td>0.98</td>
<td>1</td>
</tr>
<tr>
<td>H8 Pest control measures</td>
<td>3.87</td>
<td>1.15</td>
<td>6</td>
</tr>
<tr>
<td>H9 Building materials</td>
<td>3.85</td>
<td>0.94</td>
<td>7</td>
</tr>
<tr>
<td>Occupant comfort</td>
<td>3.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3 Building orientation</td>
<td>3.91</td>
<td>0.84</td>
<td>5</td>
</tr>
<tr>
<td>C2 Insulation</td>
<td>3.84</td>
<td>0.95</td>
<td>8</td>
</tr>
<tr>
<td>C4 Cross-flow ventilation</td>
<td>3.76</td>
<td>1.04</td>
<td>10</td>
</tr>
<tr>
<td>Operation and services</td>
<td>3.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O3 Water services connections</td>
<td>3.79</td>
<td>1.00</td>
<td>9</td>
</tr>
<tr>
<td>O2 Type of communication/data services</td>
<td>3.74</td>
<td>1.11</td>
<td>11</td>
</tr>
<tr>
<td>O1 Type of energy services</td>
<td>3.57</td>
<td>1.08</td>
<td>15</td>
</tr>
<tr>
<td>Building Durability</td>
<td>3.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B5 Non-toxic building materials</td>
<td>3.74</td>
<td>1.24</td>
<td>12</td>
</tr>
<tr>
<td>B1 Accessible bathroom/toilet</td>
<td>3.63</td>
<td>1.00</td>
<td>13</td>
</tr>
<tr>
<td>B9 Kitchen/bathroom materials – lifespan and durability</td>
<td>3.57</td>
<td>0.98</td>
<td>14</td>
</tr>
</tbody>
</table>

As shown in Table 2, across the five categories of building information, real estate agents believed that spatial planning is the most important category in their profession (mean value = 3.79). Closely followed by “Smoke alarms” (H7) is “Site area” (S1), “Number of bedrooms/bathrooms” (S5) and “Zoning/land use” (S4), with the mean value of 4.07 and 3.98 respectively. S1 and S5 with small standard deviation of 0.68 signify the almost similar opinion among the respondents on the importance of these two features. The results revealed that the current property market is more focused on building information related to spatial planning compared to all other categories. The spatial planning category is less related to sustainability of houses. It is mainly focused on the layout and functionality of general property features such as number of bedrooms and bathrooms (Miller et al., 2014), hinting towards less of involvement by real estate agents in promoting sustainability features in residential property. This is further supported by the result of the main features sought by home buyers being number of bedrooms, bathrooms and car spaces (refer to Figure 1). The pest control measures (H8) are important to real estate agents as it will affect the lifespan of the property.

The occupant health and safety is ranked second overall, with a mean value of 3.42, which confirms the need to have housing features which will enhance the health and safety of the occupants. “Smoke alarms” (H7), with a mean value of 4.23, is the most important housing features identified by real estate agents. As smoke alarm is a mandatory requirement in Australian NCC, and houses without this feature cannot be sold, this may be the reason for the highest mean value.

The third most important building category is the occupant’s comfort (mean = 3.40). “Building orientation” (C3), with a mean value of 3.91 and standard deviation of 0.84, also raised considerable amount of concern from real estate agents. The insulation and cross-flow ventilation...
are ranked number 8 and 10, respectively. This may be due to the possibility that buyers nowadays are concerned about energy costs and hence a good orientation will help to save electricity costs on air conditioning or heater.

Building durability and operation and services are ranked as the fourth and fifth most important category respectively. Real estate agents may not see the environment and economic impacts of having different sources of energy and water, hence they are not promoting these features. Building durability, which ranked as the fourth important category, is mainly focused on the expected life of the house and components and flexibility. Thus there is a possibility that the real estate agents are not really promoting residential property based on this category. As operation and services focuses on the type of services connection and this may not be a concern of real estate agents, it is reasonable for this category to be listed as the least important category among all five categories.

To further analyse the current residential property market opinion towards sustainability, the respondents were asked to rank the importance of these five categories of building information from three perspectives: as dwelling occupants, as dwelling owners/investors, and as real estate agents, with the Likert scale from “1” being “not at all important” to “5” being “extremely important”. Table 3 shows the ranking of different building categories. This ranking is different from overall ranking from Table 2. Table 3 represents the perspectives of different stakeholders from real estate agents’ point of view while the ranking in Table 2 represents the average mean value of 10 pieces of building information in each category.

Table 3: Ranking of building categories from real estate agents’ perspective and representative of their clients as dwelling occupants and dwelling owners/investors

<table>
<thead>
<tr>
<th>Perspective as dwelling occupants</th>
<th>Perspective as dwelling owners/investors</th>
<th>Perspective as real estate agents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Rank</td>
</tr>
<tr>
<td>Spatial planning</td>
<td>3.93</td>
<td>0.87</td>
</tr>
<tr>
<td>Occupants health and safety</td>
<td>3.81</td>
<td>0.88</td>
</tr>
<tr>
<td>Occupants comfort</td>
<td>3.88</td>
<td>0.82</td>
</tr>
<tr>
<td>Operation and services</td>
<td>4.05</td>
<td>0.93</td>
</tr>
<tr>
<td>Building durability</td>
<td>3.49</td>
<td>0.99</td>
</tr>
</tbody>
</table>

As shown in Table 3, the mean values from the point of view of dwelling occupants is the highest for four out of five categories of building information compared to the point of view of dwelling owners/investors and real estate agents. It is possible that dwelling occupants are occupying the house and hence they are concerned about the housing features in the category of spatial planning, occupant’s health and safety, occupants comfort, and operation and services. Building durability is not a major concern for them, as most of them might be the tenants of the property and would not occupy the property for a long period of time.

Dwelling owners/investors are more concerned about building durability (mean value = 3.91). This is justified in the literature that building owners or investors would like to own the property in the long term and hence be concerned about the lifespan of the property. This is also supported by the findings which indicated most of the home buyers are concerned about the sustainability features of the residential property (refer to Figure 2). The second highest ranked building category was operation and services, as they are considered as operation costs of the house and cost savings in the electricity and water bills are preferable.
Spatial planning is the most important category from the real estate agents’ professional point of view. This may be due to the possibility that the features in spatial planning, such as site area and number of bathrooms, are recorded in most of the real estate database (e.g. CoreLogic RP Data).

There is a discrepancy between ranking of each category from different perspectives, hinting towards the possibility that the features considered important for an occupant and/or owners/investors may not be as important to the real estate agent. Thus there is a high chance that real estate agents are not promoting certain features which may seem important to an occupant. For example, real estate agents ranked operation and services as the most important building category from their perspective as dwelling occupants, but this was ranked as the third most important category from their professional point of view.

The questionnaire results revealed that the property industry agreed that certain sustainability features are important but their main concern is still on the general property features. This indicated that sustainability is not the main concern of real estate agents when compared to the site area and number of bedrooms. However, the site area does influence the sustainability to some extent, in terms of the space of the backyard for social activity such as vegetation or playing area for children. Further calculation of the ratio of house size and site area needs to be carried out to justify this statement for individual property.

5. Conclusion

This paper has provided insights into the perspectives of real estate agents in promoting the sustainability features of residential property. Most of the real estate agents rated themselves with quite substantial knowledge on sustainable housing, and they ranked their clients as slowly gaining interest in sustainable housing. Interestingly, four respondents who rated themselves as having very substantial knowledge on sustainable housing identified a huge growing interest from their clients about sustainability.

Based on the analysis, the dwelling occupiers and dwelling investors/owners have different rankings on the importance on different building categories when compared to the professional point of view of real estate agents. The results showed that real estate agents are more focused on spatial planning, which focuses on general housing features, as opposed to durability or occupants comfort - which is more related to sustainability. However, if they ranked these building categories from the dwelling occupants’ or investors’ point of view, operation and services, and building durability are considered as the most important building categories.

Thus there is a possibility that dwelling occupants or investors have more interest in the lifespan of the property as this will affect their long term operation cost and return yield respectively. Smoke alarm, site area, zoning/land use and number of bedroom/bathroom are the top four most important features to real estate agents. This raises a further question on whether real estate agents really promote sustainability features during the home buyer’s property purchase selection phase. Further research needs to be carried out to interview real estate agents to investigate on the existence of any risks and challenges in promoting sustainable housing.

6. References


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Physical Characteristics of Residential Sprinklers’ Water Spray

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Abstract

Purpose / Context - With the development of urban economy, the number of tall and supertall buildings is increasing because of high population density, high land price and getting iconic buildings. Small residential units of less than 30 m² with an open kitchen are constructed in tall residential buildings. Apart from open kitchen, glass partition is also common because of the constraint from architectural design. Fire hazards in such tall residential buildings have raised public concern. In order to provide better protection of lives and properties in case of fire, provision of residential sprinkler system should be considered as it is not a mandatory requirement for residential premises in many countries. This paper presents the results of experimental tests about the physical characteristics of some residential sprinklers. By conducting a series of tests, including the tests in wind tunnel, tests of spray patterns and tests under controlled fires, valuable information and data were recorded for analysis.

Methodology / Approach - Small propanol pool fires were used in the fire tests to evaluate whether the residential sprinkler was able to control the fire.

Results – Physical characteristics of residential sprinkler under different pressures and flow rates have been studied and the findings were presented in this paper. Thermal sensitivity and the activation time of sprinkler heads have been measured and the spray pattern of the sprinkler and resultant water density distribution were discussed in relation to the fire development. Water characteristic tests were found useful in determining the operating pressure and flow rate.

Key Findings – It demonstrated that the installation of residential sprinklers could effectively control the fire size and lower the overall fire temperature as well as the heat release rate.

Originality - The residential sprinkler certainly reduces the probability of having fatalities and injuries in domestic fires.

Keywords - Residential sprinkler, tall buildings, fire hazards
1. Introduction

This paper presents the results of experimental tests about the physical characteristics of some residential sprinklers. By conducting a series of tests, including the tests in wind tunnel, tests of spray patterns and tests under controlled fires, valuable information and data were recorded for analysis. In Hong Kong, no sprinkler installation is required to be provided in general residential areas. Therefore, there are some suggestions on the necessity of provision of sprinkler installation in residential areas with safety concerns. The design tendency of residential buildings in Hong Kong is changing. A 30m² residential units with an open kitchen is common in Hong Kong (Chow and Pang, 2011). Apart from small unit, open kitchen and glass partition are also common in luxury houses because of architecture design consideration. Also, with the development of urban economy, the number of high-rise buildings and super high-rise buildings is increasing because of high population density and land price (Liu et al., 2012). For the fire hazards of the above building structures, it raises concerns on the need of installing sprinkler in residential areas.

Four different types of residential sprinklers were chosen for the tests, they were GL5601 and GL5651 from GLOBE, FIRE SPRINKLER CORPORATION, and Zstx-15 & K-zstx 15 from KUAI-DA FIRE SCIENCE AND TECHNOLOGY. In the first set of experiments, Response Time Index (RTI) was measured by the Wind Tunnel Test. It gave the activation time of sprinkler under pressure and flow rate. Sprinkler is used to control the heat release rate. With the help of sprinkler protection, the peak release rates, maximum heat flux and burning duration could be reduced, the system allows more time for people to escape. The survival rate of residents could be increased by about 20% after installing sprinklers in residential areas (Xin and Huang, 2013).

The residential building differs from other types of buildings on the characteristics of population. There is usually a long delay from starting of the evacuation because the occupants may be asleep or undressed. They are not ready to evacuate when there is a fire. In addition, occupants are reluctant to leave their own properties (Ronchi and Nilsson, 2013). Due to the above mentioned reasons, the suppression for the fire growth is necessary for allowing more time for people to escape. To protect resident from terrible injury or loss of life, it is important to raise the awareness of the fire safety in residential building in Hong Kong. Installation of sprinkler system inside the residential building is one of the approaches since water from sprinkler could dilute the toxic gases and cool down the hot smoke (Chow, et al., 2013). With the intention of controlling a residential fire in a more effective way before small room fills up with toxic smoke, the residential sprinkler is more sensitive to heat than the standard sprinklers (Madrzykowski, 2002). This paper will discuss the feasibility on installing sprinklers in residential areas with supporting data from the experiments.

2. Methodology

Wind tunnel was used to measure the RTI of sprinkler heads. Equations for the calculation of RTI are shown below. In equation 1, $\tau$ and $t_a$ could be expressed in terms of the time constant of the heat sensing element and the actuation time of sprinkler respectively. In addition, $\Delta T_A$ and $\Delta T_g$ could be expressed in terms of the activation temperature of the sensing element (temperature rating) above the initial temperature and the gas temperature above the initial temperature respectively. In equation 2, $v_g$ could be expressed in terms of the air velocity.

$$\tau = -\frac{t_a}{\ln(1-\frac{\Delta T_A}{\Delta T_g})} \quad (1)$$

$$RTI = \tau \cdot \sqrt{v_g} \quad (2)$$

Flow rate, pressure and Water Density Distribution of different sprinkler head model were obtained. The amount of heat taken away by sprinkler is stated as below. Where $m'$ and $L$ could
be expressed in terms of mass flow rate and latent heat respectively. (With the assumption that sensible heat is ignored)

\[ Q = m' \times L \] \tag{3}

Equations for heat release rate (HRR) of a pool fire are shown as below. Where \( m_r \) and \( \Delta H_c,_{\text{eff}} \) could be expressed in terms of mass loss rate in kg/s and the effective heat of combustion in MJ/kg respectively. The effective heat of combustion of 2-propanol is 30.11 MJ/kg.

\[ Q = m_r \Delta H_c,_{\text{eff}} \] \tag{4}

The results obtained by the strain gauge and the thermocouple tree would be compared with the results obtained by the measurement of water characteristic test. This comparison would show the relationship between the combustion performance and the water characteristic of residential sprinkler. Also, it would show how it controls the fire size and whether it is capable to extinguish the fire.

The provision of residential sprinkler system is suggested to be provided for whole premises including the open kitchen, illegal glass partition, super tall building as well as the store room. The fire hazards behind the above residential areas have been discussed (Chow and Pang, 2011; Chow et al., 2013; Chow, 2014; Woo et al. 2015). The comparison of the overseas codes and the application of the overseas codes into Hong Kong have been made. Understanding the limitations of the application and the installation of sprinkler in residential areas could facilitate the fire fighters to carried out their rescue works which have been discussed in other literatures (British Automatic Fire Sprinkler Association, 2008; Cote et al., 2008; National Fire Protection Association, 2013a, 2013b).

3. Experiments

As a result, 3 sets of experiments had been conducted (Chan 2015). For the wind tunnel test in Figure 1, it was the first set of experiments used to simulate the ceiling jet of smoke. The tunnel was constructed by 1.2 mm mild steel sheet with the dimensions 3 m long, 1.6 m high and 0.7 m wide. The tunnel air temperature was controlled to respond to any programmed change immediately with its relatively low thermal mass. When the air was blown by the centrifugal fan with a specific frequency, the inlet air was expected to pass through the heating section with finned air heater. The heated air entered the contraction section and passed the working section before reaching the outlet. Finally, the RTIs of 4 different types of sprinkler heads were obtained.

The second set was the measurement of the water density distribution (WDD). About 64 water buckets were used to collect the water projected from sprinkler head in array of 4m x 4m. By the measurement of the volume of each bucket, the WDD contour could be drawn for each type of sprinkler. The photos of distribution patterns were also be taken after the actuation of sprinkler heads under specified pressure flow and flow. With such information, the heat to be taken by the water spray could also be calculated.

The final set of experiment was the measurement of strain gauge and the temperature from thermocouple tree in Figure 3 & Figure 4. A pool fire was ignited on a weight balance which is connected with the strain gauge and the data logger to present the mass change of the 2-propanol in terms of voltage during the combustion. At the same time, the thermocouple tree with 4 measurement points at vertical position, i.e. 30cm, 60cm, 84cm and 120cm, on top of the pool fire was set. The sprinkler heads were actuated when the temperature reached their operating temperature. The data had been recorded for the first 7 mins and some photos were taken for analysis.
Woo, W  
Physical characteristics of residential sprinklers’ water spray

Figure 1 Setting up of Wind Tunnel Test

Figure 2 Measurement of Distribution Patterns

Figure 3 Measurement by Strain Gauge

Figure 4 Setting up of Thermocouple Tree

<table>
<thead>
<tr>
<th>Points</th>
<th>Distance from the detected point from the fire (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>84</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
</tr>
</tbody>
</table>
4. Results and Discussion

Fast response type sprinkler refers to the sprinkler with RTI less than 50 (meters-seconds)\(^{1/2}\). For the residential building in Hong Kong with extreme high-occupant density, it is necessary to adopt the fast response type sprinklers to provide better protection for high life risk premises. From the results of Wind Tunnel Test at Table 1, GL5601 and K-zstx 15 are fast response type sprinklers while GL5651 and Zstx-15 are standard type. Fast response type sprinklers are installed for the areas with greater fire hazard so that it is able to actuate the system faster in order to allow people the leave in the early fire stage.

Table 1: Summary of the results from Wind Tunnel Test

<table>
<thead>
<tr>
<th>Sprinkler head Model</th>
<th>Data</th>
<th>Gas temperature(°C)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>GL5651</td>
<td>Time Constant</td>
<td>41.25</td>
<td>41.85</td>
</tr>
<tr>
<td></td>
<td>Response Time Index</td>
<td>(RTI) (ms (^{1/2}))</td>
<td>58.34</td>
</tr>
<tr>
<td>GL5601</td>
<td>Time Constant</td>
<td>23.12</td>
<td>15.55</td>
</tr>
<tr>
<td></td>
<td>Response Time Index</td>
<td>(RTI) (ms (^{1/2}))</td>
<td>33.51</td>
</tr>
<tr>
<td>Zstx-15</td>
<td>Time Constant</td>
<td>4</td>
<td>43.05</td>
</tr>
<tr>
<td></td>
<td>Response Time Index</td>
<td>(RTI) (ms (^{1/2}))</td>
<td>60.82</td>
</tr>
<tr>
<td>K-zstx 15</td>
<td>Time Constant</td>
<td>24.57</td>
<td>15.55</td>
</tr>
<tr>
<td></td>
<td>Response Time Index</td>
<td>(RTI) (ms (^{1/2}))</td>
<td>34.75</td>
</tr>
</tbody>
</table>

Compared the heat release rate and the total amount of heat released in the fire tests (Table 3), it was noted that the heat release rate (HRR) was smaller at the tests with sprinkler installation. The actuation of system could reduce the speed of fire spread and allow more time for occupants to escape. In addition, it was found that the total amount of heat release for the sprinkler model GL5651 and GL5601 were smaller than that of the scenario without the sprinkler installation. This implied that they extinguished the fire before the fire consumed all the fuel (2-propanol). The spray pattern of the sprinkler models are accounted for the phenomenon. For the sprinkler model GL5651 and GL5601, the water was mainly discharged to the area just beneath the sprinkler heads.

The burning period for 300 ml pool fire of 2-propanol was 432s when there was no sprinkler installation. For the fire stage period from 1 minute to 5 minutes (Table 3), the air temperature was above 300 °C for the vertical distance was 15cm above the fire. It lasted for about 4 minutes. For sprinkler model GL5651 and GL5601, the water was mainly distributed to the centre according to the water characteristic results. From the pool fire test results, it revealed that the burning period could be reduced to the half of the test without sprinkler installation. From the thermocouple tree’s results, it was observed that the air temperature could be controlled below...
**100°C** at a vertical distance of 15cm above the fire. As the water distribution is likely at the centre (Table 2), it is suitable to be used at the location with concentrated fire load such as open kitchen.

**Table 2: Summary of the results from Water Characteristic Test**

<table>
<thead>
<tr>
<th>Sprinkler models</th>
<th>GL5651</th>
<th>GL5601</th>
<th>K-zstx15</th>
<th>Zstx15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (bar)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Flow rate (L/s)</td>
<td>0.444</td>
<td>0.442</td>
<td>0.440</td>
<td>0.440</td>
</tr>
<tr>
<td>Heat taken away (kJ/L)</td>
<td>1003</td>
<td>999</td>
<td>994</td>
<td>994</td>
</tr>
<tr>
<td>Distribution pattern</td>
<td><img src="image1" alt="Distribution pattern GL5651" /></td>
<td><img src="image2" alt="Distribution pattern GL5601" /></td>
<td><img src="image3" alt="Distribution pattern K-zstx15" /></td>
<td><img src="image4" alt="Distribution pattern Zstx15" /></td>
</tr>
<tr>
<td>Description on the distribution pattern</td>
<td>Water was mainly distributed in the water buckets around the middle one.</td>
<td>Water was mainly distributed in the water buckets around the middle one.</td>
<td>Water was mainly distributed in the water buckets to the side areas. Therefore, very small amount of the water was collected by the water buckets around the middle one.</td>
<td>Water was mainly distributed in the water buckets to the side areas. Therefore, very small amount of the water was collected by the water buckets around the middle one.</td>
</tr>
</tbody>
</table>

(Remark: The specific latent heat of vaporization of water is 2260kJ/kg)

For sprinkler model K-zstx15 and Zstx-15, the water was mainly distributed to the side areas due to its deflector from the water characteristic results. From the pool fire test results (Table 4), it was found that the burning period was slightly longer than the case without the sprinkler installation. As water discharged to the sides which could lower the overall fire temperature in the surrounding and the cooling effect by the water projected directly on the pool fire, the heat release rate was decreased accordingly. From the thermocouple tree's result, it was observed that the air temperature in different periods of times was lower than the case without the sprinkler installation. In addition, the air temperature above 300 °C at the vertical distance of 15cm above the fire shortened to about **2 minutes**. All the above could increase the rescue time for the fire fighters and increase the evacuation time for the occupants by controlling the fire. Since the water distribution was not concentrated at the centre, it is suitable to be used at the location with fire load which is evenly distributed such as store room.
Table 3: Summary of the results from Pool Fire Test (Strain gauge) with 300ml of 2-propanol used

<table>
<thead>
<tr>
<th>Time(s)</th>
<th>Without the sprinkler installation</th>
<th>Sprinkler models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GL5651</td>
<td>GL5601</td>
</tr>
<tr>
<td>5s (Just before the sprinkler actuated)</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>30s</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>1min</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>3min</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
<tr>
<td>5min</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
<tr>
<td>7min</td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Burning Period</th>
<th>Mass loss rate (kg/s)</th>
<th>Heat Release Rate (kW)</th>
<th>Total amount of heat released (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7mins12s</td>
<td>0.00052</td>
<td>15.61</td>
<td>6743</td>
</tr>
<tr>
<td>3min07s</td>
<td>0.00061</td>
<td>15.45</td>
<td>2890</td>
</tr>
<tr>
<td>4min41s</td>
<td>0.00050</td>
<td>15.20</td>
<td>4271</td>
</tr>
<tr>
<td>8mins 19s</td>
<td>0.00045</td>
<td>13.53</td>
<td>6740</td>
</tr>
<tr>
<td>8mins</td>
<td>0.00047</td>
<td>14.04</td>
<td>6738</td>
</tr>
</tbody>
</table>
### Table 4: Summary of the results from Pool Fire Test (Thermocouple tree)

<table>
<thead>
<tr>
<th>Fire stage at different period of time</th>
<th>Sprinkler head models</th>
<th>0s</th>
<th>30s</th>
<th>1 min</th>
<th>3 min</th>
<th>5 min</th>
<th>7 min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without the sprinkler installation</td>
<td>GL5651</td>
<td>GL5601</td>
<td>Zstx-15</td>
<td>K-zstx 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Point 1</td>
<td></td>
<td>18.4</td>
<td>18.4</td>
<td>18.4</td>
<td>18.4</td>
<td>18.4</td>
<td>18.4</td>
</tr>
<tr>
<td>Point 2</td>
<td></td>
<td>19.1</td>
<td>19.1</td>
<td>19.1</td>
<td>19.1</td>
<td>19.1</td>
<td>19.1</td>
</tr>
<tr>
<td>Point 4</td>
<td></td>
<td>19.4</td>
<td>19.4</td>
<td>19.4</td>
<td>19.4</td>
<td>19.4</td>
<td>19.4</td>
</tr>
<tr>
<td>Point 1</td>
<td></td>
<td>260.4</td>
<td>49.8</td>
<td>66.4</td>
<td>254.5</td>
<td>262.1</td>
<td>262.1</td>
</tr>
<tr>
<td>Point 2</td>
<td></td>
<td>115.2</td>
<td>42.3</td>
<td>54.1</td>
<td>106.4</td>
<td>105.6</td>
<td>105.6</td>
</tr>
<tr>
<td>Point 3</td>
<td></td>
<td>48.1</td>
<td>31.6</td>
<td>30.2</td>
<td>62.6</td>
<td>61.9</td>
<td>61.9</td>
</tr>
<tr>
<td>Point 4</td>
<td></td>
<td>56.7</td>
<td>32.4</td>
<td>39.6</td>
<td>48.9</td>
<td>48.1</td>
<td>48.1</td>
</tr>
<tr>
<td>Point 1</td>
<td></td>
<td>335.8</td>
<td>64.1</td>
<td>57.8</td>
<td>488.8</td>
<td>448.8</td>
<td>448.8</td>
</tr>
<tr>
<td>Point 2</td>
<td></td>
<td>115.1</td>
<td>41.7</td>
<td>52.5</td>
<td>125.1</td>
<td>138.2</td>
<td>138.2</td>
</tr>
<tr>
<td>Point 3</td>
<td></td>
<td>65.8</td>
<td>29.9</td>
<td>42.7</td>
<td>73.9</td>
<td>75.8</td>
<td>75.8</td>
</tr>
<tr>
<td>Point 4</td>
<td></td>
<td>58.3</td>
<td>27.4</td>
<td>44.8</td>
<td>46.3</td>
<td>47.5</td>
<td>47.5</td>
</tr>
<tr>
<td>Point 1</td>
<td></td>
<td>585.5</td>
<td>37.2</td>
<td>47.9</td>
<td>322.2</td>
<td>436.5</td>
<td>436.5</td>
</tr>
<tr>
<td>Point 2</td>
<td></td>
<td>148.7</td>
<td>25.6</td>
<td>35.7</td>
<td>179.9</td>
<td>180.4</td>
<td>180.4</td>
</tr>
<tr>
<td>Point 3</td>
<td></td>
<td>81.9</td>
<td>23.3</td>
<td>30.7</td>
<td>107.3</td>
<td>106.6</td>
<td>106.6</td>
</tr>
<tr>
<td>Point 4</td>
<td></td>
<td>65.1</td>
<td>22.5</td>
<td>32.2</td>
<td>63.8</td>
<td>62.7</td>
<td>62.7</td>
</tr>
<tr>
<td>Point 1</td>
<td></td>
<td>495.5</td>
<td></td>
<td>Fire is extinguished</td>
<td>Fire is extinguished</td>
<td>195.9</td>
<td>270.1</td>
</tr>
<tr>
<td>Point 2</td>
<td></td>
<td>134.8</td>
<td></td>
<td>Fire is extinguished</td>
<td>Fire is extinguished</td>
<td>163.3</td>
<td>98.3</td>
</tr>
<tr>
<td>Point 3</td>
<td></td>
<td>76.5</td>
<td>88.7</td>
<td>51.8</td>
<td>66.4</td>
<td>43.4</td>
<td></td>
</tr>
<tr>
<td>Point 4</td>
<td></td>
<td>66.3</td>
<td>90.9</td>
<td>55.9</td>
<td>50.8</td>
<td>55.1</td>
<td>37.5</td>
</tr>
</tbody>
</table>

Remark: The temperature is in °C. The highlighted figures in red refer to air temperatures above 300°C.
5. Conclusions

Residential areas in Hong Kong that require the installation of sprinkler was identified. It demonstrated that the installation of residential sprinklers could effectively control the fire size and lower the overall fire temperature as well as the heat release rate. Different sprinkler heads have different deflectors leading to different WDDs. Therefore, the application of the sprinkler in the residential areas should be in accordance with the scenario. From the results of the study, the sprinkler head model GL 5601 is one of the suitable sprinklers to be applied in Hong Kong since it is a fast response type sprinkler and it is able to extinguish the domestic fire promptly.

It is believed that installation of residential sprinkler can protect lives and reduce property losses. In case of fire, the occupants could be alerted by the fire alarm system and escape from the premises in early stage. In the meanwhile, the fast response type sprinkler could be actuated and put out / control the fire accordingly. For the new high-rise residential building, the system should be considered to be installed as a standard requirement. The residential sprinkler will certainly reduce the probability of having fatalities and injuries in domestic fires. From economic point of view, the protection by the system could mitigate the damages or losses in case of fire, particularly in premises with high property value / high rental value like Hong Kong. Other benefits, like reducing the water usage and environmental issues, should also be addressed.

6. References

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Methamphetamine Contamination in Homes – Contamination and Risk Levels

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Abstract

Methamphetamine contamination has the potential to be present in residential and commercial buildings as a result of illicit manufacture and drug use, in particular smoking. The illicit manufacture of methamphetamine and the smoking of methamphetamine results in the generation and deposition of drug aerosols/residues on all surfaces, porous and non-porous. These drug residues can remain in the home for a long period of time and if they are not properly identified and cleaned this can result in unwitting exposures and adverse health effects by individuals and families who subsequently rent or purchase these properties. Research has been undertaken to better understand what levels of methamphetamine contamination remains in homes following manufacture or smoking, and what factors related to the manufacture and building design affect the spread of contamination throughout the property.

Data on contamination levels, and property observations, has been obtained from 100 homes and apartments throughout Australia to assist in better understanding the level of methamphetamine contamination that may be present. This data has been reviewed to develop a risk matrix that can be used at the start of an investigation or property assessment to determine the level of risk a property may pose to the public. The level of risk then determines the level of further investigation and remediation work that may be required to ensure the property is safe for future occupants. The risk matrix can be used by property managers including managers of public housing authorities where a significant number of illicit drug laboratories are located.

Originality – This study provides data on the level and spread of methamphetamine contamination in former clandestine drug laboratories in Australia.

Keywords methamphetamine contamination, illicit drug manufacture, risk, health effects
1. Introduction

Illicit drugs, in particular amphetamine-type stimulants (ATS) such as methamphetamine (ACC 2011a) are manufactured in Australia within clandestine laboratories that range from crude, make-shift operations using simple processes to sophisticated operations. Clandestine laboratories are commonly located within residential homes, units, hotel rooms, backyard sheds and cars, with increasing numbers detected in Australia each year (744 laboratories detected in 2013-2014) (ACC 2015). Unlike the legal manufacture of industrial and pharmaceutical chemicals, clandestine drug operations may not involve any care in the storage, handling and disposal of chemicals and wastes nor any responsibilities in relation to health and safety during and after the cook.

The operation of clandestine methamphetamine laboratories results in the presence of a wide range of hazards and risks within the premises including the contamination of all indoor surfaces and materials with methamphetamine residues (Wright, Edwards & Walker 2016). This has the potential to expose the public to contamination that live in these premises before remediation or if no remediation is conducted. These are individuals who have not chosen to be exposed to methamphetamine, and such exposures have been associated with significant intakes of methamphetamine and adverse health effects (Wright et al. 2015). As a result it is important that the level of risk posed by these properties is understood so that appropriate measures can be implemented to manage exposures and remediate the property.

Recent guidelines are available for the assessment and remediation of former clandestine drug laboratories (Australian Guidelines on the Remediation of Clandestine Drug Laboratories)(ACC 2011b), More specifically, in relation to the assessment of these premises, these guidelines have resulted in the testing and evaluation of methamphetamine contamination levels at a number of properties across Australia. These data have been collated and reviewed with the aim of understanding the level of contamination that remains in these properties in Australia, how widespread the contamination may be, and if there are any key observations or indicators that can be used to assist in determining a preliminary view on the level of public health risk that may be posed by the property.

2. Methods

Permission was obtained from companies involved in the assessment and remediation of clandestine drug laboratories to obtain and collate data collected for the purpose of characterising contamination within former drug laboratories.

Data that characterise the level and spread of methamphetamine contamination in a premises formerly used for manufacture of methamphetamine have been obtained from the following sources:

- Data collected by companies involved in the assessment (and sometimes remediation) and validation of former clandestine drug laboratories. The data collected reflected the use of both quantitative and semi-quantitative methods.
- Data collected by the researcher using semi-quantitative methods from a limited number of former clandestine drug laboratories identified in South Australia Housing (Housing HA) properties. Flinders University has an established Memorandum of Understanding (MoU) in relation to the testing of former clandestine drug laboratories in Housing SA premises. Where former clandestine drug laboratories were identified during the research period these premises were sampled using a semi-quantitative method.

Quantitative methods involved laboratory analysis to provide precise levels of methamphetamine residues on the surface sampled. All quantitative results were obtained from commercial laboratories using GC-MS methods, with analytical limits of reporting typically in the range of 0.02 to 0.5 µg/100 cm².
Semi-quantitative sampling involved the use of an immunoassay sampling method. The method adopted was developed by the U.S. National Institute for Occupational Safety and Health (NIOSH) to identify the presence of methamphetamine residues on surfaces at or above a particular level. The sampling test kits, MethChek, are available from SKC Incorporated (SKC) and can be used to detect the presence of methamphetamine at 0.05, 0.1, 0.5 or 1.5 µg/100 cm². The accuracy of the MethChek tests was reported to be ≥ 97% within ± 20% of the method cut-off, with no false positives were reported. In relation to cross-reactivity, MDMA is 100% cross-reactive with MethChek. Other drugs of abuse and methamphetamine precursors are reported to be less than 10% reactive. No known negative interferences have been reported (SKC 2015).

Where collected, other data relevant to contamination that may remain in former drug laboratories such as total volatile organic compounds (VOCs, typically reported using a photoionization detector), pH, presence of inorganics (such as lead, mercury, iodine and phosphorous measured using an X-ray fluorescence instrument) and the use of iodine swabs was also collected. While this data is useful in understanding the nature of contamination in these premises, less than one third of the properties evaluated included at least one of these other tests.

Only data obtained from premises known, or suspected, to have been involved in the manufacture of methamphetamine have been included in this study. The data obtained has been de-identified so that the address and property owner cannot be linked with, or inferred from the data.

Where available, additional information about the premises and specific observations relevant to the manufacture of methamphetamine and characteristics of the property that may enhance or restrict the spread of contamination was obtained. This information related to the following:

- the likely method of manufacture;
- likely location of manufacture;
- type of building (including whether it was privately owned or public housing);
- characteristics of the property that may either assist or prevent the spread of contamination in the premises;
- type of sampling undertaken, sampling and analytical methods;
- location of samples;
- any other chemicals detected;
- results of any preliminary testing; and
- results of any testing undertaken outside in soil and/or septic systems.

It is noted that the methods used by different companies for the assessment of contamination at different premises varies. Some of the data has come from semi-quantitative immune-assay tests, while other data was quantitative (based on laboratory analysis using standard methods). In addition not all investigators report details about the property (with none of the reports providing details on whether the property is open-plan or has isolated rooms) or other observations that may be relevant to this study. The information provided was not consistent between the different companies who provided access to the data, or within the companies themselves as techniques were observed to change/refine over time. Specifically assessment techniques and data collected was different before and after the release of the Australian guidelines on assessing and remediating clandestine drug laboratories in 2011 (ACC 2011b). Hence the information and data considered in this study, derived from these companies, is limited by the methods adopted and the information provided by each company for each individual property.

3. Results

3.1 Properties included in the study

Data have been obtained from 100 individual premises in Australia. The data obtained are derived from 5 states in Australia: New South Wales (25 premises); Victoria (18 premises); Queensland (3
premises), South Australia (20 premises) and Western Australia (34 premises). No sites were obtained from Tasmania, The Northern Territory or the Australian Capital Territory.

The majority (88%) of the properties were located in urban areas, with these equally split between privately owned properties and public housing. Rural and semi-rural properties accounted for 10% of the properties evaluated, with the remaining 2% comprising mobile caravans. No commercial premises were included in this study.

Of the properties included in this study the majority were low-density residential homes (58%, which were mostly single storey homes), units (36%) and townhouses (6%).

3.2 Manufacture methods and location

The information available in relation to each of the properties included in this study did not always provide specific information (such as that from a police report) in relation to the manufacturing method likely to have been used to manufacture methamphetamine. In some cases information was available on the range of chemicals and equipment seized by police, observations from inspections (such as iodine staining) and preliminary screening data (such as the detection of iodine and phosphorus on surfaces) from which the manufacturing method could be inferred. For data collected from South Australia, these were assumed to all be derived from the hypophosphorous method (which is the most common method in South Australia (ACC 2015)). For data collected from Western Australia, information was cross checked with details held by the Western Australian Department of Health as to whether the method was the Nazi/Birch method or a non-Birch method. Overall the most common method of manufacture was the hypophosphorous method (55%) followed by the Nazi/Birch method (35%). Other methods included the red-phosphorous method (5%) and other methods (likely P2P) (5%).

Table 1 presents a summary of the distribution of manufacturing methods between states relevant to the properties included in this study. The manufacturing methods relevant to these premises are consistent with those reported in the national statistics (ACC 2014, 2015), with the use of the Nazi/Birch method predominantly reported in Western Australia and the hypophosphorous and red-phosphorous methods predominantly reported in the eastern states. The other methods (likely to be the P2P method) were all reported from NSW.

In relation to the location of manufacture at the property, the available data are limited to information provided on police reports. Sometimes this information identified the location (or locations) of manufacture however in a number of cases the specific location is not known but the location of where chemicals and equipment are found are noted. In these situations a number of locations may be possible and are reported. For a number of other properties limited information is available on the likely location of manufacture, however observations provided during the preliminary assessment provide additional information on the likely location of manufacture. Figure 1 presents a summary of the available information on the location of manufacture (some sites had more than one location so total is greater than 100%). Where reported, the most common locations for manufacture are the kitchen and shed/garage.
Table 1: Contamination Data: Manufacturing Methods by State

<table>
<thead>
<tr>
<th>State</th>
<th>Proportion of Laboratories Known or Suspected to use Manufacture Method in this Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nazi/Birch</td>
</tr>
<tr>
<td>Western Australia</td>
<td>94%</td>
</tr>
<tr>
<td>South Australia</td>
<td>100%</td>
</tr>
<tr>
<td>Victoria</td>
<td>11%</td>
</tr>
<tr>
<td>New South Wales</td>
<td>60%</td>
</tr>
<tr>
<td>Queensland*</td>
<td>33%</td>
</tr>
</tbody>
</table>

* Note that a limited number of premises were included from Queensland (3 in total) affecting the reliability of this distribution

3.3 Methamphetamine residue levels on surfaces

Surface residue samples obtained in this study were collected from a wide range of locations, depending on the location of manufacture and chemical storages, presence of staining, layout of the premises and results of preliminary testing (where undertaken). The number of samples collected in each premises varied significantly.

Methamphetamine surface residues were reported in 99 of the 100 premises included in this study. The one premises where indoor surface residues were not collected only involved the sampling of contamination outdoors. Of these premises, 36 have been characterised on the basis of semi-quantitative methods, with the remaining 63 properties characterised using laboratory analysis using GC-MS methods. For these premises a code was allocated that relates to the state in Australia where the property is located, whether the property is a house (H) or unit (U) and a unique number.

Figure 2 presents a summary of the range of concentrations reported at each of the premises where methamphetamine surface residues have been reported indoors or surfaces, grouped by the reported method of manufacture. The figure has combined both quantitative data as well as semi-quantitative data. The semi-quantitative data includes data that indicates surface residue levels are either less than a test reporting limit, greater than a test reporting limit or within a range of test reporting limits. For different areas within the premises evaluated, Table 2 presents a summary of the range of concentrations reported.
4. Discussion

4.1 General

As the data collected in this study were obtained from a range of different sources they are highly dependent on the sampling locations, sampling protocols, analysis methods and subjective and variable observations adopted and reported by each company, and individuals within these companies. This has resulted in a data set that is of mixed quality. However the data are suitable for the purpose of evaluating whether properties formerly used for the manufacture of methamphetamine remain contaminated with methamphetamine, whether the level of contamination could be characterised as low, medium or high and whether the data indicate the contamination has spread throughout the home.

4.2 Level and extent of methamphetamine residues

The range of methamphetamine surface residues reported in homes evaluated in Australia are generally consistent with the range reported in former drug laboratories and homes used for controlled cooks in the US (Wright, Edwards & Walker 2016). Some higher residue levels of contamination have been reported in former clandestine drug laboratories in the US, however these higher levels were reported from stained areas on ceilings and inside microwave ovens (used for cooking), neither of which were evaluated in any of the Australian premises included in this study.

When reviewing the range of concentrations reported inside premises in Australia, it should be noted that the criteria methamphetamine residues on surfaces in residential homes is 0.5 µg/100 cm² (ACC 2011b). This is health-based criteria, below which contamination levels on surfaces in residential homes were considered (in the ACC 2011b guidelines) to be acceptable and suitable for habitation. Housing SA assessments utilise semi-quantitative MethChek kits with a detection limit of 0.05 µg/100 cm² and adopt and action level, for remediation, of 0.1 µg/100 cm².

The highest levels reported from all the premises tested was within the air conditioning ducting and kitchen range hoods. Contamination in air conditioning ducts and ventilation systems have the potential to result in the ongoing movement or re-distribution of contamination throughout a home. Such mechanisms are of importance for understanding the spread of contamination and providing information that may be relevant to the assessment of inhalation exposures that may occur in premises where contamination is not remediated.
Figure 2: Range of methamphetamine surface residues reported indoors at each premises
Table 2: Summary of Methamphetamine Surface Residues on Hard Surfaces in Homes

<table>
<thead>
<tr>
<th>Location/Activity</th>
<th>Range of Maximum Methamphetamine Surface Residue Reported (µg/100 cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls and surfaces within:</td>
<td></td>
</tr>
<tr>
<td>kitchen including benches</td>
<td>0.05 to 791</td>
</tr>
<tr>
<td>dining/family room</td>
<td>0.03 to 460</td>
</tr>
<tr>
<td>lounge room</td>
<td>0.02 to 179</td>
</tr>
<tr>
<td>bedrooms</td>
<td>0.02 to 260</td>
</tr>
<tr>
<td>bathrooms</td>
<td>0.03 to 320</td>
</tr>
<tr>
<td>entrance hall/foyer</td>
<td>0.03 to 27.7</td>
</tr>
<tr>
<td>study/sun-room</td>
<td>0.05 to 100</td>
</tr>
<tr>
<td>laundry</td>
<td>0.03 to 65</td>
</tr>
<tr>
<td>upstairs (ground floor used for manufacture)</td>
<td>0.09 to 71</td>
</tr>
<tr>
<td>shed/garage</td>
<td>0.04 to 1400</td>
</tr>
<tr>
<td>Ventilation and fans (including kitchen range hood)</td>
<td>0.13 to 5171</td>
</tr>
<tr>
<td>Kitchen Appliances (microwaves, burners, ovens, refrigerators)</td>
<td>0.25 to 180</td>
</tr>
<tr>
<td>Roof space</td>
<td>0.2 to 12.8</td>
</tr>
<tr>
<td>Neighbouring unit or house (not used for manufacture)</td>
<td>0.14 to 3.1 (&lt;1% maximum in unit used for manufacture)</td>
</tr>
</tbody>
</table>

It is noted that data summarised in Figure 2 and Table 2 includes a number of properties and areas where the range of methamphetamine surface residues varies significantly, in some cases by five orders of magnitude or a factor of 10,000. This reflects the highly individual nature and spread of contamination that is present in each of the properties. The potential for significant variability in surface residue levels in a property should be considered when conducting a preliminary evaluation of potential contamination and in the design of more detailed sampling plans.

Further review of the data collected indicates that where the location of manufacture was known, samples from these areas showed the highest level of methamphetamine contamination. However it is noted that in some cases the information on the potential location of manufacture was not available or potentially not well understood. Hence knowledge or guidance in relation to the likely location of manufacture is valuable in directing testing for contamination in a property.

In relation to the potential spread of contamination within a premises the available data is limited by the information available on the location of manufacture and the number and location of samples collected in each premises, which varied depending on the size of the property and the professional collecting the samples. As there is no consistent sampling protocol followed by each of the investigators who collected the samples, the data set is of mixed quality. In addition the reporting of the manufacture location is dependent on information provided by police when the premises was seized. Most of the laboratories seized are not active laboratories and hence the information provided typically relates to the location of chemicals and equipment, with some information also provided on potential manufacture location based on powder residues and stains/burns. Review of the quantitative data indicates that the potential location of manufacture reported does not always correlate with the location where maximum surface residues are reported.

Based on the data obtained 83% of the properties evaluated reported some level of spread of contamination throughout a home and 58% of the properties evaluated reported wide-spread movement of contamination in the home.

Based on information and data collected and presented in this research, and literature, the following factors have been identified that affect the level and spread of contamination in a home, which then affects the level of risk posed by a property and the approach adopted to remediate the property:
• The method of manufacture is important as contamination from laboratories using the Nazi/Birch reduction method are typically lower than for other methods (confirmed from the assessment and residue data from former drug laboratories).
• The scale of the manufacture is important as the manufacture of large quantities of drug, regardless of the method has the potential to result in higher levels of contamination (WA Health 2012).
• Closing up the home to prevent detection contains contamination in the building. While it has been reported that an open plan home is more likely to be associated with the spread of contamination, compared with homes with isolated rooms (Hammon & Griffin 2007; Light 2009; Patrick, Daniell & Treser 2009), this could not be confirmed in this study as the layout of homes where data was available was not provided.
• The most common places for cooking methamphetamine was in a shed/garage or inside the home, in the kitchen, bathroom or bedroom.
• Use of ventilation systems inside the home which are a common method for removing gases during the cook, resulted in the spread of contamination in a home. The observations reported in this study are consistent with published data (McKenzie 2014).
• Fire and explosion results in elevated levels of contamination. This observation is consistent with data from premises evaluated in the US (Martyny et al. 2007).
• Observation of burns, stains and powder residues are associated with widespread contamination in the property. This is likely to reflect that little care was taken during the cook, which may have resulted in the spread of contamination.

Where preliminary data is collected in a property, the following were identified as those that provided good indicators on the presence of methamphetamine contamination in a premises:

• Preliminary/screening testing for methamphetamine residues using an immune-assay test (targeted at the likely location of manufacture) have provided a confirmation of the presence and, in some cases, the spread of contamination. This has been identified as a key preliminary assessment technique in another study (Light 2009).
• Elevated levels of total VOCs as reported using a PID were associated with elevated levels of contamination in the property. This is identified as a key preliminary assessment technique in another study (Light 2009).
• pH levels are indicative of the presence or use of acids and alkalis. While not found to be a unique indicator of the presence of contamination evidence of acids and alkali spills suggests little care was taken during the cook, which may have resulted in the spread of contamination.

4.3 Risk Matrix

The characteristics and parameters identified in this study, and other published studies as summarised above, can be used in the development of a preliminary risk assessment tool to enable moderate to high level risk premises to be identified separately from low level risk premises. The level of assessment and remediation required to address these categories of premises is expected to be different.

A risk scoring system/risk matrix enables a score to be calculated that is based on information that may be obtained from the Police report and/or a preliminary site inspection. The matrix can be used by housing officers from state housing authorities or individuals undertaken a preliminary site inspection (that may include Environmental Health Officers [EHOs] or consultants engaged by EHOs). Any preliminary investigation should be undertaken with appropriate PPE.

The risk matrix aims to categorise premises based on the potential for a low, medium or high risk of methamphetamine contamination within the property. The level of risk is based on the potential for the presence of methamphetamine residues to exceed the health-based criteria of 0.5 µg/100
cm² for residential homes (ACC 2011b), and the potential for the contamination to be spread throughout the premises. The risk matrix considers and scores the following aspects:

- Information from the Police report, where available, that includes the drug manufactured, the manufacture method determined directly from the police report or the chemicals reported to be found and removed from the premises and the size of the lab. Where details on these aspects are not available the default position should be to allocate a higher level score, consistent with elevating the level of risk relevant to the property.
- Information that can be obtained from property observations including evidence of staining, burns, scorch marks and powder residues, the presence of air conditioning, presence of room ventilation and the overall cleanliness (or not) of the property.
- Information that can be obtained from preliminary tests including the semi-quantitative surface test, pH test from locations where manufacture is suspected or there are stains present and a screen of VOCs in air using a PID.

5. Conclusions

Data collected from the assessment of former clandestine drug laboratories, for the purpose of remediation, provides a valuable insight into the levels and spread of methamphetamine contamination that remains inside premises in Australia. The available data indicates that premises used for the manufacture of methamphetamine have variable levels of contamination. However there are a significant number of premises where the methamphetamine contamination is present at levels that exceed the current guidelines for residential use. Review of the data and other information collected in this assessment has identified key information and observations that can be used to distinguish between low and high risk properties in relation to the level and spread of contamination. Data obtained from a police report, property observations and preliminary tests can be used to rank potential risks a property poses to public health. This may be undertaken using a risk matrix approach. This is important as the level of assessment and remediation required to ensure these properties are safe for future occupants will differ depending on the level of risk posed.

6. References

SKC 2015, Performance of the MethChek Immunoassay Wipe Kits, SKC Incorporated,


The Relationship between Indoor and Outdoor PM2.5 Concentrations in the Severe Cold Region of China: Based on a Long-term Field Experiment

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Abstract

The objective of this study is to analyze the characteristic of indoor particles and the connection between indoor particles and outdoor particles. A long-term sampling and measurements of fine particulate matter (PM2.5) has been carried out around an resident area in Harbin (a typical urban in Chinese severe cold regions), which including indoor PM2.5 concentrations in two different types of residences, outdoor PM2.5 concentrations in the residential area, and PM2.5 concentrations near the regional heat source which supply heat for the residential area. This study analyses the affection of people's behavior on the indoor PM2.5 characteristic, the characteristic of PM2.5 in different seasons especially the uncommon characteristic during the heating season, and the influence of weather conditions (temperature, relative humidity, wind speed and solar radiation) on the characteristic of PM2.5. Besides, it shows the influence of outdoor atmospheric PM2.5 on the indoor environment is very strong based on the analysis of I/O ratios, outdoor PM2.5 is the main source of indoor PM2.5. If the outdoor haze intensifies, indoor PM2.5 concentrations will increase significantly.

Keywords- PM2.5; concentration; indoor; outdoor; I/O ratios
1. Introduction

In recent years, fine particulate matter pollution has been one of the most serious environmental pollution issues in China. Several studies have found that PM2.5 showed strong relationships with respiratory, cardiovascular and reproductive (Ebelt ST, Wilson WE and Brauer M, 2005). Now, the air quality is getting worse, besides people spend most of their time indoors, so it is becoming more important epidemiologic and exposure studies should pay more attention to the influence of outdoor particles on indoor particles (Schweizer, C et al., 2007).

There are many studies showing that there is strong relationship between indoor particle and ambient particle (Chun Chen & Bin Zhao, 2011; Avril Challoner & Laurence Gill, 2014), and especially in the high-rise buildings which were built more and more (Jo W K & Lee J Y, 2006).

I/O ratios are the most commonly used parameter to describe the connection between indoor and outdoor pollutants, and it can respond to the relationship between indoor and outdoor pollutants concentrations directly. I/O ratios are defined as following:

$$ I / O = \frac{C_{in}}{C_{out}} $$

As for particulate pollution, $C_{in}$ is the indoor particle mass concentration and $C_{out}$ is the outdoor particle mass concentration.

There have been lots of studies that using I/O ratios to estimate the relationship between indoor and outdoor particles, Chen and Zhao measured concentrations of PM2.5, PM10, particles of 0.001-0.5um and particles of 0.5-15um in Nepal (Chun Chen & Bin Zhao), and results showed that the largest value of I/O ratios happened in a common residence, and the smallest value happened in a unmanned telephone equipment room. Besides, there were some studies showing that I/O ratios of PM2.5 are lower than those of PM10 (Rojas-Bracho, L, Suh, HH and Koutrakis, P, 2000; Liu DL & Nazaroff WW, 2003).

The main source of indoor PM2.5 consists of two categories mostly: indoor PM2.5 concentration of outdoor origin by infiltration and ventilation, and the indoor generated PM2.5 by indoor source such as cooking, cleaning and smoking. So different ambient environment and different building design can influence indoor PM2.5 concentration, and different human behavior can influence the indoor PM2.5 concentration at the same time. This study aims to understand the impact of ambient PM2.5 characterization on indoor PM2.5 characterization by comparing sampling results of indoor and outdoor PM2.5 and the impact of human behavior on indoor PM2.5 characterization by comparing sampling results of two different indoor environments.

Harbin is a typical urban in Chinese severe cold regions, and its heating period lasts 6 months (from October 15th to April 15th next year), so heating is one of the most important source of PM2.5 in Harbin, and in this study, analysis about the specific characterization of PM2.5 at the heat source have been made.

2. Methods

2.1 Instrument

Instruments of measuring PM2.5 concentration is Qingdao Laoying 2030 type median traffic intelligent TSP sampler of which sampling flow is 60~130L/min and was set at 100L/min in this study, and it can work in Harbin winter outside because the application temperature of which is -30~99°C. Sampling filters are 90mm Whatman quartz microfiber filters. The sampling was made in 5 months (3 days a month), which lasts for 8 hours one day (from 9:00am to 5:00pm).
2.2 Sampling site

During the sampling, 4 sampling sites were sited at a residential area around a regional heat source (as shown in Figure 1). The outdoor sampling sites located on the roof of a two-story building, and south of this sampling site is a major roadway. There are 2 different indoor sampling sites (Indoor-1 and Indoor-2) located in 2 resident families, the style of Indoor-1 is more modern, the material of the windows is plastic with better sealing performance, and there are 4 people living in this residence, cooking everyday normally, and cleaning sometimes. The style of Indoor-2 is comparatively old, windows of which are double wooden windows, and there is only one old man living in this residence, and the way of life is relatively sample with no cooking. Besides, neither Indoor-1 nor Indoor-2 exists smoking source or mechanical ventilation. The temperature of Indoor-2 is a little higher than Indoor-1 in winter, because the first family pay more attention to artificial ventilation in winter. The heat source sampling site is located in an open space near the regional heat source, and the sampling at the heat source only carried out during heating periods.

![Sampling site location in a residential area in Harbin](image1)

2.3 Sampling protocol

Sampling of PM2.5 conducted simultaneously indoors and outdoors. Sampling location was 1.5m above the floor of each sampling site which is the height of a person’s breathing zone approximately (as shown in Figure 2) (Li Zhao et.al, 2015).

![Sampling equipment setup at sampling site](image2)
3. Results and Discussion

3.1 The PM 2.5 mass concentration of different sampling sites

The concentration of particles usually can be expressed in two ways, the mass concentration and the number concentration, and the mass concentration was used more commonly. We counted the daily average PM2.5 mass concentration of 4 different sampling sites in 5 months (as shown in Figure 3).

![Figure 3 PM2.5 mass concentration with sampling days of different sampling sites](image)

Figure 3 PM2.5 mass concentration with sampling days of different sampling sites

The PM2.5 mass concentration of 4 different sampling sites changes with time in the same trend, and in the medium-term of heating seasons, values are higher than other periods. Besides, PM2.5 concentrations of heating source are higher than outdoor, especially in the medium-term of heating seasons.

The maximum of PM2.5 mass concentration at 4 different sampling sites are 150.02ug/m³ (Indoor-1), 120.84ug/m³ (Indoor-2), 189.63ug/m³ (outdoor), 218.80ug/m³ (heating source), respectively, all happened in December. According to the Ambient Air Quality Standard (GB3095-2012), China’s PM2.5 limit value is 75ug/m³, and during the measurement, the number of days higher than 75ug/m³ were 3 days in 15 days (Indoor-1), 2 days in 15 days (Indoor-2), 6 days in 15 days (outdoor), 9 days in 12 days (heating source). The proportion of days that are higher than the Chinese limit values is obviously greater outdoors, especially at the site of heating source, showed in the Figure 3.

3.2 I/O ratios

With the same outdoor PM2.5 mass concentration, I/O ratios of Indoor-1 and Indoor-2 vary with different indoor environments (as shown in Figure 4). As for the same indoor sampling site, I/O ratios vary in a large range (Indoor-1: 0.46-1.12, Indoor-2: 0.37-1.18) due to different sampling periods. Larger I/O ratios happened in early and late of heating seasons, while smaller values happened in the medium-term of heating seasons. Most of I/O ratios are less than 1 no matter at Indoor-1 or Indoor-2, and especially at the date of the ambient PM2.5 mass concentration is very high, I/O ratios became very low conversely. I/O ratios of Indoor-1 and Indoor-2 are different because of the different indoor environments, different ventilation conditions and different human behaviors, but variation trends are the same.

I/O ratios not only can describe the relationship between indoor and outdoor particle concentration simply, but also can determine whether outdoor particles are the main source to indoor particles preliminarily (Zhang Zhenjiang et al., 2013; Li Y G & Chen Z D, 2003). A greater range of variation
indicates that the different measuring day can influence the I/O ratio obviously, and there are big differences between indoor and outdoor concentrations of different residences.

<table>
<thead>
<tr>
<th>Date</th>
<th>Indoor-1</th>
<th>Indoor-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/26</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>9/27</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>9/28</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>11/21</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>11/22</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>11/23</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>12/20</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>12/21</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>12/22</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>1/28</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>1/29</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>1/30</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>3/22</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>3/23</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>3/24</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Figure 4 I/O ratios with sampling days of indoor-1 and indoor-2

3.3 The relationship between meteorological conditions and I/O ratio

In previous studies, many researchers have proved that different meteorological condition can influence the particle concentration and the correlation between indoor and outdoor particle concentration by varying degrees (Qing Yu Meng et al., 2009; Dilinuer ·TALIP et al., 2011; Yang Han et al., 2015). Meng et al. conducted the nonparametric regression to analyze the relationship between the infiltration factor and the outdoor temperature quantitatively, and liner regression to analyze the relationship between infiltration factor and indoor-outdoor temperature differences. The result demonstrated that there is a certain degree of correlation between the infiltration factor and the temperature. Dilinuer ·TALIP et al. measured the ambient particle mass concentration and meteorological parameters constantly from 9th 2008 to 2nd 2010 in Urumqi City, and the result showed that there is significant negative correlation between winds and particle mass concentration and the precipitation is also an important factor to impact the atmospheric fine particles mass concentration. Yang Han et al. estimated the influence of meteorological conditions on ambient air PM2.5 concentrations and temporal trends of PM2.5 in indoor and outdoor air.

The temperature difference is one of the momentum that lead to the connection of indoor and outdoor particles. In this study, relationships between I/O ratios and the indoor-outdoor temperature difference of Indoor-1 and Indoor-2 are weak negative correlation (as shown in Figure 5), and slopes are negative and not significant at the level of 0.05. According to Figure 5, the indoor-outdoor temperature difference is not the main influence factor to the ability that outdoor PM2.5 penetrate into the residence, but there are negative correlations as a certain extent.
Figure 5 Correlation between I/O ratios and indoor and outdoor temperature difference

Besides, analyses about the correlation between I/O ratios and differences of the relative humidity and wind speed have been carried out, and the correlation was very weak.

3.4 The correlation analysis between indoor and outdoor PM2.5 mass concentration

The correlation between indoor and outdoor particles can estimate the contribution to indoor particles of outdoor origin, in this study we selected paired values of indoor and outdoor PM2.5 mass concentrations to conduct linear regression analysis (as shown in Figure 6).

The quantitative relationship between indoor PM2.5 mass concentration and outdoor PM2.5 mass concentration can be calculated by the mass balance equation, the equation can be expressed as follows (Wenjing Ji & Bin Zhao, 2015; E. Diapouli et.al, 2013):

$$C_{in} = \frac{a \cdot P}{a + k} C_{out} + \frac{Q_v}{(a + k) \cdot V}$$  \hspace{1cm} (2)

Where $C_{in}$ is the indoor PM2.5 mass concentration ($\mu g/m^3$), $C_{out}$ is the outdoor PM2.5 mass concentration ($\mu g/m^3$), $P$ is the PM2.5 penetration factor, $a$ is the air exchange rate per hour ($h^{-1}$), $k$ is particle deposition rate ($h^{-1}$), $Q_v$ is the indoor PM2.5 source strength ($\mu g/h$), $V$ is the volume of the room ($m^3$). Totally 69 groups of penetration factor and deposition rate of PM2.5 have been calculated based on the size dependent particle penetration factor and deposition rate recommended by Nazaroff (Nazaroff WW, 2004; Liu DL & Nazaroff WW, 2001; Riley WJ, McKone TE, Lai ACK and Nazaroff WW, 2002).
The infiltration of outdoor particles to indoor particles can be estimated by a characteristic parameter, the infiltration factor \( F_{\text{inf}} \). The infiltration factor corresponds to the fraction of outdoor PM2.5 that enter an indoor space and remain suspended, which can be expressed by the following equation:

\[
F_{\text{inf}} = \frac{a \cdot P}{a + k}
\]  

Thus, equation (2) can be expressed as following:

\[
C_{\text{in}} = F_{\text{inf}} \cdot C_{\text{out}} + \frac{Q_{\text{in}}}{(a + k) \cdot V}
\]  

According to the equation (4), the slope of the fitting curve represents the \( F_{\text{inf}} \), and the intercept represents the term of \( \frac{Q_{\text{in}}}{(a + k) \cdot V} \), which expressing the indoor PM2.5 emission strength. Defining the contribution rate of outdoor particles on indoor particles:

\[
\rho = \frac{F_{\text{inf}} \cdot C_{\text{out}}}{C_{\text{in}}} \times 100\%
\]

and according to fitting results, the quantitative analysis of the source of the indoor PM2.5 can be made (as shown in Table 1).

Table 1: Estimates of PM2.5 of ambient origin using mass balance model.

<table>
<thead>
<tr>
<th>Site</th>
<th>Indoor-1</th>
<th>Indoor-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration factor( (F_{\text{inf}}) )</td>
<td>0.626</td>
<td>0.461</td>
</tr>
<tr>
<td>Indoor generated PM2.5</td>
<td>10.458</td>
<td>19.097</td>
</tr>
<tr>
<td>Contribution rate( (\rho) )</td>
<td>82.05%</td>
<td>64.83%</td>
</tr>
</tbody>
</table>

Figure 6 Correlation between indoor and outdoor PM2.5 mass concentration
According to Table 1, the indoor PM2.5 emission strength of Indoor-2 is stronger than Indoor-1, so the contribution rate of Indoor-2 is lower than Indoor-1. The infiltration factor of Indoor-1 is 0.626, Indoor-2 is 0.461 contrastively, the reason maybe the ventilation condition of Indoor-1 in better than Indoor-2, so particle can penetrate into the residence more simply.

4. Conclusion

This paper analyses the characteristic of PM2.5 mass concentration in the typical severe cold urban (Harbin) by scene sampling, and then assess the relationship between indoor and outdoor PM2.5 mass concentration mainly by using two parameters: I/O ratio and infiltration factor. Several conclusions have been drawn by this work:

1) In the medium-term of heating seasons, PM2.5 mass concentrations would increase obviously, and at the heating source sampling site, PM2.5 concentrations were significantly higher than other 3 sites, and the rate that out of limits was much higher.
2) I/O ratios would be different with different building design of residence, types of windows and human behaviors would influence I/O ratios, but in the same ambient environment, variation trends of I/O ratios were the same.
3) The meteorological conditions, including indoor-outdoor temperature differences, indoor-outdoor relative humidity differences, and ambient wind speed, influenced PM2.5 mass concentrations and I/O ratios to varying degrees, the correlation with temperature differences was weak negative correlation, but the correlation with relative humidity differences and wind speed was too weak.
4) The correlation between indoor and outdoor PM2.5 mass concentration was stronger (R2=0.831, R2=0.764), and in different residences, the infiltration factor would be different, and there would be distinction in emission strength of indoor PM2.5 and contribution rate of outdoor PM2.5 on indoor PM2.5.

5. Acknowledgments

Sampling equipment was provided by Mr. Gao Peng and Ms. Song Weiwei, and Mr. Li Bo helped to make pretreatment of sampling. We greatly appreciated their assistance.

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Investigation and Improvement of Indoor Air Quality in Office Buildings

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Abstract

Purpose / Context - Improve indoor air quality.

Methodology / Approach - Investigate the objectives of the study through subjective questionnaire survey and field test of the selected parameters.

Results – According to the practical problems of the office building, the reasonable solution is put forward.

Key Findings / Implications – The indoor thermal and humid environment, air quality and thermal comfort of human body were studied and analysed in order to determine practical strategies for improvement program, aimed at addressing the problems existing in office buildings.

Originality - Investigate the office building alone, make a concrete analysis of the factors influencing the quality of indoor air, propose an antidote against the disease of the office environment.

Keywords - office building, indoor air quality, pollutant, questionnaire.
1. Research Background

As people’s work environment is increasingly shifting to the interior, especially in the city, office plays a very important role in daily life. People spend more than 8 hours in the building, therefore, air quality of office buildings have high requirements. The comfort of indoor personnel is also a major concern, so the study of indoor air quality office building is becoming important and of great significance (Indoor Air Quality Standard GB/T 18883-2002; People’s Republic of China Industry Standard - Office Building Design Code JGJ 67-2006).

2. Research methods and contents

2.1 Indoor air quality assessment method

This study adopted the objective evaluation and subjective evaluation methods, that is, field test and questionnaire survey. Each measuring point was selected according to the size and type of the office, and the parameters of each measuring point were tested and measured in different time periods. The questionnaire survey was conducted on the employees of different age groups in the office, and the results were analysed.

2.2 Test object

This study selected the office building in Jiulongpo District, Chongqing City as the research object. The total construction area was about 30000 m2, 31 floors. The first floor consisted of the equipment room and reception hall, the second floor is the restaurant, 3rd -25th floors are architectural design office, the 26th floor is the network management center and the creative center, 27th and 28th floors are administration areas, and 30th is the big report hall.

2.3 Test parameter

Indoor temperature, relative humidity, CO2 concentration and HCHO concentration.

2.4 Test instrument

Detailed information of the test instruments are shown in Table 1 and Figures 1-4.

Table 1: Test instruments

<table>
<thead>
<tr>
<th>Test item</th>
<th>Instrument name</th>
<th>Response</th>
<th>Test range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>TSI-7565 Indoor air quality detector</td>
<td>30s</td>
<td>0~60</td>
<td>±0.6</td>
</tr>
<tr>
<td>Humidity</td>
<td>TSI-7565 Indoor air quality detector</td>
<td>20s</td>
<td>5~95%RH</td>
<td>±3%RH</td>
</tr>
<tr>
<td>Air velocity</td>
<td>Testo425 Hot-wire anemometer</td>
<td>30s</td>
<td>0~20m/s</td>
<td>±0.03m/s</td>
</tr>
<tr>
<td>HCHO</td>
<td>PPM-HTV Formaldehyde detector</td>
<td>8~60s</td>
<td>0~10ppm</td>
<td>2%</td>
</tr>
<tr>
<td>CO2</td>
<td>TSI-7545 CO/CO2 tester</td>
<td>20s</td>
<td>0~5000ppm</td>
<td>50ppm</td>
</tr>
</tbody>
</table>
2.5 Test condition

The test time was from January 5 to 9, 2015 (during working days). When testing the air conditioning start was at least 1 hour.

2.6 Arrangement of measuring points

The measuring points are arranged according to the suggestions of Ambient Air Quality Standards (GB3095-2012). In accordance with the specific situation adjustments were made to the corresponding part. Arbitrary extraction of an office survey point layout can be seen in Figures 5 and 6.

As it is shown in Figures 5 and 6, the direction of the East and West is the X axis, the north south direction is the Z axis, the vertical direction is the Y axis. Due to the fact that people's activity area is mainly focused on 1m to 2m, face Y = 1.1m plum arranged five points, number as P①(1, 1.1, 0.8), P②(4, 1.1, 0.8), P③(4, 1.1, 2.5), P④(1, 1.1, 2.5) and P⑤(2.5, 1.1, 1.5). And face Y=1.5m take the centre of the square diffuser Z=1.45m, people standing in the respiratory side of the 3 points, number as P⑥(1, 1.5, 1.45), P⑦(2.5, 1.5, 1.45) and P⑧(3.6, 1.5, 1.45). This measuring point distribution method meets the requirements of the specification.
2.7 Questionnaire

In order to investigate the basic situation of indoor air quality comprehensively, questionnaire survey was disseminated to unearth information about the health conditions of the staff in the office and the feeling of the indoor environment. Part of the questionnaire is shown in Figure 7.

The questionnaires were distributed in the lower, middle and upper levels. The respondents were randomly selected, covering the staff of different ages and gender. 270 questionnaires were issued with high response rate because they were taken back on the spot. 241 questionnaires were recycled, and there were 232 valid questionnaires.
3. Results and Analysis

In order to study the relationship between the parameters and the subjective evaluation, the results of each test point were taken as averages, as shown in Table 2.

Table 2: The average value of each measuring point

<table>
<thead>
<tr>
<th>Average value</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>P7</th>
<th>P8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>19.1</td>
<td>20.0</td>
<td>19.9</td>
<td>19.0</td>
<td>21.0</td>
<td>20.1</td>
<td>20.7</td>
<td>19.9</td>
</tr>
<tr>
<td>Humidity (%)</td>
<td>52.7</td>
<td>53.7</td>
<td>51.9</td>
<td>55.9</td>
<td>54.9</td>
<td>55.4</td>
<td>54.5</td>
<td>55.8</td>
</tr>
<tr>
<td>CO2 (ppm)</td>
<td>645</td>
<td>637</td>
<td>625</td>
<td>640</td>
<td>668</td>
<td>634</td>
<td>649</td>
<td>636</td>
</tr>
<tr>
<td>HCHO (ppm)</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
<td>0.03</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Air velocity (m/s)</td>
<td>0.06</td>
<td>0.11</td>
<td>0.12</td>
<td>0.10</td>
<td>0.07</td>
<td>0.08</td>
<td>0.07</td>
<td>0.11</td>
</tr>
</tbody>
</table>

SPSS software, Pearson square test and Fisher exact probability test were used to explore the correlation between personal indoor quality of the office building and the unacceptable indoor air quality. The acceptable indoor air quality is not similar because of the differences in personal preferences of office building indoor environment. The results are shown in Table 3. In the table, there are 3 influencing factors, which were gender, poor breathing, and eye fatigue, when P is less than 0.05. In other words, it can be considered that no circulation, air velocity, thermal environment and acoustic environment caused different unacceptable indoor air quality.

Table 3: The P value of chi-square test between each variable

<table>
<thead>
<tr>
<th>Factor</th>
<th>Dirty</th>
<th>No circulation</th>
<th>Carpet and document smell</th>
<th>Copy machine smell</th>
<th>Decoration smell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p</td>
<td>0.192</td>
<td>0.000</td>
<td>0.757</td>
<td>0.171</td>
<td>0.323</td>
</tr>
<tr>
<td>p</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.
4. Conclusion and Suggestions

4.1 Conclusion

4.1.1 Thermal environment and humidity
The data showed that the temperature around the body was about 21°C, and the temperature of the working area was maintained at around 20°C. When the office workers are in a stable mental state, the temperature can make people feel comfortable. From the overall point of view, the overall temperature difference was less than 2°C. The temperature distribution is reasonable, in accordance with the standard requirements of the thermal comfort of air conditioning. Also, the relative humidity was also within the scope of the standard control.

4.1.2 Air velocity
The change of air velocity was small, and 0.06~0.12m/s was controlled within the standard range. However, people still felt uncomfortable and the air being polluted. There is still an urgent need to enhance ventilation to ensure comfort and efficiency of the human body.

4.1.3 Acoustic environment
People did not feel satisfied mainly because the office building was closer to the highway, bus station and the subway station. More sound insulation materials should be used.

4.2 Suggestions

1) Windows should be intermittently opened for ventilation. It cannot only contribute to the circulation of the air, but also can improve indoor air quality.
2) Air conditioning equipment should be cleaned regularly. By doing this, the supply of quality air could be guaranteed, and the efficiency of the air conditioner better.
3) Plants can relieve eye fatigue by absorbing radiation and CO2. This is another way to enhance the freshness of the air, which can make people feel comfortable.
4) Cleaning the office frequently. A neat and tidy environment could also improve air quality level, on the contrary untidy environment reduces air quality.

5. References

Effects of UV on radiation properties of cool coating

Abstract

Purpose / Context - Cool coating is a passive technique for reducing the solar heat gain and cooling energy consumption of buildings. However, the radiation properties (i.e., solar reflectance and thermal emittance) of cool coating would be changed, usually adversely, during its ageing process, and its thermal performance would be degraded accordingly. UV could cause photolysis and photo-oxidative reactions in cool coating, thus is believed to be one cause for the degradation.

Methodology / Approach – Groups of cool coating samples were exposed to UV radiation in an accelerated ageing chamber. The effects of UV were quantified by comparing the radiation properties of the samples before and after the exposure. Furthermore, the results of this UV exposure experiment were compared to a nature exposure experiment, to figure out the contribution of UV in the whole ageing process, which comprises the effects of numerous factors. Soiling is an important factor in the ageing process, thus its effects were investigated in this UV study as well.

Key Findings / Implications – UV was found to be responsible for several percent of the total loss of solar reflectance of cool coating; while soiling was found to be the most significant factor for the total loss in the ageing process.

Originality - Few studies have been conducted on quantifying the UV effects on the changes of radiation properties of cool coatings. This study fills this gap.

Keywords - UV, soiling, cool coating, radiation properties
1. Introduction

Cool coating is characterised by high solar reflectance and high thermal emittance. Solar reflectance is a measure of the ability to reflect the irradiation, and thermal emittance is a measure of the ability to emit energy by radiation. Solar reflectance and thermal emittance of cool coating are always high when it is fresh, which enable the cool coating to outperform the traditional coating in cooling down the buildings. The cooling benefits of cool coating have been demonstrated by numerous studies. For instance, a study in Trapani, Sicily showed that the application of cool coating led to an average reduction of 2.3°C for the indoor temperature, which was estimated to be equivalent to a 54% reduction of the cooling energy demand (Romeo & Zinzi, 2013). Another study based on building monitoring and calibrated simulations indicated that cool roof can save about 4.5 - 7.4 kWh/m²/year of cooling energy for air-conditioned building, in the climate of California, U.S. (Akbari, Levinson, & Rainer, 2005).

Nevertheless the radiation properties (mainly solar reflectance) of cool coating decreases during its service life due to the ageing process. Studies showed the solar reflectance of cool coating generally decrease by 0.08 - 0.47 after 5 - 8 years’ natural ageing, which would degrade the thermal performance of cool coating (Akbari, Berhe, et al., 2005). As illustrated by a study in Athens, Greece, when the solar reflectance of cool coating changes from 0.85 to 0.6, the energy saving of building drops accordingly from 40% to 25% (Synnefa, Santamouris, & Akbari, 2007).

The ageing process is caused by many environmental factors, including UV (ultraviolet), soiling, etc. UV is the electromagnetic radiation with the wavelength between 100 nm and 400 nm (ISO 21348 (Definitions of Solar Irradiance Spectral Categories)). However, most of the radiation between 100 nm and 300 nm has been absorbed by the atmosphere before reaching earth (Ronnen Levinson, Berdahl, & Akbari, 2005), therefore the UV we discuss in this study refers to the radiation between 300 nm to 400 nm. UV is believed to be one factor for the ageing of cool coating (Berdahl, Akbari, Levinson, & Miller, 2008; Jacques, 2000; Sleiman, W.Kirchstetter, & Gilbert, 2012). The energy of the UV photon is larger than 3 eV (Berdahl et al., 2008), it can deteriorate the cool coating by the combined effect of photolysis and photo-oxidative reaction, which is more commonly known as UV degradation (Ammala, Hill, Meakin, Pas, & Turney, 2002). The chemical bonds of cool coating could be broken, and pursuant oxidation would occur, leading to changes of chemical and mechanical properties (Asmatulu, Mahmud, Hille, & Misak, 2011). Many studies have been conducted about some changes caused by UV, such as yellowing and chalking of coating (Santos, Costa, & Santos, 2007; Singh, Tomer, & Bhadraiah, 2001). However the effects of UV on the loss of solar reflectance of cool coating have been rarely touched.

Soiling, another factor in the ageing process, is regarded as the most significant contributor for the loss of solar reflectance (Berdahl, Akbari, & Rose, 2002; R. Levinson, Berdahl, Berhe, & Akbari, 2005). During the ageing process, soiling agent (mainly the atmospheric particulate matter) would deposit on the cool coating and reduce its solar reflectance, as the soiling agent usually has lower solar reflectance than cool coating (Sleiman et al., 2014).

Another untouched topic is that whether the effects of UV would be affected by the soiling on cool coating. This question raises from the fact that some component of the soiling agent, such as black carbon (Favez, Cachier, Chabas, Ausset, & Lefevre, 2006), is UV absorber and might mitigate the degradation induced by UV (Fechine, Rabello, & Souto-Maior, 2002). Therefore the loss of solar reflectance caused by UV might be different when the cool coating is soiled. And different soiling agents might have different impacts.

To fill the research gaps, this study investigated the effects of UV on the change of solar reflectance and thermal emittance of cool coating through an accelerated ageing method. Two types of soiling agent, real dirt and carbon micropowder, were tested in the UV exposure, to investigate their impact on the loss of solar reflectance caused by UV.
2. Methodology

2.1 Sample preparation

A total of twenty-one cool coating samples were prepared by coating cool paint on substrates. Three materials were used as the substrates, namely concrete, stainless steel and aluminium alloy. These materials were purchased from roof construction suppliers so as to represent typical roof materials for both the industrial and residential buildings. The water-based acrylic cool paint used in this study was provided by SkyCool Pte Ltd., Singapore, which had been used in building industry for years. The substrates were cut into squares of 65 mm × 65 mm, a size that fits the measuring instruments and test chamber. Then they were washed and totally dried before being coated with the cool paint. The thickness of the coating were controlled between 500 µm and 700 µm, as recommended by the paint supplier, to match with the normal thickness of the cool coating applied on real buildings. Then all the samples were fully conditioned before being measured and tested.

2.2 Measuring instruments

The solar reflectance of each sample was measured by a Solar Spectrum Reflectometer (Devices & Services; Dallas, Texas). For each sample, 5 spots (centre and four corners) were measured and the mean was calculated. The spectral solar reflectance of each sample was measured during 300 - 2500 nm at 5 nm interval by a UV–VIS–NIR spectrophotometer (Perkin-Elmer Lambda 900) equipped with a 150 mm diameter Labsphere integrating sphere. The thermal emittance of each sample was measured by a portable emissometer (Devices & Services Model AE1). The coating thickness of each sample was measured by a portable coating thickness gauge (Elcometer 456). For each sample, 20 spots were measured and the mean was reported.

2.3 Artificial soiling

As introduced, this study aims not only to investigate the effects of UV on the radiation properties of cool coating when it is fresh, but also to investigate the effects when the cool coating is soiled. To reproduce the soiled samples in laboratory, an artificial soiling method was developed in this study, when currently no method of this kind was widely accepted in this field (Sleiman et al., 2014).

2.3.1 Soiling agents

Two soiling agents were selected for the artificial soiling: “real dirt” and carbon micropowder. Real dirt, the airborne that would deposit on roof in natural environment, was collected from the fresh air intake filter of the air-conditioning units on the roof of a 3-storey building in Singapore. Carbon micropowder, suggested as the most significant component of real dirt that decreases the solar reflectance of coating (Berdahl et al., 2002), was purchased from the market. The analysis and treatment of the real dirt and carbon micropowder is introduced as below:

a) Real dirt: milled for 12 hours with a speed of 250 rpm, using Netsch P 400 plenary ball milling system, with 30 pieces of agate ball with diameter of 10 mm and weight 4.0 g each.

b) Carbon micropowder: VWR International - Carbon black, Acetylene, 50% COMP 99.9+% - ALFA39724.30, with a spherical powder size range between 0.4-12 µm was selected as the other test contaminant.

2.3.2 Soiling method

Real dirt and carbon micropowder were loaded onto the samples by wet deposition method in the clean room. The steps are described below, as illustrated in Figure 1.
a) A cool coating sample was sealed on the edges by silicon sealant, fencing its surface with a 2 mm high sealant barrier. Then the sample was conditioned under room temperature for 2 hours for the sealant to dry.
b) A certain amount of soiling agent (real dirt or carbon micropowder) was weighted.
c) The soiling agent was transported into a tube, with a certain amount of deionized water, forming a soiling mixture with a designed concentration.
d) The tube was capped and sealed, then sonicated for 30 minutes for creating uniformly dispersed mixture.
e) A designed amount of the mixture was dipped onto the surface of the cool coating sample by a clean pipette.
f) The sample was kept in an oven for 4 hours at 50 °C, evaporating the water and leaving only the soiling agent on the sample surface.

By this method, the soiling agent deposits uniformly on the sample, and the solar reflectance of samples could be decreased to designed range.

Figure 1. Steps of soiling cool coating samples: (a) bordering the sample with silicon sealant; (b) weighing soiling particles; (c) particle mixture; (d) sonic bathing of particle mixture; (e) drying in oven; (f) soiled samples.

2.4 Accelerated UV exposure

2.4.1 Sample information

Twenty-one samples were prepared, with three types of soiling condition (no soiling, soiled by real dirt, and soiled by carbon micropowder) and three types of substrates (concrete, stainless steel, and aluminium alloy). The initial solar reflectance of the unsoiled (fresh) samples were 0.8 (± 0.02), while the initial reflectance of the soiled (by real dirt or carbon micropowder) were 0.5 (± 0.02). The former was to investigate the effects of UV on clean cool coating, while the later was to investigate whether the soiling on cool coating would affect the effects of UV. All subgroup samples were prepared in duplicates or triplicates. The sample number is listed in Table 1.
Table 1. List of cool coating samples for UV exposure experiment. "Initial solar reflectance" is the solar reflectance before UV ageing experiment (but after soiling, if any). "RD" stands for "real dirt", and "CM" stands for "carbon micropowder".

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Initial solar reflectance</th>
<th>Soiling agent</th>
<th>No. of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>0.8 (± 0.02)</td>
<td>RD</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>0.5 (± 0.02)</td>
<td>CM</td>
<td>3</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>0.8 (± 0.02)</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.5 (± 0.02)</td>
<td>RD</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.5 (± 0.02)</td>
<td>CM</td>
<td>2</td>
</tr>
<tr>
<td>Aluminium alloy</td>
<td>0.8 (± 0.02)</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.5 (± 0.02)</td>
<td>RD</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.5 (± 0.02)</td>
<td>CM</td>
<td>2</td>
</tr>
</tbody>
</table>

2.4.2 Test apparatus and process

A QUV test chamber (Q-Lab Corp.; Westlake, OH) was used for the accelerated UV ageing of the cool coating samples. It exposes the samples to repetitive cycles of UV irradiation and moisture under controlled environmental conditions. The UV irradiation (UVA, peak wavelength 340 nm) is generated by fluorescent lamps in the chamber, which mimics the UV part of natural sunlight but with higher intensity. The moisture is mimicked by condensation of hot vapour of deionized water on the surface of samples.

The accelerated UV ageing experiment was conducted in the QUV chamber for 8 weeks, following ASTM G154 cycle 6 (8 hours of UV 1.55W/m² at 340nm, T = 60°C; followed by 4 hours water condensation at 50°C). The total UV exposure during the period of this experiment provided the samples with a UV dose of 536 MJ/m², which is equivalent to that of 22 months natural exposure in tropical climate (Tan & Goh, 1977).

3. Results and discussion

3.1 Evaluation of the artificial soiling agents

Though real dirt and carbon micropowder have different composition, both of them can decrease the solar reflectance. When using them to decrease the solar reflectance of cool coating samples to the same level, the spectral solar reflectance of the samples before soiling and after soiling were measured, as shown in Figure 2. It shows three curves of spectral solar reflectance: one for the cool coating before soiling, one for cool coating soiled by carbon micropowder, and one for cool coating soiled by real dirt. It could be observed that the latter two are very close to each other, which means the loss of the solar reflectance caused by the two soiling agents is highly similar through the whole solar spectrum.

However, to decrease the solar reflectance to the same level, it takes much less carbon micropowder than real dirt. In Figure 2, the solar reflectance of the two soiled cool coatings is 0.65. To achieve this level from the fresh solar reflectance of 0.8, the surface concentration of carbon micropowder on sample is 740 mg/m², while for real dirt it is 14.7 mg/m², which means carbon micropowder is about 50 times as effective as real dirt in decreasing the solar reflectance of cool coating.

The explanation for this might be that carbon dirt is a component in real dirt. Though it accounts for only a small part of the real dirt, it absorbs much more solar irradiation than other components. Therefore the decrease of spectral solar reflectance caused by real dirt is dominated by this effective component.
3.2 Effects of UV on the loss of solar reflectance

At the end of the 8-week accelerated UV exposure, the final solar reflectance of all samples were measured, and compared to the solar reflectance before UV exposure, to determine the loss of solar reflectance. For each sample, 5 spots (centre and four corners) were measured and the mean was calculated. Results are summarised in Figure 3. It shows that most samples have their solar reflectance decreased after UV exposure. The average solar reflectance loss of all the samples is 0.012.

Paired t-test was conducted by SPSS software on “solar reflectance before UV exposure” and “solar reflectance after UV exposure”. The analysis results are summarized in Table 2. The P value (Sig.) is almost 0, much smaller than 0.05, indicating the difference between “solar reflectance before UV exposure” and “solar reflectance after UV exposure” is statistically significant. This suggests that UV does reduce the solar reflectance of cool coating, no matter whether it is clean or soiled. After UV exposure whose dose is equivalent to that of 22-month natural exposure in tropical climate, the average loss of solar reflectance of these cool coating samples is about 0.012.
Figure 3. Solar reflectance of cool coating samples before and after UV exposure. Each black dot presents a sample, its x-axis reading is its solar reflectance before UV exposure, and its y-axis reading is its solar reflectance after UV exposure. If the dot falls below the red dashed line, it means its solar reflectance decreased after the UV exposure.

Table 2. Paired t-test for means of “solar reflectance before UV exposure” and “solar reflectance after UV exposure” of cool coating samples

<table>
<thead>
<tr>
<th>Paired Samples Statistics</th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1 solar reflectance</td>
<td>.6038095</td>
<td>21</td>
<td>.15255464</td>
<td>.03329015</td>
</tr>
<tr>
<td>before UV exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>solar reflectance</td>
<td>.5918667</td>
<td>21</td>
<td>.15018131</td>
<td>.03277225</td>
</tr>
<tr>
<td>after UV exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Paired Samples Correlations

<table>
<thead>
<tr>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>0.999</td>
<td>.000</td>
</tr>
</tbody>
</table>
We can compare this reflectance loss to that of another batch of cool coating samples which had been exposed in natural environment for 3 years. These natural exposed samples are of the same substrates and the same cool paint with the UV exposed samples. The natural exposure results showed that the average loss of solar reflectance after 22 months is 0.17, which coincides with the findings of previous studies (Akbari, Berhe, et al., 2005). The comparison between these two figures (0.012 vs. 0.17) suggests that the solar reflectance loss caused by UV is even lower than 10% (just 7%) of the total loss. Actually our other studies (not presented here due to the limitation of space) also suggests that it is soiling the most significant factor in reducing the solar reflectance of cool coating.

### 3.3 Impacts of soiling on the loss of solar reflectance caused by UV

In Figure 4, the solar reflectance loss of the samples are categorized into three subgroups, based on the soiling agents (soiled by carbon micropowder, or by real dirt, or unsoiled). Similar to the statistical analysis in previous section, the relationship between the soiling agents and the solar reflectance loss were investigated, by independent-sample t test. The results suggested statistically significant difference between “unsoiled” and “CM”; and significant difference between “unsoiled” and “RD”, but no statistically significant difference could be concluded between “CM” and “RD”.

In other words, “CM” and “RD” have similar impacts on the loss of solar reflectance caused by UV, which could be explained by the results in section 3.1. These impacts are different from that of “unsoiled”. It could be observed from Figure 4 that the soiled samples (by “CM” or “RD”) has less loss of solar reflectance than the unsoiled samples. The possible reason is that the soiling agents would absorb UV and mitigate the degradation.
3.4 Effects of UV and soiling on thermal emittance of cool coating

Thermal emittance of the cool coating samples were monitored before and after UV exposure. It was found that the emittance changed little during the UV exposure, and real dirt and carbon micropowder have insignificant effects on it. This was also observed in other studies (Al-Sanea, 2002; Cheng, Miller, New, & Berdahl, 2012). Explanation for this might be that the thermal emittance of real dirt and carbon micropowder are close to that of cool coating, so it remains almost the same even when part of the coating surface is covered by real dirt or carbon micropowder.

4. Conclusions

In this study, accelerated UV exposure experiment was conducted on new and soiled cool coating samples. Based on the results, some conclusions could be drawn:

1) Real dirt and carbon micropowder have similar effects in reducing the solar reflectance of cool coating through the spectrum. But carbon micropowder is more effective than real dirt.
2) UV would decrease the solar reflectance of cool coating. However this decrease is small, when compared to that caused by soiling. It accounts for only 7% of the total loss occurred in natural environment.
3) Soiling on the surface of cool coating would affect the solar reflectance loss caused by UV.
4) Substrate of cool coating has no significant effect on UV degradation.
5) Thermal emittance of cool coating changed little during the UV exposure, regardless whether they are soiled or not.

5. References


Study on Association Between Indoor Thermal Environment of Residential Buildings and Cerebrovascular Disease in a Cold Climatic Region of Japan

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Abstract

Purpose / Context - The aim of this study was to determine whether the quality of the indoor thermal environment during winter could increase the risk of cerebrovascular disease.

Methodology / Approach - An epidemiological survey of approximately 200 elderly persons living in a cold climatic region of Japan was conducted. The survey was divided into three phases, and the investigated areas were three rural towns with different rates of death due to cerebrovascular disease.

Results – Results indicate that feeling a draft in the living room while operating heating equipment and the style of bathtub were positively associated with an increased rate of death due to cerebrovascular disease. The bathroom with a traditional type bathtub tends to be cold, and its indoor thermal environment during winter is poor.

Key Findings / Implications – Poor quality of the indoor environment during winter could increase the risk of cerebrovascular disease.

Originality – The findings of this study will contribute to accumulate the knowledges showing the associations between indoor thermal environment and health.

Keywords - Cerebrovascular disease, Indoor thermal environment, Questionnaire survey
1. Introduction

According to statistical data reported by the Japanese government, the major causes of death for Japanese people are cancer, heart disease and cerebrovascular disease. The incidence rate of cerebrovascular disease in particular is higher during winter than summer (UK Department of Health, 2009). One possible reason for this seasonal difference is that exposure to cold temperatures can cause fluctuations in blood pressure. In houses with poor thermal insulation, indoor temperature differences between heated and non-heated spaces, such as the bathroom, corridors, and lavatory can be larger during winter. Many houses in the Tohoku region have a poor thermal environment during winter, and the incidence rate of cerebrovascular disease in this area is the highest compared to other areas in Japan. Yoshino et al. (Hasegawa and Yoshino, 1985) investigated indoor thermal environment in houses of Yamagata prefecture, which is included in Tohoku region, during heating season and the death rate of cerebrovascular disease in 1983 and 1984. As a result, the temperature difference between the heated living room and the unheated rooms was found to be great. Also it was revealed that if the lavatory temperature was low or the bedroom was not heated, the occupants living in such houses statistically tended to be susceptible to cerebral vascular accident.

To clarify the association between the indoor environment of residential buildings and cerebrovascular disease, an epidemiological survey of approximately 200 elderly persons living in Yamagata Prefecture in the Tohoku region of Japan was conducted. The specific areas investigated included three rural towns (Towns A, B and C) and these areas are same as the investigated areas 30 years ago. The survey was divided into three phases. The first phase (Phase 1) was a cross-sectional questionnaire on housing characteristics related to the indoor thermal environment and occupants' lifestyle habits among 188 elderly persons. This paper describes the results obtained from this questionnaire and presents the characteristics of the indoor thermal environment and occupants' lifestyle habits during winter. Moreover, an association between the increase in rate of death due to cerebrovascular disease and factors that influenced the indoor environment of houses is examined using multivariable logistic regression analysis.

2. Materials and Methods

Table 1 presents the demographics of Towns A, B and C. These towns are located in Yamagata Prefecture, which has a population density of 120 persons/km² (2015). The rate of death in Town A due to cerebrovascular disease is approximately 1.6 times higher than the national average, and the rates in both Towns B and C are half of the national average. The heating degree days based on 18 °C of these areas is approximately 3,000, and the mean outdoor temperatures are –1 to 2 °C and 24 to 25 °C for January and August in Town A, B and C, respectively.

<table>
<thead>
<tr>
<th>Items</th>
<th>Town A</th>
<th>Town B</th>
<th>Town C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>6,519</td>
<td>9,059</td>
<td>8,770</td>
</tr>
<tr>
<td>Number of households</td>
<td>1,904</td>
<td>2,330</td>
<td>2,311</td>
</tr>
<tr>
<td>Population density</td>
<td>31.9</td>
<td>83.7</td>
<td>44.6</td>
</tr>
<tr>
<td>Number of elderly persons</td>
<td>2,148</td>
<td>2,687</td>
<td>2,798</td>
</tr>
<tr>
<td>Rate of aging</td>
<td>32.9</td>
<td>29.6</td>
<td>31.9</td>
</tr>
<tr>
<td>Standardized mortality ratio</td>
<td>164.2</td>
<td>50.6</td>
<td>61.6</td>
</tr>
</tbody>
</table>


This survey was divided into three phases, as shown in Figure 1. A preliminary survey was conducted before these phases to ask elderly residents if they would be willing to participate in subsequent surveys. Phase 1 was a cross-sectional questionnaire on housing characteristics related to the indoor thermal environment and occupants' lifestyle habits among 188 elderly persons. The
second phase (Phase 2) was conducted over a week during the winter, and included field measurements, measurements of indoor temperatures in a living room, bedroom, lavatory and other rooms and home blood pressure measurements of 55 elderly persons. The final phase (Phase 3) included long-term field measurements of indoor and outdoor temperatures and home blood pressure measurements of 30 elderly persons. This paper presents the results from the questionnaire survey and a statistical analysis of the results through Phase 1.

Table 2: Number of questionnaires distributed and response rate for Phase 1

<table>
<thead>
<tr>
<th>Town</th>
<th>No. of distributed questionnaires (N)</th>
<th>No. of respondents (N)</th>
<th>Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>99</td>
<td>78</td>
<td>78.8</td>
</tr>
<tr>
<td>B</td>
<td>33</td>
<td>32</td>
<td>97.0</td>
</tr>
<tr>
<td>C</td>
<td>100</td>
<td>78</td>
<td>78.0</td>
</tr>
<tr>
<td>Total</td>
<td>232</td>
<td>188</td>
<td>81.0</td>
</tr>
</tbody>
</table>

In Phase 1, which lasted from January to February 2015, questionnaires were distributed by mail to the 232 households that agreed to participate during the preliminary survey. The completed questionnaires were returned by post within 2 weeks. The total response rate for Phase 1 was 81.0%, as shown in Table 2. The self-reported questionnaire included questions on: (1) respondents’ characteristics (gender, age, smoking status, occupation, etc.); (2) housing characteristics (housing location, housing type, finishing materials of building, frequency of heating equipment use, etc.); (3) indoor thermal environment during winter; and (4) indoor temperatures (measured using a liquid crystal thermometer for 1 week during the study period).

![Figure 1 Flowchart of survey](image)

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*HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.*
Table 3 shows the characteristics of participants and houses in the three towns.

Male participants accounted for 73.1%, 81.3% and 20.5% of total participants in Towns A, B and C, respectively. There was a greater number of female participants in Town C.

Half of the respondents were in their 70s in Town A, 60s in Town C, and 80s in Town C. There was a clear difference in ages among the participants in the three towns.

Most of the participants in each area were not current smokers.

Approximately 30% of the houses in each area were built after 1990, and half of all of the houses were built between 1965 and 1990. Approximately 82.1% and 78.2% of building envelopes in Towns A and C, respectively, had thermal insulation. Based on the time the houses in these towns were constructed, the thermal performance of the buildings was judged to be low. A single window with a single pane of glass was a popular characteristic of homes, with approximately 60% of the houses in each area having this style of window.

Vented kerosene heaters were used in more than 20% of houses in each area. However, an un-vented kerosene heater was still being used in nearly 60% of houses. Of all respondents in Towns A and C, 16% used air-conditioning units for space heating during the winter. Use of an electric ‘kotatsu’ heater is very popular in the towns studied, and approximately 30% of respondents used this type of heater in combination with a space heater. The electric ‘kotatsu’ heater uses a heating element mounted under a low table that is covered with a quilt.

Heated toilet seats are also very popular in Japan, and most of the respondents reported using one during the study period.

More half of participants in Town A and B felt slightly cold when they moved to the bathroom from the living room where was heated. Approximately 40% participants in Town C felt slightly cold. Participants felt neutral were more in Town C than Town A and B.

33.3% of participants in Town A were < 1.00 clo and they were thinly dressed compared to Town B and C.
Table 3: Characteristics of participants and houses in the three towns included in the study

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender of respondents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>57 (73.1)</td>
<td>26 (81.3)</td>
<td>17 (20.5)</td>
</tr>
<tr>
<td>Female</td>
<td>20 (25.6)</td>
<td>6 (18.8)</td>
<td>66 (79.5)</td>
</tr>
<tr>
<td>Age of respondents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60s</td>
<td>22 (28.2)</td>
<td>18 (56.3)</td>
<td>10 (12.0)</td>
</tr>
<tr>
<td>70s</td>
<td>39 (50.0)</td>
<td>9 (28.1)</td>
<td>30 (36.1)</td>
</tr>
<tr>
<td>80s</td>
<td>15 (19.2)</td>
<td>4 (12.5)</td>
<td>43 (51.8)</td>
</tr>
<tr>
<td>≥90</td>
<td>2 (2.6)</td>
<td>1 (3.1)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Smoking status of respondents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>5 (6.4)</td>
<td>4 (12.5)</td>
<td>2 (2.4)</td>
</tr>
<tr>
<td>No</td>
<td>71 (91.0)</td>
<td>27 (85.4)</td>
<td>81 (97.6)</td>
</tr>
<tr>
<td>When house was constructed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before 1965</td>
<td>7 (9.6)</td>
<td>3 (7.4)</td>
<td>14 (18.2)</td>
</tr>
<tr>
<td>1965–1990</td>
<td>44 (57.1)</td>
<td>19 (61.3)</td>
<td>34 (43.6)</td>
</tr>
<tr>
<td>After 1990</td>
<td>26 (33.3)</td>
<td>10 (31.3)</td>
<td>27 (34.6)</td>
</tr>
<tr>
<td>Thermal insulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>64 (82.1)</td>
<td>25 (78.1)</td>
<td>61 (78.2)</td>
</tr>
<tr>
<td>No</td>
<td>13 (16.7)</td>
<td>6 (18.1)</td>
<td>16 (20.5)</td>
</tr>
<tr>
<td>Window style</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single pane</td>
<td>46 (59.0)</td>
<td>21 (65.6)</td>
<td>47 (60.3)</td>
</tr>
<tr>
<td>Double pane</td>
<td>31 (39.7)</td>
<td>9 (28.1)</td>
<td>29 (37.2)</td>
</tr>
<tr>
<td>Triple pane</td>
<td>1 (1.3)</td>
<td>0 (0.0)</td>
<td>1 (1.3)</td>
</tr>
<tr>
<td>Heating equipment in living room</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vented heater</td>
<td>18 (23.4)</td>
<td>8 (25.8)</td>
<td>17 (21.7)</td>
</tr>
<tr>
<td>Unvented heater</td>
<td>51 (66.2)</td>
<td>20 (64.5)</td>
<td>50 (64.1)</td>
</tr>
<tr>
<td>Electric kotatsu</td>
<td>28 (36.4)</td>
<td>9 (29.0)</td>
<td>22 (28.2)</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>13 (16.9)</td>
<td>2 (6.5)</td>
<td>13 (16.7)</td>
</tr>
<tr>
<td>Use of a heated toilet seat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>72 (92.3)</td>
<td>26 (84.4)</td>
<td>70 (91.0)</td>
</tr>
<tr>
<td>No</td>
<td>6 (7.7)</td>
<td>5 (15.6)</td>
<td>7 (9.0)</td>
</tr>
<tr>
<td>Thermal sensation when moving the</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>living room to the bathroom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>23 (29.5)</td>
<td>5 (15.6)</td>
<td>27 (34.6)</td>
</tr>
<tr>
<td>Slightly cold</td>
<td>50 (64.1)</td>
<td>17 (53.1)</td>
<td>30 (38.5)</td>
</tr>
<tr>
<td>Cold</td>
<td>8 (10.3)</td>
<td>7 (21.9)</td>
<td>16 (20.5)</td>
</tr>
<tr>
<td>Clothing when staying at home</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 1.25 clo</td>
<td>5 (6.4)</td>
<td>7 (21.9)</td>
<td>13 (16.7)</td>
</tr>
<tr>
<td>1.00 – 1.25 clo</td>
<td>45 (57.7)</td>
<td>18 (56.3)</td>
<td>47 (60.2)</td>
</tr>
<tr>
<td>&lt; 1.00 clo</td>
<td>26 (33.3)</td>
<td>5 (15.6)</td>
<td>14 (17.9)</td>
</tr>
</tbody>
</table>
3. Results and Discussion

The association between different rates of death due to cerebrovascular disease and indoor environmental factors and occupants’ eating habits in the investigated areas is presented in Fig. 2(a–d). These figures present the proportions for each answer to questions regarding the quality of the indoor environment and eating habits according to the three investigated towns. The rate of death due to cerebrovascular disease in Town A was higher than the rates in the other towns, and factors that influenced the rate of death due to cerebrovascular disease were expected to be revealed by comparing the house characteristics and occupants’ living habits between each area.

Regarding the style of bathtub, a greater number of traditional style bathtubs were used in Town A than in Towns B and C (Fig. 2(a)). There was also a higher frequency of feeling a draft in the living room during the winter in Town A (Fig. 2(b)). Approximately 60% of participants felt some draft in the living room. More participants in Town C did not drink alcohol during the week than in Towns A and B (Fig. 2(c)). This is likely because of the higher number of female participants in Town C (approximately 80%). A high salt diet may contribute to high blood pressure and could therefore cause the onset of cerebrovascular disease. Many Japanese people customarily have ‘miso’ soup with every meal, and ‘miso’, a traditional Japanese seasoning made from soybeans, has a high salt content. The ratio of participants having ‘miso’ soup two or three times a day was the highest in Town A. These eating habits may increase the risk of death due to cerebrovascular disease.

![Figure 2 Proportions for each answer to questions regarding the quality of the indoor environment and eating habits (a) Style of bathtub, (b) How often a draft is felt in the living room, (c) Alcohol consumption during one week, (d) Daily intake of miso soup](image-url)
Table 4: Adjusted ORs for Town A, which has a death rate higher than the national average

<table>
<thead>
<tr>
<th>Items</th>
<th>Frequency</th>
<th>Adjusted ORa</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Style of bathtub</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prefabricated bath</td>
<td>107</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>Traditional style bathtub</td>
<td>32</td>
<td>4.85***</td>
<td>1.48–15.94</td>
</tr>
<tr>
<td>How often a draft is felt in the living room</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>74</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>Intermittently</td>
<td>44</td>
<td>8.74***</td>
<td>1.68–45.57</td>
</tr>
<tr>
<td>Only during strong wind</td>
<td>21</td>
<td>5.78***</td>
<td>1.83–18.29</td>
</tr>
<tr>
<td>Daily intake of miso soup</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Once</td>
<td>50</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>Twice</td>
<td>67</td>
<td>3.86</td>
<td>0.83–18.01</td>
</tr>
<tr>
<td>Three times</td>
<td>22</td>
<td>2.57</td>
<td>0.90–7.35</td>
</tr>
<tr>
<td>Thermal sensation when moving from the living room to the bathroom during winter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>47</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>Slightly cold</td>
<td>73</td>
<td>0.97</td>
<td>0.20–4.62</td>
</tr>
<tr>
<td>Cold</td>
<td>19</td>
<td>0.23**</td>
<td>0.07–0.76</td>
</tr>
<tr>
<td>Clothing when staying at home</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;1.25 clo</td>
<td>16</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>1.00–1.25 clo</td>
<td>87</td>
<td>6.78**</td>
<td>1.10–42.01</td>
</tr>
<tr>
<td>&lt;1.00 clo</td>
<td>36</td>
<td>7.15**</td>
<td>1.36–37.69</td>
</tr>
</tbody>
</table>

*a Adjusted by age and gender. ** P<0.05; *** P<0.01. CI = Confidence interval.

The association between the difference in the rate of death due to cerebrovascular disease (Towns A and C) and factors related to the quality of the indoor thermal environment and occupants’ living habit was estimated using multivariate logistic regression analysis with adjustment for age and gender of participants. Adjusted odds ratios (ORs) were estimated including the 95% confidence interval (CI). Potential risk factors with a significance level of P < 0.2 in the single regression analysis were included in a stepwise logistic regression analysis to identify independent risk factors for significant indoor environmental conditions. Data were analyzed using the Statistical Package for the Social Sciences (SPSS, version 23).

The adjusted ORs for Town A are presented in Table 4. The adjusted OR for a traditional style bathtub (OR = 4.85, 95% CI = 1.48–15.94) was statistically significant for Town A, which had a high rate of death due to cerebrovascular disease. Bathrooms with a prefabricated bath tend to be well insulated thermally. On the other hand, houses with a traditional style bathtub are usually old, and their indoor thermal environment during winter is poor. The adjusted ORs for feeling a draft both intermittently and when a strong wind is blowing (OR = 8.74 and 5.78, P < 0.01) were significant for Town A. These results indicate that a poor indoor thermal environment may contribute to an increase in the rate of death due to cerebrovascular disease. A high salt diet may contribute to the onset of cerebrovascular disease. However this statistical model doesn’t present the significant associations with daily intake of ‘miso’ soup. When participants moved from a living room to a bathroom during winter, they reported feeling thermal sensations, such as ‘warm’, ‘neutral’ and ‘cold’. The adjusted OR for ‘cold’ when entering a bathroom (OR = 0.23, 95% CI = 0.07–0.76) was significant for Town A. These results indicate that participants in Town A did not feel cold, although the temperatures of bathrooms in Town A (average: 8.1°C, standard deviation: 4.2°C, maximum: 17.9 °C, minimum: 2.0 °C) and Town C (average: 7.8°C, standard deviation: 3.1°C, maximum: 20.0 °C, minimum: 3.1 °C) were similar. The adjusted OR for light clothing when staying at...
home was significant for Town A. Participant in Town A were thinly dressed during heating season. Therefore they may be more readily exposed to a cold indoor environment than those in Town C.

4. Conclusions

To clarify the association between the indoor environment of residential buildings and cerebrovascular disease, an epidemiological survey of 188 elderly persons living in three areas of Japan that have different rates of death due to cerebrovascular disease was conducted. Results indicate that feeling a draft in the living room while operating heating equipment and the style of bathtub were positively associated with an increased rate of death due to cerebrovascular disease. The bathroom with a traditional type bathtub tends to be cold, and its indoor thermal environment during winter is poor. This poor quality of the indoor environment during winter could increase the risk of cerebrovascular disease.

5. Acknowledgement

The authors would like to thank the residents who were involved in this study for their cooperation. This survey was supported partly by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology in Japan.

6. References


An evaluation of stakeholder management approach for improving energy efficiency outcomes in housing

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Abstract

Context - Energy efficient housing is influenced by a number of attributes that describe the key players involved in its production. Stakeholders’ levels of interest, motivation, awareness and power to impose their decision can have an impact on housing energy performance. Understanding these stakeholder attributes can help resolve barriers to energy efficiency performance.

Approach - This paper examines a number of stakeholder management approaches, compares their classification and prioritisation approaches and analyses each approach’s suitability to be adopted for managing energy efficiency stakeholders.

Results - Energy efficiency stakeholders can be classified as internal and external, with the attributes of power, interest, proximity and knowledge. The most suitable stakeholder management approach enables these attributes to be quantified, and with the addition of a time management, could enable a better understanding and management of energy efficiency stakeholders.

Implications - This approach may enable a correlation between stakeholder management strategies and the energy performance of housing, and manage the relationships between stakeholders in a way that ensures the achievement of both their individual interests and sustainability goals.

Originality - This paper explores the possibility of applying stakeholders’ theories that are commonly used for managing organisations to one aspect of the housing industry (energy efficiency).

Keywords – Energy efficiency- Housing- Stakeholders- Sustainability
1. Introduction

Housing construction is an industry that comprises a variety of participants with different interests, needs, levels of commitment and goals. They participate in the decision making process according to their own set of rules (Crabtree & Hes, 2009), and their communication is based on temporary networks, contrasting priorities and lack of cooperation (Berardi, 2013). The fragmented nature of the housing industry leads to the emergence of issues that "contribute to producing low performance houses, such as the lack of trust among participants, short term demands rather than the long term goals, opportunistic behaviours, and the lack of communication" (Tzortzatou, 2007). It also results in the development of a "circle of blame" where each stakeholder within the industry blames another stakeholder for the lack of implementation of energy efficiency (Crabtree & Hes, 2009; L. Davis, 2010; Pitt & Sherry, 2014).

Research by Miller (Miller, 2012) strongly suggested that an energy efficient house is "an integrated system" that incorporates the interconnections between multiple stakeholders, scopes of work, and components. Collectively these interconnections contribute to creating the product (an energy efficient house). Consequently, achieving the goals of energy efficiency in housing is not the responsibility of any one stakeholder (Pitt & Sherry, 2014). It is related to the decisions made by all the stakeholders within the six broad segments of the housing industry (legislative, market, planning, design, construction and occupancy/ownership) (Miller et al., 2014), where any decision could have an impact not only on the overall energy efficiency outcomes, but also on the competence of decisions taken by other stakeholders who participate in the same process.

To be able to contribute to the transition towards this "integrated system", approaches aside from top-down regulations need to be taken into consideration, since stakeholders usually treat these regulations as a burden that needs to be fulfilled with minimum effort (Pitt & Sherry, 2014). It has been argued that organizational/regulation institutes (that orchestrate rather than regulate) should devise interactive, higher transparency process policies, and a broader design process that integrates other actors (Rohracher, 2001). A strategy that aims to engage stakeholders, address their interests and guarantee their benefits is needed, so that energy efficiency aspects become a demand rather than a burden. Interest can be perceived from two perspectives; the first is regarding the interest in energy efficiency as a final goal, while the second is the personal interest of each stakeholder. This paper hypothesises that linking both types of interests as a project management strategy can allow for achieving both personal and collective goals and act as a means to enhance energy efficiency outcomes in owner-occupied housing.

An approach that links stakeholders’ interest and their impact on the collective outcomes of a project is stated in the stakeholders’ theory by Freeman, where “a stakeholder in an organisation is any group or individual who can affect or is affected by the achievement of the organisation's objectives” (Freeman, 1984). Stakeholders seek to influence organisations’ decisions to match their needs and priorities, and organisations should understand, balance and try to fulfil the various stakeholders’ interests (Freeman, 1984; Ribeiro Soriano, Wagner Mainardes, Alves, & Raposo, 2012; Soriano & al., 2012). However, according to Clement (2005) and Fassin (2008), meeting every stakeholder's needs puts too much pressure on organisations and is not feasible. This led to the necessity of classifying stakeholders based on their degree of influence and importance to organisations, as a way to analyse their impact on organisations' outcomes and prioritise some stakeholders’ needs over others (Ribeiro Soriano, et al., 2012).

2. Applying a stakeholder management approach to energy efficiency in housing

A stakeholder management approach, normally used for managing organisations’ stakeholders, could potentially be used to tackle the problem of fragmentation and conflicting interests of the housing industry and to enhance the energy efficiency outcomes of its end product. To do this such an approach might need to be modified to be able to be applied to only one aspect of the
housing industry (energy efficiency), rather than a whole organisation. Such an approach would aim to identify and classify energy efficiency stakeholders, and determine their relationships, interests, importance, and influence on outcomes. Following this approach a strategy could be developed to fulfil stakeholders’ individual interests (such as lowering utilities cost, building faster or better marketing) without lowering the quality of energy efficiency. Such a proposed modified strategy would aim to promote individual benefits (that do not conflict with the collective goals) to each stakeholder rather than promoting energy efficiency benefits as the common goal to all.

This paper aims to evaluate several stakeholder management approaches to identify which might be suitable for adaptation to the management of energy efficiency outcomes in housing. This will be done through reviewing a number of stakeholder management approaches and evaluating the degree to which they could be applied to the classification and prioritisation of energy efficiency stakeholders. This paper is focusing only on the stakeholders of owner-occupied energy efficient homes. Owner-occupied apartments and rented houses and apartments are not included in this analysis because they involve different stakeholders. It is also important to note that the concept of an energy efficient house in this paper is limited to the energy consumed during the operation/use of the house. It does not include the energy consumed during other stages of its life cycle (such as construction, manufacturing, transport, etc.).

The energy efficiency stakeholders were identified based on the analysis of the relationships maps of the Australian housing industry stakeholders demonstrated by Zedan & Miller (Zedan & Miller, 2015). The stakeholders of the whole industry were reduced to only the stakeholders who might affect or be affected by the energy efficiency of an owner-occupied house, as shown in figure 1.

3. Evaluation of stakeholder management approaches

The next sections demonstrate a number of categorisation and prioritisation approaches that have been discussed in literature and analyses each approach’s suitability for application to energy efficiency stakeholders.

3.1 The Classification approaches

Freeman (Freeman, 1984) classified stakeholders of an organisation into either internal stakeholders (who work as a part of the organisation) or external stakeholders (who are not a part of the organisation but can affect or be affected by its outcomes). To apply this approach to energy efficiency in housing, internal stakeholders could be considered as the ones who have direct responsibility for decision making and execution of work that could have direct impact on energy efficiency. External stakeholders could be considered as those who can sometimes monitor, impose rules, influence internal stakeholders’ decisions or indirectly impact energy efficiency outcomes, but are not directly involved in the decisions or execution of work that might affect the outcome of energy efficiency.

Clarkson (Clarkson, 1995) also divided stakeholders into 2 groups: (i) primary stakeholders (who have contractual relationships with the company) and (ii) secondary stakeholders (who have no such contracts). This approach could be understood as the items in contracts/law that could impact energy efficiency, which could be in the design brief, energy certificate, builders’ contract,
and the suppliers contracts (e.g. the R value and U value agreement between the builder/owner and the suppliers, or between the supplier and the manufacturer etc.). Applying Freeman’s approach mentioned previously, internal stakeholders could be considered to have contractual agreements with each other that could impact on energy efficiency. The external stakeholders may or may not have contractual agreement with internal stakeholders however they may exert an influence that impacts on energy efficiency.

Vos and Achterkamp (Vos & Achterkamp, 2006) followed a different approach that classifies stakeholders based on their role within an organisation. Stakeholders were classified as: client, decision maker, designer, and passively involved. When applied to the case of owner-occupied housing, the client and designer could be considered as decision makers (they make decisions that impact on energy efficiency), and the passively involved can include all stakeholders who are not directly involved in the decision making process (external stakeholders). So the four stakeholders’ roles could be reduced to two categories: actively involved (the same as internal stakeholder) and passively involved (the same criteria as the external stakeholder).

Turner (Achterkamp & Vos, 2008; Turner, 2006, 2014) had a similar approach to Vos and Achterkamp, where stakeholders are classified based on the seven roles they play in project management: owner, users, sponsors, resources (human material or financial), brokers, steward, and manager. These stakeholders are responsible for managing five functions within a project: the scope, the project organisation, the quality, the cost, and the time. This approach is very specific to a corporation’s structure and is difficult to apply to the stakeholders of energy efficiency in owner-occupied housing as its categories do not translate well into the housing supply chain.

The approach of Callen et al. (Achterkamp & Vos, 2008; Callan, Sieimieniuch, & Sinclair, 2006) on the other hand classified stakeholders based on their responsibilities within a certain project. Four types were generated: controllers, executors, constraining advisors (whose advice cannot be ignored), and discretionary advisors (whose advice can be ignored). All the categories in this approach are for “internal” or “actively involved” stakeholders. In an energy efficient house production process, “controllers” could be considered as the decision makers, while “executors” should follow the decisions makers’ orders. Some energy efficiency stakeholders can be regarded as advisors, providing advice that could be constraining (e.g. the structural engineer’s advice to add a column), or discretionary (e.g. energy simulator’s advice to use double glazing).

Bourne (Bourne & Walker, 2005) also divided stakeholders into four categories based on the direction of influence on the project work: (i) upwards (who are responsible for managerial decisions (e.g. senior managers); (ii) downwards (who make decisions regarding specific tasks e.g. team members); (iii) sideways (who are peers to the managers e.g. competitors); and (iv) outwards (who do not execute work themselves e.g. suppliers, unions, governments). To apply this approach to energy efficient houses, “upwards” and “downwards” could be regarded together as the “actively involved” or “internal” stakeholders, who are in direct contact with decision making and the work that impacts on energy efficiency. “Sideways” and “downwards” could be regarded as the “passively involved” or “external” stakeholders. They are not directly involved in the work or decision making but could still influence the decisions of the internal stakeholders. A further classification of the outwards stakeholders could be made to differentiate between stakeholders with legal authority or claim, and stakeholders who can influence outcomes without legitimate claims.

Fassin’s (Fassin, 2009) stakeholders are divided into three types based on the degree of claim they have over the organisation: Stakeholders (who have a stake, legitimate claim, power, and influence), stakewatchers (who have pressure, power and indirect claim), and stakekeepers (who act as regulators who impose external control and regulations on the firm but have no claim). These types could be regrouped into two categories, where the stakeholders are the internal players, and the stakewatchers and stakekeepers are external players with authority to cause change.
Wagner et al. are reported to follow a different approach that is based on the degree that the stakeholder and the organization impact each other (Ribeiro Soriano, et al., 2012). Six stakeholders’ types were generated: (i) regulator (the stakeholder can influence the organization but not vice versa); (ii) controller (the stakeholder has higher influence than the organization); (iii) partner (neither party predominates); (iv) passive (the company has higher influence); (v) dependent (the stakeholder can’t influence the organization but can be influenced by it); and (vi) non-stakeholder (neither party has influence over the other). Applying this approach to energy efficiency stakeholders will not give accurate results. For example, all the stakeholders (except the end-user) could be regarded as “Regulators” since energy efficiency has minimum influence on them.

3.2 Evaluation of classification approaches

From the evaluation of the degree of suitability of each stakeholder classification approach, two approaches (Wagner et al. & Turner) were evaluated as not applicable. The remaining approaches that could be applied to manage the stakeholders of energy efficiency are presented in Table 1.

Table 1: Applicable classification approaches

<table>
<thead>
<tr>
<th></th>
<th>Freeman</th>
<th>Clarkson</th>
<th>Vos and Achterkamp</th>
<th>Callen et al.</th>
<th>Bourne</th>
<th>Fassin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td>Primary</td>
<td>Active involvement</td>
<td>Controller Executor Constraining Advisor Discretionary Advisor</td>
<td>Upwards Downwards Sideways Outwards</td>
<td>Stakeholders Stakewatchers Stakekeepers</td>
<td></td>
</tr>
<tr>
<td>External</td>
<td>Secondary Passive Involvement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Collectively these approaches classify stakeholders from two perspectives: their relationship with the organisation and the role they play within (or outside) an organisation. The integrated model (figure 2) illustrates the hierarchy and similarities between all the classification approaches and each category’s location in the hierarchy. The colour of each category matches the colours utilised in table 1, to be able to identify which approach covers the greatest portion of the integrated model (which means better covering of the energy efficiency categories). The integrated model shows that energy efficiency stakeholders can be divided into ‘internal’ stakeholders (‘actively involved’, ‘primary’) who have contractual agreements with each other, and ‘external’ stakeholders (‘passively involved’) who are either ‘primary’ or ‘secondary’. Applying the role based perspective, classifications could be regarded as sub categories of internal and external stakeholders. Internal stakeholders could include stakeholders who make the most influential decisions that could impact energy efficiency (e.g. the owner, builder and designer) and ‘executors’ (e.g. trades, labour, etc.) who are hired by the decision makers. External stakeholders could include (i) ‘outward stakeholders’ who have indirect impact on the decisions made by the internal stakeholders (e.g. external authorities like unions, councils, government or external influencers like suppliers, manufacturers, the media, non-government organisations, universities etc.) and (ii) ‘sideward stakeholders’ such as industry peers, competitors etc.

Figure 2 shows that Bourne’s approach (purple) is the only one that covers both the internal and external stakeholders’ categories. However, an addition of the “advisors” category presented by Callen et al. (Callan, et al., 2006) could present more accurate description of some of the internal stakeholders. Another useful addition to Bourne’s approach could be sub-categorising the “outwards” category into stakeholders that have legal authority to impose influence on the decisions of the internal stakeholders and energy efficiency outcomes, and Influencers who might have influence but not the authority to impose it.
3.3 The prioritisation approaches

Identifying the level of influence of each stakeholder on project/activity outcomes is essential to prioritise the fulfilment of interests of different stakeholders during the management process. Researchers used a number of attributes to differentiate between the degrees of importance of stakeholders. This section will evaluate the relevancy of these attributes in assessing the importance and influence of stakeholders on energy efficiency.

Mitchell et al. (Mitchell, Agle, & Wood, 1997) developed one of the most established approaches for identifying the degree of stakeholders’ salience and influence. It is based on three relationship attributes (power, legitimacy, urgency) and ranked according to which of those attributes each stakeholder possesses: (i) low salient “latent” stakeholders who possess only one attribute; (ii) moderately salient “expectant” stakeholders who possess two attributes; and (iii) highly salient “definitive” stakeholders who possess all attributes. When applying these attributes to energy efficiency, “power” could be regarded as the power to make and implement decisions that could result in enhancing energy efficiency. “Legitimacy” would be hard to adopt due to the lack of clear lines of responsibilities among stakeholders for energy efficiency outcomes. “Urgency”, i.e. the degree that a stakeholder can demand immediate action, is not highly relevant to the implementation of energy efficiency, since energy efficiency is not the result of a single action but of a number of decisions and tasks that develop through all stages of the project.

Savage et al. (Savage, Nix, Whitehead, & Blair, 1991) ranked the degree of stakeholders’ support to the organization based on their potential to threaten or cooperate with it. Four types of stakeholders were generated: (i) supportive (low potential threat but high potential for cooperation; (ii) mixed blessing (potentials to threaten or to cooperate are equally high); (iii) non-supportive (high potential threat but low potential cooperation) and (iv) marginal (neither threatening nor cooperative). The potential threat could be regarded as the negative influence on energy efficiency. The potential to threat/enhance or negatively/positively influence energy efficiency could be identified by a range of attributes (power, authority, legitimacy, urgency, etc.) as discussed previously in Mitchell’s et al. approach. Therefore, the potential to threaten is too broad when compared to Mitchel and Wood’s approach that could provide more accurate and comprehensive explanation of the causes of the potential threat of certain stakeholders. The attribute of cooperation is important for managing the relationships between stakeholders and maximising energy outcomes. However cooperation can also be thought of as one criterion used to identify the value that a stakeholder holds for energy efficiency. The degree of this value could be identified by the actions that the stakeholder is willing to make (such as the willingness to
cooperate, to learn, spend time, spend money, etc.). So the willingness for cooperation is only one of the criteria that are used to identify the interest in energy efficiency.

Rowley (Rowley, 1997) used social network analysis principles instead of attributes to construct a theory of stakeholder influences. Four types of firm behaviours related to resisting stakeholder pressures were generated: commander, compromiser, subordinate, and solitarian. This approach addresses the dynamic nature of the stakeholders’ relationships, and how they impact each other as much as they impact the organization. The application of this concept to energy efficient houses was discussed by Zedan & Miller (Zedan & Miller, 2015). This is a more complex approach that could be a further step after the identification of stakeholders and quantifying their influence.

In Scholes and Clutterbuck’s approach (Scholes & Clutterbuck, 1998), stakeholder groups are assessed and their demands are prioritised according to three sets of criteria: (i) their potential to influence the business outcomes; (ii) the impact of business activities on them; and (iii) the alignment of their shared values/purpose with the business goals. To adapt this approach to energy efficiency, the potential to influence the business could be regarded as the potential power to enhance energy efficiency. The shared value could be regarded as the common interest in certain aspects that could enhance energy efficiency (such as low energy bills, using energy efficient materials, etc.). The impact of company activity on stakeholders could be understood as the impact of energy efficiency outcomes on stakeholders and the value of these outcomes to the stakeholder (such as the lower operation costs for the occupier, the good business reputation for the insulation supplier, etc.).

Johnson et al. (Johnson, Scholes, & Whittington, 2008) developed the power interest matrix to identify the influence that every stakeholder has on a project based on their levels of interest and power. So the potential to influence the outcomes of an activity is directly proportional to the degrees of interest in the outcomes of this activity and power to influence it. This can be applied to energy efficiency since the interest in energy efficiency and the power to implement it into the house could potentially impact the degree of influence of stakeholders on achieving energy efficiency.

Berardi (Berardi, 2013) then developed the approach of Johnson et al. to include the time dimension, to demonstrate that the levels of power and interest of a stakeholder can change based on the stage that a stakeholder becomes involved (for instance, a designer’s involvement at the late stages of construction will have less influence on energy efficiency than involvement in the initial stages). This supports Zedan and Miller’s argument that stakeholders’ participation in the decision making process should start from the early stages of the project to ensure making informed decisions and limiting risks that could result in lower performance of homes (Zedan & Miller, 2015). So the time dimension should be taken into consideration to check the significance of the attributes used to prioritise the influence of the energy efficiency stakeholders at each stage of the housing lifecycle.

Bourne’s (Bourne & Walker, 2005; Bourne, 2009) prioritisation method gives each stakeholder a numerical index based on: the degree of power, the proximity to the organisation/project, and the urgency, which determines the importance of the organisation outcomes to each stakeholder (the urgency is derived from the vested stake or the value that the stakeholder holds for the organisation’s outcomes, and the actions that they are prepared to do). To apply this approach to energy efficiency, the power attribute could be understood as discussed previously in Mitchell and Wood, Johnson & Scholes, and Berardi’s approaches. The two attributes that identify the urgency should be focusing on energy efficiency. (the value of energy efficiency to each stakeholder, and the action they are willing to make (for example, sacrifice, time, money or effort) to achieve energy efficiency. The two attributes could identify and quantify the degree of alignment of interests between the stakeholder and the activity (Energy efficiency). The proximity could be comprehended as the degree of involvement in the decisions that could impact on energy efficiency.
efficiency. This is particularly important to energy efficiency stakeholders since small decisions or modifications during construction could have big impact on energy efficiency outcomes.

Turner (Turner, 2014) proposed more than one approach to identify the degree of influence of stakeholders. The approaches proposed always used matrixes of two attributes such as, the knowledge/support matrix, the power-impact matrix, and the support-agree matrix.

The power, support (which can understood as interest) and agree (which can be understood as alignment with project goals) attributes were used in other approaches. The addition of Turner’s approach is the Knowledge attribute, which could be an important attribute to energy efficiency, since knowledge of design, building techniques, materials properties etc. can contribute to enhancing energy efficiency.

3.4 Evaluation of the prioritisation approaches

Table 2 compares the attributes used by each of the prioritisation approaches discussed in section 3.3. The shaded cells indicate attributes and approaches considered unsuitable for energy efficient housing purposes, because of complexity and deviance from other approaches (Rowley, 1997), because attributes are too broad or narrow (Savage, et al., 1991), or attributes would be difficult to apply or give inaccurate results (Mitchell, Agle, & Wood, 1997). The remaining attributes were considered to be suitable for prioritising energy efficiency stakeholders:

- **Power**: The power to implement energy efficiency, impose decisions and take actions that will result in enhancing the energy efficiency of the house.
- **Interest/value**: The value of energy efficiency to each stakeholder. The value/interest attribute could be understood as the actions that a stakeholder is willing to make to enhance energy efficiency (the willingness to pay, cooperate, spend time, effort, etc.), and the degree that their interests align with the goal of enhancing energy efficiency,
- **Proximity**: How involved and close to the decision making and execution processes are these stakeholders.
- **Knowledge**: The degree of knowledge about the requirements needed to achieve energy efficiency (e.g. designers who have the knowledge about energy efficiency design principles have more power to implement energy efficiency).

Table 2: Analysis of prioritisation attributes applicable to energy efficiency

<table>
<thead>
<tr>
<th>Authors</th>
<th>Mitchell et.al.</th>
<th>Savage et al.</th>
<th>Rowley</th>
<th>Scholes and Clutterbuck</th>
<th>Johnson et al.</th>
<th>Berardi</th>
<th>Bourne</th>
<th>Turner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes</td>
<td>Power</td>
<td>Potential threat (too broad)</td>
<td>No attributes</td>
<td>Impact (power) on business</td>
<td>Power</td>
<td>Power</td>
<td>Power</td>
<td>Power</td>
</tr>
<tr>
<td></td>
<td>Legitimacy / inapplicable</td>
<td>Potential cooperation (too narrow)</td>
<td>Shared purposes (interests)</td>
<td>Interest</td>
<td>Interest</td>
<td>Value &amp; action</td>
<td>Interest</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urgency / inapplicable</td>
<td></td>
<td>Impact by business</td>
<td>Time</td>
<td>Proximity</td>
<td>Knowledge</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The time dimension could be useful as a sub-attribute for analysing/quantifying the significance of each one of the four main attributes since their significance could vary depending on the stage of the house lifecycle that a stakeholder becomes involved in.

Table 2 illustrates that three out of the four relevant attributes are inherent in the approaches of both Bourne and Turner however there are other factors that favour the former over the latter. First, Bourne’s approach provides a numerical value for the overall priority of a stakeholder to the
organisation, possibly enabling quantifiable outcomes of prioritising stakeholders to be compared with the quantifiable outcomes of energy efficiency. Second, this approach’s visualization tool enables the immediate comparison of a number of attributes between different stakeholders. With the addition of the knowledge attribute and the time dimension, it appears that Bourne’s approach could be the most suitable approach for prioritising energy efficiency stakeholders.

4. Conclusion

This paper has analysed 16 approaches to stakeholder management in order to evaluate which approach is theoretically best suited for evaluating stakeholders that could influence energy efficiency performance outcomes for housing. This evaluation has shown that Bourne’s classification and prioritisation approach is the most suitable for this purpose however it will require some modification, such as the addition of a knowledge attribute and a time dimension. Further research will apply the identified modifications and test the applicability of the modified tool on a range of practices that aim to maximise housing’s energy performance. Potential applications of such a modified tool include: optimisation of housing industry’s stakeholders conflicting goals; quantifying the impact of each stakeholder on energy performance; correlating stakeholders’ relationships models with energy efficiency; developing policies that are embraced by the majority of stakeholders; and tailoring a combination of instruments that aim to steer the cultures and behaviours of stakeholders towards more energy efficient practices.

Further areas of research could be expanded also to include other stages of stakeholder management such as the engagement and monitoring that comes after the identification, categorisation and prioritisation stages discussed in this paper, to discuss and investigate the most suitable strategies for engaging and monitoring energy efficiency’s stakeholders.

5. References


An evaluation of stakeholders’ management approach for improving energy efficiency outcomes in housing


Energy Consumption, CO₂ Emissions of Urban Residential Buildings in China and Their Modelling

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Abstract

Purpose / Context - The purposes of this study are to clarify the trend of unit energy consumption (UEC) and its related CO₂ emissions in urban residential buildings, and to develop models to predict the UEC in the future.

Methodology / Approach - Statistical method is adopted to clarify the UEC and related CO₂ emissions.

Results – (1) The UEC averaged over all regions grows from 14.3GJ/household/year to 23.0GJ/household/year during the period of 2002 - 2012. Coal and LPG decrease and electricity, district heating increase in percentage.
(2) The CO₂ emissions are growing from 2,170 kgCO₂/household/year to 3,671 kgCO₂/household/year during the period of 2002 - 2010. CO₂ emissions by electricity and district heating account for 54% and 35%, respectively.
(3) Models are developed to estimate UEC for heating and non-heating regions, respectively.

Key Findings / Implications – In order to reduce CO₂ emissions by electricity and district heating it is efficient to improve the energy efficiencies of buildings, energy conversion systems, such as boilers, pipelines, generators, etc. It is also important to convert energy source from coal to cleaner energy, such as natural gas.

Originality – This study makes clear quantitatively the energy consumption in the urban residential buildings, and CO₂ emissions caused by the energy consumption.

Keywords - UEC, CO₂ emissions, Statistics, Modelling, China
1. Introduction

In recent years, with the rapid economic growth and improvement of living standard in China, energy consumption has been increasing significantly. Energy conservation is the most important issue for a sustainable society in China. In the residential sector, structure of energy consumption and CO₂ emissions should be clarified for policy makers as well as researchers and engineers. Energy conservation and CO₂ emission reduction may contribute significantly to the sustainability of buildings which is an important topic of the present conference.

Some studies have been carried out on residential energy consumption for apartment houses in cities of China. Yoshino et al. have made clear the energy consumption of apartment houses for six Chinese cities by surveying (Yoshino et al., 2004); Zhang et al. clarified the energy consumption for the major cities of China in 1997 using official statistics, developing a model predicting energy consumption in the residential houses in China (Zhang et al., 2003); Ning et al. investigated the structure of energy consumption by its types in urban and rural areas in China using the Chinese statistics (Ning et al., 2007); Ling et al. investigated the consumption of electricity and gas for 23 areas in Beijing and made clear the average energy consumption except energy for district heating (Ling et al., 2012). All these studies can be classified into two methods: statistical and survey methods. With the statistical method, researches often face the problem of lacking the items needed for their analyses; but with the survey method, it is difficult to tell if the results can represent the average. Because the statistical method is based on large number of samples, it is adopted in this study. All the studies mentioned above have not been able to make clear the trend of energy consumption in the urban houses, nor the CO₂ emissions caused by the energy consumption.

The purposes of this study are to clarify the trend of unit energy consumption (UEC) and its related CO₂ emissions in urban residential buildings, and to develop models to predict the UEC in the future. First, 82 cities are selected as the objects of this study; using the official statistics of the Chinese government, the average unit energy consumption is calculated throughout the period of 2002-2012. The changes of the UEC and related CO₂ emissions are analyzed. Models are developed to estimate UEC for heating and non-heating regions, respectively.

2. Cities as the objects of research

According to the China City Statistical Yearbook (National Bureau of Statistics of China, 2002-2013a), there are 290 cities in China in total, from which 82 cities are selected as the objects of this study. A list of the cities is shown in Table 1. According to the Thermal Design Code of Residential Buildings (Ministry of Housing Urban and Rural Development of China, 1993), China is classified into 5 kinds of regions: Severely cold region, Cold region, Hot-summer-cold-winter Region, Hot-summer-warm-winter Region, and Mild Region as shown in Figure 1. Furthermore, the former two regions are called heating regions because district heating systems are equipped in these regions; the others are called non-heating regions because no district heating system is equipped in these regions in urban planning.

Of all the 82 cities to be studied in this paper, 37 cities are located at heating regions and other 45 cities are located at non-heating regions.

3. Unit energy consumption and energy types

The energy consumption per capita of different types is calculated using the residential consumption of electricity, coal, coal and natural gases, LPG for each city divided by population in the same city, then energy consumption for each household is calculated by multiplying energy consumption per capita by population per household.
Table 1 Cities to be studied in this paper

<table>
<thead>
<tr>
<th>Heating regions</th>
<th>Provinces</th>
<th>Cities</th>
</tr>
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<tbody>
<tr>
<td>Beijing</td>
<td>Beijing</td>
<td></td>
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<tr>
<td>Tianjin</td>
<td>Tianjin</td>
<td></td>
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<tr>
<td>Hebei</td>
<td>Shijiazhuang, Tangshan, Xingtai, Baoding, Zhangjiakou, Chengde</td>
<td></td>
</tr>
<tr>
<td>Shanxi</td>
<td>Taiyuan, Yuncheng</td>
<td></td>
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<tr>
<td>In. Mongolia</td>
<td>Hailaer</td>
<td></td>
</tr>
<tr>
<td>Liaoning</td>
<td>Shenyang, Benxi, Dandong, Jinzhou, Yingkou, Chaoyang</td>
<td></td>
</tr>
<tr>
<td>Heilongjiang</td>
<td>Harbin, Qiqihar, Jixi</td>
<td></td>
</tr>
<tr>
<td>Shandong</td>
<td>Jinan, Qingdao</td>
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<tr>
<td>Henan</td>
<td>Zhengzhou, Anyang, Nanyang, Xinyang, Zhumadian</td>
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<tr>
<td>Shaanxi</td>
<td>Xi’an, Baoji, Yan’an, Hanzhong, Ankang</td>
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<tr>
<td>Gansu</td>
<td>Lanzhou, Tianshui, Pingliang, Jiuquan</td>
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<td>Qinghai</td>
<td>Xining</td>
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<tr>
<td>Heating regions</td>
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<tr>
<td>Non-heating regions</td>
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<tr>
<td>Shanghai</td>
<td>Shanghai</td>
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<td>Jiangsu</td>
<td>Nanjing, Xuzhou</td>
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<td>Zhejiang</td>
<td>Hangzhou, Quzhou, Lishui</td>
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<tr>
<td>Anhui</td>
<td>Hefei, Wuhu, Bengbu, Anqing, Buyang</td>
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<td>Fujian</td>
<td>Fuzhou, Xiamen, Nanping</td>
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<td>Nanchang, Ganzhou</td>
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<td>Hubei</td>
<td>Wuhan, Yichang</td>
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<td>Hunan</td>
<td>Shaoyang, Yueyang, Changde, Chenzhou</td>
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<td>Guangdong</td>
<td>Guangzhou, Shaoquan, Shantou, Meizhou, Yangjiang</td>
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<td>Guangxi</td>
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<td>Haikou, Sanya</td>
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<td>Chongqing</td>
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<td>Sichuan</td>
<td>Chengdu, Luzhou, Mianyang, Nanchong, Ya’an</td>
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<tr>
<td>Guizhou</td>
<td>Guiyang, Zunyi</td>
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<tr>
<td>Yunnan</td>
<td>Kunming, Baoshan, Shaotong</td>
<td></td>
</tr>
</tbody>
</table>

3.1 Average population per household

According to China Statistics Yearbook (National Bureau of Statistics of China, 2002-2013b), the average population per household decreased from 3.47 to 3.16 during the period of 2002 – 2012, which shows the size of families in China keeps small because of the birth control policy starting from 1970s.

3.2 Consumption of electricity for each household

As shown in Figure 2, during the period of 2002-2012, electricity consumption for each household increased from 1,145 to 2,365 kWh. The main reason for this is the increase of electrical appliance, such as air conditioners, personal computers, etc. Comparing the electricity consumption in Japan which is 5,177 kWh/household/year in 2012, the level of electricity consumption is still low, and will increase further in the near future with the improvement of living standards in cities of China.

3.3 Consumption of liquid petroleum gas (LPG) for each household

As shown in Figure 3, consumption of LPG decreases from 58 kg/household/year to 39 kg/household/year during the period of 2002 - 2012, in spite of the increasing trend of energy consumption. The main reason for the decreasing trend is probably the inconvenience when changing the containers.
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3.4 Consumption of coal for each household

Coal was a main energy source in 1990s, but has been gradually replaced by gases since then. Because there are no direct data on coal consumption for urban households, the consumption of coal for each household was estimated in a previous study by the authors (Zhang and Yoshino, 2016), the results of which are adopted in this paper. During the period of 2002 – 2012, coal consumption per household is between 44 to 50 kg/household/year.

3.5 Consumption of natural and coal gases for each household

In China City Statistical Yearbook consumption of coal and natural gases is given. The consumption of coal and natural gases is shown in Figure 4. The consumption of natural gas is in a growing trend, while that of coal gas has no obvious change.

3.6 Energy consumption for district heating

As mentioned before, China is classified into heating regions where district heating systems are equipped; and non-heating region where there are not district heating systems. In the non-heating regions energy consumed for individual space heating, if any, is included in other types of energy,
such as coal, electricity, etc. For the heating regions, energy for district heating is calculated from the total energy for heating in the energy balance tables divided by urban populations for each province.

As shown in Figure 5, energy consumption for district heating averaged over all regions has been growing from 3.6 GJ/household/year to 9.0 GJ/household/year, while the value averaged over the heating regions grows from 8.0 to 18.0 during the period of 2002-2012.

### 3.7 Unit energy consumption

As shown in Figure 6, unit energy consumption is calculated by summing different types of energy mentioned above. The UEC averaged over all regions grows from 14.3GJ/household/year to 23.0GJ/household/year during the period of 2002 - 2012. Coal and LPG decrease and electricity, district heating increase in percentage.
4. CO₂ emissions related to energy consumption in residential buildings

4.1 CO₂ emissions by fossil fuels

The gas of CO₂ is emitted with the consumption of fossil fuels. CO₂ Emissions by coal, gas, LPG can be calculated using the following equation:

\[ U_f = \left( \sum (Q_i \cdot H_i \cdot f_i) \right) \cdot \frac{44}{12} \]  \hspace{1cm} (1)

where \( U_f \) is the CO₂ emissions with the consumption of fuels in residential buildings, kgCO₂/household; \( Q_i \) is the consumption of fuel \( i \) (m³/household for gases, kg/household for coal and LPG); \( H_i \) is the calorific value of fuel \( i \) (GJ/m³ for gases, GJ/kg for coal and LPG), \( f_i \) is the carbon emission factor of fuel \( i \) (kgC/GJ) shown in Table 2 (China National Development and Reform Commission, 2011).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Calorific values and carbon emission factor of different fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal (GJ/kg)</td>
</tr>
<tr>
<td>Calorific value</td>
<td>0.0209</td>
</tr>
</tbody>
</table>
| Carbon emission factor | 26.97 | 15.32 | 13.58 | 17.20 @
4.2 CO₂ emissions by electricity consumption

In China, carbon dioxide emission factor differs from region to region, the value of which is shown in Table 3 (China National Development and Reform Commission, 2011). The value for Nanfang Grid is the smallest, and that for the Huabei Grid is the largest.

4.3 CO₂ emissions by district heating

According to the energy balance table of China, the energy source of district heating is mainly coal. The efficiency of district heating system including boilers, pipelines, etc. is 70%±1% during the period of 2002-2012. In this study, the efficiency is supposed to be fixed at 70% when estimating CO₂ emissions. CO₂ emissions estimated by summing the emissions by various types of energy are shown in Figure 8. CO₂ emissions are growing from 2,170 kgCO₂/household/year to 3,671 kgCO₂/household/year during the period of 2002 - 2010. CO₂ emissions by electricity and district heating account for 54% and 35%, respectively. It is clear that in order to reduce CO₂ emissions by electricity and district heating it is efficient to improve the energy efficiencies of buildings, energy conversion systems, such as boilers, pipelines, generators, etc. It is also important to convert energy source from coal to cleaner energy, such as natural gas, and so on.

5. Modeling of the UEC

Zhang et al. developed a model to predict the UEC using heating degree-days, cooling degree-hours, energy price, floor area, etc. as parameters (Zhang, Q. and Asano, K., 2003). Errors in the predicted results occurred because the same model was used for both heating and non-heating regions.
In this study, models to predict the UEC are developed for the heating and non-heating regions, respectively.

5.1 Modelling of UEC for heating regions

It is known that the unit energy consumption is influenced by weather conditions (heating degree-days, cooling degree-hours, solar radiation in summer and winter), latitude, income, etc. For heating regions, the following model can be created using the least square method:

\[
E = 0.0077 - 0.1984 \cdot \varphi + 0.01102 \cdot HDD + 0.0024372 \cdot CDH \\
+ 0.000691 \cdot I + 0.05903 \cdot R_1 - 0.0701R_7
\]  

(2)

where \(E\) is the UEC in GJ/household/year; \(\varphi\) is the latitude; \(HDD\) is the heating degree-days, \(CDH\) is the cooling degree-hours; \(I\) is the income in YUAN/employee; \(R_1\) and \(R_7\) are the monthly solar radiation in January and July in GJ/month, respectively.

The correlation between UECs by Eq.(2) and statistics is shown in Figure 9. The root mean square error from Eq.(2) is 3.43, which shows the UEC in heating regions can be estimated with limited errors.

The correlations coefficients of each parameter with the UEC in Eq.(2) are shown in Table 4. Both the latitude and heating degree-days have strong relations with the UEC.

Table 4 Corelation coefficients of parameters in Eq.(2)

<table>
<thead>
<tr>
<th></th>
<th>(\varphi)</th>
<th>HDD</th>
<th>CDH</th>
<th>I</th>
<th>(R_1)</th>
<th>(R_7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coef.</td>
<td>0.82</td>
<td>0.70</td>
<td>0.44</td>
<td>0.41</td>
<td>0.071</td>
<td>0.044</td>
</tr>
</tbody>
</table>

5.2 Modelling of UEC for non-heating regions

Similarly, a model for the non-heating regions is developed:

\[
E = 14.98 + 0.0324 \cdot \varphi - 0.00411 \cdot HDD - 0.000364 \cdot CDH \\
+ 0.000566 \cdot I - 0.01324 \cdot R_1 - 0.0158 \cdot R_7
\]  

(3)

The correlation between UECs by Eq.(3) and statistics is shown in Figure 10. The root mean square error from Eq.(3) is 3.54, but the decisive coefficient \(R^2\) is as low as 0.55. One of the reasons for the low decisive coefficient and large error is that no strong factor such as heating degree-days exists and space heating is a personal behavior in the non-heating regions. The residents can either use space heating individually or put on more clothes, which make the estimation of UEC more difficult.
The correlation coefficients of each parameter in Eq.(3) with the UEC are shown in Table 5. Only income has strong relations with the UEC, while correlation between other parameters and UEC is very weak. The correlation coefficient between heating degree-days and UEC is only 0.22, which is much smaller than that in the heating regions shown in Table 4. This also demonstrates that residents in the non-heating regions not only rely on heating equipment but also adjust clothing to achieve thermal comfort. The income of residents may influence the decision making in winter on whether or not heating equipment should be used.

Because different power grids have different CO₂ emission coefficients which are decided by the types of fuels, it is difficult to develop models to estimate CO₂ emissions in China.

6. Summary

In this paper, using statistical data, the unit energy consumption and CO₂ emissions caused by energy consumption in residential buildings are made clear.

The main conclusions are as follows:
(1) The UEC averaged over all regions grows from 14.3GJ to 23.0GJ during the period of 2002 to 2012. Coal and LPG decrease and electricity, district heating increase in percentage.
(2) CO₂ emissions are growing from 2,170 kgCO₂/household/year to 3,671 kgCO₂/household/year during the period of 2002 - 2010. CO₂ emissions by electricity and district heating account for 54% and 35%, respectively.
(3) Models are developed to estimate UEC for heating and non-heating regions, respectively.

7. Acknowledgment

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8. References

What can we learn if we measure the indoor and outdoor number concentration of PM2.5 at the same time?

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Abstract

Purpose / Context - Indoor airborne bioaerosol, which has an outdoor origin, plays an important role in determining the exposure of humans to bioaerosol, since people spend most of their time indoors. However, there are few studies focusing on the indoor bioaerosols that are generated outdoors.

Methodology / Approach - In this study, indoor-outdoor size resolved concentrations of airborne fluorescent bioaerosol in an office room were measured continuously for six days (144 h) by using a fluorescent bioaerosol detector. We focused on the particulate matter with an aerodynamic diameter <2.5μm.

Results – The ratios of indoor to outdoor particle concentration and those of bioaerosol to aerosol concentrations in various size ranges vary significantly. The measured and predicted concentrations have a linear relationship for the studied size fractions, with R² of all size fractions larger than 0.83.

Key Findings / Implications – Correlations between indoor and outdoor bioaerosol concentrations show significant concentration-attenuation and time-lag over time.

Originality - A two-parameter, semi-empirical model was proposed to predict the concentration of indoor bioaerosol with outdoor origin.

Keywords - Bioaerosol; Indoor air; Outdoor origin; WIBS; Size distribution
1. Introduction

Epidemiological and toxicological researches have shown that exposure to PM (Particle Matter) in air can increase the rates of cardiac and respiratory morbidity, premature death, hospital admission and mortality (Pope et al., 2004, Davidson et al., 2005, Pope and Dockery, 2006, USEPA, 2009, Lim et al., 2012, Chen et al., 2013). Exposure to bioaerosol can cause atopic diseases and other adverse health effects, such as asthma, allergic, toxic, rheumatic, and infectious diseases (Burger, 1990, Menetrez et al., 2001, Hanski et al., 2012). Ambient air population exposure is closely linked to indoor environment. On the one hand, people spend 85–90% of the time indoors (Brauer et al., 2000, Klepeis et al., 2001, Adgate et al., 2002, Wang et al., 2010). On the other hand, indoor PM2.5 is principally contributed by outdoor infiltration, if do not consider the origin of indoor human activities, the gas to solid phase transformation and indoor PM re-suspension.

In general, the relationship of PM between indoor and outdoor environment can be described by the mass balance equation. When indoor particles generation can ignore, the relationship between indoor and outdoor PM depends on three key parameters: air change rate, penetration efficiency and deposition rate, based on the mass balance equations. In these parameters except a are a function of both time and particle size (Chen and Zhao, 2011). Infiltration becomes the main ventilation mode without the mechanical ventilation, the penetration determines how much ambient particle can be brought from outside into the indoor environment and deposition on indoor-surface is one of the major particle losses. (Chao et al., 2003, Hoek et al., 2008). The fine particulates are dominated indoors because most large size particles in suspended particulates are removed by the penetration progress during airflow across building enclosure. (Liu and Nazaroff, 2001, Chao et al., 2003, Chen et al., 2012). The penetration efficiency depends on the geometry of building gaps, the differential pressure between indoor and outdoor and the size spectrum of particles (Liu and Nazaroff, 2001, Chao et al., 2003, Chen et al., 2012). Nevertheless, the fine particulates are mainly removed by the mechanisms of diffusion and thermophoresis effect. (Mak et al., 2011). Particularly, the effect of filter efficiency will replace penetration efficiency when using mechanical ventilation. Overall, estimates of the infiltration factor generated using dynamic models and infiltration surrogates show good agreement (Diapouli et al., 2013).

However, there are very few studies focusing on indoor bioaerosols that are generated outdoors. In the present study, indoor emissions were controlled strictly to ensure that indoor bioaerosols originate entirely from an outdoor environment, thus the infiltration factor, which is the parameter quantifying the contribution of outdoor bioaerosols could be obtained. A model that can predict the indoor bioaerosol concentration with an outdoor origin was developed. Particle size distributions and concentrations of indoor and outdoor fluorescent primary biological aerosol particles (FBAP) were recorded.

2. Methods

2.1 Study design

Aerosol measurements were performed continuously for a total of 144 h, from 10/03/2015 to 16/03/2015. Indoor and outdoor measurements were made using a single WIBS-4A, which records the optical size and levels of the sphericity, in addition to the fluorescence emission matrix from individual particles at a constant sample flow rate of 0.3 L/min (total flow: 2.5 L/min, sample flow: 0.3 L/min, and sheath flow: 2.2 L/min). Continuous measurements of indoor and outdoor bioaerosol concentration relied on a single WIBS instrument using an automated control box, consisting of two globe valves (KLD20S 2-way motorized ball valve) and a timer device controlling the switch of the measured aerosol between the indoor and outdoor environment passing through the spectrometer every 5 minutes. The waveband WIBS 4A is a single particle UV-induced fluorescence spectrometer. It excites and detects fluorescence in particles sized from 0.5 to 15 μm, by using two UV xenon lamps that provide two sequential ultraviolet pulses centered at 280 and 370 nm. Uncertainties related to WIBS measurement.
2.2 Analytical model

The concentration of indoor PM$_{2.5}$ can be evaluated as a function of the infiltration rate ($F(t)$) and outdoor PM$_{2.5}$ concentration ($C_{\text{out}}(t)$), when indoor particles generation can ignore

$$C_{\text{in}}(t) = F(t)C_{\text{out}}(t)$$ (1)

When use the steady-state assumption form the mass balance equation, the equation can be described as:

$$C_{\text{in}} = \frac{aP}{a + K}C_{\text{out}}$$ (2)

When use the dynamic assumption, the relationship of PM$_{2.5}$ between indoor and outdoor environment can be described by the mass balance equation:

$$V \frac{dC_{\text{in}}(t)}{dt} = aP C_{\text{out}}(t) - (a + K)VC_{\text{in}}(t) + \overline{C}$$ (3)

Where $C_{\text{in}}(t)$ is the indoor PM concentration and $C_{\text{out}}(t)$ is the outdoor concentration ($\mu g / m^3$); $a$ is the air change rate ($h^{-1}$); $P$ is the penetration efficiency of particles; $K$ is the deposition rate of particles ($h^{-1}$); $V$ is the volume of the indoor space ($m^3$); $\overline{C}$ is the indoor particles generation rate ($\mu g / h$).

Particularly, $P$ can be describe as $1 - \eta$ when using mechanical ventilation.

$$P = 1 - \eta$$ (4)

Where $\eta$ is the filter efficiency.

Air change rates of the office were measured using the tracer gas decay method. Carbon dioxide gas was released and the concentration increased up to 2000 ppm. In our experiment room, only one process may add bioaerosol to the indoor air: infiltration through leaks in the building envelopes. Two processes may remove bioaerosol material: (1) ventilation airflow out of the building, and (2) deposition onto room surfaces. Thus the equation can be written as:

$$V \frac{dC_{\text{in}}(t)}{dt} = aP C_{\text{out}}(t) - (a + K)VC_{\text{in}}(t)$$ (5)

Where $V$ is the volume of the room ($L$), $C_{\text{in}}$ the number concentration of indoor aerosol ($#/L$), $a$ the air exchange rate in the room ($h^{-1}$), $P$ the penetration ratio $C_{\text{out}}$ the number concentration of outdoor aerosol ($#/L$), $K$ the deposition rate ($h^{-1}$).

To show the result in a simpler way, we define $\phi = aP$, $\varphi = a + K$; then the equation can be written as:

$$\frac{dC_{\text{in}}(t)}{dt} = \phi C_{\text{out}}(t) - \varphi C_{\text{in}}(t)$$ (6)

We assume that $\phi$ and $\varphi$ are constant within certain time range.

3. Results

We analyze the size-resolved indoor-outdoor airborne bioaerosol in time series and use a mass balance equation to model the outdoor-indoor relationship. The number concentration of outdoor non-fluorescent aerosols and Bioaerosols, show a periodic fluctuation in all size ranges. The indoor concentration changes according to the outdoor conditions, but it shows significant concentration-attenuation and time-lag. The concentration of bioaerosols made up no more than 10% of non-fluorescent aerosols and the test result showed that the uncertainty there is in an hour, the lower is the concentration. The variation trend of bioaerosols and non-fluorescence aerosols is similar except for the changing amplitude. More detailed information can be found in Figure 1 (a, b, c and d).
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What can we learn if we measure the indoor and outdoor number concentration of PM2.5 at the same time?

HealthyHousing2016: 20-24 November, 2016, Queensland University of Technology, Brisbane, Australia.

4. Discussion

The indoor bioaerosols of an outdoor origin are mostly fine particles. Therefore, we choose the airborne bioaerosol in the size range of 0.5 to 2.5 μm to build the two-parameter iteration model. The two-parameter iteration model does not completely conform to previous theoretical studies (Kulmala et al., 1999, Allen et al., 2012, Diapouli et al., 2013, Nazaroff, 2004). In the absence of indoor emission such as smoking, cooking, burning, and housekeeping in this study, the indoor particle sources can be ignored; resuspension is also ignored because of the low wind speed indoors in this study. Therefore, the indoor emission and resuspension are not incorporated in equation (5). The mass balance model assumes that the indoor space is well mixed and can be described using lumped parameters. In fact, the distribution of bioaerosols is not well-distributed in indoor space. The physical meaning of parameter \( \phi \)
can be considered as the characteristic parameters of outdoor addition, so the parameter $\phi$ can be larger near the windows. In fact, it is very difficult to ensure species in the air uniformly distributed for a typical room. The age of air near windows is younger than room air age and the air change rate near windows can be larger than the mean air change rate according to the equation $\tau = \frac{1}{a}$. Moreover, the air change rate, penetration, and deposition are time-varying parameters in the strict sense. However, the two-parameter iteration model can predict indoor concentration successfully when the indoor flow field is under steady-state approximation.

The results from our week long experiment suggest that indoor concentrations of bioaerosols from outdoor environment are consistently lower than the concentrations outdoors, and $\phi / \phi$ is approximately equal to the mean I/O ratio. This study offers a near real-time evaluation in the variation of indoor FBAP from the outdoor environment for a typical office without HVAC systems, which are yet abundant in many locations, and provide a universal model to assess the contribution of the outdoor bioaerosols.

5. Conclusion

The main conclusions could be drawn based on this study, in which the indoor and outdoor particle size distributions and concentrations of fluorescent primary biological aerosol particles (FBAPs) were measured using a Waveband Integrated Bioaerosol Sensor (WIBS) over six days:

1. Both indoor and outdoor bioaerosol size distributions can be fit with a two-mode, log-normal distribution (indoor $R^2=0.935$, outdoor $R^2=0.938$), AF distributions can also be fit with a log-normal distribution (indoor $R^2=0.992$, outdoor $R^2=0.992$).
2. Correlations between indoor and outdoor bioaerosol concentrations show significant concentration-attenuation and time-lag over time.
3. The concentrations measured by WIBS and predicted by the two-parameter, semi-empirical model have a linear relationship for the studied size fractions, with $R^2$ of all size fractions larger than 0.83.

6. Acknowledgement

This work was supported by fundings from Innovative Research Groups of the National Natural Science Foundation of China (No. 51521005).

7. References

What can we learn if we measure the indoor and outdoor number concentration of PM2.5 at the same time?


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Effect of phase change materials on indoor thermal comfort of a flat building located in different climate regions of China

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Abstract

In this research, the effect of phase change material (PCM) on indoor thermal comfort of a flat building located in five different climate regions of China was studied by an angle coefficient method and EnergyPlus. EnergyPlus was used to calculate temperatures of wall surfaces, and the angle coefficient method was used to calculate PMV (predicted mean vote) value located different indoor position.

Based on the calculated PMV values for different distance to south wall, it can be known that phase change materials can obviously increase the time of the indoor PMV value within the range (-1, 1) in climate region of cold & mild. It can also reduce fluctuations of different location indoor PMV value.

In climate regions of both hot summer & cold winter and hot summer & warm winter, there is little effect of phase change materials on PMV.

Keywords: Indoor thermal comfort; PCM; PMV; Angle coefficient method
1. Introduction

The indoor thermal comfort is a kind of subjective consciousness, which means the degree of people's satisfaction often surrounding thermal environment [1]. Generally speaking, there are two kinds of calculation model for the indoor thermal comfort. One is PMV (Predicted Mean Vote) /PPD (Predicted Percent Dissatisfied) model [2], the other is the adaptive comfort model [3]. The first method is a complex formula based on human body heat balance, and the latter is a simple equation combined with the indoor thermal comfort temperature and outdoor environment temperature. In this paper, we choose the PMV/PPD as a calculation model to study the indoor thermal comfort.

2. Methodology

2.1 PMV calculation model

PMV (Predicted Mean Vote) is based on human body heat balance and the level of subjective sensation of indoor thermal in Psychology, considering the comprehensive factors like the human body thermal comfort. The partition of human thermal feeling and PMV is shown in Table 1, when the value is between (-1, 1), it is said the indoor thermal comfort is good.

Table 1: The degree of PMV

<table>
<thead>
<tr>
<th>Thermal feeling</th>
<th>hot</th>
<th>warm</th>
<th>slightly warm</th>
<th>middle</th>
<th>Slightly cool</th>
<th>cool</th>
<th>cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>The value of PMV</td>
<td>+3</td>
<td>+2</td>
<td>+1</td>
<td>0</td>
<td>-1</td>
<td>-2</td>
<td>-3</td>
</tr>
</tbody>
</table>

There are four environmental factors, including air temperature, the average radiation temperature, relative humidity and air velocity, and two personal factors, thermal resistance of clothing and human metabolism rate, considered in this thermal comfort index. PMV calculation model has been demonstrated in a variety of climatic conditions [4].

Table 2: The related parameters of PMV

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
<th>Origin</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>human metabolism rate</td>
<td>69.78 W/s²</td>
<td>GB 18049-2000</td>
<td>46.52 W/s²—232.6 W/s²</td>
</tr>
<tr>
<td>air velocity</td>
<td>0.1 m/s</td>
<td></td>
<td>0 m/s—1 m/s</td>
</tr>
<tr>
<td>thermal resistance of clothing</td>
<td>0.08 m²°C/W</td>
<td></td>
<td>0 m²°C/W—0.31 m²°C/W</td>
</tr>
</tbody>
</table>

2.2 Improvement of PMV calculation model --- Angle coefficient method

Through the building thermal comfort calculation method --- PMV method, it only roughly calculates the average thermal comfort of buildings. This rough method can be used in small buildings. But with the increasing of building area, indoor temperature and thermal comfort in different location may have obvious difference. As is known to all, the closer to the walls, the hotter in summer indoor. The reasons for this phenomenon is that the radiation temperature of wall is higher, keep in heat emission of human body by radiating through the walls. Thus it can be seen that the radiation temperature in different position indoor is not the same, the radiation temperature in position close to outer walls is higher, and the thermal comfort is worse. In order to analysis the thermal comfort indoor more accurately, in this paper we consider the distance between the human body and the building envelopes when calculating the radiation temperature. Improve PMV calculation model...
with Angle coefficient, to calculate the influence of phase change materials for indoor thermal comfort.

Angle coefficient refers to the ratio of one surface receiving radiation energy which is emitted by another surface. And it can be said the influence of the distance between two surfaces and geometrical relationship for radiation heat transferring. In this paper, we choose the human body as a surface receiving radiation energy and the building envelope as another surface. The calculation formulas of angle coefficient of the human body and the building envelope parallel or perpendicular to the human body are shown as follows:

\[ F_{dA_1-A_2} = \int_{A_1} \frac{\cos \theta_1 \cos \theta_2}{\pi L^2} dA_2 = \int_0^a \int_0^b \frac{h^2}{\pi (x^2+y^2+h^2)^2} \, dx \, dy \quad (1) \]

\[ F_{dA_1-A_2} = \int_{A_1} \frac{\cos \theta_1 \cos \theta_2}{\pi L^2} dA_2 = \int_0^a \int_0^b \frac{h\sqrt{x^2+y^2}}{\pi (x^2+y^2+h^2)^2} \, dx \, dy \quad (2) \]

\[ t_s = t_1^1 F_{A_1-A_2} + t_2^2 F_{A_1-A_3} + \ldots + t_n^n F_{A_1-A_n} \quad (3) \]

Where:
- \( F \): Angle coefficient;
- \( \theta_1 \): The angle of the radiating surface relative to the position of the radiated surface and the normal of radiating surface;
- \( \theta_2 \): The angle of the radiated surface relative to the position of the radiating surface and the normal of radiating surface;
- \( L \): The distance between the radiating surface and the radiated surface;
- \( a, b \): The length of side of the radiating surface;
- \( H \): The vertical distance between the radiating surface and the radiated surface;
- \( t_1, \ldots, t_n \): The radiation temperature of different radiating surfaces.

### 2.3 The verification of the results to Angle coefficient method

In order to verify the correctness of radiation temperature calculated through the Angle coefficient method, Angle coefficient method is used to calculate the radiation temperature at intermediate point of the building model (i.e. ignore of the distance between the human body and the outer wall), and comparing the calculation results with that of the EnergyPlus software. Figure 2 shows the difference of the average radiation temperature calculated using EnergyPlus and that calculated by Angle coefficient method in the middle position. The red line is the different of building model with phase change materials, and the black line is that of building model without PCM. It's easy to see...
that the results of these two calculation methods is very close whether or not containing phase change materials, and the maximum error is less than 1 °C, which proves the accuracy of Angle coefficient method.

![Figure 2 Angle coefficient calculation results and the EnergyPlus simulation results](image)

### 3. Results and discussion

#### 3.1 Influence of PCM for thermal comfort indifferent climate regions

The outer walls around the buildings are considered as building envelopes parallel to the human body. The roofs and floors are considered as building envelopes perpendicular to the human body. When calculating indoor thermal comfort in this paper, it is assumed that the distance between the human body and perpendicular envelopes is constant, just changing the distance between the human body and the south & north walls. To study the ability of phase change materials to improve indoor thermal comfort near the walls and rule out other factors, a building of flat house with area of 360 m² (30 m X 12 m) is chosen as a building model, which is shown in Figure 3. The main parameters of building envelopes are shown in Table 3. Calculate the PMV value of different location (1m, 3m, 5m and 7m far from the wall), and analysis indoor thermal comfort.

![Figure 3 Building mode](image)

**Table 3: The main parameters of building envelopes**

<table>
<thead>
<tr>
<th>Building envelopes</th>
<th>Structural layers (outer to inside)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofs</td>
<td>Concrete (40mm), Insulating (25 mm), Concrete (50 mm), Plasting (10 mm)</td>
</tr>
<tr>
<td>Walls with PCM</td>
<td>Plasting (5 mm), Concrete (20mm), PCM (10mm), Plasting (12mm)</td>
</tr>
<tr>
<td>(south walls)</td>
<td></td>
</tr>
<tr>
<td>Outer walls</td>
<td>Plasting (5mm), Concrete (20mm), Plasting (12mm)</td>
</tr>
<tr>
<td>Floors</td>
<td>Concrete (100mm), Plasting (12mm)</td>
</tr>
</tbody>
</table>
3.2 The influence of PCM for indoor thermal comfort in different climate regions

According to “Design code for heating ventilating and air conditioning”, when calculating indoor thermal comfort, it is necessary to comply with the rule of determining PMV & PPD and thermal comfort conditions in mild thermal environment (GB/T 18049-2000). Evaluate indoor thermal comfort with the index predicted mean vote (PMV) and the index predicted percentage of dissatisfied (PPD), and when PPD is less than 27%, the PMV is within the range (-1, 1) [5]. In this research, indoor thermal comfort is analyzed in summer, from June 15 to September 15, a total of 2230 hours.

In this paper, we choose seven representative cities in different climate regions of China (Shenyang in severe cold climate region, Zhengzhou in cold climate region, Changsha in hot summer & cold winter climate region, Hong Kong in hot summer & warm winter climate region and Kunming in mild climate region), shown in Figure 4, and five kinds of phase change materials with different phase transition temperature (Tpcm=21°C, 23°C, 25°C, 27°C and 29°C).

The PMV value of same building model with different phase change materials in different climate regions is calculated. The total time which PMV is within the range of (-1, 1) of building with PCM is shown in Table 4. The difference between the total time which PMV is within the range of (-1, 1) of building with PCM and that of building without PCM is shown in Table 5 and Figure 5. The more obvious the difference is, the greater the contribution of phase changes materials to maintain indoor thermal comfort.

![Figure 4 Chinese climate regions(2009)](image)

Table 4: Thermal comfortable time in different cities

<table>
<thead>
<tr>
<th>City</th>
<th>Total Time</th>
<th>No PCM</th>
<th>Tpcm=21°C</th>
<th>Tpcm=23°C</th>
<th>Tpcm=25°C</th>
<th>Tpcm=27°C</th>
<th>Tpcm=29°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenyang</td>
<td>2230</td>
<td>1617</td>
<td>1770</td>
<td>1772</td>
<td>1779</td>
<td>1761</td>
<td>1760</td>
</tr>
<tr>
<td>Zhengzhou</td>
<td>2230</td>
<td>931</td>
<td>971</td>
<td>975</td>
<td>986</td>
<td>981</td>
<td>977</td>
</tr>
<tr>
<td>Changsha</td>
<td>2230</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2230</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kunming</td>
<td>2230</td>
<td>1116</td>
<td>1207</td>
<td>1211</td>
<td>1221</td>
<td>1218</td>
<td>1216</td>
</tr>
</tbody>
</table>
Table 5: The increase of thermal comfortable time of building model with PCM

<table>
<thead>
<tr>
<th>City</th>
<th>T_{pc}=21°C</th>
<th>T_{pc}=23°C</th>
<th>T_{pc}=25°C</th>
<th>T_{pc}=27°C</th>
<th>T_{pc}=29°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenyang</td>
<td>153</td>
<td>157</td>
<td>152</td>
<td>144</td>
<td>143</td>
</tr>
<tr>
<td>Zhengzhou</td>
<td>40</td>
<td>44</td>
<td>55</td>
<td>50</td>
<td>46</td>
</tr>
<tr>
<td>Changsha</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kunming</td>
<td>91</td>
<td>95</td>
<td>105</td>
<td>102</td>
<td>100</td>
</tr>
</tbody>
</table>

After the above analysis, according to the difference, a regional distribution diagram of the indoor thermal comfortable time can be drawn, shown in Figure 6. From the diagram, it is easy to seethat phase change materials can obviously increase the time the PMV value within the range (-1, 1) in regions of cold, cool & mild climate. Especially in Shenyang, after using suitable phase change materials, the thermal comfortable time increases 150h in summer, about ten percent. But in regions of both hot summer & cold winter and hot summer & warm winter region, phase change materials have little effect on increasing comfortable time. For example, there is no obvious increase of thermal comfortable time after using phase change materials in Hong Kong and Changsha. The reason for this phenomenonis that the indoor air temperature and PMV value all are decreased, but not enough to make the PMV value within range (-1, 1). Namely, although indoor thermal comfort can be improved by phase change materials, but it is not enough to achieve a comfortable range. In addition, Hong Kong and Changshaare both famous oven cities. Air temperature in summeris very high, more than 33°C in long time, so the energy storage characteristic of phase change materials is difficult to play. Comparing with Figure 4, climate regions in China, the divisions of them are the same, which also shows that the phase change materials are suitable for climate regions of cool, cold and middle.

According to Figure 5, it can be inferred the phase change temperature of phase change materials of each climate region, that of Harbin, Shenyang and Dalian are all 23°C, because of the low air temperature; and that of Kunming and Zhengzhou in middle climate region is 25°C.
3.3 The influence of PCM for indoor thermal comfort in different position of room

In order to study the effect of the phase change materials on improving indoor thermal comfort at different position of room, four points (far from the PCM wall/south wall 1 m, 3 m, 5 m and 7 m) were chosen. For ease to calculation and analysis, it is assumed that four points are located in the middle of east wall and west wall and the distance from human body to floor & roof is also constant. Calculate the PMV and the total time which PMV is within the range of (-1, 1) of building model with suitable PCM in different position, shown in Table 6, and compare them with those of building model without PCM in the same location, calculate the increase of thermal comfortable time, shown in Table 7 and Figure 7.

Table 6: Thermal comfortable time in different position in different cities

<table>
<thead>
<tr>
<th>City</th>
<th>Total Time</th>
<th>No PCM</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenyang</td>
<td>2230</td>
<td>1617</td>
<td>1778</td>
<td>1775</td>
<td>1773</td>
<td>1773</td>
</tr>
<tr>
<td>Zhengzhou</td>
<td>2230</td>
<td>931</td>
<td>1002</td>
<td>999</td>
<td>988</td>
<td>986</td>
</tr>
<tr>
<td>Changsha</td>
<td>2230</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2230</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kunming</td>
<td>2230</td>
<td>1116</td>
<td>1225</td>
<td>1223</td>
<td>1222</td>
<td>1222</td>
</tr>
</tbody>
</table>

Table 7: The increase of thermal comfortable time of building model with PCM

<table>
<thead>
<tr>
<th>The distance from the south wall</th>
<th>1m</th>
<th>3m</th>
<th>5m</th>
<th>7m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shenyang</td>
<td>161</td>
<td>158</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>Zhengzhou</td>
<td>71</td>
<td>68</td>
<td>57</td>
<td>55</td>
</tr>
<tr>
<td>Changsha</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kunming</td>
<td>109</td>
<td>107</td>
<td>106</td>
<td>106</td>
</tr>
</tbody>
</table>
According to Figure 7, the lesser the distance from south wall, the more the increase of thermal comfortable time of building model with PCM, which is evident in all cities. It is said that phase change materials have greater ability to adjust for indoor thermal comfort near the wall. In different cities, the effect of phase change materials on improving indoor thermal comfort is different. Similar to the conclusion above, using phase change materials has great improvement on indoor thermal comfort near the wall in Shenyang, thermal comfortable time which PMV is within the range (-1, 1) respectively increase 161h; That in Zhengzhou and Kunming increase 50~100h; In Changsha and Hong Kong, the increase is almost zero, which is consistent with the conclusion above.

In order to better show the effect of phase change materials, we make a specific analysis on the improvement of PCM on indoor thermal comfortable time in different location of building model from 0 clock to 23 clock on August 1. According to analysis, the difference between the PMV in the position 1m far from the south wall and that 7m far from the south wall is biggest, so the indoor thermal comfort fluctuation according to the location of the situation is shown by the difference between these two PMV. The smaller the difference is, the more constant the PMV in different location, the smaller the indoor temperature fluctuation, and the better the indoor thermal comfort. In Figure 8, the upper boundary of the band chart means the difference of building model without PCM, and the lower boundary is that of building model with PCM. The larger the area of the band chart, the greater the contribution of the phase change materials to reduce the difference in the region, the stronger the ability to increase indoor thermal comfort.

Shown in Figure 8, the area of band chart of Shenyang is significantly greater than that of other regions, which means PMV can more obviously maintain the indoor thermal comfort in different location of room in these two regions. The area of band charts on behalf of Kunming and Hong Kong are smaller, which means the ability of PCM to adjust the indoor thermal comfort is limited in these regions. Additionally, it is obvious to reduce indoor thermal comfort fluctuation after using PCM in Changsha (shown in Figure 8), but it has little impact on increasing thermal comfortable time (shown in Figure 4). The reason is that using phase change materials in such a hot summer climate region like Changsha, although can adjust the indoor temperature and reduce the PMV obviously, but it is not enough to be thermal comfortable and make PMV within the range (-1, 1).
4. Conclusion

In this paper, the PMV calculation model is improved, the distance between the human body and the building envelopes are taken into consideration. So as to solve the limitation of PMV calculation model that it can calculate the average radiant temperature of the room, thus to judge the influence of phase change materials for indoor thermal comfort in different location of the room more accurately. Draw regional distribution diagrams of the indoor thermal comfortable time with the results, and in these diagrams it can be more clear to know the effect of the phase change material to maintain the PMV value within the scope of (-1, 1) in different climate regions, so as to judge the feasibility of phase change materials used in these climate regions.

Research results show that after using phase change materials, the indoor PMV value fluctuations have a significantly reducing, which is more apparent in cold region, cool region and middle climate region, however the phase change materials has a little impact on the indoor thermal comfort in a hot region, including climate region with hot summer and warm winter, climate region with hot summer and cold winter, i.e. the phase change materials suitable for cold, cool and middle climate regions, instead of hot summer climate regions.

5. References

Thermal Performance of Passive Techniques for Roofs in Tropical Climate

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Abstract

Problem: Roofs receive the most intense solar heat load among all building envelope surfaces in Equatorial-region. Solar heat gain through roof contributes to a significant portion of building heat load. In tropics where building cooling is needed all-year-round, passive methods to reduce heat gain through roof could provide significant cooling energy-savings.

Approach: Currently, the most widely adopted practices to curb the heat flux through roof include using thick building material-layer (30-40 cm-thick concrete) or insulation (5-10 cm-thick). This study investigates the thermal performance of emerging methods: cool roof and green roof. Cool roof works by applying a coating-layer having high-solar-albedo. Green roof works by adding a soil-layer and vegetation. This study numerically compares the heat curbing performances of these technologies under the tropical climate using an experimentally-calibrated EnergyPlus model.

Results and discussion: Cool roof performs best in reducing annual net heat gain in tropical climate of Singapore, which receives abundant irradiation. Cool roof reduces heat gain during daytime and promotes heat loss during night-time. Insulation and green roof are effective in curbing heat gain during day-time but they prevent heat loss during night-time.

Research limitations: This paper reports the investigation on a flat concrete roof as the base. Investigations on other roof base materials, e.g., metal roof, will be reported in future.

Originality: This is the first study that compares performances of cool roof, green roof and insulation against original concrete roof in tropical climate.

Keywords: Cool roof; green roof; tropical climate; heat flux, EnergyPlus.
1. Introduction

Energy consumption in the world is rising at an alarming rate. In developed countries, around 40% of the global primary energy is consumed by the building sector, which is currently the largest energy use sector in the world (Laustsen, 2008; Eicker, 2009; Castelton et al., 2010). A significant percentage of the energy consumed in the building sector is used by heating, ventilation and air-conditioning (HVAC) systems to improve the indoor environment thermal comfort (Kua & Wong, 2012; Wee et al., 2008; Zingre, 2015). Studies performed in the tropical climate of Singapore show that HVAC systems consume up to 57% of total electricity consumption in buildings. A computational study performed in an air-conditioned residential apartment (12-storey) building in Singapore showed that the heat gains through the opaque envelope (roof and walls) surfaces constitute about 30% of the total electricity consumption for air-conditioning of the building (Zingre et al., 2015). This highlights the importance of curbing the solar heat gains through opaque envelope (roof and walls) surfaces. Among all building envelope (roof and walls) surfaces, flat and low-slope roof receives the most intense solar heat load and undergoes the highest temperature fluctuations. A study (Nahar et al., 2003) showed that the flat roof can contribute up to 50% of the total thermal load of buildings in hot climates. Therefore, lessening the thermal load of roof would lead to a considerable reduction of energy consumption, hence mitigation of CO₂ emission and urban heat island effect (Xu et al., 2012).

An opaque roof surface (exposed to outdoor) receives solar radiation throughout the daytime. Part of the incident solar radiation is reflected, and the remaining is absorbed. The generated heat at the opaque surface (due to the absorption of incident solar radiation) is dissipated in three parts as: stored heat in the material due to its thermal storage capacitance, conducted heat into the building and lost heat to outdoor by thermal emission and convection (Akbari et al., 2005). Green roof, cool roof and insulated roof are three commonly adopted passive roofing technologies for curbing the solar heat gain into buildings (Castelton et al., 2010; Lam et al., 2005, Tong et al., 2014, Zinzi & Agnoli., 2012). Nevertheless, they have different working principles and different energy saving performance. Cool roof are roofs which can emit heat and reflect incident solar radiation, maintaining the coolness of the roof when exposed to irradiation. In principle, the incident solar radiation entering the roof is greatly reduced as the cool roof reflects the incident solar radiation. Hence, lesser heat load is entering the building, which results in a reduction in the energy usage from the active cooling equipment. Green roof refers to a vegetative system, consisting of real life plants, built on top of a roof of a human-made structure. It is made up of plants with drainage system, waterproofing, filter cloth, root repellent system and a light-growing medium. Green roof works by maintaining a steady surface temperature, mirroring the air temperature or cooler. The vegetation also provides as insulation from the solar rays and reduces heat gain. The plants use a process called evapotranspiration, whereby when the water is evaporated from the plant, it reduces the air temperature. Insulated roof works by using a thick layer of high thermal resistance materials to limit the heat transfer through the roofs. It acts as a barrier, keeping the heat out of the house during hot period and keeping the heat in during cold period. Studies indicated that the three technologies provide different capacities of energy savings (Castelton et al., 2010; Lam et al., 2005, Tong et al., 2014, Zinzi & Agnoli., 2012). Green roof (Sailor, 2008; Zinzi & Agnoli., 2012) was reported to be able to attenuate the heat gain of roof by about 60% when the soil is dry with respect to a traditional roofing with an insulating layer, under the weather condition of northeast of Italy. Cool roof could decrease the air conditioning energy consumption by up to 52% for a retail store building in Sacramento, California during summer time (Akbari et al., 2005). Roof insulation layer can reduce the cooling load by more than 50% for a building compared to uninsulated roof (Tong et al., 2014). The studies also suggested that the energy saving benefits of the three technologies would vary when the climate or the condition of original roof changes. Simulations were performed for the energy saving benefits of cool roof in 27 cities around the world representing different climates. It was found that after increasing the roof solar reflectance from 0.20 to 0.85, Abu Dhabi observed a saving of 48 kWh/m², while Mexico City observed a saving of only 8 kWh/m² (Synnefa et al., 2007).
Several studies compared the energy saving benefits of these technologies. Studies (Zinzi & Agnoli, 2012) found applying cool roof (increased the solar reflectance of roof from 0.20 to 0.89) saved more energy than adding insulation layer (30mm of polystyrene), under the climate of Crete, Greece. Reagan & Acklam investigated the potential energy saving of different combinations of green roof plus insulation layer under the climate of Athens, Greece, and found that adding green roof could save only 2% of the annual energy of the well-insulated building, while could save up to 31-44% annual energy when the building is non-insulated. Zinzi and Agnoli (2012) compared the energy saving benefits of various sets of green roof and cool roof in the Mediterranean region, however, the winter heating penalty occurred in this study suggests that the conclusions may be not applicable to the tropical climate. As of now, the thermal performance of all these technologies has been not been compared in one paper, based on the same primary roof and the same climate conditions.

To fill this research gap, current study investigates the energy saving performance of the three technologies (green roof, cool roof and thermal insulation) in the various climates. A computational study is performed on a real scale building to investigate the energy savings performance of the three technologies in various climates.

2. Computational modelling

In this study, a single-storey building (Hall of residence-4) with a solid flat concrete roof (100-mm-thick concrete + 10-mm-thick plaster on the ceiling) located in Nanyang Technological University, Singapore is used for this comparison study (as shown in Fig. 1). The test building is of rectangular shape having a total opaque roof surface area of about 40 m² (without any skylight surface). EnergyPlus software is used to model the Hall of residence-4 model with detailed and precise data inputs such as site location, dimensions, material properties, construction properties, HVAC system, as well as compact schedules for internal loads. Before conducting the simulations, an accurate model needs to be created. Google SketchUp and OpenStudio plugin comes as an external interface to the EnergyPlus software works work as the 3D modeling tool in this case. Google sketch up is a simple modeling tool that helps to input certain input conditions to the model at the pre-processing stage such as geometric parameters, thermal zones, as well as material properties. It also allows to create the .idf file to be input to Energy plus. Once the 3D model is ready, another EnergyPlus platform called “EP Launch” is used to input all the other parameters and the TMY weather data of the site to the model. EP launch allows to select huge range of input conditions such as HVAC templates, output variables to be simulated, Internal loads, material properties, construction details etc... Once the input data is selected and the file is fully pre-processed, it can be simulated to obtain the desired outputs. However, in order to do any changes in to the .idf file EnergyPlus provides a platform called IDF Editor, where the input file can be edited any time after post processing.

A 3-D model of NTU Hall of residence 4, block 26 and block 27 were created in actual scale and precise parameters as the computational model using Google SketchUp and OpenStudio plug-in. Since the experiments were conducted to take actual measurements of indoor and outdoor air temperature and the solar radiation using a single room at each block in hall 4, the computational model included the thermal zones for the particular rooms and input the identical parameters. As shown in the Fig. 1 each room of hall 4 contained one east facing window and north facing door. PBU is a small rectangular block with surface area of 28.8 m² included one window, a door and a flat roof. For both models, the simulations were conducted with conventional type of concrete and lightweight concrete. The material properties prescribed by the manufacturers were incorporated in EnergyPlus accordingly for the comparison of simulations.
2.1 Physical details of the model

All input parameters, weather conditions and desired output variables in EnergyPlus can be set in the EPLaunch, preprocessing interface. These weather data have attained from International Weather for Energy Calculations (IWEC), which are typical weather data files that contain long term compiled data for a particular location using a certain statistical measure. The weather files are resulted from about 18 years of hourly weather data archived at the U.S National Climatic Data Center. The weather data of a typical metrological year (TMY) for more than 2100 locations can be downloaded from EnergyPlus website, and the weather file for a certain location can be browsed accordingly in EPLaunch before the simulation is run. The other input conditions such as site location, latitude, longitude, time zone, elevation, also can be included under ‘Site Location’ tab of EPLaunch. Table 1 shows the physical parameters input in the computational model in the simulations.

Table 1 Input parameters of Hall of residence-4 in EnergyPlus modeling

<table>
<thead>
<tr>
<th>Location</th>
<th>Nanyang Technological University, Singapore</th>
</tr>
</thead>
<tbody>
<tr>
<td>South and East facing wall Area</td>
<td>7.2 m²</td>
</tr>
<tr>
<td>North and West facing wall Area</td>
<td>13.8 m²</td>
</tr>
<tr>
<td>Roof surface Area</td>
<td>11 m²</td>
</tr>
<tr>
<td>Terrain</td>
<td>Urban</td>
</tr>
<tr>
<td>Latitude and longitude</td>
<td>1.39°N and 103.9°E</td>
</tr>
<tr>
<td>Elevation</td>
<td>35 m</td>
</tr>
<tr>
<td>Air-conditioning system</td>
<td>Unitary System (Single coil) On/Off</td>
</tr>
<tr>
<td>Indoor set temperature</td>
<td>24°C</td>
</tr>
<tr>
<td>Cooling Capacity</td>
<td>2.5 kW</td>
</tr>
<tr>
<td>COP</td>
<td>3.5</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>0.75 kW</td>
</tr>
<tr>
<td>Occupancy</td>
<td>1</td>
</tr>
</tbody>
</table>
2.2 Building material properties

Material properties for Hall of residence-4 are assigned at the “Materials” tab at EPLaunch, as confirmed by the building developer. Certain materials properties such as lightweight concrete and cool coating are as referred to the manufacturer’s guide and past research respectively. The properties of the materials assigned are shown in Table 2.

Table 2 Material properties of the building (Hall of residence-4)

<table>
<thead>
<tr>
<th>Building Materials</th>
<th>Heat transfer coefficient (W/m²-K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td></td>
</tr>
<tr>
<td>Concrete block (150 mm)</td>
<td>21.5</td>
</tr>
<tr>
<td>Gypsum Plaster layer (12 mm)</td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td></td>
</tr>
<tr>
<td>Concrete slab (150 mm)</td>
<td>21.5</td>
</tr>
<tr>
<td>plaster a (12 mm)</td>
<td></td>
</tr>
<tr>
<td>Clear Glazing a (3 mm)</td>
<td>6.5</td>
</tr>
<tr>
<td>Windows</td>
<td></td>
</tr>
<tr>
<td>Air (13 mm)</td>
<td></td>
</tr>
<tr>
<td>Clear Glazing a (3 mm)</td>
<td></td>
</tr>
<tr>
<td>Floor</td>
<td></td>
</tr>
<tr>
<td>Concrete block (300 mm)</td>
<td>18.5</td>
</tr>
<tr>
<td>Acoustic tile (20 mm)</td>
<td></td>
</tr>
<tr>
<td>Doors</td>
<td></td>
</tr>
<tr>
<td>Wood (30 mm)</td>
<td>6.5</td>
</tr>
</tbody>
</table>

2.3 EnergyPlus model calibration using experimental measurements

The computational EnergyPlus model created is calibrated by comparing the measured experimental data and the simulation results for the roof surface temperature and the ceiling surface temperature. Resistance Temperature Detectors (RTD) were installed on the inside and outside surfaces of south, east facing walls and the roof of selected identical rooms at each block as shown in Figs. 2 and 3. Experimental measurements were performed at Hall of residence-4 from January 2016 and hourly surface temperature measurements were collected weekly basis using 8 channels RTD temperature recorder. For the safety of the data recorder, and for easy access, it was kept inside a metal box and placed outside the room. Humidity and indoor temperatures are recorded with a single channel data logger which is kept hanging inside the room. The illustration shown below is the experiment setup at Hall of residence-4. Solar radiation measurements were taken from the center for Climate Research Singapore (research division of the Meteorological Service Singapore). Measurements of global solar radiation were taken by using a Pyranometer installed in NTU.

Figure 2 Illustration of the EnergyPlus model of Hall of residence-4.
Simulations were run based on the different material properties that were used to represent different passive cooling technologies. A total of five different set of material properties were used to represent the following types of roof, original concrete roof, cool roof, green roof and insulation roof material. Table 3 show the five sets of material properties that were used in the simulations.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Original (150 mm lightweight concrete)</th>
<th>Cool roof material</th>
<th>Green roof material</th>
<th>Insulated roof material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness</td>
<td>Medium Rough</td>
<td>Medium Rough</td>
<td>Medium Rough</td>
<td>Medium Rough</td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>0.15</td>
<td>0.15</td>
<td>0.2</td>
<td>0.0508</td>
</tr>
<tr>
<td>Conductivity (W/m.K)</td>
<td>0.49</td>
<td>0.49</td>
<td>0.4</td>
<td>0.03</td>
</tr>
<tr>
<td>Density (kg/m3)</td>
<td>512</td>
<td>512</td>
<td>550</td>
<td>43</td>
</tr>
<tr>
<td>Specific Heat (J/kg.K)</td>
<td>880</td>
<td>880</td>
<td>1000</td>
<td>1210</td>
</tr>
<tr>
<td>Thermal Absorptance</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Solar Absorptance</td>
<td>0.7</td>
<td>0.2</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Visible Absorptance</td>
<td>0.7</td>
<td>0.2</td>
<td>0.75</td>
<td>0.6</td>
</tr>
<tr>
<td>Height of plants (m)</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>-</td>
</tr>
</tbody>
</table>

3. Results

3.1 Computational model calibration

Collected data from NEA climate research center for month of January was compared with the measured data at the NTU Hall of residence-4. For accuracy of the process, two factors were taken into considerations which are outdoor air temperature and total solar radiation. By comparing the data, days with similar weather profiles were chosen to precede the calibration of the model by comparing the measured data and computationally simulated data for the surface temperatures. Roof surface temperature and the ceiling surface temperature for the chosen period of time in month of January using the computational model. The simulated and measured temperature data profiles were found to be within ±5% deviation, as shown in Fig. 4. This calibrated model was used in the rest of the analysis. In the test building, the infiltration rate is unknown. In order to obtain a proper infiltration rate, computational simulations are run for the same week in April (during which the test building measurements were conducted) under different infiltration rate settings. Fig. 4 shows the matching between measurements and simulation data after calibration. The
simulation results obtained under each infiltration rate setting are compared to the measurements results. The roof surface temperature and the ceiling surface temperature are compared in this calibration exercise since these two parameters are used in the subsequent calculation of heat gain through the roof. An infiltration rate of 0.90 air changes per hour (ACH) gives the best matching between simulation and measurement data with errors fall within 5%. The infiltration rate of 0.90 ACH is used in all subsequent computational simulations. The calibrated model is further used to investigate the effect of solar reflectance and thermal emittance on annual heat gain, annual heat loss and annual net heat gain reduction.

Figure 4 Comparison of computational simulated temperatures (after calibration) against measured temperatures for ceiling.

3.2 Effect of cool roof

In this analysis, simulations are performed on an original roof ($\varepsilon = 0.90, \rho = 0.10$) and cool roof ($\varepsilon = 0.90, \rho = 0.74$). The calibrated model is used for this analysis. Figure 6 shows the annual heat gain, annual heat loss and annual net heat gain (summation of annual heat gain and loss) through the three roofs. Table 4 compares the effect of solar reflectance properties on annual heat gain.

Table 4 Comparison of effect of cool roof on annual heat gain.

<table>
<thead>
<tr>
<th>Reduction</th>
<th>Original roof</th>
<th>Cool roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual heat gain</td>
<td>Reference</td>
<td>79%</td>
</tr>
</tbody>
</table>

The difference between annual net heat gains for original roof and cool roof shows the effect of solar reflectance increment of 0.45 (from 0.30 to 0.74) on annual net heat gain reduction. It can be observed (from Table 4 and Fig. 5) that the cool roof provides 79% reduction in annual net heat gain.

Figure 5 Comparison of annual heat gain, annual net heat gain and annual heat loss for original roof and cool roof.
3.3 Effect of green roof

The green roof method provides passive cooling due to two components: 1) conduction resistance offered by the soil layer (about 100-mm-thick) and 2) evapotranspiration by vegetation and evaporation of moisture content in soil. In order to investigate the effect of each component, simulations are performed using the green roof model. In this analysis, simulations are performed on an original roof and green roof with leaf area indices \( \text{LAI} \) = green roof. It can be observed (from Fig. 6) that green roof significantly reduce the annual net heat gain as compared to the original roof.

Table 5 Comparison of effect of green roof on annual heat gain.

<table>
<thead>
<tr>
<th>Reduction</th>
<th>Original roof</th>
<th>Green roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual heat gain</td>
<td>Reference</td>
<td>47%</td>
</tr>
</tbody>
</table>

Figure 6 Comparison of annual heat gain, annual net heat gain and annual heat loss for original roof and green roof.

3.4 Effect of thermal insulation

Thermal insulation provides additional conduction resistance to the original roof. Extruded polystyrene insulation (50-mm-thick) is simulated. In this analysis, simulations are performed on the original roof and the thermal insulation. Fig. 7 and Table 6 show the effect of insulation on annual heat gain reduction through the original roofs. The comparison between original roof and insulated roof (50-mm-thick) indicates the effect of extra thermal resistance due to the insulation layer.

Table 6 Comparison of effect of insulation on annual heat gain.

<table>
<thead>
<tr>
<th>Reduction</th>
<th>Original roof</th>
<th>Insulation (50-mm-thick)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual net heat gain</td>
<td>Reference</td>
<td>78%</td>
</tr>
</tbody>
</table>
3.5 Comparison between cool roof, green roof and thermal insulation

Figure 8 shows the annual heat gain reduction due to the application of cool roof, green roof, and extruded polystyrene insulation (50-mm-thick) over original roof. It can be observed (from Fig. 8) that the increment in solar reflectance (by 0.44) and addition of thermal insulation provide higher annual heat gain reduction (about 79%), than green roof.

4. Conclusions

The thermal performance of various passive roofing technologies on a flat concrete roof (cool roof, green roof and thermal insulation) is compared by performing computational simulations on an air-conditioned, single-storey building (Hall of residence-4) in tropical climate of Singapore. The computational model was calibrated using experimental measurements. It is found that for the commonly used roofs in tropical climate, the annual heat gain reduction provided by
- a cool roof is about 79%,
- adding extruded polystyrene insulation (50-mm-thick) is about 78%, and
- a green roof is about 47%.

This shows that the annual heat gain reduction provided by cool roof and thermal insulation is highest among the three passive cooling technologies in the tropical climate.
5. References


Posters
Levels and Sources of Volatile Organic Compounds in Homes of Hong Kong

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Abstract

The speciation and concentrations of volatile organic compounds (VOCs) were measured in 100 Hong Kong homes using passive samplers. Sixteen VOCs including formaldehyde were identified and quantified in the samples. The 24-h average formaldehyde concentration in 37 homes exceeded the good class of the Hong Kong Indoor Air Quality Objectives (HKIAQO), whereas the total VOCs concentration in all homes was lower than the HKIAQO. Compared to the values concurrently measured in other East Asian cities, formaldehyde and styrene levels in Hong Kong homes were the highest revealing the impact of household products and materials.

The measurement data were applied into a receptor model i.e. principal component analysis (PCA)/absolute principal component score (APCS) to investigate the major sources and their contributions to indoor VOCs in Hong Kong. It was found that pressed wood products, room freshener, consumer products, household solvent, mothball and preservative were the major sources in Hong Kong homes. The pressed wood products made the most significant contribution i.e. 77% ± 1% to indoor VOCs mainly due to the release of formaldehyde. The contributions of room freshener, household solvent and mothball were 8% ± 4%, 6% ± 9% and 5% ± 3%, respectively. The preservative made 4% ± 3% contribution to indoor VOCs and the contribution from consumer product was less than 1%.

Keywords - Volatile organic compounds; PCA/APCSp; Source apportionment; Hong Kong
Verification of the Improvement of Indoor Allergens and Occupants' Allergic Symptoms in Homes with Allergen Countermeasures

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Abstract

Allergic symptoms are closely related to indoor allergens, such as airborne particulate matter, fungi, and house dust mites. A whole house air-conditioning system integrated with an electrical dust collector was developed as an allergen countermeasure. It is possible to remove fine particles, including PM2.5, with this air-cleaning system.

The purpose of this study was to determine the relationship between indoor allergens and allergic symptoms of home occupants. The concentrations of fine particles, airborne fungi, and the amount of mite allergen in the dust were measured before and after the occupants moved into the house with the installed air-cleaning system. In addition, the ratio of activated CD4+ T cells was measured via a blood test, as an indicator of allergic symptoms.

The results indicate that the concentrations of fine particles, airborne fungi, and mite allergens significantly decreased compared with the levels in the houses before the occupants moved in. The ratio of activated CD4+ T cells also significantly decreased. These findings demonstrate that allergic symptoms of occupants improved after moving into houses with installed air-cleaning systems as an allergen countermeasure.
Estimation of Ventilation by Using Occupants' Carbon Dioxide Included in Exhaled Breath

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Kochi University of Technology, Tosayamada, Kami, Kochi, Japan

Abstract

It is difficult to estimate ventilation aspects using tracer gas under occupancy conditions, because of some limitations. In this case, carbon dioxide included in occupants' exhaled breath is often used. However, an accurate estimation of ventilation requires personal carbon dioxide production rate with a certain accuracy. Therefore, the authors have developed an equation for estimating a personal carbon dioxide production rate, which uses variables such as height & weight, gender, age, and Mets, with analysing Japanese subjects' exhaled breaths.

In this study, accuracy checks of carbon dioxide concentration yielded by using the equation are performed by comparing with measured concentration under mechanically ventilated conditions in single/multi zones. 10 cases of experiments were conducted to obtain the concentration. The calculated values yielded by using the equation are also compared with theoretical values calculated by using the other carbon dioxide production rates shown in a JIS (Japanese Industrial Standard) and an ASTM (American Society for Testing and Materials).

RMSE yielded by subtracting from the calculated value to the measured value is used for the accuracy check. The RMSE using the authors' equation shows totally the smallest value compared with using the JIS's and the ASTM's production rate. Therefore, the accuracy of the authors' method is confirmed in mechanically ventilated single/multi zones with Japanese occupants. Additionally, it is confirmed that the accuracy rises when the number of occupants increases, e.g. six occupants' RMSE is smaller than four occupants', and occupants are engaged in lighter work, e.g. Met 1.0 activities shows the smallest RMSE.
Thank you for attending