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

Zakaria Amin
Queensland University of Technology (QUT)
Australia
zakaria.amin@qut.edu.au

Wendy Miller, Queensland University of Technology, Australia, w2.miller@qut.edu.au (corresponding author)

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 exisiting 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

Amin, Z. DOI: http://dx.doi.org/10.4225/50/581074c84d777
HealthyHousing2016: Proceedings of the 7th International Conference on Energy and Environment of Residential Buildings, November 2016, edited by Miller, W., Susilawati, C. and Manley, K. Brisbane: Queensland University of Technology, Australia. DOI: http://dx.doi.org/10.4225/50/58107c8eb9c71

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 adapatation 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; Suarex & 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 (Åström, Forsberg, & Rocklov, 2011; Dalip, Phillips, Jelinek, & Weiland, 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

(NatHERS). The NatHERS tools rank 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 pre-determined 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

Star rating	**1**	**3.5**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
$MJ/m^2.yr$	203	83-72	71-56	55-44	43-35	34-26	25-18	17-11	10
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)

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

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 $36m^2$ to $74m^2$, with the typical internal floor area $55\text{-}60m^2$. This study focuses on the single storey units constructed prior to 2006 (units 1-46 shown in Figure 1) with an indepth 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. Methology

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 predominate in the early development of the site: single storey dwellings with shared walls (party walls); floor area $55m^2$ and $56m^2$ 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.

Figure 1: Site layout of the aged care facility showing apartments under study

Table 3: Building properties

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

Layout A1

Layout B1

Figure 2: The units under study (Case A and Case B)

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 amoung 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^{o}C while heating thermostats are set at 18^{o}C, (dropping down to 15^{o}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^{o}C assumed by NatHERS (rounding up 25.5 to 26^{o}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.

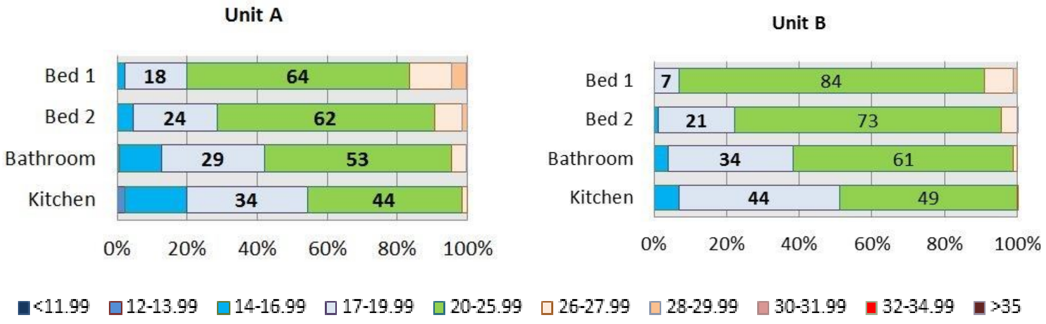

Figure 3: Temperature Distribution in Case A and Case B

Table 5: Base Run (as constructed)

	All Zones (MJ/m^2)	**Bedroom 1 (MJ/m^2)**	**Bedroom 2 (MJ/m^2)**	**Lounge/Kitchen (MJ/m^2)**
Case A				
Cooling	80.8	10.8	38.5	89.5
Heating	8.2	7.7	0.6	7.1
Total	89	18.5	39.1	96.6
Case B				
Cooling	64.5	5.2	28.1	86
Heating	13.1	5	7.9	14.2
Total	77.6	10.2	36.1	100.1

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/m^2 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 6: Summary of Simulation Results

Simulation	**Case A**			**Case B**		
	Rating	Total Actual Energy (MJ/m^2)	Change in Actual Energy (%)	Rating	Total Actual Energy (MJ/m^2)	Change in Actual Energy (%)
As constructed	4	89	NA	4.5	77.6	NA
R2 bulk insulation added to ceiling	5	68.9	22.6%	5.5	61.9	20.2%
Single glazing replaced with double glazingg	4	85.2	4.3%	4.5	72.5	6.6%
2 ceiling fans added to Lounge/Kitchen	6	52	41.6%	6.5	45.7	41.1%
2 ceiling fans added to lounge/kitchen and 1 fan added to bedroom 2	7	42.3	52.5%	7.5	38.8	50%

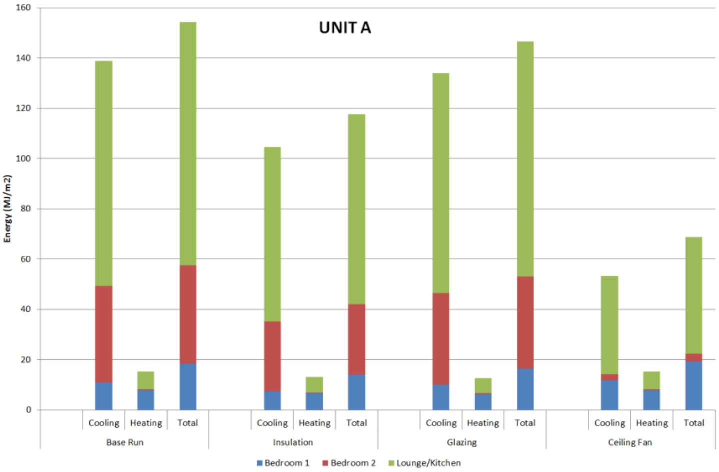

Figure 4: Case A simulation comparison

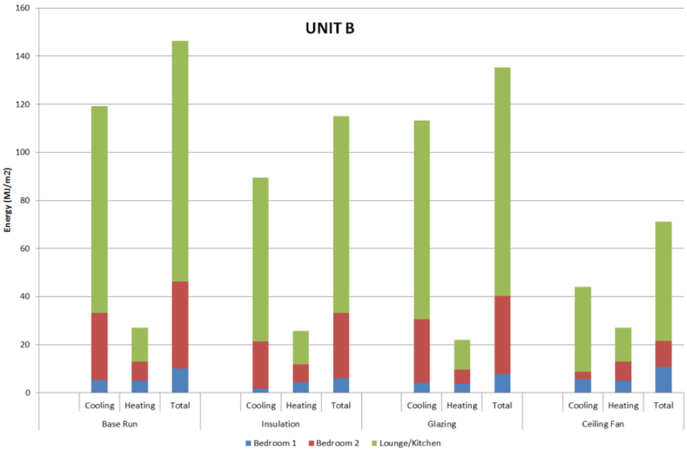

Figure 5: Case B simulation comparison

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

Ahrentzen, S., Erikson, J., & Fonseca, E. (2015). Thermal and health outcomes of energy efficiency retrofits of homes of older adults. *Indoor Air, 26*(4), 582. doi: 10.1111/ina.12239

Ambrose, M., James, M., Law, A., Osman, P., & White, S. (2013). The evaluation of the 5-star energy efficiency standard for residential buildings. *Commonwealth of Australia, Canberra*.

Åström, D. O., Forsberg, B., & Rocklov, J. (2011). Heat wave impact on morbidity and mortality in the elderly population: A review of recent studies. *Maturitas, 69*(2011), 99-105. doi: 10.1016/j.maturitas.2011.03.008

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

Aynsley, R. (2007). Circulating fans for summer and winter comfort and indoor energy efficiency. *Environment Design Guide, TEC 25*(November 2007).

Bell, J., & Miller, W. (2008). *The use of advanced glazing in combating residential greenhouse emissions in subtropical and tropical regions in Australia*. Paper presented at the World Renewable Energy Congress, Glasgow.

Brown, S., & Walker, G. (2008). Understanding heat wave vulnerability in nursing and residential homes. *Building Research & Information, 36*(4), 363-372. doi: 10.1080/09613210802076427

Chantrelle, F. P., Lahmidi, H., Keilholz, W., El Mankibi, M., & Pierre, M. (2011). Development of a multicriteria tool for optimizing the renovation of buildings. *Applied Energy, 88*(2011), 1386-1394.

Dalip, J., Phillips, G. A., Jelinek, G. A., & Weiland, T. J. (2015). Can the elderly handle the heat? A retrospective case-control study of the impact of heat waves on older patients attending an inner city Australian emergency department. *Asia-Pacific Journal of Public Health, 27*(2), 1837-1846. doi: 10.1177/1010539512466428

Hee, W. J., Alghoul, M. A., Bakhtyar, B., Elayeb, O., Shameri, M. A., Alrubaih, M. S., & Sopian, K. (2015). The role of window glazing on daylighting and energy saving in buildings. *Renewable and Sustainable Energy Reviews, 42*, 323-343. doi: 10.1016/j.rser.2014.09.020

Howden-Chapman, P., Viggers, H., Chapman, R., O'Sullivant, K., Taflar Barnard, L., & Lloyd, B. (2012). Tackling cold housing and fuel poverty in New Zealand: A review of policies, research, and health impacts. *Energy Policy, 49*(October 2012), 139-142. doi: 10.1016/j.enpol.2011.09.044

Leinartas, H. A., & Stephens, B. (2015). Optimizing Whole House Deep Energy Retrofit Packages: A Case Study of Existing Chicago-Area Homes. *Buildings, 5*, 323-353. doi: doi:10.3390/buildings5020323

Lewis, A. (2015). Designing for an imagined user: Provision for thermal comfort in energy-efficient extra-care housing. *Energy Policy, 84*, 204-212. doi: 10.1016/j.enpol.2015.04.003

Loughnan, M., Carroll, M., & Tapper, N. J. (2015). The relationship between housing and heat wave resilience in older people. *International Journal of Biometeorology, 59*(9), 1291-1298.

Mendes, A., Pereira, C., Mendes, D., Aguiar, L., Neves, P., Silva, S., . . . Teixeira, J. P. (2013). Indoor air quality and thermal comfort - results of a pilot study in elderly care centers in Portugal. *Journal of Toxicology and Environmental Health, Part A, 76*(4-5), 333-334. doi: 10.1080/15287394.2013.757213

Nationwide House Energy Rating Scheme. (2014). Nationwide Home Energy Rating Scheme. from www.nathers.gov.au

Nicol, F., & Roaf, S. (2007). Adaptive comfort and passive buildings In M. Santamouris (Ed.), *Passive Cooling* London: James and James Science Publishers.

Oswald, F., Wahl, H. W., Schilling, O., Nygren, C., Fänge, A., Sixsmith, A., . . . Iwarsson, S. (2007). Relationships between housing and healthy aging in very old age. *The Gerontologist, 47*(1), 96-107.

Ramirez-Villegas, R., Eriksson, O., & Olofsson, T. (2016). Assessment of renovation measures for a dwelling area - Impacts on energy efficiency and building certification. *Building and Environment, 97*(2016), 26-33.

Roelofsen, P. (2015). Healthy Ageing: differences between elderly and non-elderly in temperature sensation and dissatisfied. *Intelligent Buildings International*, 1-15. doi: 10.1080/17508975.2015.1063474

Suarex, R., & Fernandez-Aguera, J. (2015). Passive energy strategies in the retrofitting of the residential sector: A practical case study in dry hot climate. *Building Simulation, 8*, 593-602. doi: 10.1007/s12273-015-0234-7

Tweed, C., Humes, N., & Zapara-Lancaster, G. (2015). The changing landscape of thermal experience and warmth in older people's dwellings. *Energy Policy, 84*(2015), 223-232.

Van Hoof, J., Kort, H., Hensen, J., Duifnstee, M., & Rutten, P. (2010). Thermal comfort and the integrated design of homes for older people with dementia. *Building and Environment, 45*(February 2010), 358-370. doi: 10.1016/j.buildenv.2009.06.013

Vandentorren, S., Bretin, P., Zeghnoun, A., Mandereau-Bruno, L., Croisier, A., Cochet, C., . . . Ledrans, M. (2006). August 2003 heat wave in France: risk factors for death of elderly people living at home. *European Journal of Public Health, 16*(6), 583-591. doi: 10.1093/eurpub/ckl063

Walker, H., & Paliadelis, P. (2016). Older peoples' experiences of living in a residential aged care facility in Australia. *Australasian Journal on Ageing, 35*(3), E6-E10. doi: 10.1111/ajag.12325

Wei, S., Hassan, T. M., Firth, S. K., & Fouchal, F. (2016). Impact of occupant behaviour on the energy saving potential of retrofit measures for a public building in the UK. *Intelligent Buildings International*. doi: 10.1080/17508975.2016.1139538

World Health Organisation. (2002). *Active Ageing: A Policy Framework*. Geneva: WHO.

Zhai, Y. C., Zhang, Y. F., Pasut, W., Arens, E., & Meng, Q. L. (2015). Human comfort and perceived air quality in warm and humid environments with ceiling fans. *Building and Environment, 90*, 178-185. doi: 10.1016/j.buildenv.2015.04.003