Policy for low carbon (energy efficiency) retrofit/renovation of residential buildings

COAG Research Question #3 “Retrofit” - Summary

Rapid systematic review

Report (Phase 2)

V1.3.2

Project: SP0020p7
Policy for low carbon (energy efficiency) retrofit/renovation of residential buildings: Rapid review

Low carbon policy, energy efficiency policy, residential building retrofit, residential building renovation, rapid review, systematic review, low carbon energy efficiency, residential energy efficiency

Acknowledgements

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All authors declare no conflicts of interests.

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The author(s) confirm(s) that this document has been reviewed and approved by the project’s steering committee and by its program leader. These reviewers evaluated its:

- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007) and provided constructive feedback which was considered and addressed by the author(s).

Abbreviations and Acronyms

LCA: Life Cycle Analysis
GHG: Greenhouse Gas

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Executive Summary

Background
A wide range of regulatory policy measures have been enacted around the world to improve the energy efficiency of new residential buildings. However, a large percentage of the existing residential building stock constructed prior to the appearance of these policy measures is appreciably less efficient than most newly constructed residences. Moreover, this stock will continue to use significant amounts of energy long into the future. This highlights the importance of programmes for building retrofits. However, there is uncertainty over the most effective policies that guide the refurbishment of the existing building stock.

Objectives
Our main objective was to rapidly locate and synthesize knowledge from scholarly peer reviewed literature, employing rapid meta-analytic approaches, to answer the question: What policies work or could potentially work to achieve low carbon outcomes from retrofit/renovation of residential buildings, to what extent do they work, and how is that measured?

A secondary objective was to assess the time and resources needed to perform a rapid review on a topic related to the Built Environment.

Data sources
Data sources included Scopus, Web of Science and EBSCOHost.

Study eligibility criteria
We included peer-reviewed studies-of-studies of retrofit/renovation of residential buildings published in English after 2006.

Study appraisal and synthesis methods
We qualitatively summarised findings from studies that fulfilled our inclusion criteria. We provide a qualitative summary in the form of tables and narrative description of the patterns and gaps observed in the literature.

Results
We included eight peer-reviewed studies of which one was a bibliometric analysis and four included meta-analyses. The studies reviewed and analysed a variety of studies from across the world. The focus of the studies ranged from examining risk-of-biases of electricity consumption studies to retrofit valuation approaches and the health impacts of energy efficiency interventions.

Limitations
Only peer-reviewed systematic studies in English were included in this review. The search was not fully comprehensive (e.g., specialist databases were not searched) meaning some relevant studies might have been omitted. Many of these studies did not evaluate policy or compare policies directly or as sub-categories meaning that implications for policy are inferred from the findings.

Conclusions and implications
This rapid review identified common themes across the included studies which offer information for low carbon residential retrofit/renovation policy:
1) Tailor policy to decision-makers dispositions and perspectives.
2) Funding or subsidies should target up-front costs. But subsidies for operations may encourage free-riding.
3) No one-size fits all. Tailor for contextual factors.
4) Implement earlier rather than later (including in the building life-cycle).
5) Take a comprehensive systems approach to policy design & implementation.

The answer to the final part of our question: the methods used by the included studies demonstrate the ways in which interventions in the residential built environment are measured. However, the small number of included studies limits our ability to draw definitive conclusions. Overall, we found insufficient and inconclusive evidence to determine which policies work, and the extent to which they work for encouraging energy efficiency residential retrofit/renovation. Our quick and selective qualitative summary of findings means that we might have missed themes emerging from the studies. This also highlights the need for further primary and secondary research in this space.

Registration
The protocol for this review has been preregistered using Open Science Framework system at https://osf.io/tyu3p/.

Amendments to the protocol
Snowballing was excluded from the review due to the limited time available. Findings were extracted from included papers and are shown in Tables 3, 4 and 5, in order to better reflect the similarities and differences in the study contents.
Introduction

Rationale
Countries around the world have recently taken significant steps to improve the energy efficiency of new buildings. Their measures have addressed energy efficiency through a variety of means, from technological improvements to enacting various regulatory requirements and establishing policy initiatives. However, a large percentage of the existing residential building stock constructed prior to the appearance of these policy measures are appreciably less efficient than most newly constructed residences. Moreover, they will continue to use significant amounts of energy long into the future.

Existing residential buildings present large opportunities for energy performance improvements that reduce greenhouse gas emissions (GHG), but the barriers are numerous and complex. Australian buildings make a significant contribution to GHGs with a net Energy Star Rating of only 1.5-2 stars (compared to the state code specifying 6 stars for new dwellings). Numerous stakeholders with competing interests and at multiple levels of authority make for a complex policy space.

Determining an effective set of policies is a major challenge for policy makers everywhere. Adopting a policy for maximum efficiency or minimal energy consumption in a diverse and complex built environment can be difficult and time consuming. The challenge is how to implement policy for existing houses when, for example, cost savings might ultimately be consumed into increased energy consumption (rebound effects). Existing studies report conflicting results and, whilst technology improves, it is the householder that must weigh high upfront costs for efficient devices against high lifecycle energy costs for inefficient devices.

Finding evidence for what works is therefore an elusive task. This is because retrofit/renovation and low carbon retrofit/renovation are not driven only by policies (or energy policy specifically), but also by drivers unrelated to policy such as householder decision-making behaviour (natural drivers). While some of the policies driving low carbon outcomes from retrofit/renovation provide supporting evidence for energy-related policy, other policies unrelated to energy or low carbon (non-energy policy), such a renovating to improve health impacts, can also achieve low carbon outcomes. Furthermore, the fact that available evidence does not demonstrate low carbon effects does not prove the counterfactual even if it was the intention of the research to show there were no links in the first place. The rate of change of the building stock in response to these three policy categories (energy policy, natural drivers and non-energy policy) may vary in relation to many factors and across and between different geographical or national climatic and cultural contexts.

What counts as ‘low carbon’ retrofit/renovations is not necessarily ‘electricity’ or directly ‘energy’ related modifications. For example, modifications for ‘passive’ buildings could involve water or natural features, or it could be a change to enable waste recycling or different consumption patterns that embodies carbon through the activity. However, to count as retrofit/renovation, the change must include a change to the building and the living environment it provides for.

A wide range of regulatory policy measures have been enacted around the world to improve the energy efficiency of new residential buildings. This rapid review looks for the research that has adopted more rigorous standards of evaluation, namely studies that review and compare energy performance improvements.

The rapid review method used in this report allows gathering information on a specific research topic relatively quickly, in comparison to full systematic review (Haby et al., 2016). Seeking out and bringing together the highest standard studies allows us to identify scientifically robust results and draw more confident conclusions, but only if such studies are available.

Objectives
Our main question was: “What policies work or could potentially work to achieve low carbon outcomes from retrofit/renovation of residential buildings, to what extent do they work, and how is that measured?”

- The main objective of this systematic review is to rapidly synthesize knowledge from scholarly peer reviewed literature employing qualitative synthesis analytic approaches to answer our main question. Rapid reviews generally use simplified systematic review methodology to accelerate the review process, while still trying to minimise the risk of bias (Tricco et al. 2015).

- The secondary objective of this project was to assess the time and resources needed to perform a scoping / rapid meta-review on a topic related to the Built Environment. Thus, information relevant to the review team’s structure, review timeline and associated workloads are also included in this report.

Photo by JL.
Methods

Eligibility criteria

To locate studies, the following study characteristics were used as inclusion criteria for the review:

1. Studies published in peer-reviewed academic journals
2. Studies published in English
3. Studies published from 2006
4. Studies of drivers of retrofit/renovation of residential buildings
5. Studies of retrofit/renovation in locations with conditions similar to residential areas in Australia showing policies that work or alternatively do not work to achieve low carbon-related outcomes or that could be inferred to work or not work to achieve low carbon-related outcomes (for example installing heating to reduce mold in bathrooms is a health policy outcome with residential energy implications)
6. Studies on energy policy affecting residential buildings in developed countries, such as: Australia, EU countries, New Zealand and the U.S.A.
7. Studies comparing the effects of policies with the effects of other policies or no policy
8. Full text available

Information sources

Search engines of Scopus, Web of Science and EBSCOHost.

Literature search and study records

To construct search strings, we used combinations of keywords and phrases related to residential building types, synonyms for retrofit, policy outcome, type of policies, and type of studies. The queries used in different databases are listed in Table 1.

Records from Scopus, Web of Science and EBSCOHost electronic databases were exported to EndNote reference management software. Two reviewers (BB, JL) independently screened de-duplicated records (year, authors, titles, journal title, volume, issue) to identify relevant studies using a decision matrix reflecting the remaining eligibility criteria described in the previous section. Both reviewers confirmed the other's identified studies.

After further clarifying the studies to be included with the building sector expert (PG), two reviewers (CB, JL) screened the list of included studies for specific mention of energy efficiency to narrow the topic focus.

Full papers were retrieved for studies deemed potentially relevant. One reviewer (JL) performed screening of full papers using the same criteria for the titles and abstracts.

The overview of the search and screening process is presented in Figure 1.
Table 1. List of search queries used in different databases

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<tbody>
<tr>
<td>1. Scopus</td>
<td>{building} OR {buildings} OR occupant* OR resident* OR hous* OR {villa} OR {villas} OR {accommodation} OR {free standing} OR {semi-detached} OR {brownfield} OR {brown field} OR {brownfields} OR {indoor} OR {domestic} OR {tenant} OR {tenants}</td>
<td>{retrofit} OR {renovat} OR {refurbish} OR {improve} OR {upgrad} OR {demol} OR {modif} OR {alter} OR {extension} OR {extend} OR {extensions}</td>
<td>{policy} OR {policies} OR {code} OR {codes} OR {tax} OR {tax} OR {strateg} OR {certificat} OR {regulat} OR {label} OR {instrument} OR {mandat} OR {incentiv} OR {mechanism} OR {mechanisms} OR {expend} OR {ordinance} OR {standar} OR {permitt} OR {subsid} OR {reform} OR {regeneration} OR {target} OR {targets} OR {Passive House} OR {Passivhaus} OR {ZEB} OR {nZEB} OR {zero-energy} OR {zero energy} OR {fund} OR {financ} OR {scheme} OR {schemes} OR {progra} OR {invest} OR {compliance} OR {enforcement} OR {disclosure} OR {penalt} OR {benchmark} OR {benchmark}</td>
<td>{meta analysis} OR {meta-analysis} OR {metaanalys} OR {meta-review} OR {metareview} OR {systematic review} OR {systematic-review} OR {systematic W/3 review} OR {systematic-map} OR {evidence map} OR {evidence-map} OR {evidence-review} OR {evidence-review} OR {scientometric} OR {scientometrics} OR {bibliometric} OR {bibliometrics}</td>
<td>PUBYEAR &gt; 2005 AND (EXCLUDE (SUBJAREA, &quot;MEDI&quot;) OR EXCLUDE (SUBJAREA, &quot;NURS&quot;) OR EXCLUDE (SUBJAREA, &quot;BIOC&quot;)</td>
</tr>
<tr>
<td>2. Web of Science</td>
<td>buildingS OR occupant* OR resident* OR hous* OR villaS OR accommodationS OR {free standing} OR {semi-detached} OR brownfieldS OR brown fieldS OR indoor OR domestic OR tenantS</td>
<td>retrofit OR renovat OR refurbish OR improve OR upgrad OR demol OR modif OR alter OR addition OR extension</td>
<td>policy OR policies OR code OR tax OR strateg OR certificat OR regulat OR label OR instrument OR mandat OR incentiv OR mechanism OR expend OR ordinance OR standar OR permitt OR subsid OR reform OR regeneration OR target OR Passive House OR Passivhaus</td>
<td>meta$analysis OR metaanalys OR me$review OR systematic$review OR systematic NEAR/3 review OR systematic$map OR evidence$map OR scoping$review OR rapid$review OR evidence$review OR scientometric$ OR scientometrics OR bibliometric$</td>
<td>excluding WEB OF SCIENCE CATEGORIES: [ PUBLIC ENVIRONMENTAL OCCUPATIONAL HEALTH OR RADIATION NUCLEAR MEDICINE MEDICAL IMAGING OR MEDICINE GENERAL INTERNAL OR HEALTH CARE SCIENCES SERVICES OR DENTISTRY OR ORAL SURGERY OR GERIATRICS GERONTOLOGY OR PERIPHERAL VASCULAR DISEASE OR PSYCHIATRY OR ENDOCRINOLOGY METABOLISM OR OBSTETRICS GYNECOLOGY OR CRIMINOLOGY PENOLOGY OR GASTROENTEROLOGY HEPATOLOGY OR GERONTOLOGY OR UROLOGY NEPHROLOGY OR VETERINARY SCIENCES OR ORTHOPEDICS OR AGRICULTURAL ECONOMICS POLICY OR NURSING OR PSYCHOLOGY APPLIED OR TROPICAL MEDICINE OR CLINICAL NEUROLOGY OR RESPIRATORY SYSTEM OR HOSPITALITY LEISURE SPORT TOURISM OR SURGERY OR PHYSIOLOGY OR SPORT SCIENCES OR RHEUMATOLOGY OR PSYCHOLOGY CLINICAL OR EMERGENCY MEDICINE OR CELL BIOLOGY OR NUTRITION DIETETICS OR INFECTION DISEASES OR ALLERGY OR DERMATOLOGY OR PEDIATRICS OR MICROBIOLOGY OR PHARMACOLOGY PHARMACY OR PARASITOLOGY OR TOXICOLOGY OR PSYCHOLOGY EDUCATIONAL OR REHABILITATION OR SUBSTANCE ABUSE OR PSYCHOLOGY SOCIAL OR MEDICAL INFORMATICS OR ANESTHESIOLOGY OR IMMUNOLOGY OR ENERGY FUELS OR OTORHINOLARYNGOLOGY OR MEDICINE RESEARCH EXPERIMENTAL</td>
</tr>
</tbody>
</table>

SZEB OR zero?energy OR fund* OR financ* OR scheme* OR progra* OR invest* OR compliance OR enforcement OR disclosure OR penalty* OR benchmark

PRIMARY HEALTH CARE OR BEHAVIORAL SCIENCES OR ETHICS OR CARDIAC CARDIOVASCULAR SYSTEMS OR CRITICAL CARE MEDICINE OR HEMATOLOGY OR NEUROSCIENCES OR INTEGRATIVE COMPLEMENTARY MEDICINE OR ONCOLOGY ) AND [excluding] WEB OF SCIENCE CATEGORIES: ( BIOLOGY OR BIOPHYSICS OR BIOTECHNOLOGY APPLIED MICROBIOLOGY OR CHEMISTRY MEDICINAL OR CHEMISTRY MULTIDISCIPLINARY OR EVOLUTIONARY BIOLOGY OR LINGUISTICS OR FISHERIES OR ZOOLOGY OR GENETICS HEREDITY OR MEDICAL LABORATORY TECHNOLOGY OR PLANT SCIENCES OR ANTHROPOLOGY OR AGRONOMY OR ARCHAEOLOGY OR FORESTRY OR ENTOMOLOGY OR ERGONOMICS OR OPHTHALMOLOGY OR LANGUAGE LINGUISTICS OR BIOCHEMICAL RESEARCH METHODS OR MARINE FRESHWATER BIOLOGY OR FOOD SCIENCE TECHNOLOGY OR BIOCHEMISTRY MOLECULAR BIOLOGY OR MEDICAL ETHICS )


3.

EBSCOHost [506 hits]

building# ORoccupan* OR resident* OR hous* OR villa# OR accommodation# OR free-standing OR semi-detached OR brownfield# OR indoor OR domestic OR tenant#

retrofit* OR renovat* OR refurbish* OR upgrade* OR demoli* OR modifi* OR alter* OR addition# OR extension* OR policy OR policies OR code* OR tax* OR strateg* OR certificate* OR regular* OR label* OR instrument* OR mandat* OR incentiv* OR mechanism* OR expend* OR ordinance* OR standard* OR permit* OR subsid* OR reform* OR regeneration OR target* OR Passive House OR "Passivhaus" OR nZEB OR zero-energy OR fund* OR financ* OR scheme* OR progra* OR invest* OR compliance OR enforcement OR disclosure OR penalty* OR benchmark

limit to 2007 to 2019; medicine (except 1 record), nurs, occupa, immune, toxi, psych, cardia, cardio, hospitality, leisure, tourism, geriat, obstetric, gynec, gastro, hepat, physiog, crimin, penol, metab, geron, agric, micro, surg, ortho, clinical, biom, veter, neuro, biod, sport, emergency, denti, educa, diet, rheu, pedi, allerg, nutri (except 2), nutri, infec, pharma, respir, derma, periph, vascu, systemic, parasi, radiolo, nuclear, abuse, ethics, anest, mathe, comput, medrec, pregna, bioinf, entom, drugs, zool, arctic, diabet, cancer, genet, fish, harm, viol, paed, pain, religi, disorder, medical sci, langua, malaria, music, tobacco, virol
Data items

We extracted the following characteristics for each included study: study title, authors, self-claimed study type, type of retrofit/renovation and its driver categories, policy type, the outcome and its extent and measurement, and additional comments and details, as relevant. Table 2 presents the main extracted variables and their values / codes (also used in the tables in the Results section). The extraction of findings was performed by two reviewers (BB, JL) and checked by another reviewer (CB). For each study, overall and specific findings relevant to synthesis themes for policy were recorded.
Table 2. List of the main study variables extracted and coded for the included studies, with relevant values

<table>
<thead>
<tr>
<th>Study variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Author_year</td>
<td>Key (ID) of the article is created by concatenating the last name of the</td>
</tr>
<tr>
<td></td>
<td>first author and the year published</td>
</tr>
<tr>
<td>Title</td>
<td>Title of the article</td>
</tr>
<tr>
<td>Reference</td>
<td>Full publication reference information, including title of the article</td>
</tr>
<tr>
<td>Self-claimed study type</td>
<td>Type of study claimed by the authors, the inclusion of grey lit (if provided),</td>
</tr>
<tr>
<td></td>
<td>the analysis lens used (if provided), and how methodological quality was</td>
</tr>
<tr>
<td></td>
<td>addressed (if provided)</td>
</tr>
<tr>
<td>Theme</td>
<td>Type of retrofit/renovation and its driver categories addressed</td>
</tr>
<tr>
<td>Location conditions</td>
<td>General conditions (e.g. vulnerable communities) under which the buildings</td>
</tr>
<tr>
<td></td>
<td>are renovated, and the research scope of the secondary studies’ if known</td>
</tr>
<tr>
<td>Policy information</td>
<td>Policy type and details if available, or other notes where relevant</td>
</tr>
<tr>
<td>Study funding</td>
<td>Funding bodies</td>
</tr>
<tr>
<td>COI</td>
<td>Declared Conflicts of Interests (COI)</td>
</tr>
<tr>
<td>Key findings</td>
<td>The studies’ main conclusions and findings relevant to policy for low</td>
</tr>
<tr>
<td></td>
<td>carbon energy</td>
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</tbody>
</table>

Outcomes and prioritisation
The objectives of the rapid review were the identification and prioritisation of policies (or policy sets) that drive low carbon retrofit/renovation, the extent of their effects and how that was measured.

Risk of bias of individual studies
We recorded information on study funding sources and conflict of interest statements from the included studies. We also collected information, where available, allowing us to assess the extent to which the studies addressed study quality criteria. We noted methodological details and any concerns related to data collection or analysis. We noted if the included studies described how they maintained the quality of their study through their selection processes or other means. Collected information was used for the overall assessment of the methodological quality of the included studies.

Data Synthesis
No quantitative assessment was performed due to the heterogeneity and the small number of included studies. A qualitative summary is provided in the form of tables, with a narrative description of the types of retrofit/renovation interventions and their key driver categories, factors or explanatory variables, location conditions of where the buildings were renovated, policy types and details, and study conclusions (overall and according to the five themes identified).

Meta-bias(es)
Not applicable, due to the qualitative summary nature of this review and focus on systematic review and meta-analysis studies only.

Cited qualitative outcomes were included in their entirety from sources.

Resulting studies
The rapid review included eight studies published between 2013 and 2018 that fulfilled our inclusion criteria. Table 3 provides an overview of these studies, including publication details, main topic, location, and conflict of interests.

Overview of the included studies
All the papers were systematic reviews of other studies, three conducted additional quantitative meta-analyses. One study used bibliometrics.

Table 4 provides short descriptions of (selected, policy relevant) conclusions drawn by the authors of each included study. These conclusions are selected for their relevance to policy. They are sorted according to the five common themes identified across the studies for residential retrofit/renovation policy.

Table 5 provides a summary of the contents and main conclusions of the included studies and additional comments regarding how the study findings apply to policy.

Photo by JL
<table>
<thead>
<tr>
<th>First Author year (ID)</th>
<th>Title</th>
<th>Self-claimed study type</th>
<th>Location conditions</th>
<th>Study theme</th>
<th>Policy information</th>
<th>Study funding, conflict of interests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bigerna_2017</td>
<td>A new unified approach to evaluate economic acceptance towards green technologies using meta-analysis</td>
<td>Systematic literature search and quantitative meta-analysis of studies of end-users’ willingness to accept and/or willingness to pay for green technologies</td>
<td>Some EU countries, Canada, Australia, Korea, Japan, USA (the studies for Australia are for renewable energy only).</td>
<td>Retrofit/renovation involving four green technologies: alternative fuels vehicles, residential buildings energy savings, smart meters and renewable electricity. End-users’ attitudes and perceptions with respect to green technologies against various variables from the studies reviewed such as: geographical context, funding scenarios, socio-economic features, equipment features, methodological features.</td>
<td>Policy relevant to the four green technologies: alternative fuels vehicles, residential buildings energy savings, smart meters and renewable electricity.</td>
<td>None provided.</td>
</tr>
<tr>
<td>D’Alpaos_2018</td>
<td>Buildings energy retrofit valuation approaches</td>
<td>Systematic literature review with dynamic protocol. Qualitative thematic and descriptive analysis of the documents by year, discipline area, country and keywords. Final selection of studies that performed life-cycle costs (LCC) analyses and was cited most frequently (unclear how studies were excluded).</td>
<td>Studies of single buildings across different locations including Netherlands, Canada, Portugal, Greece, Australia, Spain, United Kingdom, and United States.</td>
<td>Retrofit/renovation interventions on the building envelope e.g., external wall insulation, floors, roofs, windows, cooling fans, electric radiators, solar shading, etc. Key factors identifying cost-optimal solutions are: climatic zone, type of retrofit intervention (and subgroup of nearly zero energy targets), choices of values of costs to calculate cost-optimal solution (e.g., energy prices, discount rate).</td>
<td>Policy relevant to various interventions, in particular for, Nearly Zero Energy Buildings (NZEBs) targets.</td>
<td>None provided.</td>
</tr>
<tr>
<td>Davis_2013</td>
<td>Setting a standard for electricity pilot studies</td>
<td>Screened studies of electricity consumption reduction interventions. Meta-analysis of those for common risk-of-bias analysis categories.</td>
<td>Households in US and Canada</td>
<td>Four residential retrofit/renovation interventions for reducing electricity customers’ overall electricity consumption (percent reduction): in-home display (IHD); pricing only; IHD + pricing; pricing + automation. Observations were made overall, and during peak-demand hours. Reported results are over- or under-estimation because of methodological problems (risks of biases).</td>
<td>Policy relevant to electricity consumption reduction.</td>
<td>The Carnegie Electricity Industry Center and the Center for Climate and Energy Decision Making, The National Science Foundation and Carnegie Mellon University, the Department of Energy. Disclaimer provided.</td>
</tr>
<tr>
<td>First Author year (ID)</td>
<td>Title</td>
<td>Self-claimed study type</td>
<td>Location conditions</td>
<td>Study theme</td>
<td>Policy information</td>
<td>Study funding, conflict of interests</td>
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</tr>
<tr>
<td>Friege_2014</td>
<td>Modelling decisions on energy-efficient renovations</td>
<td>Bibliometrics review of peer-reviewed articles and conference proceedings, including those studies’ references to energy-efficient renovations. Identified paper topic clusters, identified key papers in selected options clusters.</td>
<td>National level, mostly developed countries including Germany, EU, USA, Japan, etc.</td>
<td>Several residential retrofit/renovation options to reduce energy consumption in each of four core clusters: technical options, understanding decisions, incentive instruments and models and simulation. Key papers in the technical options cluster focused on two types of retrofitting technical options: thermal insulation and space heating. Key papers in the understanding decisions cluster focused on implementation approaches (the integration of energy efficiency measures with refurbishment) and residents’ decision context (e.g., their motivations that depend on barriers, legislative constraints, etc. and their decision-making processes that depend on economic and non-economic issues). Key papers in the incentive instruments cluster focused on 1. Regulatory and communicative instruments and subsidy programs; 2. Progressive regulation for higher renovation standard and subsidy-only measures for projects exceeding a minimum standard; 3. Energy Performance Certificates; 4. Retrofit subsidy instruments; 5. Policy packages simultaneously addressing multiple financial barriers.</td>
<td>Incentive policy instruments: A) Three main approaches used: 1. Enforcement of existing instruments; 2. Increasing economic viability; 3. New approaches that address non-economic motivators and barriers.</td>
<td>The Heinrich Böll Stiftung, the Hildegard-Dinter-Stiftung and the Wuppertal Institute for Climate, Environment and Energy.</td>
</tr>
<tr>
<td>Kastner_2015</td>
<td>Examining the decision-making processes behind household energy investments</td>
<td>Inductive, interdisciplinary literature review of household’s energy relevant investment decisions. Included academic and grey literature. Screened studies for major investment decisions and original study. Conducted various data quality checks.</td>
<td>Data was collected in Europe and North America. The studies compared persons, communities and consumers in general.</td>
<td>Seventeen investment domains from insulation to photovoltaic energy to storm windows and doors. Six main explanatory variables with further sum of all: 1. Demographics, housing and residence location 2. Decision-maker characteristics/disposition 3. Beliefs about the impacts for the households 4. Beliefs about the impacts beyond the household 5. Social influences 6. Policy measures</td>
<td>The sub-category measures of the policy explanatory variable covered (with further sum of all): A) Regulations B) Energy price C) Funding D) Energy consulting E) Governmental technical support after the investment.</td>
<td>The Helmholtz-Alliance ENERGY-TRANS, the Helmholtz-Association and the state of Saxony-Anhalt. Not a product of the National Research Council.</td>
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<td>Pomponi_2016</td>
<td>Embodied carbon mitigation and reduction in the built environment</td>
<td>Systematic literature review with quantitative meta-analysis of peer reviewed journal articles of studies assessing embodied carbon mitigation strategies with adequate LCA information.</td>
<td>Not limited by country. Geographical breadth of studies ranged from unrelated, to regional, to single country, to super-country level. Study scale ranged from component, to assemblies, to building, to supra-system level (e.g., neighbourhoods, whole sectors).</td>
<td>All opportunities mentioned in the literature for mitigating and reducing embodied carbon in the built environment. Identified seventeen thematic categories of embodied carbon mitigation strategies. Two of these strategies were policy related.</td>
<td>Two policy categories: * Government policy and regulations * Construction sector policy and regulations.</td>
<td>Funded by the Isaac Newton Trust.</td>
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<tr>
<td>First Author year (ID)</td>
<td>Title</td>
<td>Self-claimed study type</td>
<td>Location conditions</td>
<td>Study theme</td>
<td>Policy information</td>
<td>Study funding, conflict of interests</td>
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<tr>
<td>Willand_2015</td>
<td>Towards explaining the health impacts of residential energy efficiency interventions</td>
<td>A realist review to explain the outcomes for health from interventions for improving residential energy efficiency. Qualitative synthesis by categorising interventions. Included quantitative and qualitative primary studies, peer-reviewed journal articles and grey literature. Evaluated the methods used and screened the studies for inclusion.</td>
<td>UK, New Zealand, USA, Ireland, Australia, Denmark, Germany. Studies categorised by scope of intervention to the building.</td>
<td>Residential energy efficiency interventions categorised based on intervention scope: Thermal retrofit; Upgrade; Refurbishment; Purposive refurbishments; Low carbon refurbishment. This paper identifies the key mediating factors of intervention programs with three key positive outcomes for health: warmth in the house (e.g., indoor temperature, relative humidity) affordability of fuel (energy consumption and affordability and mental health), psycho-social factors (e.g., safe haven meaning, perceived autonomy and social status). Other explanatory factors not reported in this paper could include: national differences in indoor temperatures, quality of intervention, the disciplinary composition of the building team, cultural conditioning to thermal preferences.</td>
<td>Policy relevant to residential energy efficiency interventions.</td>
<td>None provided</td>
</tr>
<tr>
<td>Yeatts_2017</td>
<td>A systematic review of strategies for overcoming the barriers to energy-efficient technologies in buildings</td>
<td>A systematic review of scholarly literature including books, peer reviewed articles, government reports and reports from non-governmental organisations.</td>
<td>Variety of countries from across the world including EU countries like Germany, South American countries like Brazil, Canada, China, African countries like Ghana, and Asian countries like Thailand.</td>
<td>Examined the use of energy-efficient technologies, barriers to their use, and strategies for dealing with the barriers. Energy-efficient technologies include those such as very efficient ventilation and low-energy windows. Three categories of barriers considered: 1) knowledge barriers, 2) access barriers and 3) intent barriers.</td>
<td>Policies as strategies for overcoming barriers to the use of energy-efficient technologies.</td>
<td>None provided</td>
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<td>First Author</td>
<td>Study conclusions for synthesis (theme 1)</td>
<td>Study conclusions for synthesis (theme 2)</td>
<td>Study conclusions for synthesis (theme 3)</td>
<td>Study conclusions for synthesis (theme 4)</td>
<td>Study conclusions for synthesis (theme 5)</td>
<td>Comments</td>
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<tr>
<td>Bigerna_2017</td>
<td>The more evident the positive externalities are known for reducing CO2 emissions (i.e., the environmental consequence of green technologies are known), the higher is the acceptability. Income has a positive effect, the strongest of all socio-economic variables.</td>
<td>The effect is lower when study participants must decide about a lump sum choice and there is uncertainty over the timing of payments. Durable technologies had high negative effect (thus requires subsidies), non-durables had no significant effect.</td>
<td>The difference in effects between geographic areas is significant, higher for EU and lower for USA. Regions that had earlier implemented environmental policy show a higher attitude to green technologies.</td>
<td>Market failures and barriers limit energy savings in residential buildings due to high financial discount rates, householders experiencing lacking information of opportunities to save on fuel bills, transaction costs, technology riskiness and access to credit.</td>
<td>Regarding the theme 4 finding in this row: Analysis did not distinguish between the four green technologies.</td>
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<tr>
<td>D'Alpaos_2018</td>
<td>Limited literature on investors' interests and preferences who may be less interested in economic performance and more in comfort and environmental performance for which they may be willing to pay. Individual studies on nearly zero energy buildings draw opposing conclusions about necessity for incentive schemes to motivate investment. Yet this study concludes that generally the high investment costs mean targeting nearly zero energy buildings requires incentives. [counter evaluation] some studies find that incentive schemes may favour free riding.</td>
<td>The ranking of cost-optimal energy efficiency measures strongly depends on climate zone. Uncertainty over decision variables for investment decision calculations (e.g. discount rate, investment and maintenance costs, energy prices, energy demand) is a key factor in identifying robust energy efficient solutions.</td>
<td>N/A</td>
<td>Interventions on the building envelope (e.g., external wall insulation, floors, roofs, windows, cooling fans, etc) are most effective at increasing energy performance but require thorough design to reach cost-optimal levels.</td>
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<td>Davis_2013</td>
<td>For overall electricity use adjusted for risk of bias only the in-home display electricity savings were statistically significant.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>For peak electricity use after risk of bias adjustment showed statistically significant electricity savings for dynamic pricing only, especially when paired with automation. Further, after risk of bias adjustment the dynamic pricing effect, whilst reducing peak electricity use, only had a weak effect on overall use.</td>
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<tr>
<td>Friege_2014</td>
<td>Key papers on understanding energy efficient renovation decisions show general coverage of decision-making processes (that decision making is affected by economic as well as non-economic motivations) [counter evaluation]</td>
<td>The effectiveness of retrofit subsidy programs (based on a study from Germany) may be undermined by free-riders. Regulatory and communicative</td>
<td>Key papers on technical options for energy efficient renovation show: energy savings, emissions impact and economic viability dependent on aspects like type of intervention implemented, homeowner heating behaviour</td>
<td>The potential for socio-economic energy saving and profitability is lower than usually supposed. Studies confirm that energy efficient renovation is mostly cost effective, but there is a</td>
<td>Key papers on understanding energy efficient renovation decisions claim close integration of measures and policy instruments are necessary to start investment activity.</td>
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<tr>
<td>First Author year (ID)</td>
<td>Study conclusions for synthesis theme 1) Tailor policy to decision-makers dispositions and perspectives</td>
<td>Study conclusions for synthesis theme 2) Funding or subsidies should target up-front costs. But subsidies for operations may encourage free-riding</td>
<td>Study conclusions for synthesis theme 3) No one-size fits all: Tailor for contextual factors</td>
<td>Study conclusions for synthesis theme 4) Implement earlier rather than later in the building life-cycle</td>
<td>Study conclusions for synthesis theme 5) Take a comprehensive systems approach to policy design &amp; implementation</td>
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<td>and barriers) but show no deep understanding. Key papers on incentive instruments and subsidy programs (based on a key paper from Germany) have had little effect since it did not adequately deal with barriers in homeowners' decision making.</td>
<td>instruments and subsidy programs (based on a key paper from Germany) have had little effect since it did not adequately deal with barriers in homeowners' decision making.</td>
<td>before and after intervention, contextual factors (e.g., location, energy prices, climate), building and property characteristics (e.g., type and state).</td>
<td>difference between anticipated and actual energy savings and consumption. It leads to underestimation of payback period (poorly insulated houses is one reason for that).</td>
<td>[counter evaluation] Progressive regulation for higher renovation standards, subsidy programs limited to projects that exceed minimum standard (based on a key paper from Germany) may not work out well in the future. The problem is that the costs of retrofitting or renovating to high standards rise very quickly but the next incremental energy saving does not rise as fast. Policy packages that address multiple financial barriers simultaneously (based on key papers from EU, USA, Japan) are likely to be quite effective.</td>
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<tr>
<td>Kastner_2015</td>
<td>Promotion strategies tailored to the audience work better than untailored strategies (e.g., if they are tailored to decision maker variables such as knowledge of expected ramifications for income or the natural environment).</td>
<td>Funding was linked to more repeated energy-related investments (62.2% of the measurements), including variables related to energy price and energy consulting (both 53.3%). Funding amount and energy prices positively impacted energy-related investments. Grants and pre-financing options seemed preferred over low-interest loans. Those seeking energy-related investment seemed not to approach energy advisers as their first source of information nor perceived them as the most trusted source.</td>
<td>Location of residence brought out strong associations, but those were difficult to interpret: it probably went with different regional/country policy measures but with so many measures it remains unclear.</td>
<td>N/A</td>
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<tr>
<td>Pomponi_2016</td>
<td>The role of the designer is tightly linked to the role of the researchers, manufacturers and</td>
<td>The crucial factor that stood out was that of maintenance of the existing building stock. Furthermore, a clash exists in life</td>
<td>Energy efficiency can lead to rebound effects that increase energy demand, whilst a focus on operational impacts ignore</td>
<td>N/A</td>
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A clear conclusion from this review to reduce the embodied carbon in the built environment requires a pluralistic solution;
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<tr>
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<th>Study conclusions for synthesis theme 2) Funding or subsidies should target up-front costs. But subsidies for operations may encourage free-riding</th>
<th>Study conclusions for synthesis theme 3) No one-size-fits all: Tailor for contextual factors</th>
<th>Study conclusions for synthesis theme 4) Implement earlier rather than later in the building life-cycle</th>
<th>Study conclusions for synthesis theme 5) Take a comprehensive systems approach to policy design &amp; implementation</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Yeatts_2017</td>
<td>Residential energy efficiency interventions consolidated the meaning of the home as a safe haven, strengthened the householder’s perceived autonomy and improved social status, and revealed consequential effects on educational achievement and productivity.</td>
<td>N/A</td>
<td>The importance of the householder perspective and context specific variables on outcomes is revealed.</td>
<td>N/A</td>
<td>Tailoring to the householder and contextual factors is more likely to be achieved with comprehensive refurbishments than with isolated measures.</td>
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<tr>
<td>Willand_2015</td>
<td>Studies examining potential user’s (e.g., designer, contractor, householder) intent found that intent to use energy efficient technologies is influenced by user’s desire to get these technologies (and in turn influenced by factors like cultural and individual characteristics, reference groups and communication behaviour), their willingness to cycle analysis (LCA) literature regarding the assumed service life of buildings. Studies that aimed to extend the building’s life during refurbishment phase assumed 50 years compared to evidence in the UK, for instance, the average lifespan is 132 years. New tools, methods, and methodologies correlated nearly completely with policy strategies led by government or policy strategies promoted by the construction sector.</td>
<td>impacts of embodied carbon in new construction and shift environmental burden to other life cycle stages.</td>
<td>more than 80% of the studies recommended more than one emissions reduction strategy. Crucial elements identified for a quicker transition were increased use and re-use of materials with lower embodied carbon, better design and stronger policy drivers. Mitigation strategies are often combined and (according to the Pareto results) if they are to have an effect then 9 or more are needed in combination to give 80% reduction. To achieve a substantial change in social demand requires support from both policies strategies, a wider use of local materials including waste and by-products into the construction of buildings.</td>
<td>No one</td>
<td>We note that the effects of many strategies mentioned by this paper, for example communication (workshop, conference) and education programs, are often gradual and happen only over the long term and thus</td>
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<tr>
<td>Yeatts_2017</td>
<td>Studies examining access have claimed the importance of government intervention to overcome barriers to energy efficient technology financing through at least six strategies such as foundation grants, subsidies and tax programs. Some studies stated that new funding mechanisms were needed to establish crucial strategies for making energy</td>
<td>Studies examining the importance of education and overcoming knowledge barriers suggested the use of education/training to accelerate knowledge uptake, having reference groups (e.g., networks, peers, leaders, “integrators”) that take knowledge to users, open channels of communication for easy knowledge transfer and framing the introduction of</td>
<td>Some studies suggested education and training accelerate knowledge among potential users. Other studies highlighted time and timing as issues: for example using pre-project planning to improve logistics issues (in turn affected by communication and coordination barriers), clearly specified contracts, the time</td>
<td>In all, the suggestions by studies highlighted dozens of barriers and a huge range of strategies for overcoming the barriers, everything from the value of workshops and conferences for education to government financial programs and tax to make energy efficient technologies affordable for owners/users of buildings to easily modifiable implementation</td>
<td>N/A</td>
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<tr>
<th>First Author year (ID)</th>
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<th>Study conclusions for synthesis theme 5) Take a comprehensive systems approach to policy design &amp; implementation</th>
<th>Comments</th>
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<td>finance the technologies (and in turn influenced by uncertainties surrounding decision making), and uncertainties surrounding implementation and use of the technologies (e.g., ease of use or tailoring restrictions). efficient technologies more available. In some specific cases, e.g., United States tax policies, the schemes have been too complex or restrictive (limited to small rental properties) and have discouraged energy efficient technology investments. Further confusion comes from needing to assess and compare the many funding programs; this deters potential users. energy efficient technologies effectively (e.g., providing the right information, or setting and enforcing standards and regulations, building guidelines, best practices, pilot studies, demonstrations) and highlighting their positive effects. involved in coordination and collaboration between varied people and getting the supplies and materials for an energy efficient technology can be a deterrent, and financial viability when considering the life time of the energy efficient technology with the return on investment. procedures to match the skills of potential users. However, much research is needed to provide more specific recommendations. should be started immediately.</td>
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Results

Qualitative summary

All the included studies are systematic reviews of selections of other studies that investigated energy efficiency outcomes in retrofit/renovation of residential buildings. Each included study adopted different perspectives for their analysis of their selected studies that ranged from decision making processes behind household energy investments to health impacts of residential energy efficiency interventions.

Only three studies (not all those with meta-analyses) explicitly identified policy-related categories or policy explanatory variables involved in their topics. A fourth study included policies as strategies for overcoming barriers.

The qualitative summary of findings across all the included studies identified common themes for consideration for low carbon policy for residential retrofit/renovation.

- First, tailor policies to decision maker dispositions and perspectives in their choices over green technologies. Decision makers refer to individuals and households, but also those in the construction industry. It seems that variables other than cost and economic performance may play a larger role in decision making than expected (e.g., their health, comfort, having control). However, there is a lack of deep understanding on what these dispositions and perspectives exactly are or how to consider them.

- Second, funding or subsidies should target up-front costs since incentive schemes that reduce uncertainty may help to overcome barriers. These include clear project schedules and investment return, simple comparison between different choices, better communication, etc. However, subsidies do favour free riders, those who would have been willing to renovate without the funding. Further, funding for durable technologies is more needed than not-durable categories of technology.

- Third, no one size fits all, so tailor policies to account for contextual factors such as the location, thus climatic conditions, energy prices and many other more variables. The social-cultural contexts of the local area are also vital for successful implementation of policies. These include but not limit to: householders’ knowledge of and attitudes toward energy efficient renovation and relevant technology, people's livelihoods and expenditure on energy, preferred channels of communication, etc. With so many factors there is lack of evidence what would work the best; it seems the conclusion is what works in one place does not necessarily work in another.

- Fourth, the earlier policies are implemented, the better. For reasons such as: acceptance, urgency of the issues, having time to do more for cases where doing little will not be sufficient (e.g., upgrading the building shell is not sufficient for leaky houses so more will be needed) or where unforeseen consequences reduce positive outcomes and thus more will be needed (the rebound effect). Early implementation should also be considered in the building life cycle. For example, policy targeting at operational cost earlier in the building life cycle may help improve the return of investment.

- Fifth, take a comprehensive systems approach to retrofit/refurbishment policy design and implementation. Using a mix of policy measures is linked to the previous point. This applies not only to using a wider selection of retrofit/renovation options simultaneously but focusing also on sectors across the board and adopting other measures (e.g., using and re-using low carbon embodied materials, measures relevant to a low carbon circular economy). It also involves integrating social-cultural factors in policy programs to foster better education and communication.

Overall the included studies did not provide sufficient evidence or establish conclusive results about the effectiveness of specific low carbon policies compared to other policies. One reason is that they found that actual results of energy improvements are often reported at opposite ends of a spectrum (i.e., similar studies report opposite results) which indicates that 1) unidentified and unexamined factors are involved that means similar programs produce different outcomes, 2) diverse interventions are needed to achieve sufficient results, but studies do not all implement or make the same sets of interventions, and thus in comparison there are biasing and blurring of results between studies, and 3) differences between studies, the quality of studies and uncertainty over the input variables effect outcomes and the calculation of outcomes. A second reason has to do with unforeseen or unexamined processes that produce different actual outcomes from expected outcomes (e.g., rebound effects).

Photo: CC by Mario Hains
Main conclusions: On average for all four green technologies end-users were willing to pay a positive value to avoid carbon emissions while for the individual technologies, all have positive results except for alternative fuel vehicles. For energy savings interventions in buildings, users are willing to pay 41.8 EUR cent/Kg CO2, which is lower than for renewable electricity (41.8) and higher than smart meters (13.4). Yet, as study sample sizes increased, so the calculated price for CO2 decreased while the studies recording negative or close to zero values were those dealing with savings in residential buildings and alternative fuel vehicles.

D’Alpaos_2018
Analysed LCC studies of interventions on building envelope. The aim was to identify papers describing the most innovative and multidisciplinary valuation approaches to building energy retrofit; the authors found the most frequently cited approach was the life cycle costs methodology. A subset of studies showed increasing interest in interventions that set nearly zero energy buildings targets.

Overall the climatic zone was found to be a key factor for selection of cost-optimal retrofit solutions. The main interventions investigated were those related to the building shell. Found the issue of uncertainty over profitability of nearly zero energy buildings (and thus the need for incentive schemes or not) was debated in the literature; specifically, the choice of discount rates produced more uncertainty than future energy prices). Further, stakeholders have willingness to pay more for sustainable solutions (e.g., for intrinsic value). Yet, there is lack of research that account for their willingness to pay more.

Davis_2013
Reviewed studies of effectiveness of four interventions for reducing overall electricity consumption (percent reduction) for residential electricity customers. Electricity consumption was observed for overall and peak-demand hours. Main aim was to analyse the methodological biases of studies of electricity consumption reduction interventions for six common risk-of-bias analysis categories (e.g., intervention selection bias and volunteer selection bias). Re-evaluated the results for the four interventions after correcting for the biases.

Main conclusions: All studies displayed high risk of at least two biases—some displayed more biases—implying reported results were inflated. Only in-home displays produced significant statistical results after risk-of-bias adjustment and dynamic pricing only had a weak effect on overall electricity use after adjustment.

Friege_2014
Analysed the research on energy efficient renovation (EER) through 1. paper citation networks and 2) examined the key papers for reasons why energy opportunities are not adopted as would be expected. For 1) Papers clustered on eight topic areas. Of these, the policies cluster was strongly connected to economic assessment and behaviour. For 2) (focused on four possible reasons identified in the literature: identified clusters of four overlapping core areas: technical options (22% of papers); understanding decision-making (12%); incentive instruments (19%), models and simulation (34%)).

Main conclusions:
* There is uncertainty over the economic and non-economic factors that drive homeowners’ renovation decisions, yet the literature shows no deep understanding of such uncertainties.
* The literature indicates that energy savings potential of energy efficiency technology technical options is lower than generally expected though they are cost effective in most cases. In some cases where measures were combined, technical options were more likely to be economically viable.
* The literature is narrowly focused on incentive instruments that motivate home owners. Though several incentive instruments are inventive, and several are available to motivate improvement, their success rates have been low. Suggests this is because they have not adequately addressed home owners’ decision making. Therefore, a need for instrument enhancements and new approaches for taking the homeowners’ decision-making processes and a greater range of motivations into account.
* The literature on models of energy saving renovations contain biases and omissions leading to overestimation of EER outcomes.

Kastner_2015
Examined the decision-making processes involved in household energy investments. Policy was identified as one explanatory variable of six main variables. Five subcategories to the policy variable were identified, including a sixth for sum of all policy measures.

Main conclusions:
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<th>First Author _year (ID)</th>
<th>Summary of scope and main conclusions</th>
<th>Comments</th>
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<tr>
<td>* The availability and comparability of available research is low thus all conclusions are to be treated as tentative. Much research and standardised research with deeper and more relevant measurements still need to be done. * Regarding the investment domains (e.g., insulation, except pellet heating): they are linked to very similar explanatory variables. This suggests that their commonalities (e.g., the need for financial resources) stands out more than how they differ; suggests findings can be applied to all domains. * Supporting earlier findings, the explanatory variables in the categories of demographics, housing and location, and decision maker characteristics are less important (though some associations found for income and location of residence and some positive associations for subjective investment related knowledge) while the beliefs about consequences variables were more predictive (but not all completely convincing due to methodological problems). * The social influence measures were rarely linked with energy-relevant decisions. However, this may have been underestimated. * The results for policy measures as explanatory variable provided clearer conclusions than the other variables, particularly in terms of funding (62.2% of measures) and energy price and energy consulting (53.3%).</td>
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Pomponi_2016

Reviewed studies using LCA to assess mitigation strategies to reduce embodied carbon in the built environment. Seventeen emissions reduction strategies were identified from the literature, of which two were policy related (policy and regulations for governments and construction sector).

Main conclusions:

* Of 17 mitigation strategies identified, no single strategy used alone seemed sufficient to reduce embodied carbon but rather a strategy of multiple approaches (indeed, more than 80% of identified strategies) is necessary (based on a Pareto chart of the studies’ results given that most studies considered between two and four strategies). * Stronger policy drivers are key elements for quicker transition, as are the increased use and reuse of low embodied carbon materials and better design. These are all interconnected. * A large percentage of LCA studies are extremely incomplete and more comprehensive studies are needed.

Willand_2015

Synthesised the outcomes for health from studies of energy efficiency interventions in residential buildings. Included only studies that assessed technical energy efficiency linked to various measurements such as indoor temperature or condensation, affordability and health or mortality outcomes. The aim was to explain the impacts of energy efficiency interventions in residential buildings for the three key positive outcomes from programs according to key intervening factors and the impact of the intervention scope.

Main conclusions:

* Across the studies, no unambiguous associations found between intervention categories and program results. It could be due to diverse range of study designs or because contextual and householder factors blurred the effects (not discussed in this paper). * Although difficult to explain, even small scale interventions provided appreciable benefits. * Effective interventions to be tailored to 1) the householder (studies neglected to evaluate their behaviours and experiences), 2) address ventilation and differences in climate conditions (e.g., summer/winter temperatures and costs of cooling/heating), and 3) consider contextual factors to determine effective technical measures (e.g., how to design for warmer indoor temperatures need to consider take-back factor, energy price trends, effects of new technologies). * The outcomes of mediating factors based on improvement category were non-linear (effects were dynamic and not consistent for the intermediate and final outcomes) and this likely suggests other mechanisms also are involved (e.g., influenced by householder-dependent variables). * The key determinant seemed to be having a warm home in winter. Interventions had positive effects on internal house conditions (warmth and humidity) and positive health benefits, seemingly positive effects not from energy cost savings, but from the richer meaning of home. * Rarely identified negative impacts on health, but the risk cannot be dismissed.

Yeatts_2017

Examined the use of energy-efficient technologies, the barriers to their use, and strategies for overcoming the barriers. Catalogued strategies for overcoming three categories of barriers to energy-efficient technology use (each with discussion of numerous methods and policies for overcoming the barriers, as varied as education / training programs to standards and regulation).

Main conclusions:

Virtually all studies agreed on the desirability of using energy-efficient technologies. Yet, they did not agree on how to make that happen. Some suggested increasing knowledge, some creating new funding mechanisms, some getting interested people to live in a building with such technologies. In short, a strategy to remove barriers that works in one place may not work in another.
Quality, risk of bias and confidence in cumulative evidence

It would be beyond the scope of a rapid review to analyse the primary methodological techniques of studies reviewed by the included studies of this report. We could only rely on what the included studies revealed. However, some assessment can be made of the quality and risk of biases of the included systematic reviews and meta-analyses based on the detail provided (where available these are summarised in Table 3). All studies provided details on their literature searches and meta-analyses though their methodologies vary. Three studies (Davis 2013, Kastner 2015 and Willand 2015) mention how they considered the quality and risk of bias of their included studies. All eight studies provided some information on their literature searches. However, only three studies (Davis 2013, Kastner 2015 and Willand 2015) clearly described how they excluded studies from their final lists. This suggests there is scope for improving reporting quality of the original studies, including more details and providing easy and open access to the raw data for re-analyses.

After initially identifying over 1402 potentially relevant studies, only eight studies met the eligibility criteria of this review. The small number of studies and the differences in how the analysis frames adopted by the studies limit the generalisability of findings of this rapid review. Further, being a rapid review, the five common themes are tentative and other themes may well be found with a more in-depth and less rapid qualitative analysis.

This research highlights the need for more primary and secondary research in this space. Further primary research could consider developing studies to compare policy effects through deeper investigation as suggested by most of the studies.

Further systematic review research could consider the value of identifying and using datasets from which records could be extracted to compare policies. Records may well be available from different datasets that can provide matching independent variables to selectively compare policies and their effects. Such an approach, although more time consuming, would help focus analysis on studies with matching retrofit/renovation variables but different policies. This could be extended to include using datasets from the grey literature (reports, theses), as well as non-systematic reviews, non-English literature and studies from developing countries. However, for this the quality of the evidence base for drawing conclusions may reduce the quality of findings.

Overview of the excluded studies

Table S1 presents the list of studies excluded after full-text screening, alongside the reasons for exclusion. Most of these studies were excluded because they did not have contents related to policy interventions, did not have contents related to energy efficiency improvement, did not study residential buildings, or were not systematic reviews, etc. Nevertheless, some of the excluded papers can still provide some insights for policy related to the construction sector working with residential retrofit/renovation and their decisions making.

Review Limitations

Our literature search was not comprehensive, and some relevant papers might have been missed. We included only peer-reviewed studies. Thus, we did not include grey literature (e.g., government reports, reviews of technology or case studies) that could potentially provide additional data. We only included studies published in English.

Our quick and selective qualitative summary of the findings might have missed some themes emerging from this inter-disciplinary field. Another study may summarise the findings differently and draw out other themes.

Limited number of included studies and unknown exclusions of studies in some of the included studies can influence the reliability of the conclusions drawn from this review. Finally, some of the information necessary for assessing study quality and risk of bias was not reported by all the included papers.

Our data set is restricted to eight studies each approaching the review and analysis of low carbon energy in residential retrofit/renovation studies from very different perspectives (Table 2). The studies are highly heterogeneous. Because of this, one should not draw definitive conclusion from this review.

Photo by JL
Summary and conclusions

The purpose of this rapid review was to examine scholarly peer reviewed studies ideally presenting evidence comparing policies or policy sets and their effects for low carbon retrofit/renovation of residential buildings. Given that the number of policies targeting building energy has increased over recent years, one would expect to see evidence that some policies show better results than others.

After initially identifying over 1400 potentially relevant studies, the search and screening process resulted in only eight studies that met the pre-defined eligibility criteria. Though our search for papers started from 2007, all eight included papers were produced since 2013 and four since 2016.

The studies covered the question of residential building energy efficiency from a range of perspectives such that only some studies identified policy as explanatory variables or factors involved in affecting energy efficiency. The other studies examined residential building energy efficiency from technological perspectives, decision maker perspectives, the health effects of energy renovation, or the biases inherent in current studies of energy efficiency. Furthermore, whilst the studies all had an element of literature search to locate appropriate papers, some summarised their papers qualitatively addressing specific hypotheses about energy renovation (or the lack thereof) or to identify various themes, while others conducted further meta-analyses using different frameworks (willingness to pay, life cycle costing, or paper citations). More than half the studies were qualitative in nature, while the other included quantitative data analyses. The quality of the studies was not related to whether they were more qualitative in nature.

The heterogeneous perspectives of the included studies highlight the challenge of establishing evidence about the working of policies in an area where many adaptive factors, levels of authorities and stakeholders with competing interests create complex dynamic interactions. Furthermore, the studies demonstrate there are multiple frameworks for evaluating low carbon or energy efficiency, all of them can be ’correct’. This provides a tentative answer to our question about how low carbon policy is or can be measured.

Overall, given the eight studies, we found insufficient and inconclusive evidence to decide about which policies work and the extent to which they work for residential low carbon retrofit/renovation.

However, upon delving into the findings relevant for policy or making inferences about policy from the studies’ findings, we identified five themes from across all the studies (findings are summarised according to the themes in Table 4).

More secondary review research and primary research projects are needed to answer our questions for this rapid review. Conversely, in this study not finding evidence on the effects of policies does not necessarily mean existing policies are not having positive benefits.

The results of our review have highlighted the need for further secondary (systematic review) and primary research and trials in this area. Further secondary research could focus on evaluation and comparison of the outcomes of the implementation of matching policies where it is possible to account for the complexity of independent variables affecting outcomes. Further primary research is needed to measure and understand more deeply the variables that affect the outcomes of policies, for instance, decision makers’ dispositions, the external contextual factors, and so on. Such work could be valuable for matched-building-inhabitants-contexts analyses under the same or different policy measures.

Further systematic review research could also consider the value of including datasets potentially available from the grey literature, as well as non-English literature. Such an approach, although more time consuming, would likely result in a larger dataset for analyses from which to select matching studies for comparison of policies.
 Resources, workload and timeline
Figure 2. Review team members.

- Providing initial question
- Helping focus the question
- Approving protocol
- Approving final report

PG, MZ
PROJECT BOARD

PG, BB, JL, MZ, CB
CORE TEAM
leader
methodologists
experts

JP
STAKEHOLDERS

- Providing initial question
- Helping focus the question
- Approving final report

- Focusing initial question
- Preparing protocol
- Performing search
- Performing screening
- Coding of the evidence
- Summarising the evidence
- Documenting the review process
- Writing up

Figure 3. Review timeline.

4/3/19

Team formation
Question refinement
Protocol preparation
Search and screening
Data extraction
Synthesis/Report
Finalise/Comms

Mar
Apr
May
June

weeks
months
Table 6. Workloads (in hours) of the team members for each main review stage

<table>
<thead>
<tr>
<th>Review Stage</th>
<th>PG</th>
<th>BB</th>
<th>JL</th>
<th>MZ</th>
<th>CB</th>
<th>Total</th>
<th>Comments</th>
</tr>
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<tbody>
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<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>7</td>
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<td>Question refinement</td>
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<td>6</td>
<td>3</td>
<td>4</td>
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<tr>
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<td>36</td>
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<td>30</td>
<td>2</td>
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<tr>
<td>Synthesis / Report</td>
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<td>11</td>
<td>4</td>
<td>4</td>
<td>35</td>
<td></td>
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<td><strong>Total</strong></td>
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<td>125</td>
<td>81</td>
<td>18</td>
<td>14</td>
<td>228</td>
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Photo by BB
## Supplementary Information

### Table S1. Table of the excluded studies at the full-text screening stage, with reasons

<table>
<thead>
<tr>
<th>First Author year</th>
<th>Reference</th>
<th>PDF available</th>
<th>Reason for exclusion</th>
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<tbody>
<tr>
<td>Haby_2016</td>
<td>Haby, M. M., Chapman, E., Clark, R., &amp; Galvão, L. A. C. (2016). Energy interventions that facilitate sustainable development and impact health: an overview of systematic reviews. Intervenciones en materia de energía que facilitan el desarrollo sostenible y tienen un impacto positivo en la salud: visión panorámica de revisiones sistemáticas., 39(4), 200-207.</td>
<td>Y</td>
<td>It uses other systematic reviews which mostly focus on developing countries.</td>
</tr>
<tr>
<td>First Author year</td>
<td>Reference</td>
<td>PDF available</td>
<td>Reason for exclusion</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------------</td>
<td>--------------------------------------------------------------------------------------</td>
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<tr>
<td>Roh_2018</td>
<td>Roh, S., Tae, S., &amp; Kim, R. (2018). Developing a Green Building Index (GBI) Certification System to Effectively Reduce Carbon Emissions in South Korea's Building Industry. Sustainability, 10(6).</td>
<td>Y</td>
<td>It is a case study, not systematic review. And no policy/intervention is evaluated.</td>
</tr>
<tr>
<td>Alwisy_2019</td>
<td>Alwisy, A., BuHamdan, S., &amp; Gül, M. (2019). Evidence-based ranking of green building design factors according to leading energy modelling tools. Sustainable Cities and Society, 47.</td>
<td>Y</td>
<td>This paper focuses on Green Building Design Factors which impact the modelling and designing process, but policy isn't specified as one of the impacting factors.</td>
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References


Full references for the included papers


