Web Annex C

Report of the systematic review on the effect of insulation against cold on health

Lucy Telfar Barnard, Philippa Howden-Chapman, Mike Clarke and Ramona Ludolph

In:

WHO Housing and health guidelines

World Health Organization

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Contents

Introduction

This report assesses the potential benefits of insulation against cold in the home environment. This systematic review was conducted to support the development of the World Health Organization's (WHO) Housing and health guidelines. The aim of this systematic review is to provide the best available evidence from existing research to contribute to the deliberations of the Guideline Development Group (GDG).

The structure of this report is as follows:

- Background: provides a brief contextualization of the health effects of cold.
- Eligibility criteria and information on participants, intervention, comparator and outcomes (PICO): outlines the PICO for this systematic review, and provides the inclusion and exclusion criteria.
- Search strategies and checking of articles: presents the process of searching and identifying articles.
- Extraction of information, preparation of narrative summaries, evidence profiles and summary of findings tables: provides the process of data extraction, quality assessment, and outcomes and findings presentation.
- Findings and discussion: summarises the results and discusses the findings.
- Comprehensive appendices 1–8 present detailed information in relation to this systematic review.

Background

A range of previous research has shown that exposure to cold is deleterious to health (Mercer 2003; Nahya 2002; Wilson 2001). The purpose of this review is to contribute to discussion and decisions on the role of housing in preventing such exposure. Two previous reviews have been published including criteria relevant to the PICO for this review, but with additional criteria. Thomson et al.'s 2013 review includes a section covering interventions for "warmth and energy efficiency improvements" (Thomson 2013), while the Maidment et al. meta-analysis covers any study looking at health outcomes of energy-efficiency measures (Maidment 2014).

Thomson et al. found that the "provision of adequate and affordable space and warmth are key determinants of subsequent health and health impacts, in particular respiratory health" (Thomson 2013), while Maidment et al. found that "on average … household energy efficiency interventions led to a small but significant improvement in the health of residents" (Maidment 2014). However, these reviews effectively covered the broader issue of whether a warmer home – achieved through heating or thermal envelope improvements – is healthier, rather than the more specific question covered by this PICO, of whether housing is healthier when the thermal envelope is better at keeping out cold. The matter of indoor temperature and health is covered in a separate review informing the WHO Housing and health guidelines.

Eligibility criteria and PICO

The finalized research question for this review is:

Do people living in housing with insulation have better health outcomes than those living in housing without insulation?

Eligibility criteria were based on a reduced set of Maidment et al.'s inclusion criteria (Maidment 2014). Table 1 shows the inclusion and exclusion criteria that were used for the first search in 2015. One exclusion criterion was dropped in the 2018 search as detailed in the following section.

Table 1 Inclusion and exclusion criteria for the review

	Inclusion criteria	Exclusion criteria
Context	Domestic houses or flats in the community setting	Studies with modelled outcomes
Participants	People of all age groups	
Intervention	Insulation (loft, cavity, internal and external solid wall insulation) Other thermal envelope improvements (e.g. draft-stopping, double glazing, thermal curtains)	[2015 only] Studies that reported results of warmth measures without disaggregating results of thermal envelope measures from heating measures were also excluded.
Comparison	Absence of the relevant intervention	
Outcomes	Health related outcomes (as ranked by the GDG): • Respiratory morbidity and mortality • All cause-mortality in infants • Hospital admissions • Cardiovascular morbidity and mortality • Depression • High blood pressure Other outcomes were also reported because of the small number of studies	

Search strategies and checking of articles

The constraints of time and resources involved in the conduct of this rapid systematic review means that it is not possible to explore all potential sources of information that might be drawn upon in a more comprehensive systematic review. Such activities would require extensive searching for unpublished studies and for studies reported in the grey literature or published in journals that are not well-indexed in the major bibliographic databases. However, the intention behind the search was to try to avoid missing any pivotal study which would transform the overall findings of the systematic review or the conclusions to be drawn from these findings.

Previous research had already identified the Thomson et al. 2013 Cochrane Review (Thomson 2013) and an initial literature browse using terms based on the Cochrane Review, for papers published after its final search date, identified the Maidment et al. review from 2014 (Maidment 2014).

Both reviews covered a broader range of interventions than the insulation intervention specified in this PICO. Comparison of the two reviews highlighted the fact that the Thomson et al. review covered housing improvements, and therefore excluded studies looking at existing housing conditions, which were included in the Maidment et al. meta-analysis. That meta-analysis included not only intervention studies, but also studies which compared the health of people in insulated dwellings with similar people in non-insulated dwellings (Maidment 2014).

The review presented here took the papers identified under "warmth and energy efficiency improvements" in Thomson et al. (including excluded papers) and Maidment et al. as the starting point, supplemented by a 2015 literature search for eligible papers published after the latter of the two previous reviews' final search date, and by a 2018 search update. Supplementary literature search terms were based on the Maidment et al. and Thomson et al. searches, but limited to focus on insulation and selected outcomes; and using only the databases PubMed, Reuters Thomson Web of Knowledge and Google Scholar due to resource and time constraints. The 2015 supplementary search identified no new eligible research; the 2018 search identified five new papers.

The searches are described separately below. Decisions about the potential eligibility and need for translation of articles published in languages other than English were made on the basis of the English language abstract. It was presumed that no pivotal papers that would substantially change the findings or conclusions of the reviews would have been missed because of their publication in a language other than English. This is based on the likelihood that any such research would have found its way into the English literature or been clearly relevant from the abstract.

The retrieved records from the two previous reviews, PubMed and Reuters Thomson Web of Knowledge searches were de-duplicated before full-text screening. Google Scholar records were not de-duplicated because of technical constraints. Records retrieved from the bibliographic databases were checked twice to identify potentially relevant articles. These potentially relevant articles were then retrieved in full text, and assessed for eligibility. As expected when the searches were designed, most of the retrieved records were not relevant to this systematic review and this was obvious from scrutiny of their title or abstract. For pragmatic reasons, the reasons for the early exclusion of each of these records were not recorded. The final date for searches for the initial review was 31 March 2015.

Table 2 Number of records retrieved and checked from each source

Search component	Records identified	Full-texts screened	Eligible studies
PubMed	17	11	0
Reuters Thomson Web of Knowledge	125	7	0
Google Scholar	200	3	0
Identified by previous reviews	28	28	6
Identified in 2018 update	288	6	5
Total	658	55	11

In order to bring the systematic review up-to-date, new searches for eligible studies were done on 4 April 2018 to identify articles published since 1 January 2015. We used the original search strategies to re-run the searches in PubMed, Reuters Thomson Web of Knowledge, and Google Scholar. The retrieved records were checked by two authors (RL and MC) and the full text was sought for all studies judged to be potentially eligible.

In conducting the update of the review in 2018, the eligibility criteria were revised to include studies in which the installation of insulation was done as part of a home improvement package, even if the direct health effects of insulation could not be separated from the effects of other interventions in the package. This change was not dependent on the results of these additional studies, having been made in advance of the searches for publications from 2015 onwards, but was intended to broaden the scope of the eligible studies and boost the evidence base for this part of the WHO Housing and health guidelines. The revised eligibility criteria were not applied to the pre-2015 studies for reasons related to practicalities and the risk of bias: (1) the need to focus available resources on the updating of the reviews for the final guideline and (2) concern that any retrospective decision to change the eligibility might be perceived as biased because of detailed knowledge of the studies that had been gathered when excluding such studies from the original review in 2015.

The search strategies used in 2015 and 2018, including the number of articles identified in each of these, are shown in Appendices 1–3. 342 records were retrieved by the 2015 electronic searches; 28 from the previous reviews; and 288 by the 2018 update. The contribution of each of these sources is shown in Table 1.

During the search in 2015, a total of 49 full text articles were retrieved, checked for relevance and had their reference lists screened for additional potentially eligible studies. A list of the 43 articles that were obtained as potentially eligible and then excluded, along with the reason for their exclusion is provided in Appendix 4. The flow diagram for the identification of studies is shown in Figure 1. The update search in 2018 led to the checking of six potentially relevant full-text articles, of which five were included in the systematic review. Figure 2 presents the flow of studies during the updating process.

Figure 1 Flow diagram for identification of studies in 2015

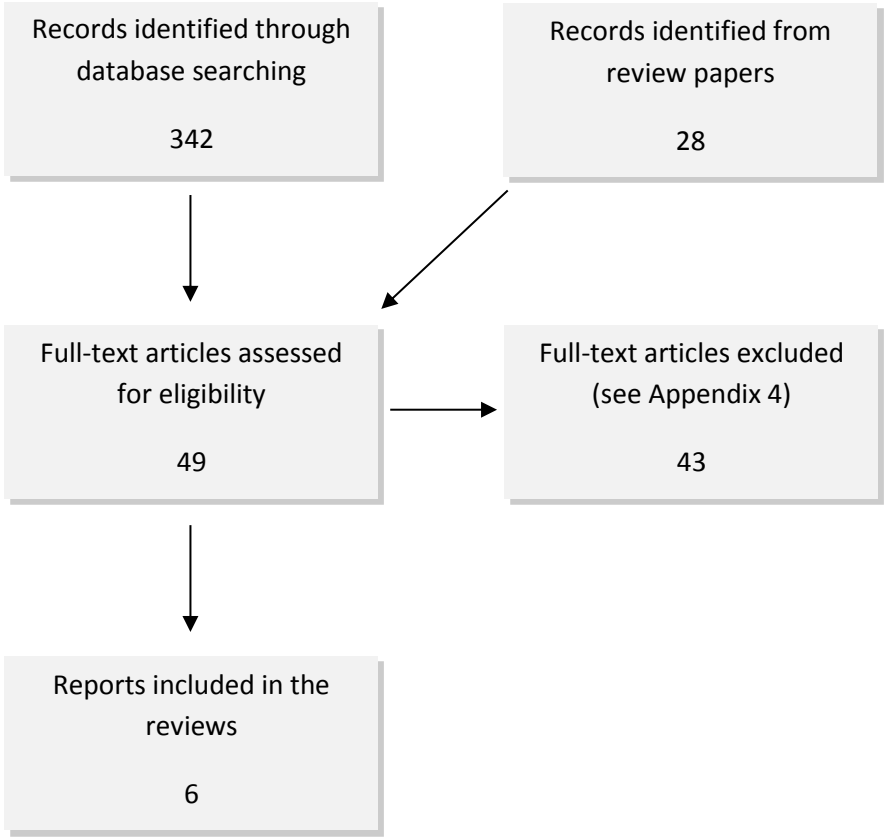
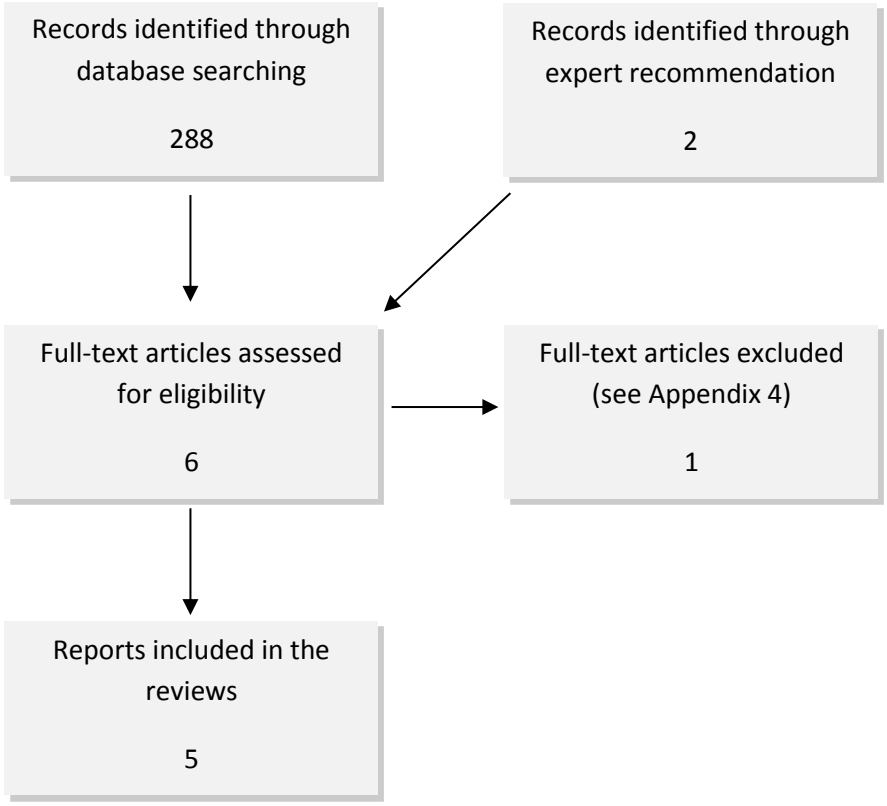


Figure 2 Flow diagram for identification of studies in 2018 update



Extraction of information, preparation of narrative summaries, evidence profiles and summary of findings tables

If an article was judged to be eligible, the following information was extracted, where available:

- Location and date of study
- Type and number of participants
- Details of the intervention and any comparator
- Design, including the methods used for any comparison
- Results for all outcomes reported.

In addition, assessments were made in relation to the following characteristics based on information available in the report and using a domain approach for assessing quality:

- Risk of bias
- Other aspects of study quality
- Relevance to the PICO.

This information was then used to complete an evidence profile for each study, along with a narrative summary (Appendix 5). Summary of Findings tables were also prepared, which describe the evidence in narrative terms, reflecting the types of study that were identified (Appendix 6).

Findings

As had been expected, only a small number of potentially eligible studies were identified for the systematic review. These studies provided evidence on the PICO ranked outcomes “respiratory illness”, “hospital admissions”, and “all-cause mortality”; the unranked PICO outcome “depression” and the related “mental health”; and also some non-PICO health outcomes, which are tabled for completeness in Appendix 7. The characteristics of the included studies are presented in Appendix 8. No studies were found covering the PICO-ranked outcomes “cardiovascular morbidity or mortality” or “high blood pressure”.

Respiratory outcomes measured were:

- Self-reported cough (Austin 1997)
- Self-reported wheeze (Austin 1997; Howden-Chapman 2007)
- Self-reported respiratory symptoms over previous month (Poortinga 2017)
- GP-diagnosed asthma (Tavernier 2006)
- Acute otitis media (Homøe 1999)
- Winter colds and flu (Maidment 2014)
- Morning cough or phlegm in adults (Howden-Chapman 2007)
- Eye irritation and dry throat (Iversen 1986).

Hospital admissions (all-cause) were measured in two studies (Howden-Chapman 2007; Telfar Barnard 2011); all-cause mortality (Telfar Barnard 2011, Preval 2017) in two studies using the same data; and adult mental health (Howden-Chapman 2007, Poortinga 2017) were measured in one study each.

The geographic distribution of studies was limited to Carmarthenshire, Wales, the United Kingdom (Poortinga 2017); Denmark (Iversen 1986); Greenland (Homøe 1999); Manchester, England, the United Kingdom (Tavernier 2006); New Zealand (Howden-Chapman 2007; Telfar Barnard 2011; Preval 2017) and Scotland, the United Kingdom (Austin 1997).

Interventions/exposures were:

- installation of ceiling and underfloor insulation and draft-stopping (x2) (Howden-Chapman 2007; Telfar Barnard 2011 and Preval 2017);
- installation of loft insulation (Poortinga 2017);
- installation of cavity wall insulation (Poortinga 2017);
- installation of external wall insulation (Poortinga 2017); including in combination with heating upgrades (Grey 2017);
- self-reported insulation (Austin 1997);
- healthy home intervention package including air sealing, new insulation and exterior cladding, and window replacement (Breysee 2015);
- self-reported carpeting (Austin 1997);
- self-reported double-glazing/glazing system (x2) (Austin 1997; Tavernier 2006);
- double-glazing and new boiler installation (Bray 2017)
- installation of air-tight windows (Iversen 1986);
- new windows and doors (Poortinga 2017); and
- self-reported drafts (as proxy for insulation) (Homøe 1999).

Risk of bias assessment

Of the 11 eligible studies, only one was judged to be of high quality. This was Howden-Chapman et al.'s randomised trial of the effects of insulation and draft-stopping on respiratory illness (Howden-Chapman 2070). Two studies were judged to be of low quality: Homøe et al 1999 had incomplete data for a self-reported indirect measure of insulation ("presence of drafts"), while Iversen et al.'s 1986 study of the effects on health of replacing windows to improve air-tightness had a high risk of selection bias.

The other eight studies, and one outcome of the Howden-Chapman study, were judged to be of medium quality. Austin and Russell 1997 had a risk of bias in its reliance on self-report of insulation status. Tavernier et al 2006 used a matched case-control study design, and self-report of "glazing system". Telfar Barnard et al 2011 and Preval et al 2017 had some risk of bias in their selection of control members for their cohorts, and, in relation to the "all-cause mortality" outcome, risk of treatment bias, since decision to insulate could be modified by severity of health status. Poortinga et al.'s 2017 study was not randomized, and may have included some effect from non-insulation interventions installed at the same time. In Bray 2017, Breysse 2015, and Grey 2017, the results are also likely to have included effects of non-insulation co-interventions. The sample size in Howden-Chapman et al. 2007 was insufficient to measure an effect on hospital admissions.

Effects of an insulated home on health outcomes

Of the 11 studies identified in the systematic review, seven found some association between the benefits of living in an insulated home and improved health. For example, a cluster randomized trial in New Zealand on the effect of insulating existing homes where at least one person in the household had existing chronic respiratory symptoms found that insulation was associated with reduced odds of poor mental health, self-reported wheezing in the past three months, winter colds or flu, and morning phlegm in adults (Howden-Chapman 2007).

While mental health was improved in one controlled trial from the United States of America, the study did not find any differences in general health status between people receiving new insulation and exterior cladding and those in the control group (Breysse 2015). One quasi-experimental study from the United Kingdom found no difference between asthmatic and healthy children with regard to different glazing systems (Tavernier 2006). Another quasi-experimental study in New Zealand found that all-cause mortality was significantly lower in people with a history of cardiovascular disease if they lived in an insulated rather than an uninsulated house and non-significantly lower in people with a history of respiratory disease (Preval 2017). Similarly, a controlled trial from the United Kingdom did not detect any effect of external insulation on general respiratory symptoms, asthma, physical or mental health or subjective well-being (Grey 2017).

A cross-sectional study from the United Kingdom investigated the effects of different types of insulation on a range of health outcomes (Poortinga 2017). The study identified positive effects of loft and external wall insulation on respiratory, mental and general health; but found a negative impact on these outcomes with cavity wall insulation.

Three retrospective cohort studies investigated the effects of living in an insulated home on health. A New Zealand study of 45 000 households, with matched controls, showed no relationship between living in an insulated home and rates of hospitalization. However, mortality rates for adults aged 65 and over who had previously been hospitalized for circulatory illness were lower for people living in insulated dwellings (Telfar Barnard 2011). A study from Scotland, looking at the indoor environment and health outcomes as reported by participants, found that rates of coughing were significantly lower in homes with double-glazed windows but no consistent relationship between wheezing and coughing, and insulation (Austin 1997). A study from Greenland, of households with children aged three to five and eight years who had a previous medical attendance for acute otitis media, found no relationship between episodes of acute otitis media and self-reported poor insulation, defined as “reports of draft along the floors and through doors and windows” (Homøe 1999). An historical cohort study conducted in the United Kingdom reported that double glazing improved the household health status by 4.8% but did not detect effects on quality of life or other measures of well-being (Bray 2017).

One case-control study from Denmark, which had a high risk of bias, found that eye irritation and throat dryness (connected to respiratory health) decreased slightly when windows were replaced, but the results were not statistically significant (Iversen 1986).

Discussion

In summary, of the measured insulation interventions and exposures, installation of ceiling and underfloor insulation and draft-stopping reduced wheeze, likelihood of low self-reported happiness, and all-cause mortality; new windows and doors, loft insulation, and external wall insulation were each associated with reduced respiratory symptoms and improved mental health; and self-reported double-glazing was associated with lower likelihood of current cough. Insulation as part of energy efficiency packages improved general health status, hospital visits, and mental health. Cavity wall insulation, however, was associated with increased respiratory symptoms and worsened mental health. Other interventions or exposures had no statistically significant effect on, nor association with, other health outcomes.

Note

As the single high quality study found for this review also included effects on indoor temperatures, it may be better considered as part of the evidence for the beneficial effect of preventing cold temperatures indoors, in the Cold PECO.

Contributors

Lead: Lucy Telfar Barnard (University of Otago, Wellington and He Kainga Oranga/Housing and Health Research Programme, New Zealand).

Team: Philippa Howden-Chapman (University of Otago, Wellington and He Kainga Oranga/Housing and Health Research Programme, New Zealand), Mike Clarke (Queen's University of Belfast, Northern Ireland and Evidence Aid, United Kingdom), Ramona Ludolph (Department of Public Health, Environmental and Social Determinants of Health, World Health Organization, Switzerland).

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Appendices

Appendix 1 Search strategy for PubMed (including MEDLINE)

2015 search

(insulation OR insulate OR “double glaze” OR “double glazing”) AND (home OR homes OR house OR houses OR housing)

Limited to humans

Limited to publication date 2012/07/01 to 2015/01/01

This search returned 17 results for title screening. Eleven were selected for full-text screening. None of the 11 met eligibility criteria for the review.

2018 update

Date of search: 2018-04-04

(insulation OR insulate OR “double glaze” OR “double glazing”) AND (home OR homes OR house OR houses OR housing)

Limited to humans

Limited to publication date 2015/01/01 to 2018/12/31

This search returned 18 results. After deduplication, 16 results remained for title and abstract screening.

Appendix 2 Search strategy for Thomson Reuters Web of Knowledge

2015 search

((insulation OR insulate OR “double glaze” OR “double glazing”) AND (home OR homes OR house OR houses OR housing)) *AND* **TOPIC:** (reduc* or improve* or decreas* or evaluat* or change* or changing or intervention* or grow* or better or worse* or effect* or achieve* or comfort or morale or harmful or impact* or gain) *AND* **TOPIC:** (health or wellbeing or “well-being” or anxiety or mental or depression or stress or happiness or distress)

Refined by: **PUBLICATION YEARS**: (2014 OR 2013 OR 2012 OR 2015)

Timespan: 2012–2015.

Search language=Auto

Returned 125 results; of these, 30 were selected for abstract screening. Thirteen of these 30 were duplicates. Of the remaining 17, seven were selected for full-text review. None met eligibility criteria.

2018 update

Date of search: 4 April 2018

((insulation OR insulate OR “double glaze” OR “double glazing”) AND (home OR homes OR house OR houses OR housing)) *AND* **TOPIC:** (reduc* or improve* or decreas* or evaluat* or change* or changing or intervention* or grow* or better or worse* or effect* or achieve* or comfort or morale or harmful or impact* or gain) *AND* **TOPIC:** (health or wellbeing or “well-being” or anxiety or mental or depression or stress or happiness or distress)

Refined by: PUBLICATION YEARS: (2015 OR 2016 OR 2017 OR 2018)

Timespan: 2015–2018.

Search language=Auto

Returned 89 results, 77 of which remained after deduplication.

Appendix 3 Search strategies for Google Scholar

2015 search

insulate AND (home OR house) *AND* (reduce OR improve OR decrease OR evaluate OR change OR intervention OR better OR worse OR effect OR impact OR gain) *AND* (health OR wellbeing OR anxiety OR mental OR depression OR stress OR happiness OR distress)

Date range 2012 to March 2015 inclusive

Returned 17 000 results. Results were sorted by relevance and the first 10 pages (100 records) were screened by title. Four results were selected for abstract/summary screening. None were selected for full-text screening.

“double glazing” AND (home OR house) *AND* (reduce OR improve OR decrease OR evaluate OR change OR intervention OR better OR worse OR effect OR impact OR gain) *AND* (health OR wellbeing OR anxiety OR mental OR depression OR stress OR happiness OR distress)

Date range 2012 to March 2015 inclusive.

Returned 1740 results. Results were sorted by relevance and the first 10 pages (100 records) were screened by title. Nine results were selected for abstract/summary screening. three results were selected for full text screening. None of these three met eligibility criteria.

2018 update

Date of both searches: 2018-04-04

insulate AND (home OR house) *AND* (reduce OR improve OR decrease OR evaluate OR change OR intervention OR better OR worse OR effect OR impact OR gain) *AND* (health OR wellbeing OR anxiety OR mental OR depression OR stress OR happiness OR distress)

Date range 2015 to 2018.

Returned 17 300 results. Results were sorted by relevance and the first 10 pages (100 records) were screened by title.

Eight results were selected for abstract/summary screening. None were selected for full text screening.

“double glazing” AND (home OR house) *AND* (reduce OR improve OR decrease OR evaluate OR change OR intervention OR better OR worse OR effect OR impact OR gain) *AND* (health OR wellbeing OR anxiety OR mental OR depression OR stress OR happiness OR distress)

Date range 2015 to 2018.

Returned 1990 results. Results were sorted by relevance and the first 10 pages (100 records) were screened by title.

Four results were selected for abstract/summary screening. None of these were selected for full text screening.

Appendix 4 Articles excluded following check of the full text in 2015

	Reason for exclusion						
Author(s)	Population	Study design	Intervention	Comparator	Outcome	Other	Notes
Thomson et al							
Barton et al 2007 (M)			X				Insulation intervention could not be separated from package
Broder et al 1991 (M)			X	X			Intervention was replacing UFFI insulation with other insulation, for formaldehyde not temperature
Eick 2001 (T)			X				Ventilation, not insulation intervention
El Ansari 2008 (T)			X				Study does not specify what improvements were implemented; insulation not separate from total package
Heyman et al 2005 (M)			X				Insulation intervention could not be separated from package
Infante-Rivard 1993 (M)				X			Not clear whether comparator was "no insulation" or insulation other than mineral wool/UFFI
Lloyd et al 2008 (T)			X				Insulation intervention could not be separated from package
Norman et al 1986 (M)				X			UFFI insulation; comparator is combined other/no insulation
Shortt and Rugkasa 2007 (M)			X				Insulation intervention could not be separated from package
Vandentorren et al 1991 (M)					X		Insulation measured as risk for heat-related death
Osman 2010 (T)			X				Insulation intervention could not be separated from package
Platt 2007 (T)			X				Heating intervention
Somerville 2000 (T)			X				Insulation intervention could not be separated from package
Hopton 1996 (T)			X				Heating intervention
Allen 2005(Ta)			X				Insulation intervention could not be separated from package
Health Action Kirklees (T)			X				Heating intervention
Caldwell 2001 (T)			X				Insulation intervention could not be separated from package [N.B. original could not be accessed, assessment based on Thompson summary]
Green 1999 (T)				X			No assessment of change
Roder 2008 (T)			X				Insulation intervention could not be separated from package
Warm Front 2008 (T)			X				Insulation intervention could not be separated from package
Winder 2003 (T)			X				Insulation intervention could not be separated from package
Windle et al 2006 (M)					X		Outcome (self-reported general health) was not included in PICO outcomes

	Reason for exclusion						
Author(s)	Population	Study design	Intervention	Comparator	Outcome	Other	Notes
PubMed							
Amundsen 2013			X				Insulation against noise: no thermal effects measured
Bright 2013	X	X		X			Single case report
Huang 2014			X	X			Measures faulty application of spray polyurethane foam insulation
Jiránek 2014	X				X		Effect of thermal retrofitting on radon concentration; direct health effects not measured
Laaidi 2013			X				No novel study of insulation
Madden 2014					X		No outcome measure
Mesa-Frias 2013		X					No novel study of insulation
Spear 2012				X	X		No health effects reported; not comparing insulated with uninsulated
Valsecchi 2014						X	Proposed action, no results
Viggers 2013					X		Results not yet available
Yarmoshenko 2014			X	X	X		Measurements of radon concentration only
Web of Science							
Liddell 2015						X	Review of other studies; conclusions do not distinguish between insulation and other energy efficiency measures
Curl 2015			X				Insulation intervention (if any) could not be separated from package
Rivier 2014					X		No health outcomes reported
Wilson 2014			X				Insulation intervention could not be separated from package
Braubach 2013							No novel study of insulation
Chungkumho 2013						X	No translation available; not clear from abstract that translation warranted
Hu 2012					X		Only published as abstract; no health data mentioned
Google scholar							
Sowden 2014			X				Insulation intervention could not be separated from package
Santamouris 2014						X	Reported health results not disaggregated by insulation levels
Cotter 2012						X	Reported illness not disaggregated by insulation status

Appendix 5 Evidence profiles for potentially eligible insulation studies, with narrative summaries for each study

Quality assessment							No. of participants	Effect	Quality	Importance
Number of studies	Designs	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations				
Respiratory morbidity and mortality										
7 (Austin 1997, Homøe 1999, Howden-Chapman 2007, Grey 2017, Iversen 1986, Poortinga 2017, Tavernier 2006)	Randomized: 1 (Howden-Chapman 2007) Quasi-experimental: 2 (Grey 2017, Iversen 1986) Cohort: 2 (Austin 1997, Homøe 1999) Case-control: 1 (Tavernier 2006) Cross-sectional: 1 Poortinga 2017)	Moderate	Consistent	Direct	Precise	Studies were in 4407 people in 1350 households in New Zealand (Howden-Chapman 2007), 782 adults in the United Kingdom (Grey 2017), 641 adults (≥18 years) in Denmark (Iversen 1986), 1537 children (12-14 years) in the United Kingdom (Austin 1997, 740 children (3-8 years) in Greenland (Homøe 1999), 180 children with and without asthma in the United Kingdom (Tavernier 2006), and 1709 people in the United Kingdom (Poortinga 2017).	Randomized trial: 4407 Quasi-experimental studies: 1423 Cohort studies: 2277 Case-control study: 180 Cross-sectional study: 1709	Randomized trial: insulation raised mean temperatures by 0.5°C, and reduced RH by 2.3% in bedrooms. The insulation reduced wheezing (OR: 0.57, 95% CI: 0.4 -0.70). winter colds or flu (OR: (0.54, 95% CI: 0.43-0.66), and morning phlegm in adults (OR: 0.64, 95% CI: 0.52-0.78) (Howden-Chapman 2007). Quasi-experimental studies: both studies found non-significant effects of external insulation on general respiratory symptoms (Cohen's d: 0.061, Beta: −0.155, SE: 0.192, p=0.419) or asthma (Cohen's d: 0.051, Beta: −0.088, SE: 0.247, p=0.722) (Grey 2017), eye smarting/irritation and throat dryness were non-significantly reduced (Iversen 1986). Cohort studies: One study found that cough was lower in houses with double glazing (RR: 0.68, 95% CI: 0.49-0.94) but there was no effect of wall-to-wall carpeting or insulation on cough or wheeze; or of double-glazing on wheeze (Austin 1997). In the other study self-reported insulation standard could not be related to episodes of acute otitis media (Homøe 1999). Case-control study: No difference by glazing system or insulation type (Tavernier 2006). Cross-sectional study: respiratory health was improved with loft insulation (beta: −0.145, SE: 0.062, p<0.01) and external wall insulation (Beta: −0.416, SE: 0.073, p<0.001) but worsened with cavity wall insulation (Beta: 0.385, SE: 0.062, p<0.001; OR: 1.47, 95% CI: 1.30-1.66) (Poortinga 2017).	⊕⊕⊕⊕ High	High

Quality assessment							No. of participants	Effect	Quality	Importance
Number of studies	Designs	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations				
Hospital admissions										
2 (Howden-Chapman 2007, Telfar Barnard 2011)	Randomized: 1 (Howden-Chapman 2007) Cohort: 1 (Telfar Barnard 2011)	Moderate	Inconsistent	Direct	Imprecise	Studies were in 4407 people in 1350 households in New Zealand (Howden-Chapman 2007) and 1,084,070 people in New Zealand (Telfar Barnard 2011).	Randomized trial: 4407 Cohort study: 1,084,070	Randomized trial: Hospital admissions for respiratory conditions were non-significantly reduced (OR: 0.53, 95% CI: 0.22-1.29) (Howden-Chapman 2007). Cohort study: No significant effect (Telfar Barnard 2011).	⨁⨁⨀⨀ Low	Low (non-significant effects on health and both studies are from one country (New Zealand)
All-cause mortality										
1 (Telfar Barnard 2011; Preval 2017)	Cohort: 2 (Telfar Barnard 2011; Preval 2017)	Moderate	Not applicable (one set of data)	Direct	Imprecise	Studies were in 10,991 adults (≥65 years) in New Zealand (Telfar Barnard 2011) and a subset of 4,848 of those adults (≥65 years) (Preval 2017).	Cohort study: 10,991 and 4,848 subset	Cohort study: Reduced mortality in adults who had previously been hospitalized for circulatory illness (RR: 0.73, 95% CI: 0.53-1.00) (Telfar Barnard 2011) Subset cohort study: Reduced mortality in adults who had previously been hospitalized for circulatory illness (Hazard ratio: 0.673, 95% CI: 0.535-0.847). No significant effect for those previously hospitalized for respiratory illness (Hazard ratio 0.830, 95% CI: 0.655 – 1.051) (Preval 2017).	⨁⨁⨀⨀ Low	Low (single dataset from one country (New Zealand)

Quality assessment							No. of participants	Effect	Quality	Importance
Number of studies	Designs	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations				
Depression/mental health										
4 (Breysse 2015, Grey 2017, Howden-Chapman 2007, Poortinga 2017)	Randomized: 1 (Howden-Chapman 2007) Quasi-experimental: 3 (Breysse 2015, Grey 2017) Cross-sectional: 1 Poortinga 2017)	Low	Consistent	Direct	Precise	Studies were in 4407 people in 1350 households in New Zealand (Howden-Chapman 2007), 62 adults in insulated homes and 612 in control group in the USA (Breysse 2015), 782 adults in the United Kingdom (Grey 2017), and 1709 people in the United Kingdom (Poortinga 2017).	Randomized trial: 4407 Quasi-experimental studies: 1456 Cross-sectional study: 1709	Randomized trial: Reduced low levels of happiness (OR: 0.56, 95% CI: 0.41-0.77) (Howden-Chapman 2007). Quasi-experimental studies: in one study insulation led to more good mental health days in the past month (p=0.026) and mean VR-12 mental component score (p=0.023) (Breysse 2015) but in the other study there was no significant effect of external insulation on mental health (Cohen's d: 0.005, Beta: −0.059, SE: 0.789, p=0.940) (Grey 2017). Cross-sectional study: mental health was improved with loft insulation (Beta: 4.281, SE: 0.660, p<0.001); and external wall insulation 2.657 (0.823), p <0.01 but was worsened with cavity wall insulation (beta: −2.052, SE: 0.687), p <0.05) (Poortinga 2017)	⊕⊕⊕⊖ Mderate	Moderate

General health										
4 (Bray 2017, Breysse 2015, Grey 2017, Poortinga 2017)	Quasi-experimental: 2 (Breysse 2015, Grey 2017) Cohort: 1 (Bray 2015) Cross-sectional: 1 (Poortinga 2017)	Moderate	Consistent	Direct	Precise	Studies were in 228 households in the United Kingdom (Bray 2015), 62 adults in insulated homes and 612 in control group in the USA (Breysse 2015), 782 adults in the United Kingdom (Grey 2017), and 1709 people in the United Kingdom (Poortinga 2017).	Quasi-experimental studies: 674 Cohort study: 228 households Cross-sectional study: 1709	Quasi-experimental studies: no significant difference in the change in general health status between people receiving new insulation and exterior cladding and other people (Breysse 2015) or in physical health (Cohen's d: 0.107, Beta: 0.987, SE: 0.664, p=0.137) or subjective well-being (Cohens's d: 0.200, Beta: 0.375, SE: 0.134, p=0.005) with external insulation (Grey 2017). Cohort study: double glazing improved household health status by 4.8% (t (226): 2.652; p=0.009) but no significant impact on quality of life (t (219): 0.583; p=0.56) or other measures of well-being (Bray 2015). Cross-sectional study: general health was improved by loft insulation (Beta: 0.183 SE: 0.066, p<0.01) and external wall insulation (Beta: 0.255, SE: 0.079, p<0.01) but worsened with cavity wall insulation (Beta: −0.253, SE: 0.067, p <0.001; OR: 0.78, 95% CI: 0.68–0.89) (Poortinga 2017)	⊕⊕⊕⊖ Moderate	Moderate

Austin J, Russell G. Wheeze, cough, atopy and indoor environment in the Scottish Highlands. Arch Dis Child 1997; 76: 22–6.

Bray N, Burns P, Jones A, et al. Costs and outcomes of improving population health through better social housing: a cohort study and economic analysis. Int J Public Health 2017; 62: 1039–50.

Breysse J, Dixon SL, Jacobs DE, t al. Self-reported health outcomes associated with green-renovated public housing among primarily elderly residents. J Public Health Manage Pract 2015; 21(4): 355-67.

Grey CNB, Jiang S, Nascimento C, et al. The short-term health and psychosocial impacts of domestic energy efficiency investments in low-income areas: a controlled before and after study. BMC Public Health 2017; 17: 140

Homøe P, Christensen R, Bretlau P. Acute otitis media and socio-medical risk factors among selected children in Greenalnd. Int J Pediat Otorhinolaryngol 1999; 49(1): 37–52.

Howden-Chapman P, Matheson A, Crane J, et al. Effect of insulating existing houses on health inequality: cluster randomized study in the community. BMJ 2007; 334: 460.

Iversen M, Back E, Lundqvist G. Health and comfort changes among tenants after retrofitting of their housing. Environ Int 1986; 12: 1–4.

Poortinga W, Jones N, Lannon S, Jenkins H. Social and health outcomes following upgrades to a national housing standard: a multilevel analysis of a five-wave repeated cross-sectional survey. BMC Public Health 2017; 17: 927.

Preval N, Keall M, Telfar-Barnard L, Grimes A, Howden-Chapman P. Impact of improved insulation and heating on mortality risk of older cohort members with prior cardiovascular or respiratory hospitalizations. BMJ Open 2017;7:e018079. doi:10.1136/bmjopen-2017–018079.

Tavernier G, Gletcher G, Gee I, et al. IPEADAM study: indoor endotoxin exposure, family status, and some housing characteristics in English children. J Allergy Clin Immunol 2006; 117: 656–62.

Telfar Barnard L, Preval N, Howden-Chapman P, et al. The Impact of Retrofitted Insulation and New Heaters on Health Services Utilisation and Costs, Pharmaceutical Costs and Mortality: Evaluation of Warm Up New Zealand: Heat Smart. Report to the Ministry of Economic Development. Wellington, 2011.

Note: Studies highlighted in red were added during the update of the systematic review.

Narrative summaries

1. **Austin J, Russell G. Wheeze, cough, atopy and indoor environment in the Scottish Highlands. Archives of Disease in Childhood 1997;76:22–26**

This retrospective cohort study surveyed parents to measure associations between self-reported wheeze, and cough and self-reported indoor environment, including roof, cavity and wall insulation, and double glazing. The authors found no consistent relationship between respiratory symptoms and insulation. Rates of cough were significantly lower in homes with double glazing (RR 0.675, 95% CI 0.486–0.936, p=0.018). The authors query whether the 12–14 years age range of included children was beyond the age at which household conditions affect the measured health outcomes.

2. **Breysse J, Dixon SL, Jacobs DE, t al. Self-reported health outcomes associated with green-renovated public housing among primarily elderly residents. J Public Health Manage Pract 2015; 21(4): 355–67**

This quasi-experimental study compared self-reported mental health, physical health and falls before and after an extensive “green renovation” package including new insulation and exterior cladding, air sealing and window replacement. The authors found improvements in self-reported good mental health days (p=0.026), VR-12 mental component score (p=0.023), and a non-significant reduction in falls (p=0.055) and general physical health (p=0.094).

3. **Bray N, Burns P, Jones A, et al. Costs and outcomes of improving population health through better social housing: a cohort study and economic analysis. Int J Public Health 2017; 62: 1039–50**

In this cohort study, participants received a new boiler and double-glazing. The authors found household health status improved by 3.25% (p=0.009), the main tenant health status improved by 4.85% (p<0.001), and hospital visits declined for outpatients (p=0.001) and accident and emergency (p=0.012). There was no significant effect on main tenant quality of life.

4. **Grey CNB, Jiang S, Nascimento C, et al. The short-term health and psychosocial impacts of domestic energy efficiency investments in low-income areas: a controlled before and after study. BMC Public Health 2017; 17: 140**

This quasi-experimental study examined health outcomes of adults receiving a home energy performance package including external wall insulation and heating upgrades. Compared to a control group, participants’ subjective well-being improved (p=0.005), but results for mental health, physical health, general respiratory symptoms and asthma symptoms were non-significant.

5. **Homøe P, Christensen R, Bretlau P. Acute otitis media and socio-medical risk factors among selected children in Greenalnd. International Journal of Pediatric Otorhinolaryngology 1999;49(1):37–52**

This study measured socioeconomic risk factors, including parental-reported poor/good insulation, defined as “reports of draft along the floors and through doors and windows”, in Greenlandic children aged 3–5 and 8 who had a previous medical attendance for acute otitis

media (AOM). The insulation standard variable was less likely to be reported than other variables, and was an indirect measure of insulation. Insulation standard showed no relationship with episodes of AOM.

6. **Howden-Chapman P, Matheson A, Crane J, et al. Effect of insulating existing houses on health inequality: cluster randomized study in the community. British Medical Journal 2007(334):460**

This RCT study measured changes in self-reported wheeze and days off school or work; GP-reported doctors' visits, and national patient identifier-linked hospital admissions following draft-stopping and installation of ceiling and under-floor insulation, in low-income households. The results of the intervention for PCIO outcomes were: self reports of wheezing in the past three months (0.57, 0.47 - 0.70), Hospital admissions for respiratory conditions were also reduced (0.53, 0.22 - 1.29), but this reduction was not statistically significant (P=0.16). Also PICO-relevant was the finding that mean temperatures were raised 0.5^{o}C, and RH reduced 2.3% in bedrooms. Non-PICO health outcomes were reduced odds of fair or poor self rated health (adjusted odds ratio 0.50, 95% CI 0.38 - 0.68), self reports of children taking a day off school (0.49, 0.31 - 0.80), self reports of adults taking a day off work (0.62, 0.46 - 0.83), and self-reports of visits to general practitioners (0.73, 0.62 - 0.87).

7. **Iversen M, Back E, Lundqvist G. Health and comfort changes among tenants after retrofitting of their housing. Environment International 1986;12:1–4**

This study used a questionnaire to measure differences in two less direct respiratory symptoms, eye irritation and dry throat between people who had had windows replaced, and people who had not. ORs for all symptoms were lower, but confidence intervals were not reported; few were significant, and which few were not reported. There was also high risk of selection bias.

8. **Poortinga N, Jones N, Lannon S, Jenkins H. Social and health outcomes following upgrades to a national housing standard: a multilevel analysis of a five-wave repeated cross-sectional survey. BMC Public Health 2017; 17: 927**

This cross-sectional study measured differences in self-reported respiratory symptoms, mental health, and general health following installation of new windows and doors; loft insulation, cavity wall insulation, or external wall insulation. New windows and doors, loft insulation and external wall insulation were each associated with improved respiratory symptoms and mental health; and external wall insulation was also associated with improved general health. Cavity wall insulation, however, was associated with worsened mental health, respiratory symptoms and general health.

9. **Preval N, Keall M, Telfar-Barnard L, et al. Impact of improved insulation and heating on mortality risk of older cohort members with prior cardiovascular or respiratory hospitalisations. BMJ Open 2017;7:e018079. doi:10.1136/bmjopen–2017–018079**

This quasi-experimental retrospective cohort study measured post-intervention mortality rates for adults aged 65+ who had previously been hospitalized for respiratory or circulatory illness. Mortality rates in the insulated group were lower for those previously hospitalized for circulatory illness, but not significantly different for those previously hospitalized for

respiratory illness. Despite matching, there remains potential bias for the mortality result, in that installing insulation may have reflected better health and/or socioeconomic circumstances.

10. **Tavernier G, Gletcher G, Gee I, et al. IPEADAM study: indoor endotoxin exposure, family status, and some housing characteristics in English children. Journal of Allergy and Clinical Immunology 2006;117:656–62**

This matched case-control study measured differences in GP-diagnosed asthma rates using a questionnaire-assessed measure of household glazing systems. There was no difference between asthmatic and healthy children in their exposure to different glazing systems.

11. **Telfar Barnard L, Preval N, Howden-Chapman P, et al. The Impact of Retrofitted Insulation and New Heaters on Health Services Utilisation and Costs, Pharmaceutical Costs and Mortality: Evaluation of Warm Up New Zealand: Heat Smart. Report to the Ministry of Economic Development. Wellington, 2011**

This retrospective cohort study measured differences in hospitalization and pharmaceutical use before and after subsidized insulation was installed, comparing insulated dwellings with control dwellings; and post-treatment mortality rates for adults aged 65+ who had previously been hospitalized for respiratory or circulatory illness. Insulation showed no relationship with rates of hospitalization or pharmaceutical use, though costs were lower. Mortality rates for those previously hospitalized for circulatory illness were lower in the insulated group. Despite matching, there remains potential bias for the mortality result, in that installing insulation may have reflected better health and/or socioeconomic circumstances.

Appendix 6 Summary of findings tables

Outcome		Effect of the exposure			Certainty of evidence
		Exposure/intervention	Effect	Summary	
Respiratory morbidity	Self-reported wheeze	Insulation and draft-stopping	Mean temperatures raised 0.5°C, and RH reduced 2.3% in bedrooms. Reduced odds of self- reports of wheezing in the past three months.	OR 0.57 (0.47-0.70, p<0.0001)	⊕⊕⊕⊕ High
	Winter colds or flu		Reduced odds of winter colds or flu	OR 0.54 (0.43–0.66, p<0.0001)	⊕⊕⊕⊕ High
	Morning phlegm in adults		Reduced odds of morning phlegm in adults	OR 0.64 (0.52-0.78, p<0.0001)	⊕⊕⊕⊕ High
	Cough	Self-reported double-glazing Self-reported insulation	Cough was lower in houses with double glazing	RR 0.68 (0.49-0.94, p=0.018)	⊕⊕⊕⊖ Medium
	Wheeze		No effect		⊕⊕⊕⊖ Medium
	Asthma		No effect		⊕⊕⊕⊖ Medium
		External wall insulation and heating upgrade	No effect	Cohen's d: 0.051 (Beta: −0.088, SE: 0.247, p=0.722).	⊕⊕⊕⊖ Medium
	Eye and throat irritation	Air-tight window installation	ORs for eye smarting/irritation and throat dryness were both lower, but did not reach statistical significance.	No significant effect	⊕⊕⊖⊖ Low
	Any respiratory symptoms previous month (self-report)	New windows and doors	Reduced incidence of respiratory symptoms over the previous month	OR -0.235 (SE 0.101, p<0.01)	⊕⊕⊕⊖ Medium
		Loft insulation		OR -0.145 (SE 0.062, p<0.01)	
		External wall insulation		OR -0.416 (SE 0.073, p<0.001)	
		Cavity wall insulation	Increased incidence of respiratory symptoms over the previous month	OR 0.385 (SE 0.062, p<0.001)	
		External wall insulation and heating upgrade	No effect	Cohen's d: 0.061 (Beta: −0.155, SE: 0.192, p=0.419).	
Respiratory mortality		No included studies			
Hospital admissions		Insulation and draft-stopping	Hospital admissions for respiratory conditions were reduced, but this reduction was not statistically significant.	OR 0.53 (0.22–1.29, p=0.16)	⊕⊕⊕⊖ Medium
			No significant effect on hospitalizations across a range of categories.	No effect	

Outcome	Effect of the exposure			Certainty of evidence
	Exposure/intervention	Effect	Summary	
Hospital visits	Double-glazing and energy-efficient boiler	Household outpatient attendance declined. Accident and emergency department attendance declined	t (223): -3.465, (p=0.001) t (221): 2.530, (p=0.012)	⊕⊕⊕⊖ Medium
All-cause mortality	Insulation and draft-stopping	Reduced mortality in adults aged 65+ previously hospitalized for circulatory illness, after adjustment for cost difference.	RR 0.73 (0.53–1.00, p=0.048) HR 0.673 (0.535–0.847, p=<0.001)	⊕⊕⊕⊖ Medium
		No difference in mortality in adults aged 65+ previously hospitalized for respiratory illness, after adjustment for cost difference.	RR 1.01 (0.73-1.40, p=0.943 HR 0.830 (0.655-1.051, p=0.122)	
Depression	Insulation and draft-stopping	Lower odds of happiness score in lower half of scale	OR 0.56 (0.41–0.29, p=0.16)	⊕⊕⊕⊕ High
	New windows and doors	Improved mental health scores	OR 2.523 (SE 0.950, p<0.01)	⊕⊕⊕⊖ Medium
	Loft insulation		OR 4.281 (SE 0.660, p<0.001)	
	External wall insulation		OR 2.657 (SE 0.823, p<0.01)	
	Cavity wall insulation	Worsened mental health scores	OR -2.052 (SE0.687, p<0.05)	
	Air sealing, new insulation and exterior cladding, and window replacement, as part of "green renovation"	Mean number of good mental health days in the past month improved. Mean VR-12 mental component score improved.	p=0.026 p=0.023	
High blood pressure	No included studies			

Appendix 7 Non-PICO-ranked health outcomes

Quality assessment						No of participants	Effect	Quality	Importance	Intervention /exposure measure	Measured outcome
Study	Design	Risk of bias	Indirectness	Imprecision	Other considerations						
Other											
Austin and Russell 1997	Retrospective cohort study (survey)	Low risk of bias for study type. Response rates were high (85-86%) and non-differential. However, self-report of insulation carries high risk of bias	Direct	Precision is good		1537 children aged 12 and 14, Scottish highlands.	Eczema showed a positive association with double glazing (RR 1.59, 95% CI 1.23 – 2.06, p=0.0003, *r*=0.092)	Medium	Low	Self-reported double glazing, carpeting, insulation	Self-reported eczema
Bray 2017	Cohort study	Some risk of bias from inadequate identification of confounding factors and incomplete follow-up	Direct	Precise		228 households (473 tenants)	Household health status improved by 3.25% (SD: 18.45, t(226): -2.652, p=0.009). Main tenant health status improved by 4.85% (SD: 20.49, t(226): -3.564, p<0.001). Main tenant quality of life declined by -0.01 (SD: 0.261, t(219): 0.583, p=0.561).	Low	Low	Installation of double glazing and new energy-efficient boiler	Self-reported household health status, main tenant health status, main tenant quality of life
Breysse 2015	Quasi-experimental	Potential risk of bias in a range of areas (abstract only so inadequate basis for judgment)	Direct	Unclear	Abstract only	40 adults (median: 66 years) and 22 adults (median: 72 years in refurbished homes, matched with 40 and 572 controls	Reported falls reduced by 16% in refurbished homes but increased by 8% in controls (p=0.055). General physical health in elders in refurbished homes improved by 9% but decline by 6% in controls (p=0.094).	Medium	Low	Air sealing, new insulation and exterior cladding, and window replacement, as part of "green renovation"	Self-reported falls; self-reported general health.

Quality assessment						No of participants	Effect	Quality	Importance	Intervention /exposure measure	Measured outcome
Study	Design	Risk of bias	Indirectness	Imprecision	Other considerations						
Other											
Grey 2017	Quasi-experimental	Low risk of bias	Direct	Unclear		Adults	No significant difference in self-reported physical health: Cohen's d: 0.107 (Beta: 0.987, SE: 0.664, p=0.137). Subjective wellbeing improved: Cohens's d: 0.200 (Beta: 0.375, SE: 0.134, p=0.005).	Medium	Low	External wall insulation and heating upgrades	Self-reported physical health and wellbeing.
Howden-Chapman 2007	RCT	Low risk of bias re: incomplete outcome data. Minimal bias due to withdrawals. Minimal potential for bias due to confounding	Direct	Fair	New Zealand housing is of poor quality, meaning potentially greater potential benefits from thermal improvements	4407 people (2262 treatment, 2145 controls) in 1350 households, all ages.	Reduced odds of fair or poor self rated health (adjusted odds ratio 0.50, 95% CI 0.38–0.68), self reports of children taking a day off school (0.49, 0.31–0.80), and self reports of adults taking a day off work (0.62, 0.46–0.83). Visits to general practitioners were less often reported by occupants of insulated homes (0.73, 0.62–0.87). GP records of visits showed no significant difference (0.95, 0.81 to 1.13; P=0.58)	High	Low	Insulation and draft-stopping	Self-reported health, days off school, days off work; self-reported GP visits; GP-reported GP visits
Iversen 1986	CBA	Assessed as high risk of selection bias by Thompson et al	Direct	Confidence intervals not reported		106 study group, 535 controls, aged 18+, Denmark	Treatment reduced rheumatic symptoms, but statistical significance was not reported. Reductions in headaches were not significant except for in one month; which month was not reported.	Low	Low	Windows replaced for air-tightness	Rheumatic symptoms, headache

Quality assessment						No of participants	Effect	Quality	Importance	Intervention /exposure measure	Measured outcome
Study	Design	Risk of bias	Indirectness	Imprecision	Other considerations						
Other											
Poortinga 2017	Cross-sectional study	Some bias from loss to follow-up; and a small risk of selection bias	Direct	Precision is good	Low income Welsh housing potentially in poor condition, meaning potentially greater potential benefits from thermal improvements	Five waves: 2075, 2219, 2015, 1991 and 1709 participants	Loft insulation (OR 0.183, SE 0.066, p<0.01) and external wall insulation (OR 0.255, SE 0.079, p<0.01) both associated with improved self-reported general health; cavity wall insulation associated with worsened self-reported general health (OR -0.253, SE 0.067, p<0.001); no effect for new windows and doors (OR -0.15, SE 0.099)	Medium	Medium	New windows and doors; loft, cavity and external wall insulation	Self-reported general health score
Telfar Barnard 2011	Retrospective cohort study	Some risk of bias in control selection and health measurement	Direct	Wide confidence interval	New Zealand housing	110 360 treated and 973 710 controls, all ages, New Zealand.	No significant effect on pharmaceutical prescription rate across a range of categories	Medium	Low	Subsidized insulation	Pharmaceutical scripts
Windle 2006 (otherwise excluded)	Retrospective cohort study (interviews)	Renters may be less likely to be aware of their dwelling's insulation status, risk of bias in survey return	Direct	n/a (not statistically significant)		423 people aged 70+ in Gwynedd, Wales	No significant effect of lack of roof or loft insulation (coefficient of self-reported health status was 0.77 but p>0.05.)	Low	Low	Self-reported roof or loft insulation	Self-reported health score

Appendix 8 Characteristics of included studies

1.	Study: Austin and Russell 1997	Title: Wheeze, cough, atopy, and indoor environment in the Scottish Highlands			
Authors: Jane B Austin, George Russell					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Retrospective cohort study (survey)	Highland region, Scotland 1992–1994	Children aged 12 and 14	N/A	Not described	Recruited via secondary schools
Samples	**Interventions**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
N=1537 n=741 (1992 cohort), =85% response rate n=796 (1994 cohort) = 86% response rate	Self-reported double glazing, carpeting, insulation		Self-reported cough, wheeze	Cough was lower in houses with double glazing ($\chi 2=5.55$, df=1, p=0.018, r=−0.0606, relative risk 0.675, 95% CI=0.486 to 0.936). No effect of wall to wall carpeting, or insulation on cough or wheeze; nor double-glazing on wheeze	Medium Direct Precise Low risk of bias for study type. Response rates were high (85-86%) and non-differential. However, self-report of insulation carries high risk of bias.
			Self-reported eczema [non-PICO ranked]	Eczema showed a positive association with double glazing (RR 1.59, 95% CI 1.23–2.06, p=0.0003, r=0.092)	
2.	**Study: Bray 2017**	**Title: Costs and outcomes of improving population health through better social housing: a cohort study and economic analysis**			
Authors: Nathan Bray, Paul Burns, Alice Jones, Eira Winrow, Rhiannon Tudor Edwards					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cohort	North East England, the United Kingdom 2014	Families living in social housing	N/A	Not described	Households recruited during retrofit scheme

Samples	Interventions	Outcome measures	Results	Quality (GRADE) and limitations
228 households (473 tenants	Installation of double glazing and new energy-efficient boiler	Health of household	Household health status improved by 3.25% (SD: 18.45, t(226): -2.652, p=0.009)	Medium Direct Precise Risk of bias from failure to identify confounding factors, and self-report of health status.
		Health of main tenant	Main tenant health status improved by 4.85% (SD: 20.49, t(226): -3.564, p<0.001)	
		Main tenant quality of life	Main tenant quality of life declined by -0.01 (SD: 0.261, t(219): 0.583, p=0.561).	
		Hospital outpatient visits	Household hospital outpatient attendance decline (t (223): -3.465, p=0.001).	
		Accident and emergency department visits	Accident/emergency department attendance declined (t (221): 2.530, p=0.012).	

3.	Study: Breysse 2015	Title: Self-reported health outcomes associated with green-renovated public housing among primarily elderly residents (abstract only)

Authors: Jill Breysse, Sherry L. Dixon, David E. Jacobs, Jorge Lopez, William Weber

Study type	Setting	Inclusion criteria	Definition of specific functional impairment	Exclusion criteria	Recruitment procedures
Quasi-experimental	Minnesota, USA Date not given	Elderly residents of a low-income public housing apartment building	N/A	Not described	Not described

Samples	Interventions	Outcome measures	Results	Quality (GRADE) and limitations
40 adults (median: 66 years) and 22 adults (median: 72 years in refurbished homes, matched with 40 and 572 controls	Air sealing, new insulation and exterior cladding, and window replacement, as part of "green renovation"	Mental health	Mental health improved: mean number of good mental health days in the past month (p=0.026) and mean VR-12 mental component score (p=0.023).	Medium Direct Imprecise Risk of bias unclear as only abstract was available
		General health	General physical health in elders in refurbished homes improved by 9% but decline by 6% in controls, difference was not significant (p=0.094).	
		Falls [non-PICO ranked]	Reported falls reduced by 16% in refurbished homes but increased by 8% in controls, difference was not significant (p=0.055).	

4.	Study: Grey 2017	Title: The short-term health and psychosocial impacts of domestic energy efficiency investments in low-income areas: a controlled before and after study			
Authors: Charlotte N. B. Grey, Shiyu Jiang, Christina Nascimento, Sarah E. Rodgers, Rhodri Johnson, Ronan A. Lyons, Wouter Poortinga					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Quasi-experimental	Wales, the United Kingdom 2013–2015	Adults in areas eligible for programme (selected using proxies of fuel poverty, including area deprivation, mixed tenure, and a high proportion of hard-to-heat, hard-to-treat homes)	N/A	Not described	Purposive sampling strategy, non-random
Samples	**Interventions**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
364 in intervention and 418 in control	Insulation (external wall) was part of a general improvement programme		Self-reported mental health	Mental health showed non-significant improvement: Cohen's d: 0.005 (Beta: -0.059, SE: 0.789, p=0.940).	Medium Direct Imprecise Some risk of bias for study from incomplete follow-up. and self-report of health status.
			Self-reported respiratory symptoms	Respiratory symptoms showed non-significant improvement: Cohen's d: 0.061 (Beta: −0.155, SE: 0.192, p=0.419).	
			Self-reported asthma symptoms	Asthma symptoms showed non-significant improvement: Cohen's d: 0.051 (Beta: −0.088, SE: 0.247, p=0.722).	
			Subjective wellbeing [non-PICO ranked]	Subjective well-being showed significant improvement: Cohen's d: 0.200 (Beta: 0.375, SE: 0.134, p=0.005).	

5.	Study: Homøe et al 1999	Title: Acute otitis media and sociomedical risk factors among unselected children in Greenland			
Authors: Preben Homøe, Rene B. Christensen, Poul Bretlau					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cohort study	Nuuk & Sisimiut, Greenland 1993–1994	Children aged 3, 4, 5 and 8 years old	N/A	Migrated to other towns prior to study period. Did not present for measurement	Unselected (full Danish National Population System register), recruited by letter
Samples	**Interventions**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
N=740 n=440 (Nuuk, 110 from each age group) = 58% of Nuuk children in age group n=300 (Sisimut, 75 from each age group) = 76% of Sisimut children in age group	Presence of insulation as estimated by “drafts”		Acute otitis media in medical records	“self-reported insulation standard… could not be related to episodes of” acute otitis media	Low Indirect measure of insulation Precision unclear (no numerical results)
6.	**Study: Howden-Chapman 2007**	**Title: Effect of insulating existing houses on health inequality: cluster randomized study in the community**			
Authors: Philippa Howden-Chapman, Anna Matheson, Julian Crane, Helen Viggers, Malcolm Cunningham, Tony Blakely, Chris Cunningham, Alistair Woodward, Kay Saville-Smith, Des O’Dea, Martin Kennedy, Michael Baker, Nick Waipara, Ralph Chapman, Gabrielle Davie					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
RCT	Seven low income communities, New Zealand 2001–2002	Non-insulated dwelling, household planning to remain in dwelling for the next two winters	Household member had reported respiratory symptoms in the past year, e.g. recurrent wheezing, or had a history of asthma, pneumonia, or chest infections		Recruited through local community organizations

Samples	Interventions	Outcome measures	Results	Quality (GRADE) and limitations
N=1350 houses N=4407 people n=2262 (treatment) n=2145 (controls) n=1350 households	Insulation and draft-stopping	Self-reported wheezing, self-reported winter colds or flu, self-reported morning phlegm in adults	Mean temperatures raised 0.5°C, and RH reduced 2.3% in bedrooms. Reduced odds of self reports of wheezing in the past three months (0.57, 0.47–0.70). Reduced odds of winter colds or flu (0.54, 0.43 to 0.66; p<0.0001). Reduced odds of morning phlegm in adults (0.64, 0.52 to 0.78;p<0.0001)	High Direct Fairly precise Low risk of bias re: incomplete outcome data. Minimal bias due to withdrawals. Minimal potential for bias due to confounding New Zealand housing is of poor quality, with potentially higher potential benefits from thermal improvements than in countries with better quality housing.
		National health index-linked hospitalization admissions	Hospital admissions for respiratory conditions were reduced (0.53, 0.22 to 1.29), but this reduction was not statistically significant (P=0.16).	Medium Direct Imprecise (wide confidence interval) Low risk of bias (see above)
		Self-reported happiness score	Lower odds of happiness score in lower half of scale (OR 0.56, 95% CI 0.41 to 0.77, p=0.0003)	High Direct Fairly precise Low risk of bias (see above)
		Self-reported health, days off school, days off work; self-reported GP visits; GP-reported GP visits	Reduced odds of fair or poor self rated health (adjusted odds ratio 0.50, 95% CI 0.38–0.68), self reports of children taking a day off school (0.49, 0.31–0.80), and self reports of adults taking a day off work (0.62, 0.46–0.83). Visits to general practitioners were less often reported by occupants of insulated homes (0.73, 0.62–0.87). GP records of visits showed no significant difference (0.95, 0.81 to 1.13; P=0.58)	High Direct Fairly precise Low risk of bias (see above)

7.	Study: Iversen 1986	Title: Health and comfort changes among tenants after retrofitting of their housing			
Authors: Martin Iversen, Elsa Bach, and Gunnar R. Lundqvist					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Controlled before and after	Denmark August and December 1981 January and February 1982	Aged 18+, resident of apartment buildings 2–5 stories high	N/A	Non-response to questionnaire Building society changed plans to replace windows	Not described
Samples	**Interventions**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
N=3,309 surveyed N=641 included n=106 (treatment) n=535 (control)	Windows replaced for air-tightness		Eye irritation, dry throat	ORs for eye smarting/irritation and throat dryness were both lower, but did not reach statistical significance.	Low Direct Insufficient information to assess precision (confidence intervals not reported) High risk of selection bias
			Rheumatic symptoms, headache	Treatment reduced rheumatic symptoms, but statistical significance was not reported. Reductions in headaches were not significant except for in one month; which month was not reported.	

8.	Study: Poortinga 2017	Title: Social and health outcomes following upgrades to a national housing standard: a multilevel analysis of a five-wave repeated cross-sectional survey.			
Authors: Wouter Poortinga, Nikki Jones, Simon Lannon, Huw Jenkins					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cross-sectional (repeated survey, 5 waves)	Carmarthenshire, Wales, the United Kingdom 2009–2016	Not described	N/A	Not described	Unselected (all social housing tenants), recruitment method not described.

Samples	Interventions	Outcome measures	Results	Quality (GRADE) and limitations
5 waves: n = 2075; n = 2219; n = 2015; n = 1991; and n = 1709, respectively. The final dataset used for the analyses consisted of 1980 properties with a single observation, 1476 properties with two observations, 968	Insulation (new windows and doors, loft, cavity wall, external wall)	Mental health	Mental health improved with new windows and doors, and loft and external wall insulation, but worsened with cavity wall insulation. Associations of the intervention measures with mental health in Beta (SE): Windows and doors 2.523 (0.950), p<0.01; Loft insulation 4.281 (0.660), p< .001; Cavity wall insulation −2.052 (0.687), p < .05; External wall insulation 2.657 (0.823), p < .01.	Medium Direct Precise Risk of bias from self-reported health status. Unclear whether confounding factors taken into account in analysis, making reliability and generalizability of results uncertain.
		Respiratory health	Respiratory health improved with new windows and doors, and loft and external wall insulation, but worsened with cavity wall insulation. Associations of the intervention measures with respiratory health in Beta (SE): New windows and doors -0.235 (0.101), p<0.01; Loft insulation −0.145 (0.062), p< .01; Cavity wall insulation 0.385 (0.062), p < .001 and (OR = 1.47, 95% CI = 1.30–1.66); External wall insulation −0.416 (0.073), p < .001	
		General health	General health improved with loft and external wall insulation, but showed no association for new windows and doors, and worsened with cavity wall insulation. Associations of the intervention measures with respiratory health in Beta (SE): Loft insulation 0.183 (0.066), p< .01; Cavity wall insulation −0.253 (0.067), p < .001 and (B OR = 0.78, 95% CI = 0.68–0.89); External wall insulation 0.255 (0.079), p < .01	

9.	Study: Preval 2017	Title: Impact of improved insulation and heating on mortality risk of older cohort members with prior cardiovascular or respiratory hospitalizations			
Authors: Nicholas Preval, Michael Keall, Lucy Telfar-Barnard, Arthur Grimes, Philippa Howden-Chapman					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Restrospective cohort study	New Zealand July 2009 to May 2010	Adults aged 65+ with address matched to national housing database and national health index	Previous hospitalization for respiratory illness; previous hospitalization for circulatory illness	No control address available	Enrolment in subsidized insulation programme (treatment) Similar house type (control)
Samples	**Interventions**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
N=3287 (79% match rate) (prior circulatory illness) n=788 (included treatment); n=209 (excluded treatments) n=2290 (controls, all treatments)	Installation of subsidized insulation		All-cause mortality	Reduced mortality in those previously hospitalized for circulatory illness: hazard ratio 0.673 (95% CI 0.535 to 0.847, p<0.001).	Medium Direct Precise Some risk of bias in control selection and health measurement.
N=1561 (79% match rate) (prior respiratory illness) n=401 (insulation treatment) n=112 (excluded treatments) n=1048 (controls, all treaments)				Nonsignificant association with reduced mortality in those previously hospitalized for respiratory illness: hazard ratio 0.830 (95% CI 0.655 to 1.051, p=0.122)	
10.	**Study: Tavernier et al 2006**	**Title: IPEADAM study: Indoor endotoxin exposure, family status, and some housing characteristics in English children**			
Authors: Gael Tavernier, Gillian Fletcher, Ivan Gee, Adrian Watson, Graeme Blacklock, Helen Francis, Angela Fletcher, Timothy Frank, Peter Frank, C. Anthony Pickering, Robert Niven					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Matched case control	South Manchester, the United Kingdom Dates not provided	Children 5–15 years	Asthmatic children, defined via screening questionnaire and physician diagnosis of asthma	Not described	Recruited from two neighbouring primary care facilities
Samples	**Interventions**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
N=200 n=105 (case) n=95 (control)	In-home questionnaire-assessed glazing system (not further defined)		Asthma (screening questionnaire + GP diagnosis)	No difference between asthmatic and healthy children by glazing system (also measured “insulation type”, but unclear comparator so excluded from this report)	Medium Direct Precision could not be measured as no result found Some risk of bias due to high non-participation response to recruitment

11.	Study: Telfar Barnard 2011	Title: The impact of retrofitted insulation and new heaters on health services utilization and costs, pharmaceutical costs and mortality. Evaluation of Warm Up New Zealand: Heat Smart

Authors: Lucy Telfar Barnard, Nick Preval, Philippa Howden-Chapman, Richard Arnold, Chris Young, Arthur Grimes, Tim Denne					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Restrospective cohort study	New Zealand July 2009 to May 2010	Address matched to national housing database and national health index	N/A	No control address available	Enrolment in subsidized insulation programme (treatment) Similar house type (control)
		Adults aged 65+	Previously hospitalized for circulatory illness		
Samples	**Interventions**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
N=1 084 070 people n=110 360 (treated) n=973 710 (controls)	Installation of subsidized insulation		All-cause hospitalization admissions	No significant effect on hospitalizations across a range of categories.	Medium Direct Imprecise (wide confidence interval) Some risk of bias in control selection and health measurement
			Pharmaceutical prescriptions	No significant effect on pharmaceutical prescription rate across a range of categories.	
N=10 991 n=3210 (treated) n=7781 (controls)			All-cause mortality	Reduced mortality in adults aged 65+ who had previously been hospitalized for circulatory illness, of RR 0.73 (95% CI 0.53–1.00, p=0.048) after adjustment for cost difference.	

Non-PICO ranked health outcomes

1.	Study: Windle et al 2006	Title: Housing related difficulties, housing tenure and variations in health status: evidence from older people in Wales			
Authors: Gillian S. Windle, Vanessa Burholt, Rhiannon T. Edwards					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Retrospective cohort study	Gwynedd, Wales September 2001–February 2002	Adults aged 70+	N/A	Refusal to participate (19%)	Door to door census conducted based on electoral roll. Potential respondents randomly selected to provide
Samples	**Interventions**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
N=423 (54% response rate) 8% from farming community, 27% for retirement destination, 12% for ex-quarrying community, 8% urban area, 20% difficult-to-let sheltered housing area, 24% market town	Self-reported roof or loft insulation		Self-reported health score	No significant effect of lack of roof or loft insulation (coefficient of self-reported health status was 0.77 but p>0.05.)	Low Direct No statistically significant result reported High risk of information bias as renters may be less likely to be aware of their dwelling's insulation status; risk of selection bias in survey return