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Healthier Futures

Tackling inequalities to deliver fairer health

Rapid Evidence Synthesis: What is the health impact of poor housing?

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Rapid Evidence Synthesis:

Rapid Evidence Syntheses (RES) use evidence synthesis approaches and draw on the GRADE Evidence to Decision framework to provide rapid assessments of the existing evidence and its relevance to specific decision problems. In the first instance they focus on evidence from guidance and existing evidence syntheses. They are undertaken in a real-time context of decision-making around adoption of innovative health technologies and are designed to provide a "good-enough" answer to inform decision problems in a short timescale. RES methods are flexible and adaptive. They have evolved in response to user feedback and differ depending on the nature of the assessment undertaken.

RES were developed by the National Institute for Health and Care Research (NIHR) Applied Research Collaboration Greater Manchester (ARC-GM). The methods used are based on a framework set out in Norman et al. 2022 and previously registered on the Open Science Framework (OSF).

RES are not intended to serve as a substitute for a systematic review or rapid review of evidence.

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1. Summary of findings

Key Questions

1. What is the evidence that housing quality and condition affects the physical and mental health of residents?
2. What is the evidence that different ways of improving housing quality and condition affects the physical and mental health of residents?

What did we do?

We searched for existing evidence syntheses of studies that investigated the Key Questions.

What did we find?

We found 40 systematic reviews of the evidence on housing and health. We also found relevant National Institute for Health and Care Excellence (NICE) guidance.

Key Messages

- There is low to moderate certainty evidence that houses with damp, mould, inadequate warmth, and inadequate air quality affect various aspects of respiratory health and cardiovascular health. Additionally, hazardous home environments are related to a greater number of falls at home.
- There is low to high certainty evidence that improving housing conditions by reducing dampness, eliminating mould, improving warmth and energy efficiency, and removing environmental hazards improves several physical health outcomes, including respiratory health, general physical health, and fall rates.
- The relationship between poor physical housing conditions and mental health is less clear, however there is some evidence of low to moderate certainty that housing precarity and overcrowding are related to poorer mental health.

See Tables 1 and 2 for a summary of the evidence for each of the Key Questions.

Table 1. What is the evidence that housing quality and condition affects the physical and mental health of residents?

Housing factor	Health outcomes
Housing condition and design	
Cold indoor temperatures	NICE guidance highlighted the link between cold homes and excess winter deaths from cardiovascular and respiratory conditions. The evidence from 1 review suggests that cold indoor temperatures are associated with increased blood pressure, reduced physical functioning, and sleep outcomes. The evidence for associations with viral infections and COPD symptoms was inconclusive.
The built housing environment	The evidence from 3 reviews suggests that aspects of the built housing environment (e.g. building type and materials) may be associated with increased asthma and poorer mental health, including depression.
Housing age	The evidence from 1 review suggests that older houses may be associated with increased asthma symptoms in children, but the evidence for adults is inconclusive.
Home hazards	The evidence from 1 review suggests that hazards within the home are associated with increased falls in older adults.
Inadequate light	The evidence from 1 review suggests that inadequate light is associated with poorer physical health, mental health, and sleep quality.
Indoor air quality	
Indoor allergens	The evidence from 1 review suggests the relationship between various indoor allergens (e.g. house dust mite exposure) and asthma and wheeze in children is inconclusive.
Damp and mould	The evidence from 5 reviews suggests that there is an association between dampness and mould exposure in the home and new cases of asthma, exacerbation of existing asthma, increased wheeze, and poorer respiratory health. The impacts appear to be strongest in infants and children compared with adults. NICE guidance was identified and supports these conclusions.
Lead exposure	No evidence identified.
Indirectly relevant evidence	
Housing tenure and precarity	The evidence from 3 reviews suggests that housing tenure and precarity are associated with increased anxiety and depression, but there was no evidence of a relationship with asthma.

Crowding	The evidence from 3 reviews suggests that there may be an association between household crowding and various close contact infectious diseases (gastroenteritis, upper and lower respiratory tract infections, hepatitis A, tuberculosis, meningococcal disease, bacterial stomach infection, and trachoma) and depression, but there was no evidence of a relationship with asthma.
Indoor pollutants and allergens related to residents' behaviour	*Pet allergens* The evidence from 1 review suggests that the relationship between exposure to various household pets and childhood asthma is inconclusive. *Domestic combustion and cleaning* The evidence from 4 reviews suggests that there is an association between exposure to indoor air pollutants from domestic combustion (e.g. volatile organic compounds) and household cleaning products with poorer health outcomes, including poorer respiratory functioning, asthma symptoms, COPD symptoms, and cancer. NICE guidance on the above noted that certain pollutants and pet dander are sometimes linked to respiratory, cardiovascular, and neurological symptoms.

Key. High, moderate, low, or very low certainty evidence.

Table 2. What is the evidence that different ways of improving housing quality and condition affects the physical and mental health of residents?

Housing factor	Health outcomes
Housing condition and design	
Warmth and energy efficiency	The evidence from 4 reviews suggests that warmth and energy efficiency interventions (e.g. the installation, upgrading, or reparation of central heating; the installation of insulation (roof, cavity wall, or both); the installation of double glazing; or a combination of these) improves the general health, asthma symptoms and respiratory health of adults and children. The impact on health outcomes of older adults was inconclusive, as was the evidence for the impact on mental health.
Retrofit	The content and nature of retrofit interventions was poorly described in the literature. It is possible that these interventions included many of the measures described above under *Warmth and energy efficiency*. The evidence from 1 review suggests that retrofit interventions may have a positive impact on general health but the evidence for effects on respiratory and mental health was inconclusive.
The built housing environment	No evidence identified by the review.
Housing age	No evidence identified by the review.
Home hazards	The evidence from 10 reviews suggests that interventions to improve home safety and reduce home hazards reduce the rate and number of falls when targeted at older adults who are at risk of falling. Provision of safety equipment appears to reduce injury rates in older adults. These interventions appear to have no effect on health-related quality of life, fall-related fractures, and falls requiring hospitalisation or medical attention.
Lighting	The evidence from 1 review on the effects of improving artificial home lighting on physical and mental health is inconclusive.
Indoor air quality	
Indoor allergens	The evidence from 7 reviews suggests that various interventions to control indoor allergens (mostly house dust mites) had no effect on asthma, lung function or eczema outcomes.
Damp and mould	The evidence from 1 review suggests that reducing damp and mould in homes improves asthma symptoms and respiratory infections in adults, and reduces the number of emergency and inpatient hospital visits in children. The interventions did not improve asthma symptoms or respiratory infections in children or asthma symptoms in older adults.

Lead exposure	The evidence from 2 reviews suggests that household environmental interventions (namely dust control measures) did not affect blood lead levels in children.
Indirectly relevant evidence	
Housing tenure and precarity	No evidence identified by the review.
Crowding	No evidence identified by the review.
Indoor pollutants and allergens related to residents' behaviour	No evidence identified by the review.

Key. High, moderate, low, or very low certainty evidence.

What are the limitations of the evidence?

Our confidence in the evidence varies from high to very low for several reasons.

Broadly, studies varied in the way they were designed and conducted, and some study designs were stronger than others. There were often concerns about the methodological quality of the studies and their risk of bias, and there was often a degree of inconsistency and imprecision in the research findings related to a particular health effect, which together limits our confidence in the research findings. Notably, most studies were conducted in North America. A minority of studies were conducted in the UK.

Specifically, the nature of the studies relevant to Question 1 means that it is generally only possible to have low confidence in the available evidence. Most of this research stems from non-experimental studies, including cross-sectional and cohort designs. Cross-sectional research is useful for identifying potential relationships between housing and health conditions but limited in establishing a clear temporal sequence (i.e. which came first – poor housing or poor health) because both housing and health are measured at the same point in time. It follows that these studies are not suitable for inferring whether a particular housing condition causes a health problem. Cohort studies are stronger in establishing temporality, particularly prospective cohort studies, and better at suggesting causality through longitudinal observation, but they still face challenges with confounding factors. These studies varied in terms of their quality (good to poor) and their research findings (no evidence of a relationship with health vs. evidence of a relationship).

The nature of the studies relevant to Question 2 means that it was possible to have somewhat more confidence in the available evidence. A larger proportion of this research stemmed from experimental studies, including randomised controlled trials and non-randomised controlled trials, which are generally better at establishing temporality and for inferring causality. However, the quality of these studies and their findings also varied. Relevant non-experimental studies were also found.

How up to date is this evidence?

The RES is current to 21st March 2024. It includes reviews published between 2001 and 2024. In turn, these reviews include primary research from the 1980s to the 2020s.

2. Methods

2.2. Search

We systematically searched Medline (Ovid) and the Cochrane Database of Systematic Reviews. We conducted hand-searches in Google Scholar and Overton. We used search terms that were based on various housing factors, physical health conditions, and mental health conditions. We also adopted and adapted search terms used in high-quality relevant reviews (e.g. (Thomson et al., 2013). We applied review filters to the search results in Medline. We hand-searched the reference lists of included reviews.

Additionally, we searched for independently commissioned reports on housing and health, and relevant evidence cited in these resources. We also searched for guidance from other relevant organisations such as the NICE and NHS England.

2.3. Key questions

Our primary question was: What is the evidence that housing quality and condition affects the physical and mental health of residents?

Our secondary question was: What is the evidence that different ways of improving housing quality and condition affects the physical and mental health of residents?

2.4. Inclusion criteria

This RES used broad inclusion criteria. We accepted review authors' definitions of populations, housing exposures, housing interventions, comparators, and outcomes.

2.4.1. Participants

Studies which included the general public and/or clinically-defined populations (e.g. children with a diagnosis of asthma) were eligible. We included studies in people of any age from high income countries (as defined by the World Bank list), as these populations are more comparable to the Greater Manchester context.

2.4.2. Exposures and Interventions

To answer the primary question, we included evidence from existing systematic reviews of studies of a broad range of housing-related factors. This included, but was not limited to, the physical condition, structure, state of repair, or fabric of housing; indoor air quality; damp and

mould exposure; thermal comfort; acoustic comfort; and the (immediate) outdoor environment (e.g. noise exposure). This evidence was considered to be **directly relevant** to the present RES.

Other housing factors and circumstances, such as housing security and affordability, were also considered, particularly when these related to the physical state or condition of housing (e.g. the impact of fuel poverty, or overcrowding, on damp and mould growth). This evidence was considered to be **indirectly relevant** to the present RES.

To answer the secondary question, we included evidence from existing systematic reviews of intervention studies designed to improve the quality, condition, or physical state of repair of housing. We considered a broad range of housing interventions, provided that these measured residents' health outcomes. This evidence was considered to be **directly relevant** to the present RES.

We included evidence from studies of residential housing, including owner-occupied, privately rented accommodation, and social housing. Where possible, we excluded studies set in occupational and educational buildings.

2.4.3. Comparators

To answer the primary question, we included systematic reviews of studies both with and without control or comparator groups.

To answer the secondary question, we included systematic reviews of studies involving any comparator, including different interventions or no intervention.

2.4.4. Outcomes

We considered the impacts of exposure to housing with different characteristics (primary question) and ways of improving housing (secondary question) on any outcomes related to residents' physical health (e.g. respiratory conditions and symptoms). Secondary outcomes of interest included healthcare utilisation, mental health outcomes (e.g. anxiety, stress), quality of life and wellbeing, and health-related behaviours.

2.4.5. Study designs

We included existing evidence syntheses, including systematic reviews of primary studies of any design and umbrella reviews (also known as a review of reviews). Informed by criteria from the Database of Abstracts of Reviews of Effects (DARE), three key elements were required for systematic reviews to be included: 1) a clear review question, 2) a transparent method for the search and selection of research studies, 3) a synthesis of results or evidence.

We included systematic reviews comprising quantitative, qualitative, and mixed-method studies. Where possible, we only reported evidence from studies conducted in high-income countries (as defined by the World Bank list).

2.5. Quality of the evidence

We employed appropriate methods to critically appraise the identified reviews. For example, Cochrane reviews are widely acknowledged to be reliable sources of evidence. We used their summaries and assessments of study quality and evidence certainty, rather than conducting new appraisals of the evidence. When considering the quality of non-Cochrane reviews, we considered the guiding questions from the Risk of Bias in Systematic Reviews (ROBIS) tool (Whiting et al., 2016) to gauge review quality. Where possible, we leveraged existing quality assessments of the primary evidence from the included systematic reviews.

2.6. Synthesis

We have produced a narrative summary of the evidence to answer the RES questions. In the process, we have highlighted the certainty and relevance of the evidence to the RES questions. We have summarised the certainty of evidence from existing evidence syntheses using either the review authors' own GRADE (Grading of Recommendations Assessment, Development and Evaluation; (Guyatt et al., 2011) assessment or a judgement based on our assessment of the GRADE considerations. While we did not perform a full GRADE assessment of the certainty of evidence for each outcome, we applied the general GRADE approach and criteria. We applied one of four categories of certainty to the evidence for each aspect of the review:

- High certainty, indicating that we are confident in the research findings.
- Moderate certainty, indicating that we are fairly confident in the research findings.
- Low certainty, indicating that we have limited confidence in the research findings, and more research is likely to change the conclusion.
- Very low certainty, indicating that there is no clear association or effect (depending on the question).

3. Results

3.1. Search results

We identified 3016 records from the database searches. Following article screening, we included 33 systematic reviews and 1 umbrella review. Hand searches of the references lists and in Google Scholar identified an additional six reviews. We included 40 reviews in total.

We also identified NICE guidance on the health impact of cold homes (NICE, 2015), indoor air quality (NICE, 2020), and outdoor air quality (NICE, 2017).

We have produced a 'reading list' of additional relevant evidence and material compiled and produced by relevant bodies and organisations.

3.2. Synthesis of the evidence

We identified common themes across similar types of systematic review question and a narrative summary of the findings is presented below. We have structured our synthesis based on our review questions:

1. What is the evidence that housing quality and condition affects the physical and mental health of residents?
2. What is the evidence that different ways of improving housing quality and condition affects the physical and mental health of residents?

We identified some overlap between systematic reviews in terms of their included studies and, where possible, have only reported the data once. However, we did not systematically consider overlap between reviews, so it is possible that some evidence has been reported more than once.

3.2.1. Housing condition and design

3.2.1.1. Thermal comfort and energy efficiency

NICE guidance reported that when people live in cold homes there is an increase in deaths from almost all causes during cold weather. Most excess winter deaths and illnesses are not caused by hypothermia or extremes of cold, but are predominantly from exacerbated cardiovascular and respiratory conditions. The risk increases as the temperature falls further (NICE, 2015).

What is the relationship between aspects of housing quality and health?

One systematic review examined the association between cold home temperatures (<18 degrees Celsius) and health outcomes (Janssen et al., 2023). Studies were included if conducted in temperate and colder climates due to the increased risk of morbidity and mortality during winter. Twenty studies of experimental (2) and non-experimental (18) designs were included. Nineteen studies were from high-income countries (including 4 UK) and one from an upper-middle-income country. Study quality varied between high (9), moderate (9), and low (1) quality (1 qualitative study was not appraised). All non-experimental studies (18) assessed indoor temperatures inside participants' homes, while the two cross-over experimental studies were conducted in a laboratory setting. Results were narratively synthesised. Overall, 17 of 20 studies found that exposure to cold indoor temperatures was associated with negative effects on health outcomes. Older people and those with chronic health problems were more likely to have a negative health impact. More details of these studies and their results are given below.

Specifically, 10 studies explored the impacts of cold indoor temperatures on cardiovascular health. Six of these studies reported a relationship between lower indoor temperatures and higher blood pressure (including 3 cross-sectional (2 UK), 1 prospective cohort, 1 randomised controlled trial (RCT), and 1 non-RCT; 19,081 participants total; Saeki et al., 2014; 2015; Shiue,

2016; Umishio et al., 2019; 2020; Zhao et al., 2019). Three studies assessed cold indoor temperatures and respiratory health. A prospective cohort study found that colder indoor temperatures of ≤18.2C were associated with increased severity of symptoms in people with COPD (82 participants) (Mu et al., 2017), while another prospective cohort and a cross-sectional study found no relationship with symptoms of respiratory viral infections (330 participants; Ishimaru et al., 2022; Quinn et al., 2017).

A prospective cohort study (1065 participants) found an increased need to urinate during the night (which disturbs sleep) in people in colder homes (13.2 ± 3.0C) compared with those in warmer homes (18.6 ± 2.4C), particularly among older people (Saeki et al., 2016). A prospective cohort study of 861 older adults found cold indoor temperatures (10C vs 25C) were associated with greater difficulties falling asleep (Saeki et al., 2015), while a cross-sectional study of 33 adults from the general population found no association between indoor temperatures (ranging from ~1C and ~38C) and self-reported sleep problems during winter (Quinn et al., 2017).

Two studies in older people investigated the impact of cold indoor temperatures on the physical performance needed for independent living. A small cross-over experimental study (88 female participants) found reduced physical performance in cold indoor temperatures (15C compared with 2C), measured by muscle power of lower limbs - a risk factor for falls and fall injuries in older people (Lindemann et al., 2014). A small cross-sectional study (36 participants) found older people living in cold homes (<18C) in winter had poorer handgrip strength compared with those in warm homes (≥18C) (Hayashi et al., 2017). Additionally, a qualitative study in the UK with 7 older participants living in <18C reported a range of chronic health problems, including osteoarthritis and asthma, which reportedly worsened in the cold (Hughes et al., 2019).

The above evidence on the impact of cold homes on health is **directly** relevant to the present RES. However, there is limited and mixed evidence from a small number of studies related to each health outcome. Most studies used observational designs (i.e. cross-sectional) in which the exposure and outcome are measured at the same time and causality cannot be determined. We consider the available evidence (including NICE guidance) for the effects of **cold homes** on **blood pressure** to be of **moderate certainty**, and the effects on **physical functioning** to be of **very low certainty**. We consider the available evidence for the remaining health outcomes to be of **very low certainty**.

Do housing improvements improve health?

Warmth and energy efficiency

We identified four relevant systematic reviews. A Cochrane review (Thomson et al., 2013) assessed the health and social impacts after improvements to the physical fabric of housing, updating a previous review by the same authors (Thomson et al., 2009). We also identified systematic reviews by Kua & Lee (2021) and Hu et al. (2022), which included studies also reviewed by Thomson et al. (2013). Therefore, only Thomson et al.'s (2013) results are reported.

Thomson et al. (2013) identified 39 studies (20 UK), including quantitative, mixed-method, and qualitative designs. Nineteen studies (12 quantitative) examined the effects of warmth and energy efficiency interventions, such as installing or upgrading central heating, insulation (roof, cavity wall, or both), and double glazing (or a combination of these). Substantial variation between studies meant that data could not be pooled statistically. Only results from studies employing the strongest designs (i.e. randomised controlled, nonrandomised controlled, and uncontrolled designs) were narratively synthesised. Study quality was moderate to low. Qualitative data were also narratively summarised. Further details of these studies and their results are provided below.

Five studies assessed general health outcomes after warmth and energy efficiency interventions, including three RCTs and two controlled before-after studies (Thomson et al., 2013). Four of these reported positive impacts on general health outcomes in adults and children (Braubach et al., 2008; Howden-Chapman et al., 2007; 2008; Platt et al., 2007). The fifth, an RCT from the UK with a high risk of bias, found no differences in the change in general health between the intervention and control groups (178 participants; Osman et al., 2010).

Ten quantitative studies assessed respiratory health outcomes after warmth and energy efficiency interventions (Thomson et al., 2013). Six of these interventions improved respiratory health in adults and children (Braubach et al., 2008; Howden-Chapman et al., 2007; 2008; Osman et al., 2010; Platt et al., 2007). Outcomes included asthma, wheeze, cough, morning phlegm, cold, flu, breathlessness, upper respiratory tract symptoms (e.g. runny nose), and respiratory conditions (e.g. bronchitis), among others (e.g. school and work absence). Two well-conducted RCTs from New Zealand (3661 participants) found better respiratory health outcomes in the intervention group than the control group (Howden-Chapman et al., 2007; 2008). These interventions targeted households with inadequate warmth and where at least one household member had a pre-existing respiratory condition. Two UK RCTs (625 people) reported no improvements in cough, wheeze, and breathlessness in children, adults, and older adults () (Barton et al., 2007; Osman et al., 2010). Two non-experimental UK studies from the UK (2465 participants from a mostly older population) reported both positive and negative impacts on respiratory health, suggesting an unclear overall impact (Platt et al., 2007; Shortt et al., 2007).

Seven quantitative studies assessed mental health outcomes after warmth and energy efficiency interventions (3 RCTs and 4 controlled before-after studies; Barton et al., 2007; Braubach et al., 2008; CHARISMA 2011; Howden-Chapman et al., 2007; Hopton et al., 1996; Platt et al., 2007; Shortt et al., 2007). Only one RCT from New Zealand (3312 participants) reported improvements to mental health (Howden-Chapman et al., 2007). The remaining six studies (3984 participants) reported inconsistent and therefore uncertain findings around mental health.

Three qualitative studies reported that improved warmth increased usable indoor space, enhancing privacy within the home and household relationships (Basham et al., 2004; Caldwell et al., 2001; Gilbertson et al., 2006). One study reported greater opportunities for educational

study (Basham et al., 2004). Two studies reported improved diet (Caldwell et al., 2001; Gilbertson et al., 2006), linked to increased income from reduced spending on fuel (Caldwell et al., 2001), and greater kitchen use due to better thermal comfort (Caldwell et al., 2001).

Additionally, Thomson et al. (2013) reported **indirectly** relevant evidence (i.e. not about health) from nine quantitative studies on changes in **housing condition outcomes** (including measures of cold, damp, mould, indoor air quality, fuel use and expenditure). Findings from four RCTs, four controlled before-after study, and one uncontrolled before-after study were mixed. Two RCTs from New Zealand (3661 participants) found improvements in several aspects of housing condition for the intervention group (Howden-Chapman et al., 2007; 2008), whereas the UK studies showed a more inconsistent pattern of results. One UK RCT (178 participants) reported no improvements in energy efficiency, fuel costs, living room temperature, and humidity, (Osman et al., 2010). A second UK RCT (447 participants) reported reduced bedroom wall dampness, but no change in temperature, humidity, and air quality (Barton et al., 2007). Four non-experimental UK studies (2669 participants) reported improvements in warmth and damp (Hopton et al., 1996; Platt et al., 2007; Shortt et al., 2007; Somerville et al., 2000).

The above evidence for the effects of these interventions on health outcomes is **directly** relevant to the present RES. The review is of high quality and includes a relatively large proportion of studies conducted in the UK. We consider the evidence for the effects of **warmth and energy efficiency interventions** on both **general and respiratory health** to be of **moderate certainty**. Notably, the review authors concluded that the evidence for improvements to overall health (general and respiratory) in adult and child populations to be of moderate certainty, but possibly not for elderly populations. We consider the evidence for the effects of **warmth and energy efficiency interventions** on **mental health** to be of **low certainty.**

Retrofit

One systematic review examined 14 studies (10 UK) of the effects of rehousing, retrofitting, and neighbourhood renewal (Thomson et al., 2013). The interventions in these studies, involving government investment to improve housing conditions in relatively deprived areas, likely included warmth and energy efficiency measures (e.g. installation or upgrading of central heating), but this was not clearly reported. It is also likely that interventions varied considerably across study populations and included wider neighbourhood changes and socio-economic regeneration activities. Among the relatively better-quality studies (5 controlled before-after studies, all UK; 1016 participants) measuring general health, there appears to be an overall positive impact on general health outcomes, but not all studies reported improvements (Barnes et al., 2003; Critchley et al., 2004; Evans et al., 2000; Kearns et al., 2008; Thomson et al., 2007). The better-quality study measuring respiratory health and mental health (5 controlled before-after studies, all UK; 2326 participants) were diverse and reported positive, negative, and no change in outcomes (Barnes et al., 2003; Critchley et al., 2004; Kearns et al., 2008; Thomas et al., 2005; Thomson et al., 2007).

Four qualitative studies reported evidence of positive impacts of retrofitting on health and housing experiences (Bullen et al., 2008; Ellaway et al., 2000; Gibson et al., 2010; Rogers et al., 2008). A range of health-related impacts were reported including improved wellbeing, happiness, and life satisfaction, reduced respiratory illness and stress, reduced smoking and sedative use, and improved diet. Residents linked improved levels of thermal comfort, reduced noise, and general improved housing satisfaction to improved health and wellbeing. Other impacts were reported in single studies, including increased space leading to greater privacy, empowerment, reduced clutter, improved family functioning, and more safe space for children to play (Bullen et al., 2008). Increased space also sometimes led to higher utility bills.

The above evidence is **directly relevant** to the present RES. However, as noted above, the specific measures or activities within retrofit interventions were poorly described the literature. We consider the evidence for the effects of **retrofit interventions** on **general health outcomes** to be of **low certainty**. We also consider the evidence for the effects of **retrofit interventions** on **respiratory and mental health outcomes** to be of **low certainty**.

3.2.1.2. The built housing environment

What is the relationship between aspects of the built housing environment and health?

We identified three relevant reviews: a systematic scoping review and narrative evidence synthesis (Howard et al., 2023), a systematic review (Rautio et al., 2018), and a rapid review of systematic reviews (Huggard et al., 2023) of the association between the built housing environment and health outcomes.

Howard et al. (2023) examined the relationship between housing characteristics and asthma. Thirty-three studies were identified (28 conducted in high-income countries). No quality assessments are available for these studies. Two relevant cross-sectional studies were conducted in Sweden (1160 participants; Wang et al., 2017) and the USA (2819 participants; Sun & Sundell, 2013), and assessed associations between building type (e.g. apartment or house) and building materials with asthma. Wang et al. (2017) found an association between living in a dwelling with crawlspace (e.g. basement or underground room) and asthma symptoms. Sun and Sundell (2013) found children aged 1-8 years living in trailers were at a higher risk of asthma than those in other dwellings. Characteristics of trailers may explain this finding, due to trailers' natural ventilation systems, dampness problems, and differences in foundations, walls, and flooring.

Rautio et al. (2018) examined the relationship between living environment and depression and identified 44 studies, of which three high-quality cross-sectional studies are relevant to the present RES. Study quality ratings must be interpreted with caution as the appraisal involved assessing study reporting quality rather than methodological quality or bias. These cross-sectional studies showed an association between adverse built housing environments and

increased risk of depression. A UK study (15,809 participants) found a greater risk of depression in individuals living in areas where <25% of homes had private gardens (compared with ≥75%), in properties built in 1970 or later (compared with pre-1940), and in properties with deck access (compared with other types of access) (Weich et al., 2002). No association was found for those living in properties built between 1940-1969 (compared with pre-1940) or those without recreational space (Weich et al., 2002). A further UK study (889 participants) found a greater risk of depression in people living in poor quality housing (compared with those with good or excellent accommodation), but the terms 'poor' and good' quality were not defined (Stewart et al., 2002). In the USA, a study of 1570 participants found increased risk of depression for those in housing with some non-functioning kitchen facilities, heating faults, large areas of peeling plaster or paint, and buildings in a deteriorating condition (Galea et al., 2005).

Huggard et al. (2023) examined the evidence on the social determinants of mental health. The review authors identified 37 relevant reviews, of which three reviews reported that the built housing environment was a determinant of mental illness (Lund et al., 2018; Remes et al., 2021; Yelton et al., 2022). However, the review authors did not present any further information beyond this statement.

Overall, there is limited evidence from a small number of observational studies that are prone to bias. Further, the reviews did perform adequate quality appraisal of their included studies. We consider the evidence for an association between the **physical built housing environment** and **asthma, depression** and **mental ill-health** to be of **very low certainty**.

Do built housing improvements improve health?

We did not identify any systematic reviews or other evidence on interventions to improve the built housing environment in terms of the factors explored above. However, there is related evidence reported earlier in this report on interventions to improve housing energy efficiency, warmth, and other retrofit measures, which involved changes to physical aspects of housing.

3.2.1.3. Housing age

What is the relationship between housing age and health?

One systematic scoping review and narrative evidence synthesis (Howard et al., 2023) examined the associations between housing characteristics and asthma. Four cross-sectional studies from high-income countries (2 Sweden, 2 USA) analysed the relationship between housing age and asthma, with mixed results. Regarding housing age and childhood asthma, one study found an association (1206 participants; Nriagu et al., 2012) while another did not (2819 participants; Sun & Sundell, 2013). Nriagu et al. (2012) observed a positive relationship whereby older housing increased the prevalence of asthma. Two studies (8714 participants) of housing age and adult asthma found no association between the two (Norback et al., 2012; Wang et al., 2017). However, the review authors did not give any indication of the age of houses in these

studies. Given the limited body of mixed evidence from cross-sectional studies (in which the exposure and outcome are measured at the same time and causality cannot be determined), we consider the evidence for the effects of **housing age** on **asthma** outcomes to be of **very low certainty.**

Do housing improvements improve health?

We did not identify any systematic reviews that assessed the effects of interventions in relation to housing age.

3.2.1.4. Home hazards

What is the relationship between home hazards and health?

One systematic review identified 97 studies (56 cross-sectional, 41 cohort studies) of the relationship between the physical environment and falls in older adults (Letts et al., 2010). Of the 41 cohort studies, 12 (7 prospective cohort, 4 retrospective cohort, and 1 case-control study) investigated home hazards as a risk factor for falls (Carter, Campbell, Sanson-Fisher, & Gillespie, 2000; Cesari et al., 2002; Clemson, Cumming &; Roland, 1996; Fletcher & Hirdes, 2002; Gill, Williams, & Tinetti, 2001; McLean & Lord, 1996; Nevitt, Cummings, Kidd & Black, 1989; Northridge, Nevitt, Kelsey & Link, 1995; Speechley et al., 2005; Studenski et al., 1994; Teno, Kiel & Mor, 1990; Tinetti, Speechley & Ginter, 1988). Other studies focused on outdoor and institutional settings. Cohort study quality scores ranged from 0 (low) to 11 (high) (mean score 4, indicating moderate-to-low quality). Specific home hazards were mostly unspecified; one study reportedly assessed hazards in the bathroom and on stairs (Speechley et al., 2015). Meta-analysis of 10 studies (12,262 participants) indicated that home hazards did not increase the fall risk for older adults (OR = 1.15 95% CI: 0.97–1.36). However, when the results from the higher quality studies only (5 studies) were pooled, home hazards increased fall risk (OR 1.38 95% CI: 1.03–1.87; 6778 participants). Overall, we consider the evidence for **home hazards** as a risk factor for **falls** in older adults to be of **low certainty**.

Does removing housing hazards improve health?

We identified 10 relevant reviews (9 systematic reviews and 1 umbrella review), including six high-quality Cochrane reviews (Clemson et al., 2023; Gillespie et al., 2012; Jian-Yu et al., 2020; Kendrick et al., 2008, 2013; Turner et al., 2011). The review by Clemson et al. (2023) is the most recent in a series of related reviews (Clemson et al., 2008; Gillespie et al., 2012; Goodwin et al., 2014), and only their findings are reported below. Similarly, Kendrick et al. (2013) is an update of their earlier review (Kendrick et al., 2008), and only the latest findings are reported below. Additional findings by Lektip et al. (2023) are also included. The umbrella review (Young et al., 2013)focused on fall prevention interventions for children at home, primarily examining the uptake of safety equipment rather than health outcomes, which makes its evidence **indirectly** relevant to the present RES.

Clemson et al. (2023) investigated the effects of environmental interventions for preventing falls in older people living in the community. The review authors identified 22 RCTs, of which 14 trials (5830 participants) assessed the impact of interventions designed to reduce hazards in the home and in turn falls. These interventions included identifying hazards and making environmental safety adaptations (e.g. non-slip strips on steps) and using behavioural strategies (e.g. avoiding clutter). Using GRADE (Guyatt et al., 2008), the review authors found high-certainty evidence that home fall-hazard interventions reduce the rate of falls and the number of fallers when targeted at high-risk individuals (e.g. those with recent falls year, hospitalisation, or needing support with daily activities). Meta-analysis showed a fall rate reduction of 38% (RaR 0.62, 95% CI 0.56 to 0.70; 1513 participants from 9 studies) and 702 (95% CI 554 to 812) fewer falls per 1000 people. However, the interventions did not reduce fall rates in people who were not at high risk of falling (high certainty evidence), or health-related quality of life (moderate certainty evidence), the risk of fall-related fractures (low certainty evidence), fall-related hospitalisations (low certainty evidence), or in the rate of falls requiring medical attention (low certainty evidence).

Another Cochrane review (Jian-Yu et al., 2020) reported an additional health outcome from the same study (Campbell et al., 2005). The intervention to improve home safety did not lead to any differences in physical activity. Using GRADE (Guyatt et al., 2008), the review authors graded the evidence for **physical activity** outcomes to be of **low certainty**.

Recently, Lektip et al. (2023) assessed the impact of home modifications on fall prevention in older adults. The review authors identified 12 RCTs with a minimal risk of bias. Interventions typically included home hazard assessments, home modifications, and training or education on home hazards, compared with a control group who received usual care. Ten RCTs were included in a meta-analysis (1960 participants). Using GRADE, the review authors concluded that there was moderate certainty evidence that home modifications reduced the number of falls in older adults (RR 0.93 CI 0.86, 1.00).

Kendrick et al. (2013) identified 98 eligible studies (2,605,044 participants; 35 RCTs). Among these, 41 studies offered low cost, discounted, or free home safety equipment to families. Results from 54 studies were pooled in meta-analyses. The review authors concluded that home safety interventions (provided as one-to-one, face-to-face education and the provision of safety equipment) may reduce injuries (IRR 0.89, 95% CI 0.78 to 1.01), particularly when interventions are provided at home (IRR 0.75, 95% CI 0.62 to 0.91). Of **indirect** relevance to the RES, the interventions **increased safety practices**, including uptake of safe hot tap water temperatures, functional smoke alarms, a fire escape plan, safe medication storage, keeping cleaning products out of reach, having fitted stair gates, socket covers on unused sockets and accessible poison control centre telephone numbers (ORs ranging from 1.07 to 3.30).

In their umbrella review, Young et al. (2013) investigated the effects of fall prevention interventions for children at home. The review authors included 13 systematic reviews, detailing 29 primary studies. Of the 29 studies, 10 (9 RCTs,1 non-RCT; 7566 participants) were relevant to

the present RES because they involved physical home modifications. These studies were of varied quality and reported a wide variety of interventions. The RCTs provided free home safety equipment (e.g. stair gates, smoke alarms, carbon monoxide detectors, window locks, fire guards, cupboard and drawer locks, furniture cover protectors, socket covers, non-slip bathmats, door handle covers, and more) with safety advice and counselling, and predominantly measured safety equipment use. Interventions increased the use of stair gates and furniture corner covers. The results for the use of window safety devices, non-slip bathmats, and other safety equipment were mixed. Only one RCT (211 participants; Odendaal et al., 2009) measured falling risk, finding no effect of the intervention. As most interventions focused on safety equipment use, rather than childhood falls and injuries at home, the effectiveness of such interventions for reducing falls in children is unclear.

Overall, these 10 reviews have synthesised a large literature on the effects of interventions to reduce home hazard risks on health outcomes. We conclude that there is **high certainty** evidence that **home safety or home hazard reduction interventions** are effective at **reducing the rate and number of falls** when targeted at older people who are at risk of falling. There is **moderate certainty** evidence that interventions involving the provision of safety equipment **reduces injury rates** in older people. We also conclude that there is **moderate certainty** evidence that these interventions have **little effect on health-related quality of life**, and **low certainty** evidence that these interventions have **little effect on fall-related fractures and falls requiring hospitalisation or medical attention**. There was **a lack of evidence** for the effects of these interventions on **health outcomes in children and the general population.**

3.2.1.5. Lighting

What is the relationship between types of lighting in the home and health?

One systematic review investigated the relationship between natural sunlight, artificial light, and light at night in the home and health (Osibona et al., 2021). Studies of outdoor lighting (e.g. streetlights) and light from electronic devices (e.g. mobile phone devices) were excluded. Twenty-eight experimental and non-experimental studies (10 high-quality, 18 moderate-quality) were identified. Of these, 25 studies found a relationship between light exposure and health. The findings from studies conducted in high income countries (18 of 28; 1 UK) are summarised below. Substantial variation between studies meant that data could not be pooled statistically.

Three cross-sectional studies found that natural light was associated with physical, mental, and sleep health. Natural morning light was associated with reduced depression scores (24 participants; Ichimori et al., 2013) and improved mood and sleep (quality, duration, and latency) (459 participants; Youngstedt et al., 2004), while inadequate natural light at home was associated with greater risk of falls and depression (6017 participants; Brown et al., 2011).

Four studies assessed whether artificial light was associated with health. Findings were inconsistent. A case-control study found an increased risk of falling on stairs in 74 adults aged ≥60 living in houses with poor lighting (Camilloni et al., 2011), while another case-control study did not find a relationship with falls or burns in 90 older adults aged 65-85 (Isberner et al., 1998). A cross-sectional study of 3636 Polish children aged six to 18 years found a relationship between fluorescent lights (compared with incandescent lights) in the kitchen and more farsightedness (Czepita et al., 2004). A crossover study in the UK (80 participants; Hopkins et al., 2017) and a cross-sectional study in Japan (351 participants; Kayaba et al., 2014) explored the impact of artificial light colours and sources on subjective sleep quality. Cooler colour temperature in lights was associated with poorer sleep quality, efficiency, time, and percentage (Hopkins et al., 2017). There was a relationship between poor sleep quality and use of light bulbs (compared with LED lights), but no evidence of a relationship with fluorescent light bulbs (also compared with LED lights) (Kayaba et al., 2014).

Ten of 11 studies found an association between light at night and poorer health outcomes. Eight studies (6 cross-sectional and 2 longitudinal) were from the Housing Environments and Health Investigation among Japanese Older People in Nara, Kansai Region (HEIJO-KYO) cohort (study samples ranged from 192 to 863 participants; Obayashi et al., 2013a; 2013b; 2014a; 2014b; 2014c; 2014d; 2015; 2018). These studies found a relationship between brighter light at night and a greater risk of plaque build-up in arteries, high blood cholesterol, Body Mass Index, abdominal obesity, higher night-time blood pressure, diabetes, depression, and taking a longer time to fall asleep. Three additional studies (cross-sectional, case-control, and crossover; 4814 participants) found a similar pattern of results and a relationship between higher nighttime light intensity and frequency and poorer health outcomes (Czepita et al., 2004; O'Leary et al., 2006; Yamauchi et al., 2014).

We consider the evidence for **lighting** as a risk factor for **all health outcomes reported above** to be of mostly **very low certainty.**

Do lighting improvements improve health?

One systematic review identified two interventions of changes to artificial lighting within homes (Osibona et al., 2021). The effects on health were inconsistent. A Swedish randomised trial of 46 adults with low vision found the provision of a singular floor lamp in participants' living rooms improved self-reported general health and depression (Brunnstrom et al., 2004). However, in Norway, a randomised trial of 60 home-dwelling elderly adults found no effects on visual problems or general health after supplying lamps in participants' living rooms (Falkenberg et al., 2019). We consider the effects of **artificial lighting** interventions on **general health, depression**, and **vision** to be of **low certainty.**

3.2.2. Indoor air quality

NICE have published guidance on indoor air quality in residential buildings (NICE, 2020). In their view, the housing conditions that put people at risk of exposure to poor indoor air quality include:

- location (external factors, e.g. high levels of outdoor air pollution, or where noise or security risks mean residents do not open windows).
- physical infrastructure (e.g. small room size, inadequate ventilation, and the building's layout and orientation).
- standard of housing (e.g. with damp and mould, physical disrepair including flood damage, or with unflued or poorly maintained fuel-burning appliances).
- overcrowding.

NICE reported that people who are particularly vulnerable to ill health as a result of indoor air quality are those with a pre-existing health condition (e.g. asthma, allergies, COPD, cardiovascular disease), pregnant women and their unborn babies, pre-school children, older people, people exposed to tobacco smoke in their homes, people who live in poverty, and people who live in poor-quality housing. To support their conclusions, NICE reference two evidence reviews of theirs of (i) the associations between building characteristics and poor indoor air quality, and (ii) clinical signs and symptoms that may signify poor indoor air quality at home.

3.2.2.1. Indoor allergens

What is the relationship between indoor allergens and health?

One systematic review of reviews and primary evidence examined the relationship between various environmental allergen exposures and asthma in children aged ≤9 years (Dick et al., 2014).Dick et al. (2014) identified 135 relevant studies (15 systematic reviews, 6 meta-analyses, 14 intervention studies, 92 cohort studies, 5 case-control studies, and 3 cross-sectional studies); 128 studies were from high-income countries (62 Europe). Sample sizes for individual studies were not reported. Studies that are relevant to the present RES are reported below.

Multiple exposures

Five cohort studies investigated the relationship between early life house dust mite exposure, plus other 'dust' exposures (including lipopolysaccharide (bacterial toxins), cat, dog, and cockroach allergens), with asthma in children aged ≤9 years (Dick et al., 2014). The studies reported mixed findings. Three studies found no evidence of a relationship between multiple exposures and asthma (Brussee et al., 2005; Finn et al., 2000; Lau et al., 2000). Two studies found that increased house dust mite exposure and lipopolysaccharide (bacterial toxins) exposures were associated with increased asthma and wheeze (Caledon et al., 2007). Higher concentrations of cat allergen was associated with increased asthma, but house dust mite was

not associated with increased asthma (Torrent et al., 2007). We conclude that the evidence for the association between **multiple exposures** and **asthma** is of **low certainty.**

House dust mite exposure

One cohort study found no evidence that exposure to house dust mites in infancy was associated with asthma (Carter et al., 2003). Another cohort study found that having more synthetic items of bedding (known to be fertile conditions for house dust mites) during infancy was associated with increased asthma (OR 1.8) (Trevillian et al., 2005). The review authors concluded that there was good evidence that exposure to house dust mites (in isolation) was not related to asthma.

Other exposures

Two cohort studies found no relationship between mouse allergen (Phipatanakul et al., 2008) and cockroach allergen (Finn et al., 2020) exposure in infancy and subsequent wheeze. The evidence for the relationship between **these allergens** and **wheeze** is limited, and we conclude that the evidence is of **low certainty**.

Does controlling indoor allergens improve health?

We identified seven relevant systematic reviews of the impact of indoor allergen control measures for asthma (Dick et al., 2014; Gøtzsche & Johansen, 2008; Leas et al., 2018; Macdonald et al., 2007; Singh & Jaiswal, 2013) and eczema management (Bremmer & Simpson, 2015; Nankervis et al., 2015).

Most recently, Leas et al. (2018) identified 67 studies (59 RCTs and 8 non-RCTs). Most studies were conducted in high-income countries, including 34 in Europe. The 67 studies (7424 participants) assessed the effects of eight allergen reduction measures on asthma outcomes, including pesticides, air purification, carpet removal, high-efficiency particulate air filtration (HEPA) vacuums, mattress covers, mould removal, pest control, and pet removal. Thirty-seven studies evaluated interventions using single measures, and 30 studies assessed multicomponent interventions using more than one measure. Substantial variation between studies meant that results could not be pooled statistically. For most measures, the evidence base was inconclusive or showed no effect on health. Interventions using single measures were generally not associated with improved asthma or lung function. Interventions using multiple measures showed some positive effects for asthma exacerbations and quality of life. A Cochrane review (Singh et al., 2013) investigated the impact of dehumidification of the home environment on asthma control, identifying two RCTs (Warner et al., 2000; Wright et al., 2009). Both studies were reviewed by Leas et al. (2018).

Another Cochrane review investigated measures to reduce exposure to house dust mites in people with asthma and known house dust mite sensitivity (Gøtzsche & Johansen, 2008). The review authors identified 55 RCTs (3121 participants with asthma). Study locations (countries) were not reported. Most trials (37) employed physical dust mite control methods, most

commonly mattress covers (26 trials). Ten trials involved chemical methods. Eight trials combined physical and chemical methods. Many of the trials were classified as low quality. The results of 44 trials were pooled in meta-analysis. No effects of the interventions were observed. There was no difference in peak flow (a measure of lung function), asthma symptoms, medication usage, or the number of patients reporting an improvement in their asthma symptoms. While reducing exposure to house dust mites is recommended in guidelines, the review did not find any health benefit of measures to reduce exposure to dust mites in people with asthma. The review authors concluded that the physical and chemical measures cannot be recommended. Another review (Macdonald et al., 2008) identified 14 RCTs (6097 participants) of house dust mite reduction interventions, concluding there is insufficient evidence to recommend measures to improve outcomes in people with asthma.

Another Cochrane review (Nankervis et al., 2015) identified seven RCTs of the effects of house dust mite reduction measures for the treatment of eczema in adults and children (324 participants; Colloff et al., 1989; Endo et al., 1997; Gutgesell et al., 2001; Oosting et al., 2002; Ricci et al., 2000; Tan et al., 1996; Terreehorst et al., 2005). Interventions to reduce or avoid exposure to house dust mite included covers for mattresses and bedding, high quality vacuuming of carpets and mattresses, and chemical sprays that kill house dust mites. The studies were generally classified as unclear and high risk of bias. Substantial variation between studies and a lack of data meant that results could not be pooled statistically. Six trials found no evidence of benefit. The seventh trial (Oosting et al., 2002) reported small improvements in people with atopic eczema who were sensitive to one or more airborne allergens, but the review authors concluded that there can be little confidence in this finding. These findings are supported by another systematic review (Bremmer & Simpson, 2015).

We conclude that there is **moderate certainty** evidence that **interventions to reduce indoor allergen exposure** do not improve **asthma symptoms** and **lung function**. Further, we conclude that there is **moderate certainty** evidence that measures to **reduce house dust mite exposure** for the treatment of juvenile and adult eczema show no effects on **eczema outcomes.**

3.2.2.2. Damp and mould

What is the relationship between damp and mould and health?

We identified five relevant systematic reviews (Caillaud et al., 2018; Dick et al., 2014; Groot et al., 2023; Quansah et al., 2012; Rautio et al., 2018).

Caillaud et al. (2018) conducted a systematic review of systematic reviews and recent longitudinal studies of the impact of indoor mould exposure on asthma and rhinitis. The review authors included research of any indoor environment (e.g. home, office, school, and hospital) and did not differentiate results specific to indoor home environments only. The review is included in the present RES because it identifies high quality research in this field. Studies

reporting only on the health effect of dampness, with no specific focus on mould exposure, were excluded. The review authors identified 61 articles (7 meta-analyses, 4 systematic reviews, and the remainder were longitudinal, case-control, and panel studies). Most studies were conducted in high-income countries and a small proportion were from lower- and middle-income countries. The review authors concluded that, together, studies on the relationships between mould exposure and allergic rhinitis provide sufficient evidence of a strong association. In children, visible mould and mould odour were associated with the development and exacerbations of asthma. The review authors deemed the findings to be sufficient evidence of a causal relationship between mould exposure and asthma.

Our searches identified two further reviews (Dick et al., 2014; Quansah et al., 2012) also included by Caillaud et al. (2018). The findings of these reviews concur with Caillaud et al. (2018). Dick et al. (2014) identified one systematic review (Tischer et al., 2011a), one meta-analysis (Tischer et al., 2011b), and four cohort studies (Iossifova et al., 200; Jaakkola et al., 2005; Reponen et al., 2011; Reponen et al., 2012) - evidence which partially overlaps with that reviewed by Caillaud et al. (2018). The systematic review included data from 16 studies and concluded that exposure to visible mould was associated with increased risk for asthma (Tischer et al., 2011a). The meta-analysis of eight European birth cohorts found an association between exposure to visible mould or dampness and increased wheeze at two years (OR 1.4) (OR 1.1) (Tischer et al., 2011b). The cohort studies also found a relationship between mould exposure in early life and increased risk for asthma in childhood (Iossifova et al., 2009; Jaakkola et al., 2005; Reponen et al., 2011; Reponen et al., 2012). Dick et al. (2014) concluded that early exposure to mould was consistently associated with increased risk for asthma symptoms.

Quansah et al. (2012) looked at the relationship between exposure to household damp and mould and new cases of asthma in adults and children. They identified 16 studies (11 cohort, 5 incident case-control; 35,887 participants) of moderate to high quality from high-income countries (none UK). Meta-analysis found a greater risk of developing asthma in homes with damp and mould present. Exposure to dampness, mould odour, and visible mould were all associated with increased risk of asthma (effect estimates ranging from 1.29-1.73). The overall effect was strongest for infants, second strongest amongst children, and third strongest amongst adults. To strengthen the causal inferences that can be drawn, this review only included evidence from studies with stronger designs and new cases of asthma (to ensure that exposure to damp and mould came before the onset of asthma).

Recently, Groot et al. (2023) looked at the relationship between exposure to household damp and mould and respiratory health in children. The review authors identified 30 studies (22 cross-sectional, 5 case-control, and 5 cohort; 156,641 participants) from high income countries (1 UK). Study quality mostly ranged from low to moderate quality; only six studies were classified as high quality. A common limitation across studies in this review was the lack of valid and reliable measures of exposure to damp and mould. Meta-analysis showed a small to moderate

association between early life exposure to household damp and mould and cases of respiratory tract infections and respiratory symptoms in children (ORs ranged from 1.28-1.75).

Finally, Rautio et al. (2018) conducted a systematic review of the relationship between living environment and depression. The review authors identified one high-quality (well-reported) cross-sectional study conducted across eight cities in Europe (6919 participants; Shenassa et al., 2007). Minimal or moderate dampness or mould was linked to depression, even after taking several other factors into consideration (e.g. city of residence, marital status, education, employment, smoking, environmental tobacco smoke exposure at home, home ownership, home size, duration of tenure, crowding, ventilation, and type of heating at home).

These reviews provide **directly relevant** evidence to the present RES. We conclude that there is **moderate certainty** evidence that **indoor damp and mould in homes** are related to **new cases of asthma** and the **exacerbation of existing asthma**, particularly in **children**. We conclude that there is **low certainty** evidence of the relationship between **indoor damp and mould in homes** and **respiratory tract infections** and **respiratory symptoms in children.** We conclude that there is **very low certainty** evidence of the association between **indoor damp and mould in homes** and **depression** in adults.

Does removing damp and mould improve health?

We identified a relevant Cochrane review (Sauni et al., 2015) of building remediation measures to reduce the impact of damp and mould on respiratory health in adults and children. The review authors identified 12 studies, of which four were housing remediation interventions (3 RCTs,1 controlled before-after study; 6538 participants). Two studies (Howden-Chapman et al., 2007; Shortt et al., 2007) have also been synthesised under '*Warmth and energy efficiency'* above*,* but their findings are summarised again here.

Two high-quality RCTs included a total of 4639 adults and children (Burr et al., 2007; Howden-Chapman et al., 2007). Burr et al. (2007; 232 participants) compared the removal of all visible mould plus fungicide treatment and the installation of an air filter in mould-damaged houses, with a no intervention control group. Howden-Chapman et al. (2007; 4407 participants) compared a standard retrofit insulation package with a no intervention control group. Meta-analysis showed a reduction in asthma-related symptoms (e.g. wheezing - OR 0.64, 95% CI 0.55 to 0.75) and respiratory infections (e.g. rhinitis - OR 0.57, 95% CI 0.49 to 0.66 – as well as colds, flu, and rhinoconjunctivitis) after remediations.

Additionally, Burr et al. (2007) also found evidence of reduced asthma medication use, a reduction in the use of preventers and relievers. Breathing problems were also reduced in the intervention group. Further, Howden-Chapman et al. (2007) found that remediations improved morning phlegm, sleep disruption, and speech disruption from wheezing. An economic evaluation concluded that a modest investment (£700 before VAT) led to improved health and fewer school absences in children and work sick days in adults (Howden-Chapman et al, 2007).

The third study was a high-quality RCT (62 participants) of the impact of remediations, compared with giving information only, on children's asthma-related symptoms (Kercsmar et al., 2006). Interventions were directed at reducing water infiltration, removing water-damaged building materials, altering heating, ventilation, and air conditioning, lead hazard control, and environmental cleaning. Results showed that the number of emergency and inpatient visits were reduced in those in the intervention group, but there were no changes in the number of asthma symptom days among children.

The fourth study was a controlled before-after study (100 households) with a high risk of bias. The study evaluated the effect of energy efficiency measures, including a central heating system, on specific illnesses in older people (Shortt et al., 2007). There were no effects of the intervention on asthma symptoms. The review authors reported a significant fall in household fuel costs, from £1113 per annum to £751.56 on average.

These studies provide **directly** and **indirectly relevant** evidence to the present RES (as damp and mould measures were accompanied by other remediation measures in some of these multicomponent interventions). The review authors highlighted the wide range of outcome measures and variation in study designs, which made it difficult to draw robust conclusions. Notably, these studies were published in 2007 and thus the evidence is dated. The review authors used GRADE (Guyatt et al., 2008) to determine the certainty of the evidence. There was **moderate certainty** evidence that **housing remediations reduced the risk of asthma-related symptoms and respiratory infections in adults** and the **number of emergency and inpatient visits in children.** There was **moderate certainty** evidence that housing remediations **did not reduce the risk of the risk of asthma-related symptoms and respiratory infections in children or older adults.** We consider the evidence for a lack of impact on the **asthma symptoms** in **older adults** to be of **low certainty.**

3.2.2.3. Lead exposure

What is the relationship between lead exposure and health?

We did not identify any systematic reviews that examined the association between lead exposure in homes and health outcomes.

Does reducing lead exposure improve health?

Two relevant Cochrane reviews (Nussbaumer-Streit et al., 2016; Nussbaumer-Streit et al., 2020) examined household measures for preventing domestic lead exposure in children <6 years old. The latter review is an updated version of the former; only the most recent findings are reported (Nussbaumer-Streit et al., 2020). The review authors identified 17 studies (none UK), including 16 RCTs (3204 children) and one quasi-RCT (78 children). Three RCTs were classified as generally low risk of bias, while the other 14 studies were deemed of unclear or high risk of bias.

Interventions were household environmental (7 studies), educational (6 studies), or a combination of education and environmental (4 studies).

Only the household environmental and combined interventions are reported as these are most relevant to the present RES. Household environmental interventions included dust control (5 studies) and soil abatement measures (2 studies). Meta-analysis found that overall dust control did not reduce blood lead levels of young children (4 studies, 565 participants; MD –0.02, 95% CI –0.09 to 0.06). The data for floor dust level control could not be pooled statistically, but the studies found no effects of the interventions. Two studies assessed the effect of soil abatement. One study showed a small reduction in blood lead levels, while the other study showed no effect. The data for the combined interventions could not be pooled statistically, and the studies reported inconsistent results. The review authors concluded that, based on available evidence, household educational interventions and environmental interventions (namely dust control measures) show **no evidence** of a difference in reducing blood lead levels in children as a population health measure (Nussbaumer-Streit et al., 2020).

The review authors used GRADE (Guyatt et al., 2008) and determined that the evidence for **overall dust control** on **blood lead levels** was of **moderate certainty**, while the evidence for **floor dust control and soil abatement** on **blood lead levels** was **very low certainty**.

3.2.3. Evidence that is indirectly relevant to the RES

Where available, evidence related to other housing factors and circumstances (e.g. housing security and affordability) was also included alongside evidence on the physical state or condition of housing. This evidence was considered to be **indirectly relevant** to the present RES and is reported below.

3.2.3.1. Housing tenure and precarity

What is the relationship between aspects of housing tenure and health?

We identified three relevant reviews, including a systematic review of the relationship between housing disadvantage and mental health (Singh et al., 2019), a rapid systematic review of reviews of the social determinants of mental health (Huggard et al., 2023), and a recent systematic scoping review and narrative evidence synthesis (Howard et al., 2023) of the associations between housing circumstances and asthma.

Singh et al. (2019) measured housing disadvantage by overcrowding, mortgage delinquency, housing mobility, housing tenure, subjective perceptions of inadequate housing, eviction, and physical housing conditions. Mental health was measured as depression, psychological impairment, anxiety, allostatic load, mental strain, and psychological health. More severe cases of poor mental health (e.g. schizophrenia) and homelessness were excluded. The review authors identified 12 longitudinal cohort studies from high-income countries (2 studies UK), in

which exposure to housing disadvantage preceded mental health outcomes. Studies were of high (5), moderate (6), and low (1) quality.

Two cohort studies (3103 participants) of high and moderate quality examined the relationship between housing disadvantage and anxiety (Kang et al., 2016; Suglia et al., 2011). Housing disadvantage was measured as housing tenure and ownership (Kang et al., 2016) and through housing instability and number of residential moves (Suglia et al., 2011). Both studies found an association between housing disadvantage and prevalence of anxiety (ORs 1.9-2.22), as well as with incident anxiety (Suglia et al., 2011) and persistent anxiety (Kang et al., 2016).

Eight cohort studies (15,047 participants; 1 UK) examined the relationship between housing disadvantage and depression, and seven of these found an association (Aro et al., 1984; Alley et al., 2011; Desmond et al,. 2015; Fowler et al., 2015; Kingsbury et al., 2018; Rollings et al., 2017; Rumbold et al., 2012; Sadowski et al., 1999). Study quality was high (2), moderate (5), and low (1).

A further high-quality UK-based study found a relationship between density of housing problems and poor mental health (Pevelin et al., 2017). Additionally, a birth cohort study of moderate quality found an association between moving between residences (residential mobility) during birth until 2 years and depression (Rumbold et al., 2012).

Huggard et al. (2023) identified 37 relevant systematic reviews, of which four reviews looked at housing circumstances. Both living alone and living with family were associated with depression among older adults (Zenebe et al., 2021). For people from refugee and asylum-seeking backgrounds, aspects of housing were consistently linked to negative mental health outcomes. This included insecure tenure and mobility, housing condition, discrimination and accessing housing, overcrowding, and a sense of safety and social connections (Ziersch & Due, 2018). The threat of home eviction (i.e. being subject to foreclosure or being in high foreclosure activity areas) increased the likelihood of anxiety, depression, psychological distress, and suicide, and negatively impacted quality of life (Vásquez-Vera et al., 2017). There was a potential relationship between communal living arrangements and positive mental health, though the included studies were largely of low quality (Carrere et al., 2020).

Based on the available evidence, we consider the evidence for the association of various **housing disadvantage** with **anxiety and depression** to be of **moderate to low certainty**.

In their review of associations between housing circumstances and asthma, Howard et al. (2023) identified 33 studies. Of these, seven studies (5 cross-sectional, 1 cohort, 1 RCT) from high-income countries (none UK) looked at the relationship between housing tenure and asthma. The studies reported mixed results. One cross-sectional study reported a relationship between living in social housing and adult asthma and receiving rental assistance and adult asthma (9554 participants; Mehta et al., 2018), while another cross-sectional study found no evidence of a relationship n between tenure (private rental, social housing, and homeownership) and adult asthma (7554 participants; Norback et al., 2014).

Two cross-sectional studies (35,020 participants) found that home ownership was associated with fewer asthma cases in children compared to those in rental housing (Hughes et al., 2017; Hwang et al., 2012), while another cross-sectional study observed this relationship for adults only (16,167 participants; Kim et al., 2022). A cohort study in Japan with 337 adults and children who had resided in temporary housing for ≥1 year reported more cases of asthma, and new asthma cases diagnosed after residents moved out, although the study authors attributed this finding to environmental circumstances whilst residing in temporary housing or in the period that followed (Oshikata et al., 2021). An RCT in the USA involving 2829 low-income social-housing residents moving to subsidised private rental housing indicated a negative relationship between relocation and asthma in children (Schmidt et al., 2014). This was contrary to expectations that the move would improve health outcomes. Overall, the review authors concluded that the evidence for the effects of **housing tenure** on **asthma symptoms** is **inconclusive**. We consider the evidence for an association between tenure and **asthma symptoms** to be of **very low certainty.**

Does increased housing security improve health?

We did not identify any systematic reviews of the health impact of housing tenure and security interventions.

3.2.3.2. Crowding

What is the relationship between crowding and health?

We identified a large systematic review (Baker et al., 2013), a recent systematic scoping review and narrative evidence synthesis (Howard et al., 2023), and a systematic review (Singh et al., 2019), which examined the relationship between overcrowding and infectious diseases, asthma, and depression.

Baker et al. (2013) identified 345 studies (13 UK) of the impact of household crowding on infectious disease spread. No randomised trials were identified and only one study investigated an intervention designed to reduce crowding. Over half of the studies (55%, 189/345) demonstrated a relationship between greater household crowding and increased risk of various close contact infectious disease. Only 1% (5/345) showed a beneficial effect of crowding. Meta-analysis showed that household crowding increased the risk of gastroenteritis, upper and lower respiratory tract infections, hepatitis A, tuberculosis, meningococcal disease, bacterial stomach infection, and trachoma. The review authors concluded that **the evidence base of high-quality research studies was relatively large for these outcomes.** We consider this evidence for these outcomes to be of **moderate to low certainty**. For other diseases, notably for skin infections and rheumatic fever, the evidence base was very small and could not be pooled statistically.

Howard et al. (2023) identified three studies (of 33 total) from high-income countries (none UK) that assessed the impact of household crowding on asthma symptoms. Two studies were cross-sectional (40,755 participants) and the third was a time series study (sample size not reported). The three studies found no evidence that household crowding was associated with asthma among children (Hughes et al., 2017; Kutzora et al., 2019) or adults (Norback et al., 2014). The time series study found a relationship between crowding and cough, a common asthma symptom (Kutzora et al., 2019). We consider the evidence for the effects of **crowding** on both **asthma and cough** to be of **very low certainty.**

Singh et al. (2013) identified a prospective longitudinal birth cohort study in England that found a relationship between overcrowding during birth and depression in men aged 32–34 years (Sadowski et al., 1999). The study was deemed to be low quality. We consider the evidence for the effects of **crowding** on **depression** to be of **low or very low certainty.**

Does reduced crowding improve health?

We did not identify any systematic reviews of the health impact of household crowding interventions.

3.2.3.2. Indoor pollutants and allergens related to residents' behaviour

3.2.3.2.1. Pet exposure

What is the relationship between pet exposure and health?

One systematic review (Dick et al., 2014) identified two further systematic reviews (Lodge et al., 2012; Takkouche et al., 2008), one meta-analysis (Lodrup et al., 2012), and six cohort studies (Brunelreef et al., 2012; Celedon et al., 2002; Kerkhof et al., 2009; Melen et al., 2001; Perzanowski et al., 2008; Sandin et al., 2004) that examined the relationship between pet exposure and health. Study sample sizes were not reported. Results were highly inconsistent. One systematic review of nine studies concluded that exposure to pets around the time of birth may reduce the risk for allergic disease (including asthma) where there is no family history of asthma (Lodge et al., 2012). The other systematic review concluded that exposure to cats reduced the risk for asthma, whereas exposure to dogs increased asthma risk (Takkouche et al., 2008). The meta-analysis found no evidence that cat exposure in early life was linked to asthma risk in childhood (Lodrup et al., 2012). The mixed results from the cohort studies paint an unclear picture. These studies found a relationship between early cat exposure and increased severe asthma at four years (Melen et al., 2001), but also no evidence of an association with asthma at four years (Sandin et al., 2004) or eight years (Kerkhof et al., 2009); and reduced wheeze by age five years (Celedon et al., 2002; Perzanowski et al., 2008), yet increased wheeze at seven years (Brunelreef et al., 2012). Early dog exposure was linked to reduced wheeze at four years (Sandin et al., 2004). We consider the inconsistent and thus inconclusive evidence for the impact of **pet allergen exposure** on **asthma** to be of **low certainty.**

Does controlling pet allergens improve health?

We did not identify any systematic reviews of the health impact of interventions to reduce exposure to pet allergens.

3.2.3.2.2. Domestic combustion and cleaning

What is the relationship between aspects of domestic combustion, cleaning, and health?

We identified four systematic reviews (Dick et al., 2014; Maung et al., 2022; Paterson et al., 2021; Vardoulakis et al., 2020), which together synthesised an extensive literature of over 350 studies (predominantly cohort). As mentioned above, NICE have also produced relevant guidance related to indoor air quality (NICE, 2020a). All review authors concluded that exposure to indoor air pollutants from domestic combustion and household cleaning products was associated with poorer health outcomes.

Maung et al. (2022) concluded that (a) there is a relationship between particulate matter (PM) (from sources such as smoking, cooking, heating, candles, and insecticides) and lung functioning, childhood asthma, and COPD symptoms, and (2) there is a relationship between volatile organic compounds (VOCs) (from sources such as household products, cleaning agents, glue, personal care products, building materials, and vehicle emissions) are associated with symptoms of the upper airway and asthma, and cancer. Paterson et al. (2021) concluded that there was evidence to suggest that VOCs, especially aromatic and aliphatic compounds, are associated with increased asthma symptoms. The review found that the evidence for a relationship between indoor PM and asthma in adults is inconclusive. Dick et al. (2014) concluded there was consistent evidence linking exposures to second-hand smoke, inhaled chemicals, and ambient air pollutants with an increased risk for asthma. Vardoulakis et al. (2020) concluded that high indoor PM, nitrogen dioxide (NO2), and VOC levels are typically associated with respiratory symptoms, particularly asthma symptoms in children. Notably, this latter review was funded by Dyson Technology Limited, which is a potential conflict of interest (Vardoulakis et al., 2020).

In their guidance, NICE (2020a) noted that pollutants such as NO2, VOCs, PM from open solid-fuel fires and polycyclic aromatic hydrocarbons (PAHs) are sometimes associated with many symptoms including those affecting the respiratory, cardiovascular, and neurological systems. Some groups are believed to be more vulnerable than others to exposure to poor indoor air quality, with emphasis on the very young, those with or at risk of developing respiratory conditions.

Overall, there is broad consensus in the literature of a relationship between indoor air pollutants and poorer health outcomes, particularly respiratory health. We consider the evidence of a relationship between **VOCs** and **impaired respiratory functioning, COPD symptoms, childhood asthma symptoms,** and **cancer** to be of **moderate certainty.** The relationship

between PMs and adult asthma appears to be unclear. We conclude that there is **moderate certainty evidence** of a relationship between **PMs** and **asthma in children**.

Does controlling domestic combustion and cleaning improve health?

We did not identify any systematic reviews of the health impact of interventions to control exposure to pollutants from domestic combustion and cleaning practices.

Environmental and neighbourhood factors

It is important to caveat the following section of evidence related to environmental and neighbourhood factors. The database searches for this RES were designed to identify research related to the physical condition of *indoor* dwellings rather than external or outdoor environmental housing factors. However, some research related to environmental and neighbourhood factors was identified and is summarised below. It is important to note that this section only presents a snapshot of the available research evidence on this topic – it is anticipated that much relevant research has not been identified and included in this RES.

What is the relationship between outdoor allergens and health?

One systematic review examined the relationship between outdoor allergens (e.g. pollen) and asthma (Dick et al., 2014). Dick et al. (2014) identified three relevant cohort studies, which all found that exposure to outdoor allergens was related to increased asthma risk. One study found that fungal spores and pollen concentrations at the time of birth were associated with increased wheeze at age two years, and those born in autumn and winter (the fungal spore season) were at increased risk for wheezing (Harley et al., 2009). A second study reported a relationship between grass pollen exposure between 4-6 months of age and increased asthma at seven years of age (Erbas et al., 2013). The third study in New York City found an association between tree canopy cover (a source of tree pollen and of altered airflow and air quality) in infancy and asthma at seven years (Lovasi et al., 2013). We conclude that the evidence for the association between **outdoor allergens** and **asthma** and **wheezing** is of **moderate to low certainty**.

Does controlling outdoor allergens improve health?

We did not identify any systematic reviews of the health impact of interventions to control exposure to outdoor allergens.

Outdoor air pollution

NICE have produced guidance on outdoor air pollution, which covers road-traffic-related air pollution and its links to poor health (NICE, 2017). NICE reported that various pollutants are related to road transport including carbon monoxide, benzene and VOCs. The guideline focused on PM and NO2 because these pollutants were deemed to have the greatest impact on health at

levels currently seen in the UK. The guideline concluded that short-term exposure (over hours or days) to elevated levels of air pollution can lead to effects on lung function, exacerbations of conditions such as asthma, and increases in hospital admissions and mortality. Long-term exposure (over several years) can reduce life expectancy, mainly because of increased risk of mortality from cardiovascular disease, respiratory causes, and lung cancer.

What is the relationship between outdoor air pollution and health?

We did not identify any systematic reviews that examined the association between outdoor air pollution and health outcomes. This is likely because our searches were not specifically designed to do so, rather than because this evidence this does not exist.

Does controlling outdoor air pollution improve health?

We did not identify any systematic reviews of the health impact of interventions to control exposure to outdoor air pollution. This is likely because our searches were not specifically designed to do so, rather than because this evidence this does not exist.

Neighbourhood noise

What is the relationship between neighbourhood noise and health?

We identified two relevant systematic reviews of the effects of neighbourhood noise (Mayne et al., 2021) and road traffic noise (Dzhambov & Lercher, 2019) on health outcomes.

Mayne et al. (2021) identified 85 articles, of which seven were cross-sectional studies of the association between neighbourhood noise and sleep outcomes among children and adolescents. Six of these (25,259 participants) found associations between higher neighbourhood noise and poorer sleep. The review authors also identified eight qualitative studies in which children or caregivers mentioned noise outdoors as a potential barrier to sleep.

Dzhambov et al. (2019) conducted a systematic review of the association between road traffic noise exposure and depression and anxiety. The review authors identified 10 studies (7 cross-sectional, 2 cohort and 1 case-control; 9 in Europe). Meta-analysis indicated no relationship between noise exposure and depression (OR 1.04, CI 0.97 – 1.11; 1,201,168 participants) or anxiety (OR 1.12, CI 0.96 – 1.30; 372,079 participants).

We conclude that the evidence for a relationship between higher **neighbourhood noise** and **poorer sleep** is of **low certainty**, and the evidence for a lack of association between **road traffic noise** and both **depression** and **anxiety** is of **very low certainty.**

Does controlling neighbourhood noise improve health?

We did not identify any systematic reviews of the health impact of interventions to control exposure to neighbourhood noise.

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