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Cold homes and their association with health and well-being: a systematic literature review

Hayley Janssen, Ben Gascoyne, Kat Ford, Rebecca Hill, Manon Roberts and Sumina Azam

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Acronyms and abbreviations in this report

BMI	Body Mass Index
CCC	Climate Change Committee
COPD	Chronic obstructive pulmonary disease
COVID-19	Coronavirus disease (SARS-CoV-2)
DBP	Diastolic blood pressure
EPC	Energy Performance Certificate
HDBP	Home diastolic blood pressure
MBPS	Morning blood pressure surge
NIH	National Institute for Health
NHLBI	National Heart, Lung, and Blood Institute
PHE	Public Health England
SBP	Systolic blood pressure
WHO	World Health Organization

Executive summary

Introduction

A growing body of evidence suggests cold temperatures within the home contribute to a range of negative health outcomes. This includes respiratory problems, poorer cardiovascular health, mental health conditions such as depression and anxiety, an increased risk of falls, loneliness and social isolation, and a poorer sense of well-being. Children, older people, and people living with long-term health conditions are known to be especially vulnerable to negative outcomes. Consequently, minimum indoor temperature recommendations[1] for homes (i.e. residential properties) are generally considered beneficial for population health and well-being.

In 2014, Public Health England (PHE) published a systematic literature review on the evidence for minimum home temperature thresholds and their impact on health[2]. Overall, this review found strong evidence that cold homes (i.e. below 18°C) have a harmful effect on health. PHE also acknowledged a clear need for further research to understand the relationship between behaviour, vulnerability to cold, and potential health risks of exposure to cold homes in the short and longer term. Increasingly urgent and rising pressures from challenges such as the rising cost of living and fuel poverty, coronavirus (COVID-19) recovery, and climate change amplify the need for further understanding of the impacts of cold homes on health and well-being to determine the appropriateness of current recommendations for home temperatures.

As part of a wider project to determine whether current indoor temperature standards for households in Wales are optimal for people's comfort, health, and well-being, **this review aims to identify and appraise the current evidence on the association between cold homes and health and well-being**.

Methods

A systematic literature review was conducted on the association between cold home temperatures and health and well-being. Peer-reviewed research papers published from 1st February 2014 to 17th February 2022 (inclusive) and conducted in the UK or in countries with comparable climates were included. Research articles were screened (title and abstract prior to full-text) independently by two reviewers, with conflict resolution for any discrepancies regarding inclusion of studies. The Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies was used to assess study quality and risk of bias of included studies. Data were synthesised narratively due to the heterogeneity in methodologies, populations, and exposure and outcome measures between studies.

Results

Twenty studies were included, the findings of which are summarised in the summary infographic. The studies examined the association between cold homes and health outcomes relating to the **cardiovascular system** (n=10; blood pressure, salt intake [linked to blood pressure], electrocardiogram abnormalities, and blood platelet count); **respiratory system** (n=3; chronic obstructive pulmonary disease (COPD) symptoms and respiratory viral infection); **sleep** (n=3; nocturia[3]

1 Since the 1980s the World Health Organization (WHO) has recommended temperatures within the home of between 18°C (minimum) and 24°C (maximum) for healthy sedentary people under certain conditions [16].

2 Wookey R, Bone A, Carmichael C, Crossley A. (2014). Minimum home temperature thresholds for health in winter – A systematic literature review. London; Public Health England.

3 Needing to wake up more than once during the night to urinate.

Summary infographic. Summary of results by outcome from individual studies (published 2014-2022) included in the review

Cardiovascular

In adults ≥20 years, a home thermal insulation intervention **increased morning temp by 1.4°C (14.5°C-15.9°C)** and reduced morning SBP and DBP [67]

In older adults ≥60 years, an intervention to heat living rooms to **24°C** before waking **increased temp on average by 2.1°C (14.1°C-16.2°C)** 4 hours after rising, and reduced SBP and DBP [65]

In adults ≥20 years, morning SBP showed a higher increase compared with evening SBP per **10°C decrease (range 3.3°C [morning] to 27.5°C [evening])**, particularly for older adults and women [69]

❄ In older adults ≥60 years, nocturnal urinary sodium excretion rate in the coldest homes **(10.1 ± 2.3°C)** was 14.2% higher than in the warmest **(19.3 ± 1.8°C)** [71]

❄ In younger normotensives and pre-hypertensive males (23-26 years), higher MBPS were recorded under cold condition **(16.67 ± 0.45°C)** compared to warm condition **(24.40 ± 0.78°C)**, with higher trends observed in pre-hypertensives [70]

❄ In older adults ≥50 years, SBP and DBP was higher for people living in cold homes **(<18°C)** compared with people living in warmer homes **(≥18 °C)** [68]

In adults ≥16 years, **a 1°C decrease** in temp was associated with an increase in blood pressure [66]

❄ In older adults ≥60 years, blood platelet count in the cold group **(<14.4°C)** was significantly higher compared to intermediate **(14.4-17.9°C)** and the warm **(>17.9°C)** groups [73]

❄ In adults ≥20 years, electrocardiogram abnormalities were more likely in those living in cold houses **(<12°C)** compared to warm houses **(≥18°C)** [72]

In older adults ≥60 years, **a 1°C decrease** in temp **(range 0.3°C [night] to 33.6°C [morning])** was associated with an increase in daytime SBP, nocturnal blood pressure fall, sleep-trough MBPS [64]

Respiratory

In adults >18 years, no association was observed between measured temp **(range ~1°C to ~38°C)** and possible or probable viral infection or sleep quality in winter [76]

❄ In children ≤15 years, there was no difference in the incidence of common cold between coldest **(<16°C ≥180min/day)** and least cold **(<16°C <30 min/day)** night-time temp groups [75]

In older people 45-85 years, with chronic obstructive pulmonary disease, more severe symptoms occurred **≤18.2°C** [74]

Sleep

❄ In older adults ≥60 years, sleep onset latency decreased from 16.7 minutes to 12.4 minutes after increasing evening temp from **10°C** to **25°C** [78]

❄ In older adults ≥60 years, nocturia was more likely in those living in colder houses **(13.2 ± 3.0°C)** compared to those in warmer houses **(18.6 ± 2.4°C)** [77]

General health

In adults ≥16 years, **each 1°C increase** in temp **(range 7.5°C to 36.8°C)** was associated with a 1.7% higher likelihood of poor self-rated health; this was a linear relationship [82]

In older adults ≥66 years living in homes **<18°C**, existing chronic health problems including osteoarthritis and asthma appeared to worsen in the cold [81]

❄ In older adults (61-98 years), room temps **<~15°C** were perceived to have a negative influence on health and well-being [83]

Physical performance

❄ In older women ≥70 years, physical performance (e.g. muscle power of lower limbs) decreased in a **15°C** room compared with a **25°C** room [79]

❄ In older people (mean 81 years), worse hand-grip strength was associated with cold houses **(<18°C)** compared to warm houses **(≥18°C)** [80]

Key: ☐ Study found an association between colder temperature and poor health. ☐ Study found an association between warmer temperature and poor health. ☐ No association identified between temperature and health.

❄ **Studies specifying a temperature threshold <18°C in line with WHO recommendation.** DBP: diastolic blood pressure; MBPS: morning blood pressure surge; SBP: systolic blood pressure; Temp: temperature.

and sleep onset latency[4]); **physical performance** (n=2; muscle power of lower limbs and hand-grip strength); and **general health** (n=3; perceived impact of cold on health and self-rated health).

Discussion

Seventeen of the twenty studies found exposure to cold indoor temperatures were associated with negative effects on health measures. More than half of these studies (n=11) investigated health effects at or below a specified temperature threshold under 18°C; these included a range of studied temperatures from 10°C to 17.9°C (see ❄ in the summary infographic). Studies reported increased blood pressure from living in cold homes in different population groups. Nevertheless, these physiological changes varied between studies and the potential health impacts of such changes require more research, including the association of indoor temperature with cardiovascular disease risk. Older people and those with chronic health problems were found to be more vulnerable to negative impacts from cold homes. Physical performance in older adults was shown to decrease following indoor cold exposure, which is an important risk factor for falls and fall-related injuries. In addition, home temperatures at or below 18.2°C were associated with increased severity of symptoms in patients with COPD. For healthy adult and child populations, there was no significant relationship between exposure to cold temperatures in the home and symptoms of viral infection.

Overall, the evidence from this systematic literature review suggests that living in cold homes (i.e. below 18°C) is associated with adverse effects on health and well-being. This evidence is not only consistent with, but builds on, findings of the PHE systematic literature review in 2014. Due to study data heterogeneity, there is insufficient evidence to draw clear conclusions regarding outcomes at specific temperature thresholds. Nevertheless, **there is consistent evidence that temperatures of below 18°C are associated with negative effects on health measures.** This suggests that the minimum temperature of 18°C to which the World Health Organisation (WHO) and UK authorities currently recommend the general population heat their homes is safe for health. However, the summarised evidence has several limitations including a lack of personal exposure measurements and the inability to clearly establish causal relationships between the temperatures achieved and outcome variables. This review highlights significant gaps in the current evidence base with further research needed in several areas including:

- An exploration of the impacts of cold homes on mental health and well-being; isolation and loneliness; and the wider determinants of health, such as educational attainment.
- Studies involving young children (under 5 years) and those living in fuel poverty.
- An examination of the specific temperature thresholds at which health effects start.
- Studies exploring the long-term health and well-being effects of exposure to cold homes.

The evidence from this review also needs to be considered in the context of challenges such as the rising cost of living, remote working as a result of the COVID-19 pandemic, climate change, and the temperatures being achieved within homes in Wales.

4 The time it takes to fall asleep after turning the lights off.

1. Introduction

1.1. Setting indoor temperature thresholds for homes to reduce the impacts of cold temperatures on health and well-being

In 2017/18, there were 32,058 excess winter deaths[5] in England and Wales[6] (five-year central moving average) [1], with 30% of these attributed to living in cold homes[7] [2]. A growing body of evidence suggests cold temperatures within the home contribute to a range of negative health outcomes [3–5]. This includes respiratory problems [2,6–8], poorer cardiovascular health [7,9], mental health conditions such as depression and anxiety [5], and an increased risk of falls, loneliness, and social isolation [10,11]. Older people, children and individuals living with disabilities or long-term health conditions, particularly cardiorespiratory disease, are known to be especially vulnerable to poor outcomes associated with living in cold homes [6].

Considering the adverse health impacts of living in cold homes, minimum indoor temperature recommendations for homes are widely seen as beneficial for population health and well-being. Since the 1980s the World Health Organization (WHO) has recommended temperatures of between 18°C (minimum) and 24°C (maximum) for healthy sedentary people under certain conditions e.g. with appropriate clothing and humidity[8] (see Table 1). The Welsh and Scottish Governments have set different home temperature recommendations, within these minimum and maximum thresholds (see Table 1) [12,13].

In the UK Government's Cold Weather Plan for England, a single minimum temperature of 18°C is recommended, based on the results from a systematic review of the evidence for minimum home temperature thresholds and health conducted by Public Health England[9] (PHE) in 2014 [7,14]. Overall, this review found strong evidence that cold homes (below 18°C) are associated with a harmful effect on health (see Box 1 and Table 2). However, PHE concluded that from the evidence available and following discussion with experts, there was insufficient evidence to support the previous minimum threshold of 21°C in living rooms, and that considering the wider health and well-being impacts from fuel poverty and increased carbon emissions the 18°C minimum threshold was appropriate [7,15]. PHE also acknowledged a clear need for further research to understand the relationship between behaviour, vulnerability to cold, and potential health risks of exposure to cold homes in the short and longer term [7].

5 Excess winter deaths are defined as the number of deaths that occur in winter (Dec-Mar) compared with the average number of deaths occurring in the preceding Aug-Nov and the following Apr-Jul [4]. Excess winter deaths are primarily due to illnesses brought on by the cold, however, they are not considered a good indicator of cold-related health burdens due to several limitations such as 40% of cold-attributable deaths occurring outside of the Dec-Mar period [115].

6 In Wales from 2020 to 2021, 32.3% excess winter deaths were recorded (see Welsh context; page 14).

7 The 'home' being the social, cultural and economic structure established by the occupier(s); and the 'dwelling' (house or flat) being the physical structure [112].

8 The moisture content of the air [114]. A relative humidity range of 30%-50% is recommended for occupant thermal comfort [116]. Lower humidity levels, which are too "dry", may feel uncomfortable and increase airborne transmission of viruses and bacteria; higher humidity levels, which are too "moist", may feel humid and promote damp and mould.

9 PHE was replaced by UK Health Security Agency and Office for Health Improvement and Disparities.

Table 1. Indoor temperature recommendations

Source, year of publication (Reference)	Indoor temperature recommendation for homes	Target population
WHO, 2018 [6]	A minimum of 18°C	General population
	A higher minimum (unspecified) may be necessary (see also WHO 2007)	Vulnerable groups*
WHO, 2007 [16]	From 1987 the temperatures of between 18°C and 24°C [17]	Non-vulnerable groups
	Between 20°C and 24°C	Vulnerable groups*
Health and Social Care Public Health Agency for Northern Ireland, 2022 [18]	Heat the main living room to around 18-21ºC and the rest of the house to at least 16ºC. At night, keep the temperature above 18°C in your bedroom	All households
UK Health Security Agency, 2021 [14]	A minimum threshold of 18°C at all times	Healthy people (aged 1 to 64 years)
	Daytime temperatures above 18°C may be beneficial for health	Older people (aged 65+ years) or those with pre-existing medical conditions
Scottish Government, 2017 [13]	21°C in the living room and 18°C in all other occupied rooms	Non-vulnerable
	23°C in the living room and 20°C in all other occupied rooms	Vulnerable to the adverse health and wellbeing impacts of living in fuel poverty
Welsh Government, 2021 [12]	21°C in the living room and 18°C in other rooms for 9 hours in every 24-hour period on weekdays, and 16 hours in a 24-hour period on weekends	General households
	23°C in the living room and 18°C in other rooms achieved for 16 hours in a 24-hour period	Households with older (aged 60+ years) or disabled people

*Including children, the elderly (aged over 65 years), and people with cardiorespiratory disease and other chronic illnesses.

Box 1. Headline findings from PHE's 2014 'Minimum indoor temperature threshold recommendations for English homes in winter: A systematic review' [7]

Based on evidence from 1973 to February 2014 (see Table 2), the review found:

- In a small number of studies, cold temperatures of around 18°C or below were associated with an increase in blood pressure in the general population. One study showed that the effect of cold on blood pressure, and other cardiovascular risk factors may be more pronounced in older age groups compared to younger age groups.
- There was inconclusive evidence on the association between colder indoor temperatures (<20°C) and having a higher body mass index (BMI).
- The range of temperatures at which people of different ages were comfortable was comparable, but older people were less able to perceive colder temperatures. Thermal comfort (i.e. the sensation of satisfaction with the ambient temperature [19]) may be an important factor in mental health, well-being and social outcomes.
- Very limited information on the effects of specific cold indoor temperature thresholds for people with chronic illnesses – one study showed people with chronic obstructive pulmonary disease (COPD) had a better respiratory symptom score when maintaining a living room at 21°C for at least 9 hours per day.
- Very few studies conducted with children (0-15 years). One study in children (aged 6-12 years) with asthma found that exposure to cold temperatures below 12°C had the greatest negative effect on lung function.

The 2014 systematic review influenced policy through the development of new minimum temperature recommendations for England (see Table 1; [14]). The review identified a number of evidence gaps including no studies quantifying the mental health impact of cold homes. The review also excluded studies involving warmth and energy efficiency improvement interventions, which may have provided additional evidence on the associations between cold indoor temperatures and health.

In 2019, the UK Climate Change Committee (CCC) identified setting thermostats[10] no higher than 19°C as one of the actions that individuals can take to reduce their household emissions [40]. Although this recommendation does not account for evidence on cold related health outcomes, the CCC does recommend the significant roll-out of energy efficiency measures to improve the thermal efficiency (i.e. energy efficiency of a dwelling given through the Energy Performance Certificate [EPC] [41]) of homes, which may help to reduce cold related deaths [40]. Warmth and energy efficiency interventions (e.g. home insulation) can lead to general health, respiratory health, and mental health improvements, especially when targeted at those with inadequate warmth and chronic respiratory disease [8,42,43].

To date, a variety of indoor temperature recommendations for homes exist (see Table 1) with a shared aim to protect the health and well-being of populations. Considering the findings from the 2014 systematic literature review by PHE, further evidence is needed to support specific temperature thresholds [7]. In addition, increasingly urgent and rising pressures from challenges such as the rise in cost of living and fuel poverty, COVID-19[11] recovery, and climate change amplify the need for further research on the impacts of cold homes on health and well-being to determine the appropriateness of current recommendations for home temperatures (see Section 1.3).

10 Thermostat settings might not reflect air temperatures in different areas or rooms in the home.
11 Coronavirus disease (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and has resulted in an ongoing global pandemic since 2020 [110].

Table 2. Summary of results from individual studies identified in the PHE 2014 systematic literature review on minimum temperature thresholds for health in winter [7]

Ref	Study design	Total sample size	Age in years (study population)	Temperature(s) studied	Main finding	QA Tool* rating
[20]	Cross-sectional	32	68-87 (n=16), 18-39 (n=16)	12°C; 16.2°C; 21°C	For sedentary adults wearing light clothing thermal comfort was achieved at 21 °C ± 2.9°C with 12°C considered too cold. For moderately active adults wearing heavy winter clothing thermal comfort was at 16.2 °C.	FAIR
[21]	Prospective cohort	1645	45-64	<18°C; 18°C-20°C; ≥20°C	Obesity (BMI >30) and hyperglycaemia associated with indoor temperature ≥20°C.	FAIR
[22]	Cross-sectional	100152	≥ 16 (Mean 47.6) (45% with chronic illness)	<19°C versus 23°C	BMI was higher at <19°C than at 23°C.	GOOD
[23]	Randomised controlled	146	18-60	12°C versus 22°C	Higher blood pressure and blood pressure surges recorded following night at 12°C versus 22°C.	GOOD
[24]	Cross-sectional	10345	40-59 (male, n=7735); 25-29, 40-44 and 55-59 (male & female, n=2610)	Each 1°C decrease	Blood pressure increased with decreasing room temperature; however, blood pressure change was no longer significant when area of residence (town) was adjusted for.	FAIR
[25]	Cross-sectional	148	Mean 69 (patients with COPD)	≥21°C	Fewer days ≥21°C in the living room for at least 9 hours had significantly worse COPD respiratory symptom scores.	GOOD
[26]	Cross-sectional	72	65-91	<16°C; <18°C	Low body (core) temperature was associated with decreased perception of cold rooms <18°C; a risk factor for developing hypothermia.	FAIR
[27]	Cross-sectional	12	66-71 (n=6), 20-23 (n=6)	18±0.5°C; 22±1°C (baseline)	Exposure to 18°C for 2 hours, after 90 mins at baseline, increased risk of blood clotting in all.	FAIR
[28]	Cross-sectional	2047	16-95	<16°C; <18°C	Blood pressure increased <18°C and further increased <16°C.	GOOD
[29]	Cross-sectional	192	>60 (many with co-existing chronic illnesses)	Each 1°C decrease	Associated with an increase in sleep-trough morning blood pressure surge (MBPS) and pre-waking MBPS.	FAIR
[30]	Birth cohort	3343	3 months-11 years	Range of 9.0°C to 21.4°C	No relationship found between indoor temperature and BMI, bedroom temperature range 9.0°C- 21.4°C (Mean 17.5°C).	FAIR
[31]	Randomised control trial	409	6-12 (with asthma)	<12°C	Exposure to cold temperatures <12°C had the greatest negative effect on lung function.	FAIR

[32]	Case control	297	3-5 (with upper respiratory tract infection	Not reported	No association between upper respiratory tract infection and indoor temperature.	FAIR
[33]	Cross-sectional	6	Mean 20.5 (men)	~10°C; 27- 28°C (baseline)	Exposure to indoor temperature ~10°C for 2 hours, after 30 mins at baseline, for 11 consecutive days, increased blood pressure and acclimatisation to 'feeling' cold.	GOOD
[34]	Cross-sectional	11	24-27 (men)	11°C; 26°C (2nd exposure)	Exposure to 11°C for 1 hour, for 5 consecutive days, caused an inflammatory response including a rise in erythrocyte count and plasma fibrinogen and decrease in lymphocytes.	FAIR
[35]	Cross-sectional	19	60-71 (men, n=10), 20-25 (men, n=9)	12°C; 17°C; 28°C (baseline)	Blood pressure increased at 17°C in both groups, but greater effect in older people at 12°C. Older men showed greater increase in blood pressure and decrease in core and skin temperature than younger group.	FAIR
[36]	Cross-sectional	9	63-70 (men, n=5), 18-24 (men, n=4)	6°C; 12°C	SBP increased, and heart rate decreased at 6°C, and at 12°C in older men.	FAIR
[37]	Longitudinal	1020	>65	<16°C; <18.3°C	Low indoor temperature (75% of rooms <18.3°C and 54% <16°C) led to reduced hand and mouth temperatures, but not core temperature.	FAIR
[38]	Cross-sectional	20	24 ± 1 & 61 ± 3 (women, n=10); 22 ± 1 & 64 ± 2 (men, n=10)	10°C; 15°C; 20°C; 28°C	Exposure to cold temp (<15°C) for 2 hours caused an increase in haemoglobin, haematocrit and plasma protein levels. These effects occurred earlier in women than men, but effect greater in men except plasma protein levels, which older women had highest levels.	FAIR
[39]	Cross-sectional	77	69-90 (n=47), <45 (n=30)	Not reported	Perception of cold decreased in older people, due to a decline in autonomic nervous function, which is a risk factor for hypothermia, compared to younger adults (<45 years).	FAIR

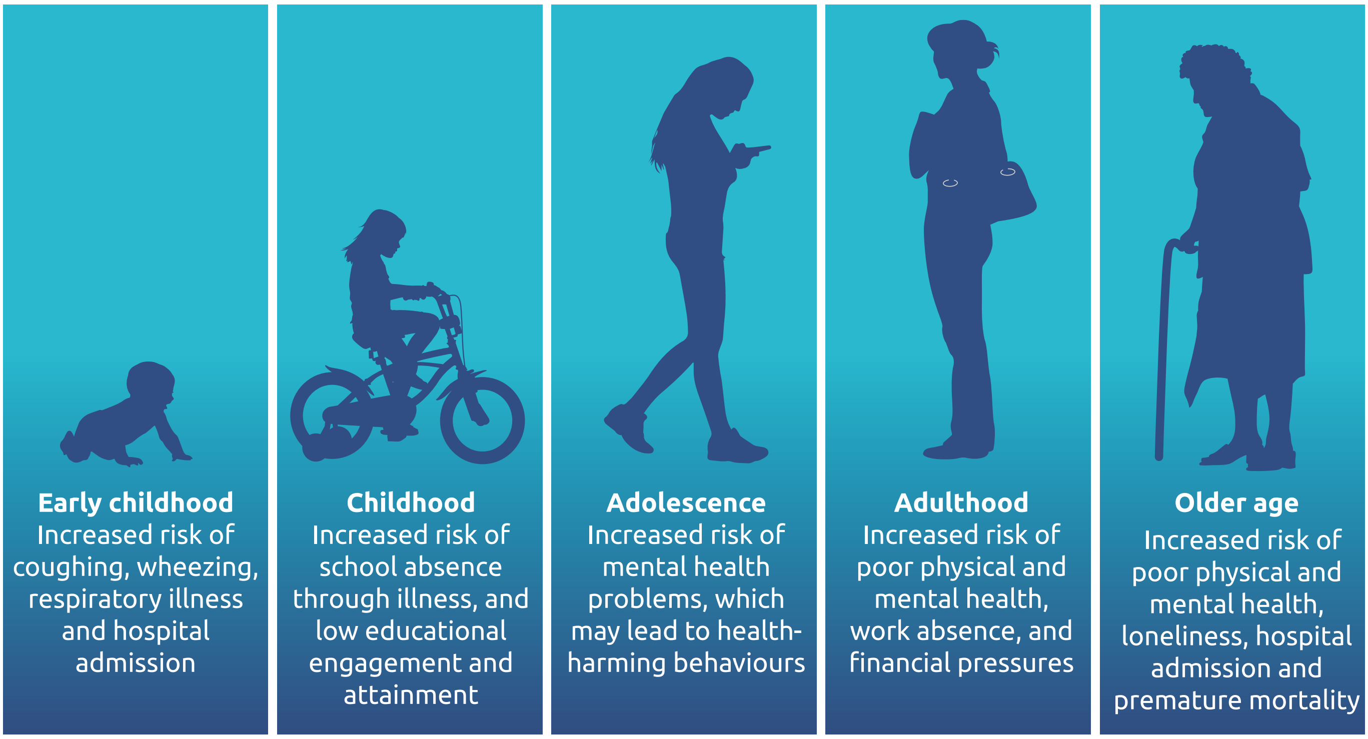
* Quality Assessment Tool rating from the PHE review using the National Institute for Health (NIH) grading system.

1.2. Population groups especially vulnerable to the harmful effects of cold homes

Although cold homes can affect health, well-being and socioeconomic outcomes across the life course (see Figure 1), some groups are known to be especially vulnerable to these harmful effects including older adults (aged over 65 years) and people with existing cardiovascular or respiratory conditions [6,7]. Older adults are more likely to have complex health and care needs and therefore spend longer periods of time indoors, make greater demands on the dwelling, and exhibit more sedentary behaviours, which increases their susceptibility and exposure to the harmful effects of cold homes. Older adults are also more likely to live in fuel poverty and are less likely to feel discomfort in colder temperatures [7,12].

Other population groups thought to be more vulnerable to health problems associated with cold homes are young children (aged under five years [44]); pregnant women; recent immigrants and asylum seekers; people with existing mental health conditions, disabilities, or addictions; the unemployed or those on low incomes; people who have attended hospital due to a fall; and people who move in and out of homelessness [45]. However, due to a limited number of studies conducted with these populations, the health and well-being impacts on many of these population groups are poorly understood.

Figure 1. Health and well-being impacts associated with living in a cold home (i.e. below 18°C)* across the life course** [3,5,6,46]

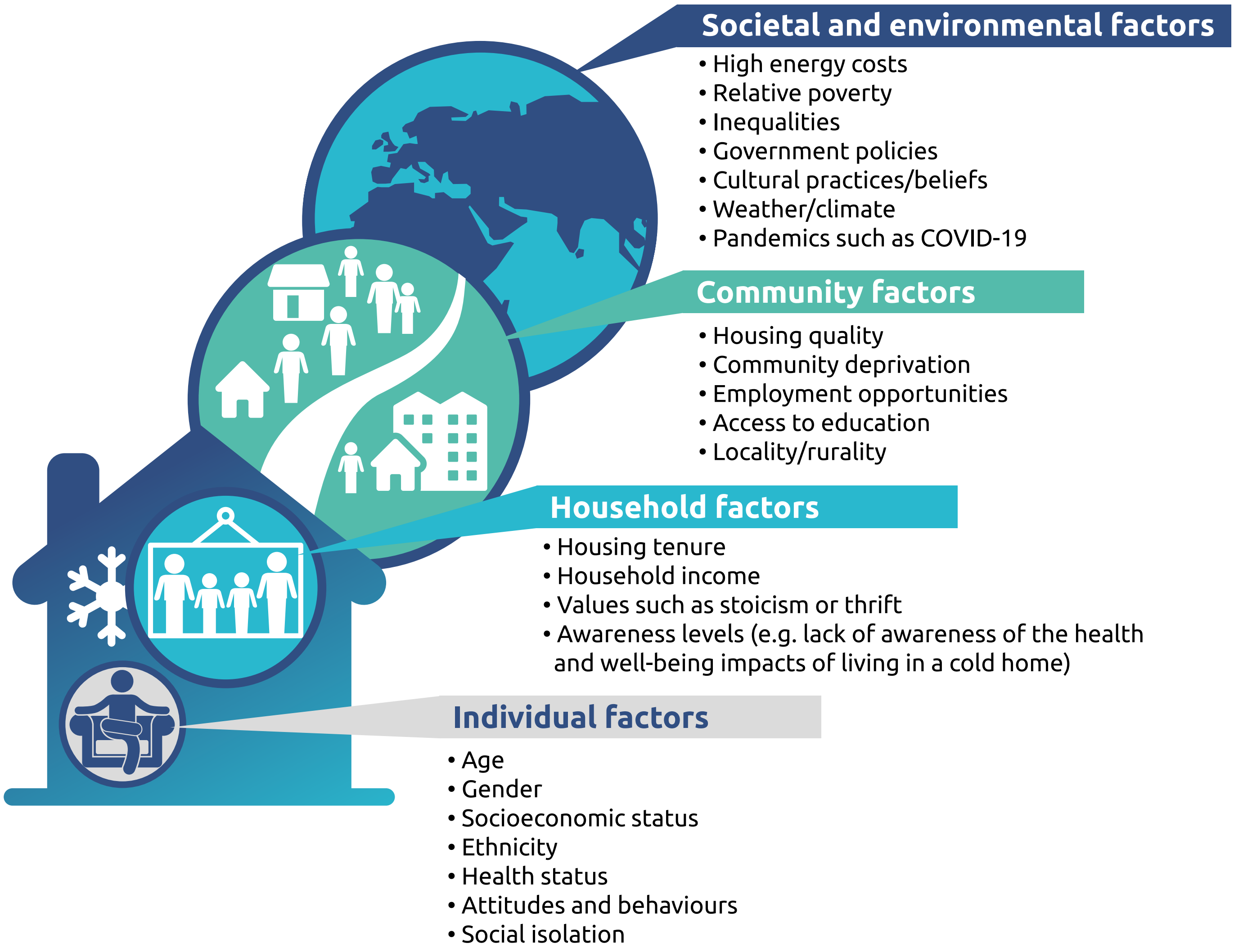


*Cold home temperature threshold (<18°C) in line with WHO recommendation [16].
**The strength in evidence across ages and health outcomes differs substantially.

1.3. Contributory factors to living in cold homes

Individual, household, community, and societal circumstances may contribute to the likelihood of living in a cold home (see Figure 2). Cold indoor temperatures tend to be a result of cold outdoor temperatures, type and age of property, structural deficiencies including a lack of insulation and airtightness, and lack of heating [6]. Countries that exhibit more extreme winters generally have lower rates of excess winter deaths than those with milder winters, suggesting that they are better adapted to low temperatures via energy efficient dwellings [2,6,47]. In milder regions of Europe, including the UK and Ireland, many houses are poorly insulated and/or lack efficient and effective heating provision, making them difficult to heat and maintain temperatures. An energy inefficient dwelling may only threaten the health of a household with low disposable income[12]. However, for those that can afford to maintain temperatures, the heat and energy used to warm an energy inefficient home would contribute more greenhouse gas emissions than an energy efficient home.

Figure 2. Examples of risk factors for living in a cold home (i.e. below 18°C)



12 The amount of money that individuals in the household sector can spend or save after income distribution measures [111].

Fuel poverty[13] results from a combination of inter-related factors[14] including an energy inefficient dwelling; low disposable income; and high cost of energy [44–46]. Low incomes may also restrict people to living in older and colder homes [6]. A 2013 systematic review found consistent evidence that low income, poor housing conditions including housing quality and low indoor temperature, and fuel poverty were associated with adverse cold temperature-related health or social outcomes [50]. Fuel poverty has also been shown to have a significant negative impact on mental health and to be a risk factor for suicide [46]. A recent literature review concluded that the current evidence base does not fully consider that vulnerable communities often experience energy insecurity in addition to other hardships [51]. Cold homes (i.e. below 18°C) have been shown to disproportionately affect groups that are particularly vulnerable, for example those with complex needs such as inadequate housing, poverty and pre-existing poor health [8]. Other contributory factors that add complexity to the issue of cold homes include the rising cost of living, COVID-19 recovery and climate change (see Box 2). In Wales, as elsewhere, the rising cost of living is continuing to widen health inequalities significantly, with 43% of people reporting a deterioration in their mental health, and 30% in their physical health, as a result of their financial situation [52].

Box 2. Contextual challenges

Rising cost of living and fuel poverty – In April 2022, following a 54% Ofgem energy price cap increase [53], it was estimated that up to 45% (~614,000) of households could be living in fuel poverty in Wales, whilst up to 98% of those on lower incomes[15] were expected to be in fuel poverty [54]. The general rise in the cost of living and tax increases may serve to exacerbate problems further, adding additional financial pressures to many households [55], with more people being forced to make financial trade-offs such as to "heat or eat" [56].

COVID-19 recovery – COVID-19 has changed the way in which people live, work, travel and socialise. Welsh Government is supporting a long-term shift towards remote working, with the aim to have 30% of Wales-based workers working at or near to home on a regular basis [57]. Home working has potential implications for home energy-use, fuel poverty levels, household carbon emissions and population health and well-being.

Climate change – The heating of homes and workplaces accounts for almost one-fifth of the UK's carbon emissions [58]. Growing public concerns over greenhouse gas emissions and climate change may alter energy use behaviours, thus exposing households to colder temperatures. In a recent survey in Wales, 44% of respondents said they always minimise energy use in the home to help reduce climate change [59]. Legislative commitments such as Welsh Government's target to be net zero (100% reduction in carbon emissions) by 2050 may also be influential on occupant behaviour [60].

13 When a household is unable to obtain an adequate level of energy services, particularly warmth, for 10% of their income [48] (see Glossary for fuel poverty definitions, page 43).

14 Other contributory factors may include the absence of savings and living in rented accommodation, both of which limit an occupant's opportunities to improve the property [117].

15 A lower income household is defined as one whose income is less than 60% of the median UK household income before housing costs [54].

Context in Wales

Excess winter deaths

For 2020 to 2021, **32.3%** more deaths occurred in the winter than in non-winter months [118].

Over **75%** of excess winter deaths are in those aged 75 years and over.

30% of excess winter deaths are attributed to living in cold homes [4].

Fuel poverty*

In April 2022 it was estimated that up to **45% (614,000)** of **households in Wales could be living in fuel poverty** [54], an increase from **12%** (155,000) in 2018 [49].

However, is it likely that fuel poverty rates are higher and may continue to rise**.

Risk factors for fuel poverty in Wales include living in: the private rented sector, single person households, pre-1919 properties, or in homes without insulation, central heating or with poorer energy efficiency [49].

Welsh housing stock

Wales has the **oldest housing stock** and the lowest proportion of dwellings with an Energy Performance Certificate [EPC] rating of band C or above in the UK, with over a quarter **(26%)** built before 1919 [119].

Many homes are **detached and in rural locations** – leading to higher space-heating energy demands and fuel poverty levels [120].

In 2017-18, **82%** of dwellings in Wales relied on mains gas as its main source of heating [119].

* A household that would have to spend >10% of their income on maintaining a satisfactory heating regime (i.e. a set of indoor temperatures that homes should be able to maintain [12]).

** Not including households in unmetered off-grid or rural locations, which are also more likely to be detached with inadequate heating. Fuel poverty levels may increase further with additional rises in the cost of living.

1.4. Context in Wales

The current recommended satisfactory heating regime for households in Wales is shown in Box 3 (also see Table 1). Welsh Government's Tackling Fuel Poverty Action Plan 2021-2035 includes an ongoing commitment to examine the appropriateness of this definition to ensure it aligns with new evidence, especially in light of changed working patterns as a result of the COVID-19 pandemic. Therefore, this review seeks to further explore the current evidence base on outcomes associated with residing in cold homes. The review is part of a wider project to determine whether current indoor temperature standards for households in Wales are optimal for people's comfort, health, and well-being in the context of challenges such as the rising cost of living and fuel poverty, remote working as a result of COVID-19 and climate change.

Box 3. Satisfactory heating regime for Wales

A home should be heated to "*23°C in the living room and 18°C in other rooms achieved for 16 hours in a 24-hour period in households with older or disabled people. For other households, a temperature of 21°C in the living room and 18°C in other rooms for nine hours in every 24-hour period on weekdays, and 16 hours in a 24-hour period on weekends is considered satisfactory.*" (Welsh Government, 2021 [12])

1.5. Review aim

Following the 2014 systematic literature review published by PHE, this review aims to identify and appraise evidence on the association between cold indoor temperatures within homes[16] (i.e. residential properties) and health and well-being outcomes.

A note on terminology: Cold homes, cold indoor temperatures, indoor cold exposure and cold conditions are common terms used to describe cold temperatures within residential properties or in laboratory settings which have been designed to replicate homes. As such, these terms have been used interchangeably within this review, retaining the terminology from the original studies. However, for the interpretation of findings, 'cold indoor temperatures' or 'indoor cold exposure' has been used as these terms broadly cover all settings relating to homes.

16 Whilst low temperature in the home is the main focus for this review, there is an inter-relationship with humidity (possibly leading to condensation and associated mould) and air quality (including ventilation), however, these factors are beyond the scope of this review [6].

2. Methods

2.1. Search strategy and selection criteria

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist [61] and Cochrane rapid review methods [62], a systematic literature review was conducted on cold home temperatures and its associated impacts on health and well-being. Searches aimed to identify peer-reviewed research papers, published from 1st February 2014 to 17th February 2022 (inclusive), by amending and updating the search[17] from the PHE 2014 systematic review [7]. Searches were supplemented through manual searching and expert consultation. All papers in the English language that indicated relations between measured cold indoor temperature(s) and health and/or well-being outcomes were considered for inclusion. Searches were conducted across: PubMed, Embase, Cochrane Database of Systematic Reviews, Cumulative Index to Nursing & Allied Health (CINAHL), MEDLINE, APA PsycInfo, Applied Social Sciences Index & Abstracts (ASSIA) and the Coronavirus Research Database. Table 3 details the search terms and Boolean operators used. The search involved combining #1, #2, and #3 using the Boolean operator AND.

Table 3. The search terms and Boolean operators used

	Search terms
#1	Cold AND (weather OR seasonal OR temperature OR "thermal comfort") OR "indoor temperature"
#2	Indoor OR room OR home OR dwelling OR house OR inside OR housing
#3	"Myocardial infarction" OR coronary OR "heart attack" OR stroke OR angina OR "blood pressure" OR hypothermia OR COPD OR "chronic obstructive pulmonary disease" OR influenza OR flu OR asthma OR bronchitis OR "respiratory disease" OR dementia OR fall OR accident OR injury OR "mental health" OR depression OR morbidity OR mortality OR "excess winter deaths" OR health OR wellbeing OR physical OR activity
#4	1 AND 2 AND 3

17 After replicating PHE's searches, a very large number of irrelevant studies were produced therefore, it was decided to create a more targeted search with advice from an expert in research methods.

2.2. Data extraction and assessment

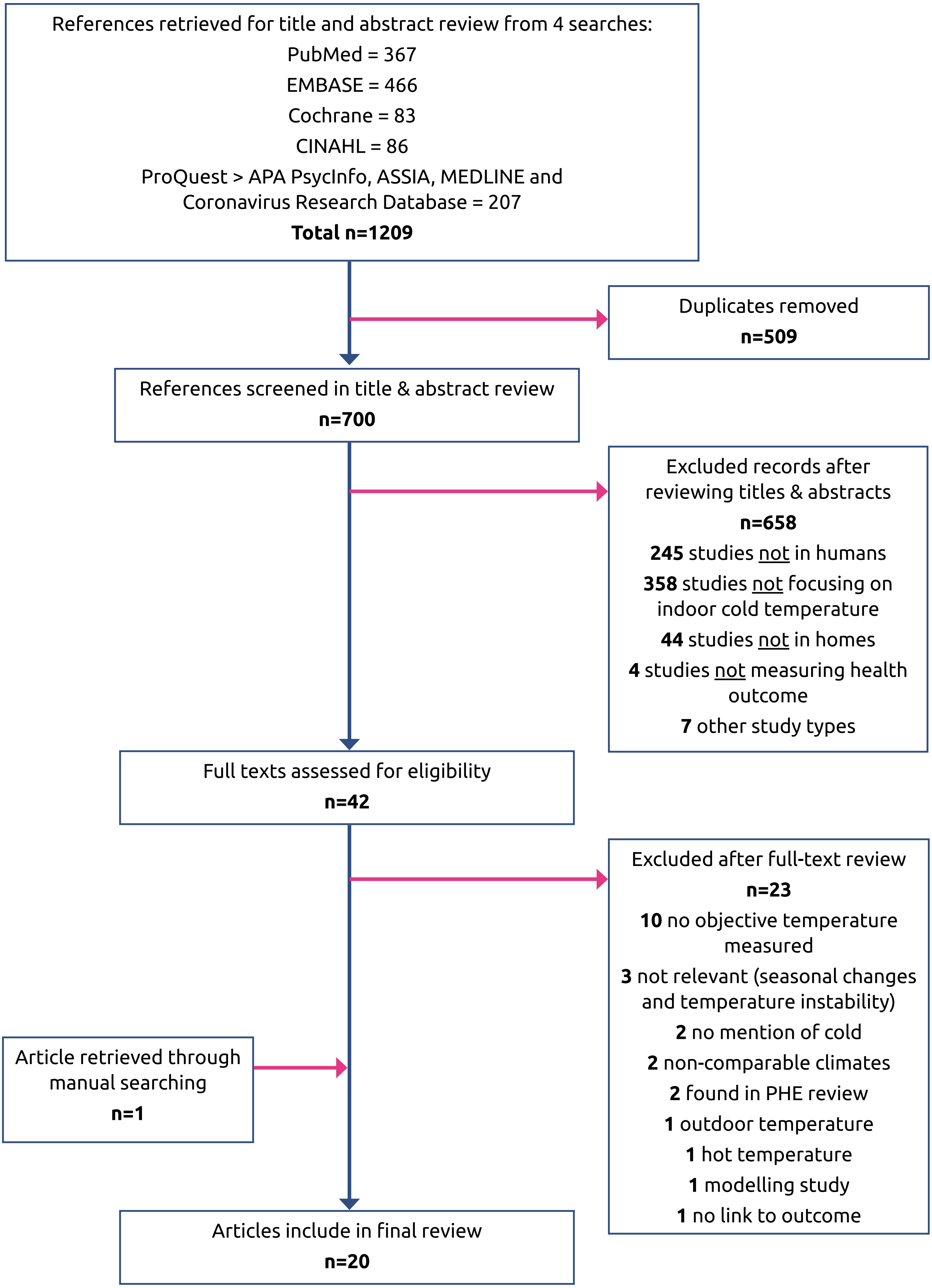
Search results were extracted into Microsoft Excel. After the removal of duplicates, title and abstract screening was undertaken by two reviewers (HJ and BG), using the inclusion and exclusion criteria outlined in Table 4. Full-text copies of relevant studies were obtained and independently screened by the two reviewers, with conflict resolution for any discrepancies regarding inclusion of studies. The Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies from the National Heart, Lung, and Blood Institute (NHLBI) was used to assess study quality and risk of bias, which included a checklist and grading system [63]. The two reviewers independently assessed and graded each included study and discrepancies were discussed. A weighting was then applied to each study, with those graded as 'good' given more emphasis in the results compared with those rated as 'fair' or 'poor'. Data extraction was conducted by the two reviewers and was checked for accuracy by a third reviewer (MR). The data were synthesised narratively due to the heterogeneity between studies (methodologies, populations, exposure and outcome measures).

Table 4. Inclusion and exclusion criteria

	Inclusion criteria	Exclusion criteria
Population	• Human subjects • All ages	• Animals, cells, food, chemicals, pollutants
Publication	• February 2014 - 2022	• Published prior to February 2014
Language	• Written in English	• All other languages
Exposure	• Reference to specific temperatures or thresholds • Energy efficiency measures/ interventions[18] (e.g. insulation or heating systems)	• No reference to temperature measurement and/or threshold studied • Studies using extreme cold exposure (colder than 5°C) or heat or over heating • Outdoor temperatures
Outcomes	• Physical health, mental health, well-being and social (e.g. loneliness and isolation) effects	• No reference to health, well-being effects • Air quality and/or pollution (e.g. radon) • Sport and/or exercise performance
Location	• Studies relating to homes, households, dwellings or residential properties • Studies conducted in UK and in countries considered to have similar climates	• Workplace/industrial environment • Other non-residential settings
Study type	• Randomised controlled trial, non-randomised controlled trial, case control, cohort study • Studies using primary and secondary data	• Evidence synthesis (e.g. systematic review, meta-analysis) or comment/editorial, ideas and opinion piece

18 Intervention studies were excluded from PHE's systematic literature review however, it was decided that relevant studies (that met the inclusion criteria for temperature measurements and health outcomes) may provide an important additional layer of evidence given the findings in Thomson's systematic review [8].

Figure 3. Search process



3. Results

After duplicate removal, searches retrieved 700 unique references for title and abstract screening, following which full-text copies of 42 relevant studies were obtained and screened, of which 23 were excluded (see Figure 3). One additional study was identified for inclusion from manual searching. The final 20 included studies examined the association between cold indoor temperatures and a range of different health outcomes (see Table 5).

Table 5. Distribution of main health outcomes

Health category	Number of studies	Detailed outcome explored
Cardiovascular	10	Blood pressure [64–70], salt intake (linked to blood pressure) [71], electrocardiogram (also known as ECG) abnormalities [72], and blood platelet count [73]
Respiratory	3	COPD [74] and respiratory viral infection [75,76]
Sleep	2	Nocturia* [77] and sleep onset latency** [78]
Physical performance	2	Physical performance [79] and hand-grip strength [80]
General health	3	Perceived impact of cold on health [81] and self-rated health [82,83]

*Needing to wake up more than once at night to urinate. **The time it takes to fall asleep after turning the lights off.

Over half (n=11) of the included studies were conducted in Japan [64,65,80,67,69,71–73,75,77,78], four were conducted in England [66,68,81,82], and one each were conducted in China [74], Germany [79], Taiwan [70], the USA [76] and Australia [83]. Study quality was predominantly fair (n=10) or good (n=9), with only one study rated as poor [76].

The majority of studies (n=18) recorded temperatures inside participant homes, with measurements often taken in different rooms (e.g. living rooms and bedrooms). The time interval of temperature measurement varied across studies from every 10 minutes (n=10) to one time point only (n=3). Most studies used branded data loggers that automatically recorded temperature and humidity (n=12), whilst others used a digital thermometer (n=3) or thermo-hygrometer (a temperature and humidity gauge; n=1). Devices were positioned at a certain height (between 60-110 cm off the floor), and away from direct heat sources such as radiators. Most studies also collected outdoor temperatures. The two remaining studies used controlled temperatures in laboratory settings under thermal test conditions [70,79].

More than half (n=11) of studies investigated the health effects of indoor cold exposure at or below a specified temperature threshold under 18°C (see in the summary infographic) [68,70,80,83,71–75,77–79]. These included a range of different cold temperatures from 10°C to 17.9°C, with multiple studies exploring the effects of indoor temperatures of 15°C or less [69,71–73,77–79,83]. Analysis was frequently based on comparison with warm indoor temperatures. In terms of population groups, eight studies concentrated on cold-related health risks associated with exposure to temperatures below 18°C in older people. Three studies researched health outcomes associated with indoor temperatures in excess of 23°C [70,78,79].

3.1. Cardiovascular health

Half of the studies (n=10/20) included in this review explored the impacts of cold homes on cardiovascular health (see Table 6). Four observational studies conducted in different population groups examined the effects on blood pressure [64,66,68,69], with all finding evidence showing a significant association between lower indoor temperatures and higher blood pressure. The observed changes in blood pressure varied between studies, for example, the increase in systolic blood pressure was 2.2 mmHg [64], 4.8 mmHg [66], and 8.2 mmHg [69] per 10°C decrease in temperature. The differential impacts of cold indoor temperatures by sex and age were explored in one study, which found that older adults and women may be more vulnerable to increased blood pressure associated with cold temperatures, than younger adults or men [69].

Results from two different intervention studies were consistent with the observational study findings, suggesting interventions that increased indoor temperatures significantly decreased blood pressure. The first was a randomised controlled trial evaluating the effect of specific home-heating instructions among older people, which increased indoor temperature on average by 2.1°C (14.1°C to 16.2°C) four hours after rising from bed [65]; the second was a non-randomised controlled trial of a thermal insulation retrofitting intervention (insulation work such as that on the outer walls, floor and/or roof), which increased morning indoor temperatures by 1.4°C (14.5°C to 15.9°C) [67]. Another experiment showed that compared to overnight warm conditions (24.40 ± 0.78°C), exposure to cold indoor conditions (16.67 ± 0.45°C) increased morning blood pressure in young men with prehypertension [70].

A single cross-sectional study explored potential pathways for the effects of cold indoor temperatures on blood pressure [71]. It found salt intake (measured by nocturnal urinary sodium excretion) was approximately 15% higher in the coldest homes (10.1 ± 2.3°C) compared with the warmest (19.3 ± 1.8°C). Additionally, two studies investigated the impacts on different cardiovascular biomarkers, which showed that colder indoor temperatures (<15°C) were also associated with higher blood platelet count and increased electrocardiogram abnormalities, both of which are known to contribute to increased risk of cardiovascular disease [72,73].

3.2. Respiratory health

Three studies assessed the associations between cold indoor temperature and respiratory health outcomes (see Table 7). One found indoor temperatures ≤18.2°C were associated with increased severity of symptoms in patients with COPD [74]. Two studies – one in the general adult population and another in a group of children aged 15 years and younger – observed no significant relationship between cold exposure and symptoms of viral infection [75,76].

3.3. Sleeping problems

The evidence from one observational study in older adults showed cold indoor temperatures (at 10°C versus 25°C) were associated with greater difficulties initiating sleep, measured by time to sleep or sleep onset latency [78]. Another study found increased nocturia (needing to urinate more than once during the night), an important cause of sleep disturbance particularly among older people, was observed in people in colder homes (13.2 ± 3.0°C) compared to those in warmer homes (18.6 ± 2.4°C) [77] (see Table 8). However, a study on a general adult population found no association between measured indoor temperatures, which ranged between ~1°C and ~38°C, and self-reported sleep problems in the winter season [76] (See Table 7).

3.4. Physical performance

Two studies investigated the impact of indoor cold exposure on the physical performance of older people necessary for independent living (see Table 9). The results of an experiment indicated a significant decrease of between 2% and 10% in physical performance measured by a range of outcomes including muscle power of lower limbs in cold conditions (15°C compared with 25°C), an important risk factor for falls and fall-related injuries in older people [78]. A small cross-sectional study also found older people living in cold homes (<18°C) had poorer hand-grip strength compared to those in warm homes (≥18°C) [79]. In addition, a large cross-sectional study investigating multiple health outcomes found worse hand-grip in older people living in cold homes (<18°C) compared to those living in warm homes (≥18°C) (Table 6) [68].

3.5. General self-rated health

The evidence from studies examining the effects of cold indoor temperatures on general health was mixed (see Table 10). Two studies found health was perceived to worsen in cold room temperatures; one below 18°C [81] and the other below around 15°C [83]. In contrast, a large cross-sectional study found people exposed to higher indoor temperatures (each 1°C increase; between temperatures of 7.5°C and 36.8°C) were significantly more likely to report poorer health [82].

3.6. Limitations within studies

Most of the studies identified were observational cohort and cross-sectional studies. These study designs have limitations including a lack of personal exposure measurements, the inability to clearly establish causal relationships between indoor home temperature and outcome variables including confounders such as behaviour (e.g. activity levels), thermal comfort (a sensation of satisfaction with the ambient temperature) and thermal adaptive behaviour (e.g. using a blanket or wearing clothes). Cross-sectional studies also lack a control/comparison group and provide only a snapshot of the specific time in which the data are collected.

Some studies did not report the method (e.g. type of device used) and/or location of temperature measurement (e.g. height from floor) in dwellings, which is important in the interpretation of the findings (see caveat 4 in Section 4.3). Methods of temperature measurement also differed between studies, for example some used a single time point, which may not be as representative of usual temperature as multiple timepoints.

Some studies involved a small number of participants with specific characteristics, limiting the generalisability of results to other populations. Other studies were conducted in laboratory settings, which lack external validity and limit generalisability.

Table 6. Cardiovascular health

Author(s), Year [Ref]	Country	Study Design	Population	Purpose	Exposure	Outcome(s)	Results	Strengths	Limitations	QA Tool rating
Saeki et al., 2014 [64]	Japan	Prospective cohort	868 home dwelling men and women (≥60 yrs).	To estimate the magnitude of association between indoor temperature (temp) and ambulatory blood pressure (BP) in colder months.	Living room and bedroom temps (indoor temp) were measured day and night 60 cm above the floor. Bed temp at centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using fixed thermo-sensors over 48-hour period in winter (Oct-Apr). Accuracy of indoor temp compared against personal-level environmental temps measured by thermo-sensor attached to ambulatory BP machine. The **indoor temp range was 0.3°C (night) - 33.6°C (morning).**	Repeated measurement over 2 consecutive days of BP (daytime systolic BP (SBP), night-time SBP, nocturnal BP fall (%), sleep-trough morning blood pressure surge (MBPS; sleep-trough MBPS is the mean SBP in the 120 min after rising minus the lowest night-time BP) and pre-waking MBPS (the difference between mean SBP in the 120min before and after rising time)).	**A 1°C decrease in indoor temp was significantly associated with an increase in: daytime SBP** (0.22 mmHg; p=0.047), **nocturnal % BP fall** (0.18%; p=0.014), **sleep-trough MBPS** (0.33 mmHg; p=0.003), **and pre-waking MBPS** (0.31 mmHg; p=0.004) in adjusted multilevel linear regression models.	Estimated BP effects independent of physical activity; accurate temp measurement; multi-level modelling allowed within-person estimates of repeated day-level measurements.	Exposure-outcome measured simultaneously so unable to establish causality; non-random sampling means generalisability of study may be limited.	Good
Saeki et al., 2015 [65]	Japan	Randomised controlled trial	359 men and women (≥60 yrs) allocated randomly to either control (n=173) or intervention group (n=186).	To estimate the short-term effectiveness of instruction in home heating on indoor temp and ambulatory BP among elderly people.	Living room temp was measured 60 cm above the floor at 10-min intervals using branded data loggers over 48-hour period in winter (Dec-Mar 2010, and Sept-Mar 2011 and 2012). **Participants in the intervention group were instructed to set the timer of the heating device in their living room to start 1 hour before their estimated rising time with thermostat set at 24°C**, and then to stay in the living room for 2 hours after rising if possible.	Indicators of ambulatory BP: sleep-trough MBPS and the pre-waking MBPS. Physical activity. Living room temp.	Compared with the control, indoor temp in the **intervention group significantly increased by 2.1°C (14.1°C to 16.2°C) 4 hours after rising**. After adjusting for confounding variables, **BP was significantly lower**: SBP by -4.43 mmHg (95% CI -7.88, -0.97) and diastolic BP (DBP) by -2.33 mmHg (95% CI -4.58, -0.08).	Study design enabled robust estimation of effect of intervention, independent of confounding factors; objective measurement of BP and indoor temp; also accounted for indoor temp at baseline.	Assessed short-term effect only; people without heating controller were excluded; consumption of energy (such as electricity or gas) not considered; participants did not achieve the target temp of 24°C so unable to determine effects of higher indoor temps on BP.	Good

Saeki et al., (2015 [71]	Japan	Prospective cohort	860 home dwelling men and women (≥60 yrs).	To quantify the association between daytime cold exposure in winter and salt intake.	Living room and bedroom temps (indoor temp) were measured 60 cm above the floor. Bed temp at centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using branded data loggers over 48-hour period in winter (Oct-Apr). The mean ambient temp during the last daytime before the nocturnal urine collection was calculated from indoor temp. The following groups were formed based on mean indoor temp: **coldest (10.1 ± 2.3°C) and warmest (19.3 ± 1.8°C) homes.**	Total nocturnal urinary sodium excretion (mmol); nocturnal urinary sodium excretion rate (mmol/h); ambulatory BP; physical activity.	A comparison of the 2 groups, adjusting for outdoor temp, showed the **nocturnal urinary sodium excretion rate in the coldest homes was 14.2% higher than in the warmest** (7.62 vs 6.54 mmol/h respectively). Higher salt intake was also linked to higher night-time ambulatory BP.	Relatively large sample; objectively measured salt intake, BP and indoor temp; estimates were adjusted for wide range of confounders.	Non-random sample; exposure-outcome measured simultaneously so unable to establish causality; nocturnal urine collection inferior to 24hr collection; lack of information about nutrition including intake of total energy.	Good
Saeki et al., 2017 [73]	Japan	Cross-sectional	1,095 home-dwelling men and women (≥60 yrs).	To investigate the association between indoor cold exposure and blood platelet count (PLT) among older people.	Living room and bedroom temps (indoor temp) were measured 60 cm above the floor. Bed temp at centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using branded data loggers over 48-hour period in winter (Oct-Apr). The following groups were formed based on mean indoor temp: **cold (<14.4°C), intermediate (14.4-17.9°C) and warm (>17.9°C).**	After collecting an overnight fasting venous sample with stasis in the morning, PLT counts were measured at a commercial laboratory.	In the fully adjusted model, **PLT count in the cold group was significantly higher compared to intermediate (4.2% lower) and the warm (5.2% lower) groups.**	Relatively large sample size; objectively measured temp; accounted for wide range of potential confounders.	Cannot determine causal directionality from cross-sectional analysis; did not quantify the amount of clothing worn; non-random sampling limits generalisability.	Good
Zhao et al., 2019 [66]	England	Cross-sectional Secondary analysis using data from the Health Survey for England in 2003, 2005 to 2014	Representative sample of 4,659 adults (≥16 yrs). Pregnant women were excluded.	To test two hypotheses: (1) a decrease in indoor temp is associated with an increase in BP, independent of other interfering factors; and (2) the indoor temp-BP relationship is moderated by factors, such as mean monthly outdoor temp.	Living room temp was measured once by nurse using a standard digital thermometer. The thermometer probe was kept away from heat sources, such as radiators or sunlight, and hung over the edge of a table where possible. The following groups were formed: **<18°C, ≤18-<21°C, ≤21-<24°C, and ≥24°C.** [Location of measurement and date/time of day not specified].	Mean SBP and DBP measured at 3 x 1-min intervals. The mean of the last 2 readings was used in the study.	After controlling for confounding variables, **1°C decrease in indoor temp was significantly associated with an increase in BP**; 0.48 mmHg (95% CI -0.72, -0.25) in SBP and 0.45 mmHg (95% CI -0.63, -0.27) in DBP.	Large population-based study; objectively measured temp; analysis adjusted for range of confounders including physical activity.	Cross-sectional design and simultaneous measurement of exposure and outcome meant unable to establish causality; single temp measurement; time of measurement not specified.	Good

Umishio et al., 2020 [67]	Japan	Non-randomised controlled trial	1,685 men and women ≥20 yrs allocated non-randomly either to intervention group (942 households and 1,578 participants) or control group (67 households and 107 participants).	To quantify the changes in home BP (HBP) due to insulation retrofitting intervention.	Living room, bedroom, and changing room temps (indoor temp) and relative humidity were measured 1.0 m above the floor at 10-min intervals using branded wireless data loggers for 2 weeks over 4 winter periods (Nov-Mar). The **intervention was the thermal insulation retrofitting of participants' homes**. This included heat-insulation work such as that on the outer walls, floor and/or roof; replacement of single-glazed windows with double-glazed windows; and replacement of window frames.	Change in HBP (follow-up HBP minus HBP measured at baseline).	**Morning indoor temp rose by 1.4°C (14.5°C to 15.9°C)** after insulation retrofitting, despite a decrease in outdoor temp by 0.2°C. The **intervention significantly reduced morning home SBP** by 3.1 mmHg (95% CI 1.5-4.6) **and morning home DBP** by 2.1 mmHg (95% CI 1.1-3.2).	Robust estimates of changes in HBP before and after intervention that increased indoor temp; objective measurement of HBP and indoor temp at multiple time points; short interval between baseline and follow-up.	Non-random sample of households which had intention of carrying out insulation retrofitting; differences between intervention and control group at baseline; study could not control the use of heating, accordingly, the frequency of heating may have decreased due to insulation retrofitting.	Good
Umishio et al., 2021 [72]	Japan	Cross-sectional	1,480 men and women (≥20 yrs).	To determine the association between the indoor temp at home and electrocardiogram (ECG) abnormalities.	Living room and bedroom temps (indoor temp) and relative humidity were measured 1.0 m above the floor at 10-min intervals using branded wireless data loggers for 2 weeks (Nov-Mar). Participants were divided into the following groups: **cold (<12°C), slightly cold (12-18°C) and warm (≥18°C) houses.**	Participants submitted results of a health check-up conducted within a year of the survey which included the doctor's judgement of whether participants had abnormal ECG waveforms or not.	**Compared to the warm group, the odds ratio of ECG abnormalities** in the slightly cold group was 1.79 (95% CI 1.14, 2.81) and **in the cold group it was 2.18** (95% CI 1.27, 3.75).	Objective ECG data and indoor temp measurements, measured over 2 weeks.	Potential for selection bias due to health check-up items being omitted at doctor's discretion; unable to test association with specific ECG abnormalities e.g. arrythmia; standard ECG provides less information than ambulatory ECG.	Good
Shiue, 2016 [68]	England	Cross-sectional Secondary analysis using data from the Health Survey for England in 2012-2013	7,997 older adults (≥50 yrs) living in private households, 1,301 (16.3%) of which lived in cold homes.	To examine the associations between a cold home (<18 °C) and a series of biomarkers measured in the blood and lung.	Indoor temp measured once in the room BP was taken by survey nurse using a digital thermometer, which was placed on a surface away from a radiator and out of direct sunlight. **The analysis compared cold (<18°C) and warm (≥18 °C) homes.** [Location of measurement and date/time of day not specified].	A series of biomarkers that were measured in the blood and lung, including BP and lung function.	**SBP and DBP was significantly higher for people living in cold homes compared with people living in warmer homes:** SBP was 136.8 vs 133.7 mmHg respectively, (p<0.001) and DBP was 76.8 vs 74.2 mmHg respectively (p<0.001). People in cold homes also had worse hand-grip, lower vitamin D levels, higher cholesterol levels, lower white blood cell count and worse lung conditions.	Very large and representative study sample (countrywide and population-based); analysed the associations between cold indoor temp and wide range of biomarkers measured in the blood and lung in England, UK.	Cross-sectional design and simultaneous measurement of exposure and outcome meant unable to establish causality; single temp measurement; time of measurement not specified; unadjusted bivariate analysis.	Fair

Umishio et al., 2019 [69]	Japan	Cross-sectional	3,514 adults (≥20 yrs) from 2,007 households intending to conduct insulation retrofitting.	To quantify the relationship between HBP and indoor temp.	Living room, bedroom, and changing room temps (indoor temp) and relative humidity were measured at 1.0 m above the floor at 10-min intervals using branded wireless data loggers for 2 weeks over 4 winter periods (Nov-Mar). **Mean morning temp was 14.5°C (range 3.3–25.2°C) and mean evening temp was 17.8°C (range 4.3–27.5°C)**.	HBP measured twice after 1 to 2 minutes resting over period of 2 weeks, at the following times: after getting out of bed in the morning (after urination, before dosing, and before breakfast) and before getting into bed in the evening.	**Morning SBP showed significantly higher sensitivity to changes in indoor temp compared with evening SBP** (8.2 mm Hg increase/10°C decrease vs 6.5 mm Hg increase/10°C decrease), particularly for older residents and women.	Self-measured objective HBP and indoor temp measurements, measured over 2 weeks.	Cannot determine causal directionality from cross-sectional analysis; non-random sample of households which had intention of carrying out insulation retrofitting; no daily survey of clothing.	Fair
Hong et al., 2016 [70]	Taiwan	Cross-over experimental	24 men (23-26 yrs): 12 normotensive and 12 prehypertensive.	To evaluate the effects of cold exposure during sleep transitions on autonomic functioning and MBPS among young pre-hypertensives.	Room temps controlled by central air conditioning and recorded by a heat-sensitive sensor placed on the forehead and extended into the air. Participants were exposed to 2 experimental conditions, sleeping in a sound-attenuated room adjusted to either **24.40 ± 0.78°C (warm condition) or 16.67 ± 0.45°C (cold condition)**, with at least 1 day in between each exposure.	Comparison of the MBPS after morning awakening under the cold and warm conditions between normotensives and pre-hypertensives.	**Significantly higher MBPS in the period of awakening after sleeping in cold conditions for both pre-hypertensives and normotensive,** but higher trends observed for pre-hypertensives.	Participants wore identical clothes for the study.	Small, young male-only sample limits generalisability.	Fair

BP: blood pressure; CI: confidence interval; DBP: diastolic blood pressure; ECG: electrocardiogram; HBP: home blood pressure; OR: odds ratio; PLT: blood platelet count; SBP: systolic blood pressure; MBPS: morning blood pressure surge; Temp: temperature; Yrs: years

Table 7. Respiratory health

Author(s), Year [Ref]	Location	Study Design	Population	Purpose	Exposure	Outcome(s)	Results	Strengths	Limitations	QA Tool rating
Mu et al., 2017 [74]	China	Prospective cohort	82 outpatients with COPD aged 40-85 yrs old.	To examine the relationship between indoor/outdoor temp and humidity on the daily self-reported COPD symptoms.	Bedroom temp and humidity measured using a standard thermo-hygrometer and recorded in diary by participant 3 times/day (8am, 2pm, 8pm) for 18-months. **Average indoor temp ranged between 12.5 ± 2.9°C and 27.1 ± 2.5°C,** and humidity from 50.2 ± 11.2% to 72 ± 13.2%, over study period.	Self-reported COPD symptoms were evaluated and categorised by severity from (5) no symptoms to (1) couldn't tolerate symptoms and had to go to hospital.	Indoor temp was negatively associated with severe symptoms of COPD (OR 0.95, 95% CI 0.94, 0.96). **The threshold for moving from less to more severe symptoms was 18.2°C**. Risk from low indoor temp for COPD patients increased as humidity increased.	Each patient had ≥100 records (a record everyday), which is a large sample size to ensure the accuracy of the study.	Exposure-outcome measured simultaneously so unable to establish causality; indoor temps were recorded by participants and could not be validated; 81% of variations in symptoms was due to baseline health status (influence of environment <19%).	Fair

Ishimaru et al., 2022 [75]	Japan	Prospective cohort	297 children (≤15 yrs) living in 173 households.	To evaluate the relationship between the type of bedroom heater and bedroom temp factors and incidence of common cold among children.	Main types of heating appliances recorded. Night-time bedroom temp measured away from any immediate heating appliances at 15-min intervals using a branded data logger for 3 months (Dec-Feb). **Average time spent <16°C, divided into 3 groups: <30 min/day (least cold); ≥30 min/day and <180min/day; and ≥180min/day (coldest).**	Incidence rates of 5 types of common cold event (catching a cold, having a fever, use of over-the-counter medications for a cold, physician's visit for a cold, absence from school/ nursery owing to a cold) and influenza virus infection.	Air conditioners were the most prevalent (n=105, 35%), followed by gas or kerosene heaters (n=50, 17%), and floor heaters (n=31, 10%). Air conditioners were associated with higher incidence of all events related to the common cold, especially having a fever (aIRR 1.84, 95% CI 1.41, 2.40). **No statistically significant differences in the incidence of common cold in the coldest and least cold night-time temp groups**. Children who always felt cold showed a higher incidence of use of over-the-counter medications and physician visits owing to a cold.	Covid-19 context controlled for variation due to hygiene practices; sample parents were permanently employed with higher salaries than the national median therefore creating more heterogeneity among the sample.	Exposure-outcome measured simultaneously so unable to establish causality; model estimates unadjusted for important confounders including housing characteristics (e.g. insulation) and socioeconomic position; cold symptoms reported by parents could be biased; relatively low response rate (60.7%).	Fair
Quinn et al., 2017 [76]	USA	Cross-sectional	33 households for 1 winter season (>18 yrs) living in apartments or condos (mean age 28.5 yrs).	To explore the relationship between indoor temp and humidity, perceptions of the indoor environment, and self-reported health symptoms (mean age 28.5 yrs).	Indoor temp and relative humidity recorded hourly using 2-4 branded data loggers with at least 1 in living area and 1 in bedroom at a height of approx. 1.5 m, away from windows and heating devices and out of direct sunlight for 5-6 months. Temp and humidity perceptions self-reported approx. every 3 weeks. **Indoor temp ranged from ~1°C to ~38°C** in winter.	Symptoms of respiratory viral infection and sleep quality.	**No significant association was observed between measured** (or perceived) **indoor temp** or humidity levels in winter **and sleep quality or possible or probable viral infection.**		Exposure-outcome measured simultaneously so unable to establish causality; small convenience sample; assumption that perceptions reported 'today' referred to the previous day's temp.	Poor

CI: confidence interval; COPD: chronic obstructive pulmonary disease; OR: odds ratio; Temp: temperature; Yrs: years

Table 8. Sleeping problems

Author(s), Year [Ref]	Location	Study Design	Population	Purpose	Exposure	Outcome(s)	Results	Strengths	Limitations	QA Tool rating
Saeki et al., 2015 [78]	Japan	Prospective cohort	861 home-dwelling men and women (≥60 yrs).	To quantify the association between indoor temp in the evening and sleep onset latency (SOL) during the colder seasons in an elderly population.	Living room and bedroom temps (indoor temp) were measured 60 cm above the floor. Bed temp at centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using branded data loggers over 48-hour period in winter (Oct-Apr). Mean indoor temp measured in the morning (2 hours after getting out bed), evening (2 hours before bedtime) and initial night-time (2 hours after bedtime).	Subjective SOL (sleep diary) and objective SOL (using an actigraph).	A significant inverse association was observed between indoor temp and both subjective and objective measures of SOL. **An increase in evening temp from 10°C to 25°C was associated with an estimated decrease in objective SOL from 16.7 minutes to 12.4 minutes**.	The measurement of indoor temps; assessment of SOL using both objective and subjective methods; similarity in the results for subjective and objective SOL.	Non-random sampling limits the generalisability of study findings; cannot determine causal directionality from cross-sectional analysis; short study duration (2 nights); short time between exposure (2 hours before bedtime) and outcome.	Good
Saeki et al., 2016 [77]	Japan	Prospective cohort	1,065 home-dwelling men and women (≥60 yrs).	To investigate the association between indoor cold exposure and the prevalence of nocturia in an elderly population.	Living room and bedroom temp (indoor temp) were measured 60 cm above the floor. Bed temp at centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using branded data loggers over 48-hour period in winter (Oct-Apr). Mean indoor temp measured based on recordings taken at 10-min intervals. Participants were grouped into **warmer (18.6 ± 2.4°C) or colder (13.2 ± 3.0°C) house groups.**	Nocturia, defined as ≥2 nocturnal voids. Nocturnal urine production rate (mL/h) was also calculated.	**A 1°C decrease in indoor daytime temp was significantly associated with increased likelihood of nocturia**, independent of potential confounders and after adjustment for nocturnal urine production rate (OR 1.10, 95% CI 1.04-1.15). Therefore, a 3°C increase in indoor temp from 15.7°C (mean temp among participants with nocturia) to 18.7°C may be associated with a 25% reduction in the prevalence of nocturia.	Few studies known to have investigated relationship; relatively large sample size; identified a urine volume-independent association between cold exposure and nocturia; analysis adjusted for range of confounders including basic characteristics, comorbidities, medications, and physical activity.	Non-random sampling limits the generalisability of study findings; cannot determine causal directionality from cross-sectional analysis; voiding frequency only measured over 1 night.	Good

CI: confidence interval; OR: odds ratio; SOL: sleep onset latency; Temp: temperature; Yrs: years

Table 9. Physical performance

Author(s), Year [Ref]	Location	Study Design	Population	Purpose	Exposure	Outcome(s)	Results	Strengths	Limitations	QA Tool rating
Lindemann et al., 2014 [79]	Germany	Cross-over experimental	88 community-dwelling older women (≥70 yrs).	To investigate the effect of cold indoor environment on the physical performance of older women, testing the hypothesis that there would be a deterioration in physical performance during exposure to an indoor cold environment.	Participants were exposed to **moderately cold (15°C) and normal/warm (25°C) temp** in a climate chamber 45 min before assessment. Both conditions were assessed in random order with an interval of 1 week. Clothing was standardised. Before and between measurements, the participants were instructed to rest to avoid internal heat production by leg muscle activity.	Primary outcome: muscle power (force × velocity) of lower limbs was assessed using the Nottingham power rig. Secondary outcomes included sit-to-stand performance velocity, walking performance, maximum quadriceps strength and hand-grip strength.	There was a statistically significant **decrease in physical performance in 15°C room compared with 25°C room**, which ranged between 2% and 10% with only hand-grip strength being unaffected by the cold temp.	Relatively large sample; standardised measurement procedures; ecological validity of climate chamber method.	Non-random sampling of older women limits external validity of findings.	Fair
Hayashi et al., 2017 [80]	Japan	Cross-sectional	36 home-dwelling older people (mean age 81 yrs).	To investigate the effect of seasonal temp differences and cold indoor environments in winter on the physical performance of older people living in the community.	Living room, bedroom and dressing room temps were measured at 10-min intervals 1.1 m above the floor using branded data loggers for approx. 2 weeks (in Dec). 28 participants were classified into **the cold group (<18°C) and 8 into the warm group (≥18°C).**	Physical performance assessed when people began using rehabilitation facility and repeated every 3 months. Assessed items were grip strength, static postural and balance control assessed by single-leg standing time, and balance and gait function.	The results from grip strength and single-leg standing tests showed physical performance was worse in the winter compared to the autumn, and **people living in cold houses had worse grip strength in the right hand.**	No differences in individual attributes between people living in cold houses and warm houses; study may serve as a feasibility study.	Small, convenience sample prevents findings from being generalised; outcome assessed in rehabilitation facility and not in participants' homes.	Fair

Temp: temperature; Yrs: years

Table 10. General self-rated health

Author(s), Year [Ref]	Location	Study Design	Population	Purpose	Exposure	Outcome(s)	Results	Strengths	Limitations	QA Tool rating
Hughes and Natarajan, 2019 [81]	England	Qualitative	6 women and 1 man (≥66 yrs).	To investigate the strategies older people use to stay warm in winter; how these were influenced by attitudes, opinions, and everyday practices; and what prevented the participants from achieving comfort.	Living room, bedroom and living-room radiator temps were measured at 90-min intervals using sensors in 43 participant homes over winter (Nov-Mar 2016-17). 7 participants were then recruited from 11 homes with **median temp <18°C** (Mar 2018). [Location of measurement not specified].	Perceived impact of cold on physical health. Other areas of exploration included whether and how participants achieve suitable internal temps and how they achieve comfort in their homes.	Most participants felt the cold more than when they were younger. **Participants reported a range of chronic health problems, including osteoarthritis and asthma, which appeared to worsen in the cold.** Conducting exercise or movement to stay warm was not particularly common.	Explored how behaviour (mentality and habits) may affect thermal comfort and health; showed that older people are not as opposed to energy efficiency measures as the literature suggests.	Small, convenience sample; no objective indicators of health status; qualitative nature means causality cannot be inferred.	N/A
Sutton-Klein et al., 2021 [82]	England	Cross-sectional. Secondary analysis using data from the Health Survey for England 2014	74,736 adults (≥16 yrs) living in England.	To investigate the relationship between indoor temp and general health.	Indoor temp measured once by survey nurse using a digital thermometer, which was placed on a surface away from a radiator and out of direct sunlight. **Indoor temp ranged from 7.5°C to 36.8°C, with a mean of 20.7°C (standard deviation 2.3).** [Location of measurement and date/time of day not specified].	Self-rated general health was based on responses to the question 'How is your health in general?', to provide a binary final outcome variable: good health (including very good and good responses) or poor health (including fair, bad and very bad).	**Each 1°C increase in indoor temp was associated with a 1.7% higher likelihood of poor self-rated health** (95% CI 0.7% to 2.6%) after adjusting for potential confounders.	Large, nationally representative, random sample of the non-institutionalised, adult population living in England.	Simultaneous measurement of exposure and outcome means no evidence on causal relationship; single temp measurement; time of measurement not specified.	Fair
Hansen et al., 2022 [83]	South Australia	Cross-sectional	71 independently living older people (aged 61–98 yrs) participated in the home monitoring stage of this research.	To determine links between the indoor thermal environment of housing and self-reported health and well-being in older people.	Main living room air temp, globe temp, relative humidity and air movement measured at 30-min intervals using a data logger placed on a table or sideboard at approx. 80–100 cm above the floor away from any radiation source (e.g. windows), and near where the participant would normally answer the survey. Main bedroom air and globe temps and relative humidity were measured using data loggers placed next to the bed, away from any heat source. **Average indoor temp ranged from 11°C to 32.7°C,** over 9-month study period (Jan-Oct).	Self-rated health and well-being.	Approximately two-thirds of participants reported "definitely yes" or "probably yes" to a **negative influence of temp on health and well-being at room temps below about 15°C**.	Fit-for-purpose measurement equipment.	Small, non-random sample limits generalisability of findings; self-reported health effects.	Fair

CI: confidence interval; OR: odds ratio; Temp: temperature; Yrs: years.

4. Discussion

4.1. Synthesis of findings

This review presents the evidence from a systematic literature review on the associations between cold home temperatures and health and well-being. Findings suggest cold exposure may adversely affect a wide range of health outcomes, with 17 of the 20 reviewed studies finding indoor cold exposure was associated with negative effects on health measures.

Blood pressure, the most studied outcome measure, increased as indoor temperatures decreased.

Study results consistently showed a decrease in indoor temperature was associated with a corresponding increase in systolic and diastolic blood pressure [64,66,68–70] even when taking into account other confounders such as physical activity and medical history. Studies measured a physiological increase of 2.2 mmHg [64], 4.8 mmHg [66], and 8.2 mmHg [69] in systolic blood pressure per 10°C decrease in temperature. The potential health impacts of such changes to blood pressure require more research, including the association of indoor temperature with cardiovascular disease risk. High blood pressure is the predominant modifiable risk factor for cardiovascular disease, which remains a leading cause of death and disability in the UK [84,85]. In this review, indoor cold exposure (10.1 ± 2.3°C) was also linked with higher salt intake [71], which is independently associated with higher blood pressure, highlighting a potential causal pathway through which cold indoor temperature could influence blood pressure.

Evidence from two good quality intervention studies – one providing occupiers with heating instruction (influencing occupier behaviour); the other providing additional insulation to the fabric of the dwelling (a dwelling intervention) – also suggests that schemes which achieve increased indoor temperatures can lower blood pressure [65,67], although the duration of these effects is not known. These findings are consistent with those in a previous systematic literature review, which found lower blood pressure, among a homogenous population living in blocks of flats, following energy efficiency housing improvements [8]. These studies also focussed on physiological changes, however, the impact of these changes on health were not explored. It is important to note that the current review has focused on the temperatures and associated health aspects of the intervention studies and not the type or extent of the intervention. Improperly installed insulation can interfere with ventilation, humidity and air quality, with possible implications for health, and therefore findings should be interpreted with caution.

In addition, several studies presented the impacts of indoor cold temperature on non-blood pressure risk factors and biomarkers. The first showed that indoor cold exposure (<12°C) was associated with increased electrocardiogram (also known as ECG) abnormalities [72], a known predictor of increased risk of cardiovascular disease [86,87]. The second found that blood platelet count was significantly higher among people living in the coldest homes (<14.4°C) compared with those residing in the intermediate (14.4-17.9°C) and warmest homes (>17.9°C) [73]. Although the changes observed in blood platelet count may not be clinically significant for an individual person, findings from large population-based cohort studies highlight the positive correlation between blood platelet count and cardiovascular risk [88,89].

The evidence summarised in this review also showed the effects of cold homes on sleeping and physical performance.

In older adults, findings suggest that cold exposure can increase sleep problems [78], as well as the incidence of conditions like nocturia associated sleep disturbance [77]. These observations were recorded in bedroom temperatures of 10°C and 13.2 ± 3.0°C, considerably lower than the recommended minimum temperature of 18°C. Sleep is a well-known determinant of health, well-being and quality of life. As such, insufficient or poor-quality sleep is a serious public health issue and has been linked to many chronic diseases and conditions such as type 2 diabetes, cardiovascular disease, obesity, and depression [90–92]. The prevalence of sleep disturbing problems such as nocturia appear to increase with age [93]. However, the majority of sleep complaints in older people reflect comorbid physical and mental health conditions [94]. Therefore, the impacts of cold exposure on sleep in older people living with comorbidities need to be further explored. In a general adult population, study findings showed no association between cold indoor temperatures and self-reported sleep problems, although the quality of this evidence was rated poor [76]. Nevertheless, for healthy child and adult populations, cooler bedroom temperatures (i.e. 18°C or slightly cooler) may be preferable for better sleep and evidence has shown that good quality sleep and comfort can be achieved at lower temperatures with the use of appropriate bedding [95,96].

Physical performance can decrease following cold exposure [68,79,80]. Physical performance is another important determinant of quality of life, particularly for older people [97]. Prolonged exposure to cold indoor temperatures may decrease grip strength, which for older frail people can increase the risk for future cognitive deterioration, disability, hospitalization, and all-cause mortality [98,99]. Warmer indoor temperatures may help to prevent these negative health outcomes. However, as limited evidence was identified in this review, with two studies conducting their physical performance measures outside of the home (laboratory and rehabilitation centre), further research should explore the impact of indoor cold exposure on physical performance within participant homes.

This review further highlights the vulnerability of older people to cold home temperatures, which may increase their risk of developing and exacerbating a wide range of health conditions.

Findings from this review show consistent evidence that cold indoor temperatures can increase blood pressure, a modifiable risk factor for cardiovascular disease (see above in section 4.1). Evidence has linked cold indoor temperature (i.e. below 18°C) with increased risk of cardiovascular disease, to which elderly populations are particularly susceptible [100]. One study in this review showed higher blood pressure sensitivity to cold indoor temperature exposure in older adults and women, than in younger adults or men [69]. A possible explanation is that older adults and women have less muscle mass than younger adults and men, which results in less metabolic heat production and vulnerability to cold [69]. Nevertheless, previous research found older women were able to control their body temperature better than selected groups (older men and younger men and women), due to metabolic advantages and body fat [38]. An additional concern for older adults is that they are less likely to feel the cold and thus may not adapt their behaviour accordingly, such as adding layers of clothes [69]. The likelihood of sleep problems and poor physical performance is also more common in older people (see above in section 4.1) [93,97]. Understanding of vulnerabilities within subpopulations of older people will be crucial for the effective targeting of interventions to improve housing and health.

Only a relatively small number of studies examined the effects on respiratory health and general self-rated health, and the evidence was mixed.

For adults with COPD, study findings suggest an increased risk of severe symptoms as a consequence of cold exposure within homes at or below 18.2°C [74]. This is consistent with the 2014 systematic literature review conducted by PHE which identified better respiratory symptom scores among older adults (65+ years) with COPD who spent more days with living room temperatures at or above 21°C (+9 hours) [7]. Yet two studies identified in the current review found no link between cold indoor temperatures and symptoms of viral infection in either child or adult populations [75,76], although the quality of this evidence was rated as fair and poor, suggesting the merit of further research in this area.

There was also mixed evidence for the associations of cold indoor temperatures and impacts on general self-rated health. Two studies in this review connected cold exposure with the perception of deteriorating health [81,83]. In contrast, another study identified in this review observed a small but significant association between each 1°C increase in indoor temperature (between temperatures of 7.5°C and 36.8°C) and poor self-rated health [82]. There are several possible explanations for this, including the paradoxical findings of one study which showed that, in winter, inadequate housing may result in the indoor thermal environment being either too cold or too warm and that both conditions could cause adverse health effects [101]. Additionally, people with worse self-rated health may have chosen or been advised to maintain warmer temperatures [82]. More research on cold indoor temperatures and self-rated health is required.

4.2. Interpretation of findings in relation to existing knowledge

This review aimed to summarise the evidence base on the association between cold homes and health and well-being. The evidence of risk to cardiovascular health posed by living in cold indoor conditions is not only consistent with, but builds on, the evidence synthesised in 2014 by PHE, with a wider range of cardiovascular outcomes examined, including blood pressure, nocturnal urinary sodium excretion, electrocardiogram (also known as ECG) abnormalities and blood platelet count. Evidence from the 2014 review suggested that cold homes were associated with decreased thermal comfort and respiratory health but found conflicting findings regarding changes to BMI. This review adds evidence relating to other health outcomes including the negative impact of cold exposure on sleep and physical performance, and mixed findings for general health.

To date, studies exploring the impacts of cold homes have predominantly focussed on older adult populations; this is possibly due to the known vulnerability of older adults to colder temperatures and because certain cold related conditions are more apparent in older adults (e.g. nocturia). A limited number of studies have explored the impact of cold homes on individuals with chronic health problems (n=3). Yet, results from these studies suggest heightened vulnerability to cold exposure for older people with COPD [25,74] and for young people with pre-hypertension [70]. Due to the limited number of studies in this population group, more research is needed to understand the impact of specific temperatures on people with different existing health conditions.

The review also identified that a limited number of studies (n=4) have also been conducted with children. Studies in children reported no association between bedroom temperature and respiratory infection [75], however, temperatures below 12°C were shown to have the greatest negative effect on lung function of children with diagnosed asthma [32]. The lack of studies conducted with children warrants further investigation, particularly into respiratory disease which accounts for the majority of excess winter health burden in children [6].

All the studies conducted to date (as identified in this review and the 2014 review) have focused on how cold temperatures within homes are associated with physical health outcomes. In contrast, there remains significant gaps in the literature relating to mental health and well-being outcomes. Research has shown a positive effect on psychological, social and financial well-being from energy efficiency improvements [102–104]. However, more research on the mental health and well-being of people living in cold homes would help to address this identified gap.

4.3. Implications for satisfactory heating regime guidelines

More than half (n=11) of studies included in this review found indoor cold exposure below 18°C associated with negative effects on health measures [68,70–75,77–80,83]; 18°C being the minimum temperature to which the WHO and UK authorities currently recommend the general population heat their homes [6,7,12,13]. Of these, eight studies explored the effects of indoor temperatures at 15°C or less [69,71–73,77–79,83]. In addition, some (n=3) studies linked better health outcomes with indoor home temperatures higher than 23°C (the threshold currently recommended for older people in Wales and Scotland), when compared to temperatures below 18°C (10°C; 15°C; 16.67 ± 0.45°C) [70,78,79]. One study found that for each 1°C increase in indoor temperature (between temperatures of 7.5°C and 36.8°C) the likelihood of poor self-rated health increased by 1.7% after adjusting for household factors [82]. However, it was unclear why people with worse self-rated health maintained higher indoor temperatures and several reasons were speculated including personal preferences and behaviours; advice from professionals to maintain a warmer home to protect health; and difference in tenure type (such as social housing compared to privately rented) [82].

Public health advice on minimum home temperatures may help mitigate serious health risks associated with indoor cold exposure, especially in vulnerable populations such as older adults. The only randomised controlled trial in this review found that an instruction for older adults to heat their living room to 24°C one hour before rising, increased living room temperatures on average by 2.1°C (from 14.1°C to 16.2°C), significantly reduced SBP and DBP four hours after rising [65]. Despite not achieving 24°C, the instruction to heat homes significantly reduced blood pressure [65]; suggesting that temperature recommendations may help to improve health in target populations who may be more at risk to poor outcomes. Alternative interventions such as thermal insulation for dwelling improvement, which have shown similar improvements to morning blood pressure [67], may also be worth considering. Nevertheless, further understanding of the impact of the rising cost of living including the increased cost of energy is recommended in addition to dwelling improvements, due to links to fuel poverty.

The evidence summarised in this review is from a relatively small number of methodologically heterogeneous studies which is not sufficient or strong enough to draw specific conclusions or recommend changes to the current advice on satisfactory heating regime guidelines for households in Wales. In addition, when setting temperature recommendations for residential properties, several other important caveats exist:

1. There is limited consideration of behavioural factors in the identified literature. Only one study identified in this review observed changes in occupant behaviour in response to cold indoor temperatures – for example, making appropriate clothing adjustments [81]. Such behaviours could confound associations between indoor cold exposure and health.

2. Although results from most studies linked conditions at or above 18°C with better health outcomes, one study compared temperatures below 18°C (14.35-17.92°C) with temperatures above 18°C, which were associated with only marginally poorer outcomes in the blood platelet count of elderly individuals [73]; another study noted the worsening of COPD symptoms at temperatures below 18.2°C [74]. These findings suggest that a “healthy” temperature range might include temperatures slightly above and below the 18°C threshold.

3. There is a lack of high-quality evidence from dwelling intervention studies due to the complexity in their design and difficulty securing funding. A 2008 randomised-controlled trial in New Zealand found that after increasing the heater capacity in pre-1980s houses with similar insulation levels, individuals experienced significantly higher indoor temperatures (compared to a control group; 17.8°C vs. 15.1°C in the living room; 16.3°C vs. 14.2°C in the bedroom) [105]. Much of the current evidence base relies on less robust study designs e.g. cross-sectional and cohort studies which also prevent causality from being examined.

4. There is currently a lack of an internationally recognised temperature measurement regime. Measuring temperature in the indoor environment, particularly in the home, can be problematic due to several factors including location of temperature measurement, temperature gradients (both horizontal and vertical), frequency of recordings, temperatures at different times of year or day, domestic activities, orientation of dwelling (e.g. north or south facing), outdoor ambient temperature and weather conditions (e.g. wind direction, sunny/raining/snowing).

5. Advice on home temperature recommendations should be balanced with the need to reduce household emissions to meet ambitious UK and global climate goals. On the one hand, home energy efficiency interventions designed to improve housing and health (e.g. general health, respiratory health, and mental health) contribute to carbon reduction targets, although substantial investment in larger-scale changes to the housing stock may be necessary to realise net zero (see Box 4) [106]. On the other hand, for energy inefficient dwellings, heating homes to higher temperatures increases emissions and the risks from long-term health effects of climate change. In addition, if heating is applied without sufficient ventilation this can exacerbate respiratory ill-health [107]. Therefore, it is important to consider the possible impact on factors such as indoor air quality.

6. This systematic literature review focussed primarily on the association between cold homes and health and well-being and excluded studies relating to maximum indoor temperature thresholds, which is also an important factor for household occupant health and an important area for consideration particularly in view of climate change.

7. Setting minimum temperature recommendations may be ineffective if households are unable to reach such targets due to financial constraints and behavioural adaptations; this may particularly be the case given increasing fuel poverty, costs of living and energy prices (see Box 4).

8. Temperature recommendations need to be considered in the context of other factors, including household occupants. For example, the Lullaby Trust [108] recommend infants sleep in a room temperature of 16-20°C to reduce the risk of overheating, which is a risk factor for sudden infant death syndrome (SIDS).

Box 4. What do these findings mean for Wales and what are the evidence gaps?

Ageing population – Older people have been identified as especially vulnerable to the impacts of living in colder homes. Compared to other UK nations, Wales has an ageing population, with approximately 21% of the total population aged over 65 years, a figure that is expected to continue rising [121]. Therefore, further research on this age group is important to improve population health outcomes.

Rising cost of living and fuel poverty rates – Given the gaps in the current literature relating to fuel poverty, and rising fuel poverty rates (estimated to be as high as 45% of the population; see context in Wales on page 14), it would be beneficial for research in Wales to understand how financial pressures impact energy use, particularly the temperatures to which people heat their homes.

Climate change – Wales has a 'Net Zero' target for reducing carbon emissions by 2050 In line with the Well-being of Future Generations (Wales) Act (2015) [60]. While changing behaviours may help to reduce fuel consumption, the renovation of old housing stock to include efficient and effective heating, insulation and controllable ventilation, is vital to improve household thermal efficiency and reduce carbon emissions [6]. For new (yet to be built) housing, an urgent review of planning and building control legislation and requirements is required that considers the orientation of dwellings [19], and the levels of insulation needed for the weather patterns and climate predicted for the next thirty years. Further research is needed to understand people's perceived concerns, impacts and actions relating to climate change.

4.4 Gaps in the recent evidence (2014-2022)

This review identified no evidence on:

- Studies exploring the association of low indoor temperatures and mental health and well-being outcomes.
- Studies looking at the relationship between cold homes and frailty: Alzheimer's disease, falls, hospital admissions, time spent in recovery, etc. Most existing evidence links frailty to excess winter deaths rather than cold homes specifically.
- Studies exploring the long-term health and well-being effects of exposure to low indoor temperatures, nor the duration of exposure that leads to illness.

This review identified limited evidence for:

- Studies involving children. Studies in this population also found mixed results.
- Studies exploring health outcomes in terms of wider contextual factors such as fuel poverty or poor quality housing (e.g. dwellings in the UK that contain a Category 1 Hazard under the Housing Health and Safety Rating System [108]), which may serve to exacerbate the effects of cold indoor temperature on health and well-being.
- Specific temperature thresholds for overall health and well-being in different populations. Within the current review, temperatures people were exposed to, or thresholds studied, varied considerably between studies.

4.5 Strengths and limitations of the review

There are several strengths to this review. The systematic approach adopted included a wide range of search terms and was conducted across a variety of databases. Two reviewers independently decided on study inclusion with conflict resolution, minimising risk of bias and error. All included studies were required to record temperatures using an objective measure, limiting the bias of perceived temperatures. This review also widened the inclusion criteria from the 2014 systematic literature review undertaken by PHE by including social outcomes, studies using secondary data and intervention studies, and used a more targeted search, with advice from an expert in research methods, to help identify relevant studies whilst reducing the number of irrelevant studies.

However, several limitations of the review should be acknowledged. This review was conducted systematically but under time constraints. Therefore, a limited number of databases (n=7) were searched, and some papers may have been missed due to the search strategy. However, the strategy was based on those utilised in previous reviews. The present review was restricted to studies published in English, which may have led to the exclusion of studies contributing to the evidence base. However, such studies may not have been conducted in countries with comparable climates to the UK. This review also excluded studies that did not record temperatures, therefore studies measuring other relevant outcomes may have been excluded and purely qualitative studies were also excluded. There are a number of limitations across the studies identified in this review, mostly relating to study design which are presented in Table 6-10 and Section 3.6.

5. Recommendations for future research

On the basis of this review, it is recommended that future research should seek to:

Develop evidence to help define specific household temperature threshold recommendations for health.

The current review adds to the evidence base on the relationship between cold homes and poorer health. However, evidence to base temperature threshold recommendations is somewhat limited due to the vast array of temperatures investigated. Therefore, further research is needed that can evidence health and well-being outcomes at specific temperatures to help guide policy and best practice.

Combine temperature measurements with qualitative insights researching the impacts of cold indoor temperatures.

Research is needed that combines objective temperature measurements and qualitative research (such as interviews) to gain in-depth insights into people's lived experiences of living in cold homes. Further understanding is also needed of the factors that may place people at risk of living in cold homes and what the impacts of these are on household health and well-being.

Develop a greater understanding of the mental health and well-being impacts of living in cold homes.

There are significant gaps in the literature relating to the impact of cold indoor temperatures on mental health and well-being, with a need for further research using validated tools. The limited available evidence suggests that interventions to improve the warmth and energy efficiency of homes can positively affect mental health and anxiety levels and social outcomes including isolation and loneliness, and that indoor cold exposure can exacerbate existing mental health problems and increase the risk of developing a range of mental health problems.

Explore the concept of thermal comfort, including occupant behaviours, and whether it is linked to health and well-being.

A person's sensation of satisfaction with the ambient temperature, which is inextricably linked to health, is defined as thermal comfort, which has been suggested as an important factor in mental health, well-being and social outcomes. In cold environments, thermal comfort can be achieved by a source of heat but also occupant behaviour such as altering activity levels and clothing worn. The number of studies exploring this topic is limited, and further research is needed that explores thermal comfort alongside physical and mental health and well-being outcomes.

Continue to conduct research in subpopulations identified as especially vulnerable to cold indoor temperatures.

Older people and those living with certain chronic health conditions such as COPD have been identified as vulnerable to indoor cold exposure (see Section 4.1). However, evidence gaps remain within these subpopulations such as the links between cold homes, frailty, and injury. In addition, significant gaps relating to other population groups such as children or those living in fuel poverty also exist.

Explore housing warmth in the context of wider issues such as the rising cost of living and fuel poverty, remote working and climate change.

There are a number of challenges facing Wales, such as climate change, rising fuel poverty and increased cost of living, decreasing affordability of good quality housing, and remote working following the COVID-19 pandemic. These factors all play a role in determining whether a home will be kept adequately warm. Further research on this topic would benefit from taking a more holistic approach, acknowledging the broader determinants of health and multiple socio-ecological influences including individual, social and environmental factors.

Explore the long-term effects of exposure to low indoor temperatures on health and well-being and the duration of exposure that leads to illness.

To date, most of the identified studies have been observational cohort or cross-sectional studies which have several limitations (see 3.6 Limitations within studies). Longitudinal studies would build on existing evidence and may increase understanding of cause and effect relationships.

6. Conclusion

This review aimed to build upon and extend the knowledge presented in a previous systematic literature review published by PHE in 2014, by identifying and appraising evidence on the association between cold home temperatures and health and well-being. The evidence identified here shows indoor cold exposure can negatively impact a wide range of health measures including those related to cardiovascular and respiratory health, sleep, physical performance and general health. It provides a greater understanding of the association between indoor cold exposure and cardiovascular health such as a potential pathway to cardiovascular disease, specifically risk factors including increased blood pressure and electrocardiogram (also known as ECG) abnormalities. Nevertheless, the observed physiological changes in blood pressure varied between studies. The potential health impacts of such changes require more research, including the association of indoor temperature with cardiovascular disease risk.

For some of the health conditions studied, such as nocturia, findings also highlight the vulnerability of older people as these conditions are most prevalent in older age groups. In addition, impacts such as increasing blood pressure from cold exposure appear to be more severe in older adults compared to younger adults. People with chronic health problems are also adversely affected, for example, patients with COPD reported increased severity of symptoms when exposed to home temperatures at or below 18.2°C. However, due to a limited number of studies, more research is needed to understand what specific temperatures may be protective for people with different conditions. For healthy adult and child populations, there was no significant relationship between cold exposure and symptoms of viral infection.

More than half of the studies identified in the review investigated health effects at or below a specified temperature threshold under 18°C, however, these included a range of studied temperatures from 10°C to 17.9°C. This suggests that the minimum temperature of 18°C to which the WHO and UK authorities currently recommend the general population heat their homes is safe for health. Due to study heterogeneity (methods, populations, exposure and outcome measures), there is currently insufficiently strong evidence to draw firm conclusions on satisfactory heating regime guidelines, although there is consistent evidence of potential health harms at temperatures below 18°C, with further research needed in several areas.

Research gaps identified in this review and opportunities for future research have been discussed (see Sections 4.4 and 5). The current lack of high-quality research on the topic of cold homes and its health and well-being impacts highlights a need for more investment and support for robust study designs. Some important areas for further research to help determine the appropriateness of a satisfactory heating regime in Wales include:

- The impact of cold indoor temperatures on mental health and well-being; isolation and loneliness; and the wider determinants of health, such as educational attainment;
- Specific temperature thresholds at which health effects start;
- The influence of contextual factors such as the rising cost of living and fuel poverty, remote working, climate change, and temperatures achieved by households.

Overall, this review has built on and extended previous research relating to cold indoor temperatures and health by bringing together the findings of multiple studies and has helped to set the scene for further work in this area.

7. References

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8. Glossary

Term	Definition
Cold home	Homes not meeting the recommended minimum indoor temperature of 18°C set out by the World Health Organization (WHO) in 1987 [17]
COVID-19	Coronavirus disease is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and has resulted in an ongoing global pandemic since 2020 [110]
Excess winter deaths	The number of deaths that occur in winter (Dec-Mar) compared with the average number of deaths occurring in the preceding Aug-Nov and the following Apr-Jul [4]
Gross disposable household income	The amount of money that individuals in the household sector can spend or save after income distribution measures [111]
Dwelling	The physical structure of the building e.g. house or flat [112]
Fuel poverty	Most widely defined according to Brenda Boardman's definition as a household that is unable to obtain an adequate level of energy services, particularly warmth, for 10% of their income [48] In Wales, fuel poverty is defined as households needing to spend more than 10% of their income on maintaining a satisfactory heating regime (Table 1, page 7) [12] In England, fuel poverty is measured using the Low Income Low Energy Efficiency (LILEE) indicator. A household is defined as fuel poor if (a) they are living in a property with a fuel poverty energy efficiency rating of Band D or below; and (b) when they spend the required amount to heat their home, they are left with a residual income below the poverty line [11]
Health	Health, as defined by WHO, is "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." [113]
Home	The social, cultural and economic structure established by the occupier(s) [112]
Humidity	The moisture content of the air [114]
Lower income household	One whose income is less than 60% of the median UK household income before housing costs as published annually in the Households below average income report [54]
Nocturia	Needing to wake up more than once during the night to urinate
Sleep onset latency	The time it takes to fall asleep after turning the lights off
Thermal comfort	A sensation of satisfaction with the ambient temperature, which is inextricably linked to health [19]

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