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Review Paper

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

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ABSTRACT

Objective: The study aimed to identify, appraise and update evidence on the association between cold temperatures (i.e. <18°C) within homes (i.e. dwellings) and health and well-being outcomes.
Study design: This study was a systematic review.
Methods: Seven databases (MEDLINE, Embase, Cochrane Database of Systematic Reviews, CINAHL, APA PsycInfo, Applied Social Sciences Index and Abstracts, Coronavirus Research Database) were searched for studies published between 2014 and 2022, which explored the association between cold indoor temperatures and health and well-being outcomes. Studies were limited to those conducted in temperate and colder climates due to the increased risk of morbidity and mortality during winter in those climatic zones. Studies were independently quality assessed using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.
Results: Of 1209 studies, 20 were included for review. Study outcomes included cardiovascular (blood pressure, electrocardiogram abnormalities, blood platelet count), respiratory (chronic obstructive pulmonary disease symptoms, respiratory viral infection), sleep, physical performance and general health. Seventeen studies found exposure to cold indoor temperatures was associated with negative effects on health outcomes studied. Older individuals and those with chronic health problems were found to be more vulnerable to negative health outcomes.
Conclusion: Evidence suggests that indoor temperatures <18°C are associated with negative health effects. However, the evidence is insufficient to allow clear conclusions regarding outcomes from specific temperature thresholds for different population groups. Significant gaps in the current evidence base are identified, including research on the impacts of cold indoor temperatures on mental health and well-being, studies involving young children, and the long-term health effects of cold indoor temperatures.

Introduction

Indoor cold exposure, cold conditions, and cold housing are common terminology used to describe cold indoor temperatures in homes (i.e. dwellings). In the present review, the terminology 'cold indoor temperatures' has been used for consistency hereafter. International evidence suggests that living in a cold home (i.e. dwelling) may contribute to a range of negative health outcomes,[1–3] including poor respiratory[3–6] and cardiovascular health,[3,7] mental illness (e.g. depression and anxiety),[2] loneliness, and social isolation[8,9] and a greater prevalence of falls.[8] Certain population groups (e.g. those of young and old age or individuals living with long-term health conditions or disability) are thought to be especially vulnerable to experiencing such outcomes.[6]

A 2016 systematic review of the impacts of cold indoor temperatures on health identified 20 studies (covering 1973 to 2014) and found negative outcomes to cardiovascular and respiratory health and to thermal comfort.[3] It also found strong evidence that homes below 18°C had a harmful effect on health but insufficient evidence to support a previously recommended minimum threshold of 21°C in living rooms.[3,10] Accordingly, and due to the wider health and well-being impacts associated with fuel poverty and the increased carbon emissions from heating homes to higher

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temperatures, the review concluded that a minimum indoor temperature of 18°C was appropriate.

Since publication of the systematic review in 2016, the UK Health Security Agency recommends a single minimum indoor temperature of 18°C.[3,11] Similarly, the World Health Organization recommends a minimum indoor temperature of 18°C for general populations during cold seasons in temperate and colder climates, but that a higher minimum temperature may be necessary for vulnerable groups, including children, the elderly and those with chronic illness.[12–14] Despite minimum indoor temperature recommendations for homes being largely consistent, the 2016 review acknowledged the need for further research to understand the relationship between behaviour, vulnerability to cold and potential risks to health in both the short term and long term.[3] To address this gap, this review aimed to identify evidence on the association between cold indoor temperatures and health and well-being published since the studies identified in the 2016 systematic review,[3] with the review expanded to include social outcomes, studies using secondary data and intervention studies.

Rising global energy prices since the latter half of 2021 have negatively affected the affordability of heating a home and have increased levels of fuel poverty, exposing more people to cold indoor temperatures.[15–17] The rising cost of energy and fuel poverty, alongside recovery from the COVID-19 pandemic and heightened awareness of climate change are all factors that may influence a household's vulnerability to living in a cold home. These current challenges exacerbate the need to further understand the impact of cold indoor temperatures on health and well-being and to help determine if temperature recommendations for homes are appropriate and, if so, at what threshold.

As such, the present review aimed to identify, appraise and update the evidence on the association between cold indoor temperatures (i.e. <18°C) and health and well-being.

Methods

Search strategy and selection criteria

Seven electronic databases (APA PsycInfo, Applied Social Sciences Index and Abstracts, Cochrane Database of Systematic Reviews, the Coronavirus Research Database, Cumulative Index to Nursing and Allied Health, Embase and MEDLINE) were searched for studies published between 1 February 2014 and 17 February 2022, which explored associations between cold indoor temperatures and health and well-being. Search terms are presented in Table 1. The search strategy expanded on that used in a previous systematic review[3] to include social outcomes, secondary data analysis and intervention studies. Database searches were supplemented through manual searching and expert consultation. Included studies met the following criteria: human subjects of all ages, measurement of specific temperatures or thresholds or energy efficiency measures/interventions (e.g. insulation or heating systems), all health and well-being outcomes, including social effects (e.g. loneliness and isolation) except sport and exercise performance, and published in the English language. Evidence synthesis (e.g. systematic review, meta-analysis), commentary/editorial, ideas and opinion pieces, studies in tropical, subtropical or arctic climates, and studies using extreme cold exposure (<5°C), overheating or outdoor temperatures were excluded. After the removal of duplicates, two reviewers (H.J. and B.G.) retrieved and independently screened titles and abstracts, then full text articles, with conflicts over inclusion resolved through discussion.

Table 1
The search terms and Boolean operators used.

Search	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

Data analysis

Included articles were independently assessed by two reviewers (H.J. and B.G.) for quality and risk of bias (good, fair, poor) using the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.[18] For each article, data were extracted for country, study design, population, purpose, exposure, outcome(s), results, strengths, and limitations, with data extraction checked (M.R.). Due to heterogeneity in study methodology, population, and outcomes, data were narratively synthesised.

Results

From 1210 references identified through searching, full text copies of 42 studies were obtained and screened, of which 20 studies were included (Fig. 1). Of these, cardiovascular, respiratory, sleep, physical performance and general health outcomes were measured (shown in Table 2). Most studies ($n = 11$) were conducted in older adult populations with varying age ranges (older age was commonly defined in the studies as aged >60 years), eight were in general adults, one in younger adults (23–26 years) and one in children (≤15 years; Table 3). Eleven studies were conducted in Japan,[19–29] four in England,[30–33] and one study each in China,[34] Germany,[35] Taiwan,[36] the United States[37] and Australia.[38] Study quality was rated (see methods) as predominantly fair ($n = 10$) or good ($n = 9$), with only one study rated as poor.[37]

The majority of studies ($n = 18$) recorded temperature inside rooms in participants' homes. Two studies were conducted in laboratory settings under thermal test conditions.[35,36] Most household studies used branded data logger devices to automatically record temperature and humidity ($n = 12$), installed at prescriptive positions (60–110 cm off the floor and away from heat sources). However, the timing of temperature measurement varied across studies (from every 10 min [$n = 10$] to a single time point [$n = 3$]). Most studies ($n = 14$) also collected outdoor temperatures.

Cold temperature thresholds varied across studies, with more than half ($n = 11$) investigating the health effects of a specified indoor temperature at or below 18°C (range 10°C–17.9°C).[19,22,23,26–29,31,34–36,38] In nine studies, analysis drew on a comparison with warmer indoor temperatures.

Cardiovascular health (n = 10)

Half of the included studies (n = 10) explored the impacts of cold indoor temperatures on cardiovascular health, although populations varied across studies (Tables 3 and 4). Four observational studies[20,25,30,31] and two intervention studies[21,24] examined the effects on blood pressure, reporting significant associations between lower indoor temperatures and higher blood pressure. In

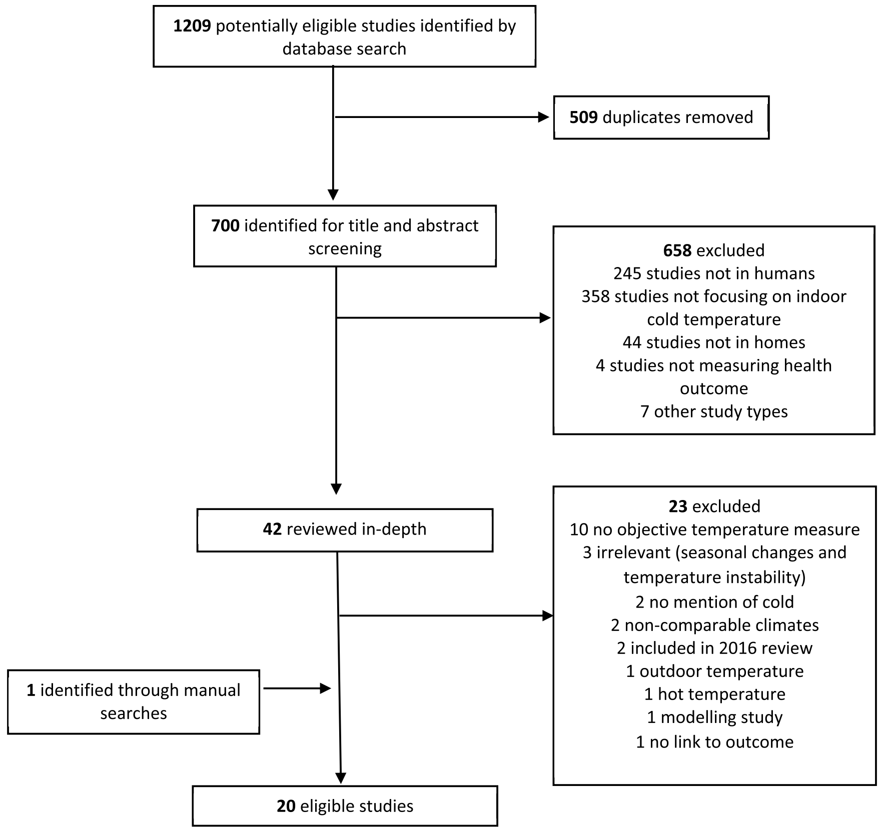

Fig. 1. Study selection flowchart.

Table 2
Outcomes measured in included studies.

Health category	Number of studies	Outcome explored
Cardiovascular	10	Blood pressure,[20,21,24,25,30,31,36] salt intake (linked to blood pressure),[22] electrocardiogram (also known as ECG) abnormalities[29] and blood platelet count[23]
Respiratory	3	Chronic obstructive pulmonary disease symptoms[34] and respiratory viral infection[19,37]
Sleep	2	Nocturia*[27] and sleep onset latency**[26]
Physical performance	2	Physical performance[35] and handgrip strength[28]
General health	3	Perceived impact of cold on health[32] and self-rated health[33,38]

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

observational studies, changes in blood pressure varied, with increases in systolic blood pressure of 2.2 mm Hg,[20] 4.8 mm Hg,[30] and 8.2 mm Hg[25] recorded per 10°C decrease in temperature. One cross-sectional study explored the differential impacts of cold indoor temperatures by sex and age, finding that older adults and women may be more vulnerable to cold temperature–associated increases in blood pressure than younger adults or men.[25] An experiment investigating overnight temperature exposure under controlled conditions showed that when compared to overnight warmth (24.40 ± 0.78°C), exposure to cold (16.67 ± 0.45°C) increased morning blood pressure in young men with prehypertension.[36]

A cross-sectional study exploring the potential pathways for the effects of cold indoor temperatures on blood pressure 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) and was associated with higher night-time ambulatory blood pressure.[22] Furthermore, two cross-sectional studies showed that cold indoor temperatures <15°C (<14.4°C and <12°C) were associated with higher blood platelet count and increased electrocardiogram abnormalities, which may contribute to increased risk of cardiovascular disease.[23,29]

Respiratory health (n = 3)

Three studies assessed associations between cold indoor temperature and respiratory health (Tables 3 and 4). One prospective cohort study found colder indoor temperatures ≤18.2°C were associated with increased severity of symptoms in patients with COPD.[34] Two studies – one cross-sectional in the general adult population and one prospective cohort of children aged ≤15 years – observed no significant relationship between cold indoor temperatures and symptoms of viral infection.[19,37]

Sleeping problems (n = 2)

One observational study in older adults showed cold indoor temperatures (at 10°C vs 25°C) were associated with greater difficulties initiating sleep, measured by time to sleep or sleep onset

Table 3
Summary of the studies included in the review.

Ref, country, design, QA tool rating	Population	Temperature measurement	Outcome(s) studied
[20]Japan, PC, good	868 home-dwelling men and women (≥60 years)	Living room and bedroom temps (indoor temp) measured day and night 60 cm above the floor. Bed temp at the centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using fixed thermo-sensors over 48-h period in winter (Oct-April). Accuracy of indoor temp compared against personal-level environmental temps measured by thermo-sensor attached to ambulatory BP machine.	Daytime SBP, night-time SBP, nocturnal BP fall (%), sleep-trough 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 120 min before and after rising time).
[21]Japan, RCT, good	359 men and women (≥60 years) allocated randomly to either control ($n = 173$) or intervention group ($n = 186$)	Living room temp measured 60 cm above the floor at 10-min intervals using branded data loggers over 48-h period in winter (December to March 2010 and September to March 2011 and 2012).	Indicators of ambulatory BP: sleep-trough MBPS and the pre-waking MBPS. Physical activity. Living room temp.
[22]Japan, P, good	860 home-dwelling men and women (≥60 years)	Living room and bedroom temps (indoor temp) measured 60 cm above the floor. Bed temp at the centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using branded data loggers over 48-h period in winter (October to April). The mean ambient temp during the last daytime before the nocturnal urine collection was calculated from indoor temp.	Total nocturnal urinary sodium excretion (mmol) and nocturnal urinary sodium excretion rate (mmol/h). Ambulatory BP. Physical activity.
[23]Japan, CS, good	1095 home-dwelling men and women (≥60 years)	Living room and bedroom temps (indoor temp) measured 60 cm above the floor. Bed temp at the centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using branded data loggers over 48-h period in winter (October to April).	After collecting an overnight fasting venous sample with stasis in the morning, PLT counts were measured at a commercial laboratory.
[30]England, CS[a], good	Representative sample of 4659 adults (≥16 years). Pregnant women were excluded.	Living room temp measured once by nurse using a standard digital thermometer, which was kept away from heat sources, such as radiators or sunlight, and hung over the edge of a table where possible (location of measurement and date/time of day not specified).	Mean SBP and DBP measured at 3 × 1-min intervals. The mean of the last two readings was used in the study.
[24]Japan, N-RCT, good	1685 men and women ≥20 years allocated non-randomly either to intervention group (1578 participants) or control group (107 participants).	Living room, bedroom and changing room temps (indoor temp) and relative humidity measured 1.0 m above the floor at 10-min intervals using branded wireless data loggers for 2 weeks over 4 winter periods (November to March).	Change in HBP (follow-up HBP minus HBP measured at baseline).
[29]Japan, CS, good	1480 men and women (≥20 years).	Living room and bedroom temps (indoor temp) and relative humidity measured 1.0 m above the floor at 10-min intervals using branded wireless data loggers for 2 weeks (November to March).	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.
[31]England, CS,[a] fair	7997 older adults (≥50 years) living in private households, 1301 (16.3%) of whom lived in cold homes.	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. (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.
[25]Japan, CS, Fair	3514 adults (≥20 years) from 2007 households intending to conduct insulation retrofitting.	Living room, bedroom and changing room temps (indoor temp) and relative humidity measured at 1.0 m above the floor at 10-min intervals using branded wireless data loggers for 2 weeks over 4 winter periods (November to March).	HBP measured twice after 1–2 min 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.
[36]Taiwan, CE, fair	24 men (23–26 years): 12 normotensive and 12 prehypertensive.	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 two experimental conditions, 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 prehypertensives.
[34]China, PC, Fair	82 outpatients with COPD aged 40–85 years.	Bedroom temp and humidity measured using a standard thermo-hygrometer and recorded in diary by participant three times a day (8 am, 2 pm, 8 pm) for 18 months.	Self-reported COPD symptoms were evaluated and categorised by severity from (5) no symptoms to (1) could not tolerate symptoms and had to go to hospital.
[19]Japan, PC, fair	297 children (≤15 years) living in 173 households.	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 (December to February).	Incidence rates of five 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.
[37]USA, CS, poor	33 households for one winter season (>18 years) living in apartments or condos (mean age 28.5 years).	Indoor temp and relative humidity recorded hourly using 2–4 branded data loggers with at least one in living area and one in bedroom at a height of approximately 1.5 m, away from windows and heating devices and out of direct sunlight for 5–6 months.	Symptoms of respiratory viral infection and sleep quality.
[26]Japan, PC, good	861 home-dwelling men and women (≥60 years).	Living room and bedroom temps (indoor temp) measured 60 cm above the floor. Bed temp at the centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using branded data loggers over 48-h period in winter (October to April).	Subjective SOL (sleep diary) and objective SOL (using an actigraph).

Table 3 (*continued*)

Ref, country, design, QA tool rating	Population	Temperature measurement	Outcome(s) studied
[27]Japan, PC, good	1065 home-dwelling men and women (≥60 years).	Living room and bedroom temp (indoor temp) measured 60 cm above the floor. Bed temp at the centre of the bed 50 cm from the headboard. Temps recorded at 10-min intervals using branded data loggers over 48-h period in winter (October to April).	Nocturia, defined as ≥2 nocturnal voids. Nocturnal urine production rate (mL/h) was also calculated.
[35]Germany, CE, fair	88 community-dwelling older women (≥70 years).	Two climate chamber conditions, both 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 handgrip strength.
[28]Japan, CS, fair	36 home-dwelling older people (mean age 81 years).	Living room, bedroom and dressing room temps measured at 10-min intervals 1.1 m above the floor using branded data loggers for approximately 2 weeks (in December).	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.
[32]England, Q, N/A	Six women and one man (≥66 years).	Living room, bedroom and living room radiator temps measured at 90-min intervals using sensors in 43 participant homes over winter (November to March 2016–2017; 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.
[33]England, CS,[a] fair	74,736 adults (≥16 years) living in England	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 (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 outcome variable: good health (including very good and good responses) or poor health (including fair, bad and very bad).
[38]South Australia, CS, fair	71 independently living older people (aged 61–98 years) participated in the home monitoring stage of this research.	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 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 measured using data loggers placed next to the bed, away from any heat source.	Self-rated health and well-being.

BP, blood pressure; COPD, chronic obstructive pulmonary disease; CE, cross-over experimental; CS, cross-sectional; DBP, diastolic blood pressure; ECG, electrocardiogram; HBP, home blood pressure; MBPS, morning blood pressure surge; N-RCT, non-randomised controlled trial; PC, prospective cohort; PLT, blood platelet count; RCT, randomised controlled trial; SBP, systolic blood pressure; SOL, sleep onset latency; Temp, temperature; Q, qualitative.

[a] Secondary analysis using data from the Health Survey for England.

latency.[26] A prospective cohort study found increased nocturia (needing to urinate more than once during the night), an important cause of sleep disturbance in people in colder homes (13.2 ± 3.0°C) compared to those in warmer homes (18.6 ± 2.4°C), particularly among older people (Tables 3 and 4).[27] However, a cross-sectional study of the general adult population found no association between indoor temperatures, which ranged between ~1°C and ~38°C and self-reported sleep problems during the winter season.[37]

Physical performance in older people (n = 2)

Two studies investigated the impact of cold indoor temperatures on the physical performance of older people necessary for independent living (Tables 3 and 4). One experiment found a significant decrease of between 2% and 10% in physical performance in cold indoor temperatures (15°C compared with 25°C), measured by muscle power of lower limbs, an important risk factor for falls and fall injuries in older people.[35] A small cross-sectional study also found older people living in cold homes (<18°C) in winter had poorer handgrip strength compared to those in warm homes (≥18°C).[28]

General self-rated health (n = 3)

The evidence from studies examining the effects of cold indoor temperatures on general health was mixed (Tables 3 and 4). Two studies, one qualitative and the other cross-sectional, found health was perceived to worsen in cold indoor temperatures (<18°C[32] and <~15°C, respectively).[38] 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.[33]

Discussion

The findings of this review update, and are consistent with, those in the 2016 review, which found that cold indoor temperatures were associated with decreased thermal comfort and worse respiratory and cardiovascular health.[3] In the present review, it was shown that cold indoor temperatures in temperate and colder climates may adversely affect a wide range of health outcomes, including cardiovascular (blood pressure, electrocardiogram abnormalities, blood platelet count), respiratory (COPD symptoms, respiratory viral infection), sleep, physical performance and general health. Most reviewed studies (*n* = 17/20) found that cold indoor temperatures were associated with negative effects on health measures.

Overall, considering the evidence from the 2016 review and the findings presented here, the evidence on the risk to cardiovascular health (measured through a range of outcomes) of exposure to cold indoor conditions was consistent. Blood pressure was the most frequently studied outcome measure. A decrease in indoor temperature was shown to be associated with an increase in systolic and diastolic blood pressure[20,25,30,31,36] and higher salt intake,[22] which is independently associated with higher blood pressure, even when confounders, such as physical activity and medical history were considered. The potential health impacts of such blood pressure changes require further study, especially as high blood pressure is the predominant modifiable risk factor for cardiovascular disease, which is currently the leading cause of death

Table 4
Main findings from included studies.

Ref	Purpose	Temp threshold	Results	Limitations
Cardiovascular				
20	To estimate the magnitude of association between indoor temp and ambulatory BP in colder months.	Range was 0.3°C (night) to 33.6°C (morning)	A 1°C decrease in indoor temp was significantly associated with an increase in daytime SBP (0.22 mm Hg; $P = 0.047$), nocturnal % BP fall (0.18%; $P = 0.014$), sleep-trough MBPS (0.33 mm Hg; $P = 0.003$) and pre-waking MBPS (0.31 mm Hg; $P = 0.004$) in adjusted multilevel linear regression models.	Exposure-outcome measured simultaneously so unable to establish causality; non-random sampling means generalisability of study may be limited.
21	To estimate the short-term effectiveness of instruction in home heating on indoor temp and ambulatory BP among elderly people.	Timing intervention with instructions for the heating device to start 1 h before estimated rising time with thermostat set at 24°C.	Indoor temp in the intervention group significantly increased by 2.1°C (14.1°C to 16.2°C) 4 h after rising from bed vs. controls. After adjusting for confounding variables, the increase in temp significantly reduced BP: SBP by −4.43 mm Hg (95% CI −7.88, −0.97) and DBP by −2.33 mm Hg (95% CI −4.58, −0.08).	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 the effects of higher indoor temps on BP.
22	To quantify the association between daytime cold exposure in winter and salt intake.	Coldest (10.1 ± 2.3°C) and warmest (19.3 ± 1.8°C) homes.	A comparison of the two 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.	Non-random sample; exposure-outcome measured simultaneously, so unable to establish causality; nocturnal urine collection inferior to 24-h collection; lack of information about nutrition, including intake of total energy.
23	To investigate the association between indoor cold exposure and PLT among older people.	Cold (<14.4°C), intermediate (14.4–17.9°C) and warm (>17.9°C).	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.	Cannot determine causal directionality from cross-sectional analysis; did not quantify the amount of clothing worn; non-random sampling limits generalisability.
30	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.	<18°C, ≤18 to <21°C, ≤21 to <24°C and ≥24°C.	After controlling for confounding variables, a 1°C decrease in indoor temp was significantly associated with an increase in BP; 0.48 mm Hg (95% CI −0.72, −0.25) in SBP and 0.45 mm Hg (95% CI −0.63, −0.27) in DBP.	Cross-sectional design and simultaneous measurement of exposure and outcome meant unable to establish causality; single temp measurement; time of measurement not specified.
24	To quantify the changes in HBP due to insulation retrofitting intervention.	Thermal insulation intervention of participants' homes, including heat-insulation work (on the outer walls, floor and/or roof) and replacement of windows and frames.	Morning indoor temp rose by 1.4°C (14.5°C –15.9°C) after insulation retrofitting, despite a 0.2°C decrease in outdoor temp. The intervention significantly reduced morning home SBP by 3.1 mm Hg (95% CI 1.5–4.6) and morning home DBP by 2.1 mm Hg (95% CI 1.1–3.2).	Non-random sample of households that 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.
29	To determine the association between the indoor temp at home and ECG abnormalities.	Cold (<12°C), slightly cold (12°C–18°C) and warm (≥18°C) houses.	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).	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. arrhythmia; standard ECG provides less information than ambulatory ECG.
31	To examine the associations between a cold home (<18°C) and a series of biomarkers measured in the blood and lung.	The analysis compared cold (<18°C) and warm (≥18°C) homes.	SBP and DBP were significantly higher for people living in cold homes compared with people living in warmer homes: SBP was 136.8 vs 133.7 mm Hg, respectively ($P < 0.001$), and DBP was 76.8 vs 74.2 mm Hg, respectively ($P < 0.001$). People in cold homes also had worse handgrip, lower vitamin D levels, higher cholesterol levels, lower white blood cell count, and worse lung conditions.	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.
25	To quantify the relationship between HBP and indoor temp.	Mean morning temp was 14.5°C (range 3.3°C–25.2°C), and mean evening temp was 17.8°C (range 4.3°C–27.5°C).	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.	Cannot determine causal directionality from cross-sectional analysis; non-random sample of households that had intention of carrying out insulation retrofitting; no daily survey of clothing.
36	To evaluate the effects of cold exposure during sleep transitions on autonomic functioning and MBPS among young prehypertensives.	24.40 ± 0.78°C (warm condition) or 16.67 ± 0.45°C (cold condition)	Significantly higher MBPS in the period of awakening after sleeping in cold conditions for both prehypertensives and normotensive, but higher trends observed for prehypertensives.	Small, young, male-only sample limits generalisability.
Respiratory				
34	To examine the relationship between indoor/outdoor temp	Average indoor temp ranged between 12.5 ± 2.9°C and	Indoor temp was negatively associated with severe symptoms of COPD (OR 0.95, 95% CI	Exposure-outcome measured simultaneously, so unable to establish

Table 4 (*continued*)

Ref	Purpose	Temp threshold	Results	Limitations
	and humidity on daily self-reported COPD symptoms.	27.1 ± 2.5°C, and humidity from 50.2 ± 11.2% to 72 ± 13.2%, over study period.	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.	causality; indoor temps were recorded by participants and could not be validated; 81% of variations in symptoms were due to baseline health status (influence of environment <19%).
19	To evaluate the relationship between the type of bedroom heater and bedroom temp factors and incidence of common cold among children.	Average time spent <16°C, divided into three groups: <30 min/day (least cold); ≥30 min/day and <180min/day; and ≥180min/day (coldest).	Air conditioners were 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.	Exposure-outcome measured simultaneously, so unable to establish causality; model estimates unadjusted for important confounders, including housing characteristics (e.g. insulation) and socio-economic position; cold symptoms reported by parents could be biased; relatively low response rate (60.7%).
Sleep				
37	To explore the relationship between indoor temp and humidity, perceptions of the indoor environment and self-reported health symptoms.	Temp and humidity perceptions self-reported approximately every 3 weeks. Indoor temp ranged from ~1°C to ~38°C in winter.	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.
26	To quantify the association between indoor temp in the evening and sleep onset latency (SOL) during the colder seasons in an elderly population.	Mean indoor temp measured in the morning (2 h after getting out of bed), evening (2 h before bedtime) and initial night-time (2 h after bedtime).	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 min to 12.4 min.	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 h before bedtime) and outcome.
27	To investigate the association between indoor cold exposure and the prevalence of nocturia in an elderly population.	Participants were grouped into warmer (18.6 ± 2.4°C) or colder (13.2 ± 3.0°C) house groups using mean indoor temp measured.	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.	Non-random sampling limits the generalisability of study findings; cannot determine causal directionality from cross-sectional analysis; voiding frequency only measured over 1 night.
Physical performance				
35	To test the hypothesis that there would be a deterioration in the physical performance of older women 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.	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 handgrip strength being unaffected by the cold temp.	Non-random sampling of older women limits the external validity of findings.
28	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.	28 participants were classified into the cold group (<18°C) and eight into the warm group (≥18°C).	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.	Small, convenience sample prevents findings from being generalised; outcome assessed in rehabilitation facility and not in participants' homes.
General health				
32	To investigate the strategies older people used to stay warm in winter; how these were influenced by attitudes, opinions, and everyday practices; and what prevented the participants from achieving comfort.	7 participants were recruited from 11 homes with median temp <18°C (March 2018).	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.	Small, convenience sample; no objective indicators of health status; qualitative nature means causality cannot be inferred.
33	To investigate the relationship between indoor temp and general health.	Indoor temp ranged from 7.5°C to 36.8°C, with a mean of 20.7°C (standard deviation 2.3).	Each 1°C increase in indoor temp was associated with a 1.7% higher likelihood of poor self-rated health (95% CI 0.7%–2.6%) after adjusting for potential confounders.	Simultaneous measurement of exposure and outcome means no evidence on causal relationship; single temp measurement; time of measurement not specified.
38	To determine links between the indoor thermal environment of housing and self-reported health and well-being in older people.	Average indoor temp ranged from 11°C to 32.7°C over 9-month study period (January to October).	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.	Small, non-random sample limits generalisability of findings; self-reported health effects.

BP, blood pressure; CI, confidence interval; COPD, chronic obstructive pulmonary disease; DBP, diastolic blood pressure; ECG, electrocardiogram; HBP, home blood pressure; MBPS, morning blood pressure surge; OR, odds ratio; PLT, blood platelet count; SBP, systolic blood pressure; SOL, sleep onset latency; Temp, temperature.

globally.[39–41] Higher blood pressure sensitivity to cold indoor temperatures in older adults and women could be due to less muscle mass and subsequently less metabolic heat production.[25] Older adults are particularly susceptible to developing cardiovascular disease[42] and are less likely to feel the cold and may not adapt their behaviour accordingly, such as adding layers of clothes.[25] Two studies, rated here as good quality, suggested that interventions that increase indoor temperatures can lower blood pressure,[21,24] although the duration of these effects is unknown. These findings are consistent with a study that found lower blood pressure among a homogenous population living in blocks of flats following energy efficiency housing improvements.[43] This review also identified the impacts of cold indoor temperatures on non-blood pressure risk factors and biomarkers of cardiovascular disease, including increased electrocardiogram abnormalities[29] and higher blood platelet count,[23] both shown to increase the risk of cardiovascular disease in other population-based cohort studies.[44–47]

Findings reported in the reviewed studies suggest that night-time bedroom temperatures <18°C (10°C and 13.2 ± 3.0°C, respectively) can increase sleep problems,[26] as well as the incidence of conditions such as nocturia-associated sleep disturbance in older adults.[27] Sleep is a well-known determinant of health, well-being and quality of life, and insufficient or poor quality sleep has been linked to type 2 diabetes, cardiovascular disease, obesity, and depression.[48–50] The prevalence of sleep-disturbing problems such as nocturia increase with age and may reflect comorbid physical and mental health conditions,[51] an area that needs further exploration in the context of cold indoor temperatures.

The findings in the current review indicate that physical performance, a known determinant of quality of life particularly for older people,[52] can decrease following exposure to cold indoor temperatures.[28,35] Prolonged exposure to cold temperatures may decrease grip strength, which for older frail people can increase the risk of future cognitive deterioration, disability, hospitalisation and all-cause mortality.[53,54] However, both studies identified in this review measured physical performance outside of the home (in a laboratory and rehabilitation centre). Future studies should therefore measure these effects within the home to accurately reflect personal exposure to cold indoor temperatures.

Evidence on the effects of cold indoor temperatures on respiratory and general self-rated health outcomes was mixed. Adults with COPD reported worsening symptoms when exposed to colder indoor temperatures ≤18.2°C.[34] This is consistent with evidence from a previous review, which identified better respiratory symptom scores among older adults (aged ≥65 years) with COPD who spent more days with living room temperatures ≥21°C (+9 hours).[3] For healthy adult and child populations, studies found no significant relationship between cold indoor temperatures and symptoms of viral infection.[19,37] This evidence was rated as fair and poor, respectively, suggesting the merit of further research in this area. Two studies connected cold indoor temperatures with the perception of deteriorating health.[32,38] In contrast, another study 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.[33] However, people with worse self-rated health may maintain higher indoor temperatures for personal preference or following advice from professionals. Difference in tenure type (such as social housing compared to privately rented) may also impact temperatures achieved.[33]

Several gaps in the evidence have been identified from this review. A predominant focus of many studies has been on the impacts of cold indoor temperatures in older adult populations due to their increased vulnerability to cold temperatures and because certain cold-related conditions (e.g. nocturia) are more apparent in this population. Nevertheless, no evidence was identified on the relationship between cold indoor temperatures and frailty (e.g. Alzheimer's, falls, hospital admissions, time spent in recovery), the duration of exposure that leads to illness, or the long-term health and well-being effects of exposure to low indoor temperatures. More research is needed to understand the impact of cold indoor temperatures on people with different chronic health conditions due to a limited number of studies in this area.[55–57] Further research should also investigate the impact of cold indoor temperature among children,[19,58] particularly respiratory disease, which accounts for most of the excess winter health burden in children.[14]

To date, no studies have explored the mental health and well-being impacts of objectively measured cold indoor temperatures in the home. Previous research using a subjective measure has shown that a lack of thermal comfort at home increases the likelihood of severe mental distress[59] and that energy efficiency improvements have a positive effect on psychological, social, and financial well-being.[60–62] This review also identified no studies using objectively measured temperature to explore health outcomes in terms of wider contextual factors such as fuel poverty or poor quality housing (e.g. dwellings in the United Kingdom that contain a Category 1 Hazard under the Housing Health and Safety Rating System),[63] which may exacerbate the effects of cold indoor temperature on health and well-being. Nevertheless, a longitudinal study using a subjective measure of energy poverty investigated the effect on mental health, cardiovascular disease and respiratory health.[64] This study found that when people could not afford to heat their homes (i.e. energy poverty), their mental health worsened, and the odds of reporting depression/anxiety or hypertension increased.[64] Furthermore, the interrelationship between indoor temperature, humidity (possibly leading to condensation and associated mould) and air quality (including ventilation)[6] may alter the impact of cold indoor temperatures on health.

More than half of the studies included in this review found cold indoor temperatures <18°C – the minimum recommended home temperature threshold[3,14] – were associated with negative effects on health.[19,22,23,26–29,31,34–36,38] In addition, some studies linked better health outcomes with indoor temperatures >23°C when compared to temperatures <18°C.[26,35,36] Only one study found that increased indoor temperature was linked to the likelihood of a poor outcome (poor self-rated health).[33] A single randomised controlled trial found that instructions for older adults to heat their living room to 24°C 1 h before rising out of bed increased average temperatures by 2.1°C (14.1°C–16.2°C) and significantly reduced blood pressure 4 hours after rising.[21] Such findings suggest that setting indoor temperature threshold guidance may help to improve health in target populations. Alternative interventions that improve indoor temperatures, such as insulation retrofitting of homes, have shown similar improvements to morning blood pressure,[24] which may be worthy of future research. Further understanding of energy prices is warranted to explore any associations with temperatures in home settings and health and well-being outcomes and to assist in the identification of vulnerable populations.

Public health advice on minimum home temperatures may help to mitigate serious health risks associated with cold indoor temperatures, especially in vulnerable populations, such as older adults. Generally, indoor temperatures of <18°C are associated with negative health effects. However, the evidence summarised in this review is not sufficient or strong enough to draw firm conclusions on the specific temperature thresholds at which health effects begin for different population groups.

Limitations

There are several limitations to this review, which should be considered when interpreting the findings. Due to time constraints, searches were limited to seven databases. However, a good variety of databases were used, the search adopted a systematic approach, and the inclusion criteria were widened compared to the 2016 review to include social outcomes, studies using secondary data and intervention studies. Two reviewers independently decided on study inclusion with conflict resolution, minimising the risk of bias and error. The review was limited to studies conducted in temperate and colder climates due to the increased risk of morbidity and mortality during winter,[65] so wider evidence from other countries has been excluded. Restricting the studies to English language only may have also led to the exclusion of relevant studies. All included studies were required to record temperatures using an objective measure, limiting the bias of perceived temperatures. Thus, studies that did not record objective temperature measurements were excluded, which may have led to the exclusion of studies exploring relevant outcomes, for example, the longitudinal study on energy poverty and health outcomes described earlier.[64] Limitations across included studies are presented in Table 4.

Conclusion

The findings from this review identify that cold indoor temperatures can negatively impact a wide range of health measures, including those related to cardiovascular and respiratory health, sleep, physical performance and general health. This evidence is consistent with, and builds on, findings in the 2016 systematic literature review on the topic.[3] Some health risks gradually increased as temperatures decreased <18°C but varied according to chronic health condition and age. Nevertheless, limitations within studies and study heterogeneity make it difficult to establish if temperatures slightly below or above 18°C may also be safe for health. Further research into the specific temperature thresholds for overall health and well-being in a range of populations is needed to inform future temperature recommendations.

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Competing interests

None declared.

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