Web Annex B

Report of the systematic review on the effect of indoor cold on health

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

In:

WHO Housing and health guidelines

World Health Organization

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Contents

Introduction

This report assesses the effects of indoor cold temperatures on health to support the development of the World Health Organization's (WHO) Housing and health guidelines. The aim of this systematic review is to provide the best available evidence from existing research to contribute to the deliberations of the Guideline Development Group (GDG). During the preparation of the systematic review for this topic, an existing up-to-date review published in October 2014 was identified, Public Health England's (PHE) "Minimum home temperature thresholds in winter – A systematic review" (Wookey 2014). A search in 2015 found only one eligible study published after the PHE review search date.

Therefore, this report provides a critical appraisal of the PHE review, with additional evidence from the single eligible study published after February 2014, when the searches for the PHE review were done, and additional evidence from a 2018 update search.

After a short background section, this report provides information on population, exposure, comparator, outcomes (PECO), and eligibility criteria for the systematic review, which were agreed with the WHO. This is followed by summary information on the search strategy and methods that were used to identify and summarize potentially relevant studies published after February 2014; and a discussion of the findings of the PHE review and subsequent eligible studies.

This report should be read in conjunction with the PHE review. PHE review results have been screened for relevance to PECO outcomes, and are provided as evidence profiles and a summary of findings table.

Background

The adverse effects of cold temperature on human physiology have been well-documented (Mercer 2003; Nahya 2002; Wilson 2001). In 1987, the WHO guidelines on indoor temperatures recommended indoor temperatures be maintained at 18^{o}C, or 20–21^{o}C in rooms used by the elderly (WHO 1987), but those guidelines were based on older recommendations, the evidential basis for which can no longer be traced.

This review topic was set with the aim of determining whether the 18^{o}C threshold is supported by current research evidence. Additional information clarified that 18^{o}C was not a predetermined threshold, but is intended to provide a starting point for determining what ideal indoor temperatures thresholds might be, for the general population worldwide, and across different vulnerable groups.

The challenge in weighing evidence for indoor temperature thresholds lies in selecting appropriate exposure measures. Multiple studies have been published showing the relationship between outdoor temperatures and health outcomes, but there are few studies of the effects of indoor temperatures. There are multiple other environmental exposures correlated with indoor and outdoor temperature, such as wind, precipitation, relative humidity, and levels of clothing; as well as possible differences in behaviour and physical activity levels while indoors or outdoors. Hence, the effects of outdoor temperature exposure may not adequately represent the effects of indoor temperature.

Similarly, the effects of specific temperature exposures in laboratory conditions may not well reflect the effects of indoor temperature exposure when engaged in day-to-day living. Consideration of an indoor cold temperature threshold should therefore weigh evidence according to the setting in which the evidence has been collected.

Eligibility criteria and PECO

The finalized research question for this review is:

Do residents living in housing where indoor temperatures are below 18^{o}C have worse health outcomes than those living in housing with indoor temperatures above 18^{o}C?

Table 1 shows the inclusion and exclusion criteria that were used.

Table 1. **Inclusion and exclusion criteria for the review**

	Inclusion criteria	Exclusion criteria
Context	Domestic houses or flats in the community setting	
Participants	People of all age groups, with a particular emphasis on vulnerable sub-populations: • Infants <12 months • Children <5 years • Adults over 65 years	
Intervention	Indoor temperature below 18°C	
Comparison	Indoor temperature above 18°C	
Outcomes	Health related outcomes (as ranked by the GDG): • Respiratory morbidity and mortality • All cause-mortality in infants • Hospital admissions • Cardiovascular morbidity and mortality • Depression	

Search strategies and checking of articles

The initial search for this review was conducted using PubMed with the following search strategy:

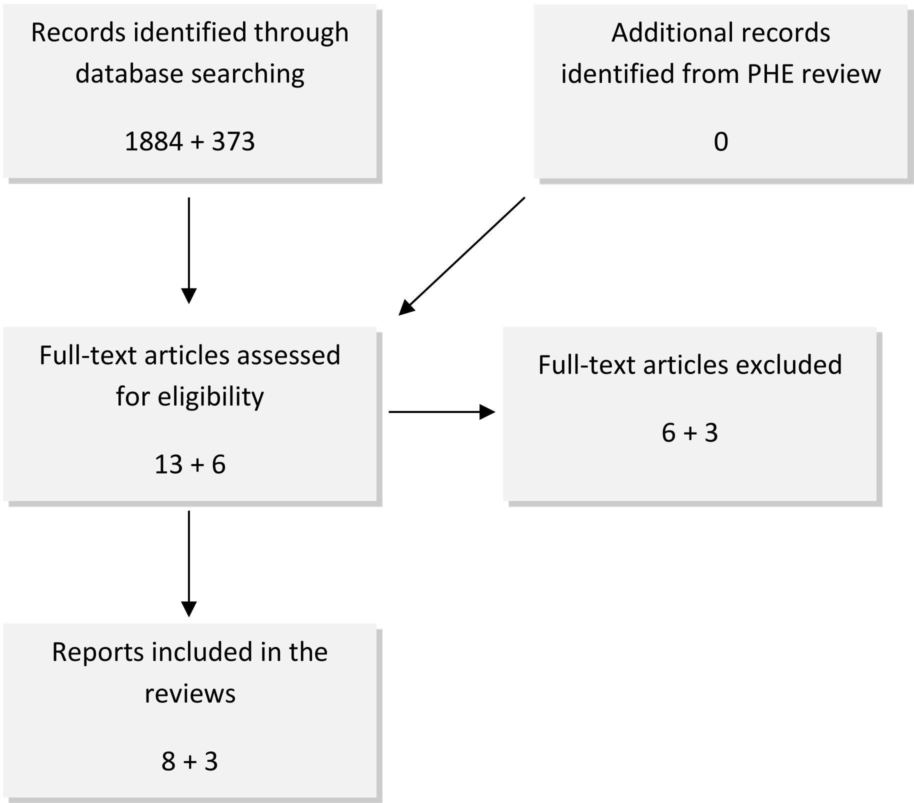
(Cold OR Cool OR Chill OR Low OR Minimum OR Severe OR Hibernal OR Hiemal) AND (Indoor OR Home OR Domestic OR Dwelling OR House OR Inside OR Household OR Outdoor OR Ambient OR Outside OR Exterior OR Threshold) AND (temperature OR climate OR thermal OR degrees OR weather) AND ("infant mortality" OR cardiovascular OR respiratory OR hospitalization OR admissions OR depression OR mood), limited to humans.

The final date on which this search was conducted was 1 January 2015, yielding 1884 results. 102 records were selected for abstract screening. After screening 44 of these abstracts, nine had been identified for full paper review. At this point, the PHE review was identified. The PHE review had considered all nine of those papers, and also resolved a set of questions about how best to address and integrate different possible additional search terms. Therefore, of the remaining 58 abstracts yet to be screened, only the 14 published in 2014 were screened. Of these, two papers met inclusion criteria and were not already included in the PHE review (Saeki 2014a; Saeki 2014b). These two papers had the same authors and published results from different aspects of the same study.

A second search was performed using the PHE search terms on 31 March 2015, including only papers published since 1 February 2014. That search identified no further eligible papers.

In order to bring the systematic review up-to-date, new searches for eligible studies were done on 28 March 2018 to identify articles published since 1 January 2015. We used the original search strategies to re-run the search in PubMed. The retrieved records were checked by two authors (RL and MC) and the full text was sought for all studies judged to be potentially eligible. When obtained, the full text of each of these articles was checked by two authors (RL and MC). Figure 1 shows the flow of articles through the original search and updating process.

Figure 1 Flow diagram for identification of studies, 2015 + 2018



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

Evidence presented in the PHE review (Wookey 2014) was screened for relevance to the outcomes identified for this PECO. Of the 20 papers covered in the PHE review, seven are included below.

Study information extracted from the PHE review included:

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

PHE review assessments of study limitations were extracted to ascertain:

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

The same information was extracted by two authors (RL and MC) from the four papers identified in the update searches for this review, as described in the previous section. The accuracy of the extracted data and the risk of bias assessments were confirmed through discussion.

This information was used to complete an evidence profile for each study. These are shown in Appendix 1. Summary of Findings tables were also prepared, which describe the evidence in narrative terms, reflecting the types of study that were identified (Appendix 2), and the characteristics of the included studies are presented in Appendix 3. The results of the risk of bias assessment of studies included during the update are shown in Appendix 4.

Findings

The findings of the relevant papers identified in the PHE review and papers identified through subsequent searches are summarized below.

Respiratory morbidity and mortality

Of the four studies investigating the effects of indoor cold on respiratory health, three found that colder indoor temperatures increased respiratory morbidity. One cross-sectional study in adults with COPD found better health status with more hours of indoor temperature at and above 21°C. A dose-response trend was observed for number of days with bedroom temperatures of 18°C and above for at least nine hours. The greatest effects were observed in adults who smoked compared with non-smokers (Osman 2008). Similarly, modelling based on the results of a randomized trial involving children with asthma found that every 1°C increase in room temperature below the threshold of 9°C, was associated with a small but significant increase in lung function. Bedroom exposure was shown to have stronger association with asthmatic children's lung function than living room exposure (Pierse 2013).

In addition, one cohort study from China, including adults with COPD, reported reduced respiratory problems with an indoor temperature at 18.2°C regardless of whether indoor humidity was low, moderate or high (Mu 2017). In contrast, a case-control study in children with and without upper respiratory tract infections showed no consistent associations with indoor temperature (Ross 1990).

The certainty of the evidence that warming a cold house (perhaps to a minimum indoor temperature of 18°C) would reduce the risk of respiratory mortality and morbidity was assessed as moderate.

Cardiovascular morbidity and mortality: blood pressure

Of the six included studies that assessed the association between indoor temperature and blood pressure, all showed that lower temperatures were associated with higher blood pressure, including two randomized trials in Japan that found higher blood pressure in people living in colder homes (Saeki 2013, Saeki 2015).

A cohort study in Japan of adults over 60 years of age found that decreases of 1°C in indoor temperatures were significantly associated with increased blood pressure levels at different times of the day, even after controlling for potential confounders (Saeki 2014a, Saeki 2014b). There was a stronger association of indoor temperature than outdoor temperature with ambulatory blood pressure, which suggested that excess winter cardiovascular mortality could be prevented by improving the housing thermal environment (Saeki 2014b). Two cohort studies from Scotland found people in housing heated to less than 18°C had a greater risk of high blood pressure (Shiue 2014, Shiue 2016). This risk increased if temperatures were below 16°C (OR 4.92) (Shiue 2014). Similarly, a cohort study in the United Kingdom found a decrease in systolic and diastolic blood pressure of 0.5 mmHg per 1°C increase in room temperature (Bruce 1991).

The review also identified six studies of temperature and blood pressure that were done under laboratory conditions (Collins 1985, Inoue 1992, Leppäluoto 2001, Mercer 1999, Neild 1994, Wagner 1987). The studies showed a relationship between warming and lower blood pressure, but because evidence for the relationship between blood pressure and housing indoor temperature was indirect, the studies were not included in the evidence summary.

The certainty of the evidence that warming a cold house (to a minimum indoor temperature of 18°C) would reduce the risk of cardiovascular mortality and morbidity was assessed as moderate.

Discussion

The PHE review concluded that heating homes to at least 18°C in winter poses minimal risk to the health of a sedentary person, wearing suitable clothing. It found this threshold to be particularly important for people over 65 years of age, or with pre-existing medical conditions, but allowed that healthy people aged 1 to 64 years might wish to heat their homes to slightly less than 18°C if they were wearing appropriate clothing and were active (during the day); or with sufficient bedding, clothing and thermal blankets or heating aids as appropriate at night.

The PHE review was strong in its methodology and comprehensiveness. However, it had two main limitations as a source of evidence for the PECO of the present review. The first of these limitations was that it was prepared for an audience from the United Kingdom and as such, was conducted with a much narrower target audience in mind than the present review. Further, the PHE review was conducted with the aim of defining indoor temperature thresholds which would "[protect] health whilst reducing carbon emissions and avoiding unnecessary expenditure on fuel" (Wookey 2014, p. 4), whereas the present review was only interested in direct health effects. These differences might have influenced the assessment of the strength of the evidence base and the conclusions drawn from it.

The second potential limitation lay in the mismatch between the limited PECO outcomes and the broader scope of the PHE review. The PHE review included studies of the relationship between indoor temperature and body mass index or obesity; perceptions of thermal comfort; and also indirect studies of the effect of temperature on biomarkers under laboratory conditions. While the evidence for a relationship between higher indoor temperature and higher body mass index was mixed and unlikely to have affected the recommendations made by the PHE review, inclusion of broader and indirect measures of health provided greater weight to the threshold recommendation.

In terms of health outcomes of interest to this review, findings of four (Saeki 2015, Shiue 2014a, Shiue 2014b, Shiue 2016) of the five studies published subsequent to the PHE review were strongly consistent with the previous PHE review findings on the relationship between blood pressure and indoor temperature; they strengthened the evidence, but did not add to it. The other study (Mu 2017) provided evidence for a relationship between low indoor temperature and COPD risk, with the risk increased by high humidity. Therefore, the evidence shows the benefits for respiratory health and blood pressure associated with the warming of cold houses, but no clear temperature threshold for these benefits, and no studies of other health outcomes originally prioritized by the Guideline Development Group such as all-cause mortality, hospital admissions and depression.

Contributors

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Pierse N, Arnold R, Keall M, Howden-Chapman P, Crane J, Cunningham M, et al. Modelling the effects of low indoor temperatures on the lung function of children with asthma. Journal of Epidemiology and Community Health. 2013;67(11):918−25.

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Appendices

Appendix 1 Evidence profile indoor cold

Quality assessment							No. of participants	Effect	Quality	Importance
Number of studies	Designs	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations				
Respiratory morbidity and mortality										
4 (Mu 2017, Osman 2008, Pierse 2013, Ross 1990)	Randomized: 1 (Pierse 2013) Cohort: 1 (Mu 2017) Case control (Ross 1990): 1 Cross sectional: 2 (Osman 2008, Shiue 2016)	Moderate	Inconsistent	Indirect (due to specific health conditions of the participants)	Precise	Studies were in 409 asthmatic children (6–12 years) in New Zealand (Pierse 2013), 82 adults (40–85 years) with COPD in China (Mu 2017), 297 children (2–5 years) with or without URTI in the United Kingdom (Ross 1990), 206 adults with COPD in the United Kingdom (Osman 2008), and 7997 adults (>50 years) in the United Kingdom (Shiue 2016).	Randomized trial: 409 Cohort study: 82 Case control study: 297 Cross-sectional study: 206	Randomized trial: small changes in indoor temperature are associated with small changes in the lung function of asthmatic children (Pierse 2013). Cohort study: When indoor humidity was low, moderate, and high, respectively, indoor temperature of above 18.2°C reduced respiratory problems (OR: 0.969, 95% CI: 0.922-1.017; OR: 0.977 95% CI: 0.962-0.999; OR: 0.920, 95% CI: 0.908-0.933) (Mu 2017). Case control study: bedrooms of children with URTI tended to be cooler overnight, but this was a very small difference which could be accounted for by differences in measurement methods (Ross 1990). Cross-sectional study: better health status was associated with more hours of indoor warmth at and above 21°C (p=0.01). Greatest effects were observed in smokers compared with non-smokers (Osman 2008). Better lung biomarkers were associated with temperatures above 18°C (p<0.01) (Shiue 2016).	⊕⊕⊕⊖ Moderate	Moderate

Quality assessment							No. of participants	Effect	Quality	Importance
Number of studies	Designs	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations				
Cardiovascular morbidity and mortality: Blood pressure										
6 (Bruce 1991, Saeki 2013, Saeki 2015, Saeki 2014a / 2014b, Shiue 2014, Shiue 2016)	Randomized: 2 (Saeki 2013, Saeki 2015) Cohort: 1 (Saeki 2014a / 2014b) Cross-sectional: 3 (Bruce 1991, Shiue 2014, Shiue 2016)	Moderate	Consistent	Direct	Precise	Studies were in 146 healthy adults (18–60 years) (Saeki 2013), 359 adults (>60 years) (Saeki 2015), 880 adults (>60 years), each in Japan (Saeki 2014a / 2014b), 10 345 adults (40–59 years) in the United Kingdom (Bruce 1991), 2047 adults (16–95 years) in the United Kingdom (Shiue 2014) and 7997 adults (>50 years) in the United Kingdom). (Shiue 2016).	Randomized trials: 505 Cohort study: 880 Cross-sectional studies: 20 389	Randomized trials: both studies showed higher BP in colder rooms: ~5mmHg higher for rooms at 12°C compared to 22°C (Saeki 2013), and 4.43/2.33mmHg (95% CI: 0.97–7.88 / 0.08–4.58 mmHg, p=0.016 / 0.059) for SBP/DBP (Saeki 2015). Cohort study: each 1°C lower was associated with a 0.2-0.3mmHg higher BP (Saeki 2014a / 2014b). Cross sectional studies: each 1°C lower was associated with a 0.5mmHg higher BP (Bruce 1991), BP was higher for people in houses below 18°C and below 16°C (Shiue 2014) and for people in houses below 18°C (Shiue 2016).	⊕⊕⊕⊕ High	Moderate (studies are from the United Kingdom and Japan only)

Bruce N, Elford J, Wannamethee G, et al. The contribution of environmental temperature and humidity to geographical variations in blood pressure. J Hypertens 1991; 9(9): 851-8.

Mu Z, Chen PL, Geng FH, et al. Synergistic effects of temperature and humidity on the symptoms of COPD patients. Int J Biometeorol 2017; 61: 1919–25.

Osman LM, Ayres JG, Garden C, et al. Home warmth and health status of COPD patients. Eur J Public Health 2008; 18(4): 399-405.

Pierse N, Arnold R, Keall M, et al. Modelling the effects of low indoor temperatures on the lung function of children with asthma. J Epidemiol Comm Health 2013; 67(11): 918-25.

Ross A, Collins M, Sanders C. Upper respiratory tract infection in children, domestic temperatures, and humidity. J Epidemiol Comm Health 1990; 44(2): 142-6.

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Shiue I, Shiue M. Indoor temperature below 18 degrees C accounts for 9% population attributable risk for high blood pressure in Scotland. Int J Cardiol 2014; 171(1): e1-2.

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

Appendix 2 Summary of findings tables

Outcome		Effect of the exposure			Certainty of evidence
		Exposure/intervention	Effect	Summary	
Respiratory morbidity and mortality	Exacerbated COPD in adults	Hours of warmth at 21°C for living rooms (LR) and 18°C for bedrooms (BR) over the monitoring week, and average temperature at 5 pm in living rooms	Better health status was associated with more hours of indoor warmth at and above **21°C** (p=0.01). Days with bedroom temperatures of at least 9 h at 18°C showed a trend to association (p = 0.04). Greatest effects were observed in those who smoke compared with non-smokers.	Beta (SE): LR hours 21°C: – 0.04 (0.02), p=0.03 LR days (9h/21°C): – 1.10 (0.42), p=0.01 BR hours 18°C – 0.04 (0.02), p=0.07 BR days (9h/18°C): – 0.93 (0.45), p=0.04	⊕⊕⊕⊖ Medium
		Bedroom temperature and humidity, with a threshold of 18.2°C derived from the data	Indoor temperatures were negatively correlated with better self-reported COPD symptoms, with the effect moderated by indoor humidity; a threshold of 18.2°C was derived from the data	Indoor humidity low: OR: 0.969 (95% CI 0.922–1.017). Indoor humidity moderate: OR: 0.977 (95% CI: 0.962–0.999). Indoor humidity high: OR: 0.920 (95% CI 0.908–0.933).	
	Decreased peak expiratory flow rate (PEFR) in children	Hourly temperature in bedroom and living room over 128 days. Bedroom temperatures from 21:00 to 08:00 (mean temp: 14.4°C) Living room temperatures from 16:00 to 20:00 (Mean temp: 16.53°C)	Small changes in indoor temp are associated with small changes in the lung function of asthmatic children. Exposure to temperatures <12°C had the greatest effect on lung function. For every 1°C increase in temperature below 9°C, PEFR improved by 0.010L/s (morning) and 0.008L/s (evening). For each 1°C increase in temperature below 12°C, forced expiratory volume (FEV) improved by 10.06mL (morning), and 12.06mL for each 1°C increase below 10°C (evening). These effects were detectable at lags up to 14/7. Bedroom exposure was shown to have stronger association with asthmatic children's lung function than living room exposure.	Best fit model: For every 1°C increase in temperature below 9°C, PEFR improved by 0.010L/s (morning) and 0.008L/s (evening). For each 1°C increase in temperature below 12°C, FEV improved by 10.06mL (morning), and 12.06mL for each 1°C increase below 10°C (evening). These effects were detectable at lags up to 14/7	⊕⊕⊕⊖ Medium
	Lung biomarkers in adults >50 years	Cold homes, threshold 18°C	Participants in cold homes had worse lung conditions. The values in these biomarkers also showed linear associations with room temperature."	For ≥18°C vs <18°C, Beta (95% CI) Lung forced vital capacity: – 0.04 (-0.04 – -0.03) Lung forced expiratory flow: – 0.03 (-0.04 – -0.02) Lung peak expiratory flow: – 0.06 (-0.09 – -0.04)	⊕⊕⊕⊖ Medium

Outcome		Effect of the exposure			Certainty of evidence
		Exposure/intervention	Effect	Summary	
	Upper respiratory tract infection (URTI) in children	Mean living room temperatures (°C) +/- reported URTI 16.5 /16.7 +/- recorded URTI 16.6 /16.8 +/- recorded AOM 16.7 /16.7 Mean bedroom temperatures (°C) +/- reported URTI 14.1 /14.4 +/- recorded URTI 14.0 /14.7 +/- recorded AOM 14.3 /14.2	No uniformly consistent results. Key findings show that when compared to the 34.7% of children in the group without upper respiratory tract infection (URTI), bedrooms of children with URTI tended to be cooler overnight, but this was a very small difference which could be accounted for by differences in measurement technique /equipment. A greater proportion of the homes of children who wheezed had fires rather than central heating. Non-wheezers tended to have radiators in their bedroom. Wheezers tended to sleep in bedrooms which were cooler. Authors conclude that this suggests that cooler bedroom temperatures may be a relevant factor in wheezing in children. Overall, the study did not show any association between URTI and indoor temps of any significant degree in practical terms. No "important difference" in incidence of acute otitis media (AOM)	Wheezers slept in bedrooms that tended to be cooler (t_{180}=1.89, p=0.060; mean difference=0.9°C, 95%CI 1.04)	⊕⊕⊖⊖ Low
All-cause mortality in infants		No included studies			
Hospital admissions		No included studies			
Cardiovascular morbidity and mortality	Increased blood pressure in 60+ years age group	Indoor temperature at home	A 1°C lower indoor temperature was significantly associated with a 0.22mmHg higher daytime systolic blood pressure (95% CI: 0.003–0.43), a 0.18% higher nocturnal blood pressure fall (95% CI: 0.04, 0.32), a 0.33mmHg higher sleep-trough morning blood pressure surge (95% CI: 0.11, 0.55), and a 0.31mmHg higher pre-waking morning blood pressure surge (95% CI: 0.10, 0.52) independent of age, sex, BMI, smoking, habitual drinking, diabetes, administration of CCB, ACE/ARB, other antihypertensive medication, evening administration of antihypertensive medication, and physical activity at BP measurements.	1°C lower indoor temperature significantly associated with: – 0.22mmHg higher daytime systolic blood pressure (95% CI: 0.003–0.43); – 0.18% higher nocturnal blood pressure fall (95% CI: 0.04, 0.32), – 0.33mmHg higher sleep-trough morning blood pressure surge (95% CI: 0.11, 0.55), – 0.31mmHg higher pre-waking morning blood pressure surge (95% CI: 0.10, 0.52)	⊕⊕⊕⊖ Medium

Outcome		Effect of the exposure			Certainty of evidence
		Exposure/intervention	Effect	Summary	
		Participants asked to set heating device in living room to start 1 hour before rising, target temperature 24°C; and to stay in living room > 2 hours after rising.	Intervention increased living room temperature by 2.09°C (95% CI: 1.28–2.90) from about 14–16°C to 16-18°C. SBP decreased by 4.43mmHg (95% CI: 0.97–7.88, p=0.012). DBP decreased by 2.33mmHg (95% CI: 0.08–4.58, p=0.042) after adjusting for confounders.	SBP decrease: 4.43mmHg (95% CI: 0.97-7.88, p=0.012). DBP decrease: 2.33mmHg (95% CI: 0.08-4.58, p=0.042)	⊕⊕⊕⊖ Medium
	Increased blood pressure in 18–60 year olds	Intensive heating group: 11h overnight at 22°C; weak heating group 11h overnight at 12°C	Morning and evening BP measurements were found to be lower in those in an intensively heated room (22°C) compared to those in a room heated to only 12°C. Morning systolic BP was lower by 5.8mmHg (95% CI 2.4–9.3mmHg p=<0.01) and diastolic by 5.1mmHg (95% CI 2.3–7.9mmHg p=<0.01). Morning BP surge was suppressed to two thirds of that observed in the colder room (sleep trough BP surge 14.3 (SD 8.7) vs 21.9 (SD 10.9) mmHg p=<0.01); pre-waking BP surge, 9.7 (SD 8.4) vs 14.9 mmHg (SD 9.6) p=<0.01). No statistically significant difference in night-time BP and authors suggest this is due to the increased use of bedclothes and blankets. Authors suggest that intensive heating to 22°C may reduce clinical stroke by 25.5% and haemorrhagic stroke by 12.4% and all-cause mortality by 12.4% in the elderly, although the sample were adults aged 18–60.	Morning: – systolic BP lower by 5.8mmHg (95% CI 2.4–9.3mmHg p=<0.01) – diastolic BP lower by 5.1mmHg (95% CI 2.3–7.9mmHg p=<0.01) – BP surge suppressed to two thirds of that observed in the colder room (sleep trough BP surge 14.3 (SD 8.7) vs. 21.9 (SD 10.9) mmHg p=<0.01); – pre-waking BP surge, 9.7 (SD 8.4) vs 14.9 mmHg (SD 9.6) p=<0.01). No statistically significant difference in night-time BP.	⊕⊕⊕⊕ High
	Systolic and diastolic blood pressure in 16–95 year olds	Single temperature measurement in subject's home	Households heated to below 18°C had a higher risk of high BP (OR 2.08, 95% CI 1.12-3.43, P=0.004) and a further increase in risk if heated to below 16°C (OR 4.92, 95% CI 1.97-12.24, P=0.001). Population attributable risk of hypertension due to an indoor temperature of less than 18°C was 9.3% and 16°C a further 4.5% risk. Authors concluded that 9% of hypertension can be prevented as a result of low indoor temperatures of below 18°C.	Higher risk of high BP in households < 18°C: (OR 2.08, 95% CI 1.12–3.43, P=0.004) Further risk <16°C: (OR 4.92, 95% CI 1.97–12.24, P=0.001).	⊕⊕⊕⊖ Medium

Outcome		Effect of the exposure			Certainty of evidence
		Exposure/intervention	Effect	Summary	
	Systolic and diastolic BP; mean arterial pressure in adults 25–59	Single room temperature measurement	Evidence of negative association for systolic blood pressure and diastolic blood pressure with room temperature (British regional Heart Study: 21.1±1.89°C) (Nine Towns Study males: 19.8 ± 1.58°C females: 19.9 ± 1.76°C). Adjusting for age, on an individual level for each rise in room temperature of 1°C an effect equivalent to 0.5mmHg decrease in sBP and dBP is seen and these findings are significant for both (p=<0.001). However, this reduction in BP is no longer significant when town is adjusted for. Indoor temperatures did not account for regional differences in blood pressure.	0.5mmHg decrease in sBP and dBP per 1°C increase in room temperature (p=<0.001).	⊕⊕⊕⊝ Medium
	Blood biomarkers in adults >50 years	Cold homes, threshold 18°C	Participants in cold homes had higher blood pressure readings, higher cholesterol levels, higher insulin-like growth factor levels, higher haemoglobin levels, and lower level of white blood cell count. The values in these biomarkers also showed linear associations with room temperature."	For ≥18 °C vs <18 °C, Beta (95% CI) sBP: -0.67 (-0.85 – -0.48) dBP: -0.61 (-0.72 – -0.50) Mean arterial pressure: – 0.64 (-0.75 – -0.52) Total blood cholesterol: – 0.02 (-0.04 – -0.01) Low-density lipoprotein: – 0.03 (-0.04 – -0.01) Insulin-like growth factor: – 0.10 (-0.15 – -0.04) Blood haemoglobin: – 0.04 (-0.07 – -0.04) White blood cell count: – 0.08 (0.06 – 0.11)	⊕⊕⊕⊝ Medium
Depression		No included studies			

Appendix 3 Characteristics of included studies

1.	Study: Mu 2017	Title: Synergistic effects of temperature and humidity on the symptoms of COPD patients			
Authors: Zhe Mu, Pei-Li Chen, Fu-Hai Geng, Lei Ren, Wen-Chao Gu, Jia-Yun Ma, Li Peng, Qing-Yun Li					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cohort	Shanghai, China	COPD outpatients (40–85 years)	COPD outpatient	patients with bronchial asthma; cystic fibrosis; active pulmonary tuberculosis; bronchopneumonia; bronchiectasis; advanced cardiovascular, nerve, endocrine, blood, liver, or kidney diseases; cancer; requirement of mechanical airway management; long-term oxygen therapy (more than 12h a day) or respiratory rehabilitation; and lack of reliability and compliance.	Enrolled randomly from hospital outpatients register
Samples	**Exposure measure**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
82	Bedroom temperature and humidity, with a threshold of 18.2°C derived from the data		Respiratory symptoms	Indoor humidity low: OR: 0.969 (95% CI 0.922–1.017). Indoor humidity moderate: OR: 0.977 (95% CI: 0.962–0.999). Indoor humidity high: OR: 0.920 (95% CI 0.908–0.933).	Medium Consistent Direct Precise Not all confounding factors identified.
2.	**Study: Osman et al 2008**	**Title: Home warmth and health status of COPD patients**			
Authors: Liesl M. Osman, Jon G. Ayres, Carole Garden, Karen Reglitz, Janice Lyon, J. Graham Douglas					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cross sectional study	Aberdeen City, Scotland Jan 2003–Oct 2004	Admitted to Aberdeen Royal Infirmary with an exacerbation of COPD	N/A	Patients in nursing or sheltered homes, where individual control over-heating was not possible, were excluded.	Via Aberdeen Royal Infirmary, not further described

Samples	Exposure measure	Outcome measures	Results	Quality (GRADE) and limitations
N=206 homes (Mean age 69 (SD 8.2) years, 55% female. 18 mild COPD, 91 moderate COPD, 39 severe COPD. 58 smokers, 90 non-smokers)	1 week monitoring: of living room hours at 21°C; Bedroom hours at 18°C: number of days with living room at 21°C for 9 hours: number of days with bedroom at 18°C for 9 hours	St Georges Respiratory Questionnaire scores for symptoms of COPD, impact of COPD and activity limitations of COPD. Euroquol Visual Analogue Scale to measure level of thermal comfort.	9 hours of LR warmth of 21°C not achieved in more than 50% of homes. 8 subjects had LR temperature at 5pm of below 18°C and two below 14°C. BR was more likely to be maintained at recommended levels. Better health status was associated with more hours of indoor warmth at and above 21°C ($p=0.01$). Days with bedroom temperatures of at least 9 h at 18°C showed a trend to association ($p = 0.04$). Greatest effects were observed in those who smoke compared with non-smokers.	High Consistent Direct Precise However, the sample are taken from a population of those who were admitted to hospital with complications of their illness and so may not be representative of the total COPD population as effects may be smaller in those with milder disease. In addition, less than 50% of the eligible population took part in the study and there is not a comprehensive examination of how this population differed from those who took part other than deprivation scores. Therefore this population may not be representative of those with severe COPD. In terms of recommendations for indoor temperatures, findings from this study are most applicable to smokers where the effects were greater compared with non-smokers.

3.	Study: Pierse et al 2013	Title: Modelling the effects of low indoor temperatures on the lung function of children with asthma.			
Authors: Nevil Pierse, Richard Arnold, Michael Keall, Philippa Howden-Chapman, Julian Crane, Malcolm Cunningham, the Heating Housing and Health Study Group					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cohort study	New Zealand June–October 2006	Children aged 7–13 years in homes with inefficient heating	Doctor-diagnosed asthma	Not described	Data collected from existing study

Samples	Exposure	Outcome measures	Results	Quality (GRADE) and limitations
N=409 households n=286 children mean age 10.4 years 59% male 34% Maori 17% Pacific Island % other ethnicities not provided (categories are not mutually exclusive) 19% had smoker living in the home	Hourly temperature in bedroom and living room over 128 days. Bedroom temperatures from 21:00–08:00 (mean temp: 14.4°C) Living room temperatures from 16:00–20:00 (Mean temp: 16.53°C)	Primary outcomes: self-recorded, forced expiratory volume, peak expiratory flow rate with indicator of validity of blow: morning and evening.	Small changes in indoor temp are associated with small changes in the lung function of asthmatic children. Exposure to temperatures <12°C had the greatest effect on lung function. Models demonstrated that for every 1ºC increase in temperature below 9ºC, Peak Expiratory Flow Rate (PEFR) improves by 0.010L/s (morning) and 0.008L/s (evening). Likewise, for each 1ºC increase in temperature below 12ºC, Forced Expiratory Volume (FEV) would improve by 10.06mL (morning) and 12.06mL for each 1ºC increase below 10ºC (evening). These effects were detectable at lags up to 14/7. Bedroom exposure was shown to have stronger association with asthmatic children's lung function than living room exposure.	Medium Consistent Direct Precise RH not accounted for as possible confounder; imperfect reliability of self-recorded FEV may bias towards the null. Effect of damp, housing quality and other potential confounders which could account for effects observed were not stated as having been adjusted for. Whether there was a smoker in the household was ascertained, but not whether the child was exposed to smoke. Severity of exposure examined but not severity of asthma. Study examined which metric has strongest association rather than size of effect.

4.	**Study: Ross et al 1990**	**Title: Upper respiratory tract infection in children, domestic temperatures, and humidity**			
Authors: Alistair Ross, Mike Collins, Christopher Sanders					
Study type	**Setting**	**Inclusion criteria**	**Definition of functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Case control	North Staffordshire, the United Kingdom December 1984 – May 1985	Children aged 24–59 months	Upper respiratory tract infection, defined as episode of one or more of the following: cold; coryza; cough; sore throat; tonsillitis; pharyngitis; acute otitis media; tracheitis.	Not described	Selected in random order from practice age-sex register, invited to participate.

Samples	Exposure	Outcome measures	Results	Quality (GRADE) and limitations
N=297	Mean living room temperatures (°C) +/- reported URTI 16.5 /16.7 +/- recorded URTI 16.6 /16.8 +/- recorded AOM 16.7 /16.7 Mean bedroom temperatures (°C) +/- reported URTI 14.1 /14.4 +/- recorded URTI 14.0 /14.7 +/- recorded AOM 14.3 /14.2	Primary outcomes: Reported URTI (Incidence of URTI reported on questionnaire) Recorded URTI (incidence of URTI recorded in child's medical records) Incidence of acute otitis media recorded in medical notes	No uniformly consistent results. Key findings show that when compared to the 34.7% of children in the group without upper respiratory tract infection (URTI), bedrooms of children with URTI tended to be cooler overnight, but this was a very small difference which could be accounted for by differences in measurement technique /equipment. A greater proportion of the homes of children who wheezed had fires rather than central heating. Non-wheezers tended to have radiators in their bedroom. Wheezers tended to sleep in bedrooms which were cooler. Authors conclude that this suggests that cooler bedroom temperatures may be a relevant factor in wheezing in children. Overall, the study did not show any association between URTI and indoor temps of any significant degree in practical terms. No "important difference" in incidence of acute otitis media (AOM)	Low Null finding inconsistent with other result; imprecise (numerical results not provided). This is a small home based study from a single GP practice in North Staffordshire and it is unclear as to how this population compares to other areas. The age range is very specific and it is unclear as to how the findings from this group are applicable to other population groups. Although numerous measurements (144 per child) were made, these took place over a 6-day period during December to March and do not establish long term effects of exposure on acute respiratory disease. No measure-ments were taken during November, a month for which we would seek to make recommendations. The authors suggest that a limited period of measurement will present challenges and question whether these findings can be extrapolated over the remaining months where cold weather is problematic. Potential confounders such as heating methods, smoking and other socioeconomic factors and housing type were taken into account but other exposures such as school not accounted for. It is unclear as to whether the children had existing chronic respiratory disease, such as asthma. Outdoor conditions were adjusted for to control for effects of seasonal variation. Individual exposure is challenging to quantify and behavioural considerations are crucial to understanding exposures, neither of which are accounted for in their statistical analysis. Methods of taking and recording temperatures were robust and steps were taken to limit bias.

					No consideration of other factors such as outdoor, school or other potential confounders were taken into consideration. possible evidence of reporting bias with unusually high number of reported URTO cases

5.	**Study: Saeki 2015**	**Title: Short-term effects of instruction in home heating on indoor temperature and blood pressure in elderly people: a randomized controlled trial**			
Authors: Keigo Saeki, Kenji Obayashi, and Norio Kurumatani					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Randomized	Japan December to March 2010, September to March 2011, and September to March 2012	60 years and older	n/a	Excluded if they did not own a thermostat-controlled heating device with an automatic start timer function, or if they used their living room as a bedroom	Participants were recruited from a club for senior citizens and a residents' association.
Samples	**Exposure measure**		**Outcome measures**	**Results**	**Quality (GRADE) and limitations**
359	Participants were asked to set the heating device in the living room to start 1 hour before estimated rising time with target temperature at 24°C, and to stay in the living room until 2 hours after rising as long as possible.		Ambulatory blood pressure	Intervention increased living room temperature by 2.09°C (95% CI: 1.28–2.90) from about 14–16°C to 16–18°C SBP decreased by 4.43mmHg (95% CI: 0.97–7.88, p=0.012) DBP decreased by 2.33mmHg (95% CI: 0.08-4.58, p=0.042) after adjusting for confounders.	High Consistent Direct Imprecise Cohort recruitment had potential to recruit healthier-than-average participants, and to exclude lower socioeconomic groups

6.	**Study: Saeki et al 2014a and 2014b** **N.B. Saeki et al 2014a is subsequent to PHE review**	**Title: Stronger association of indoor temperature than outdoor temperature with blood pressure in colder months** **and** **The relationship between indoor, outdoor and ambient temperatures and morning BP surges from inter-seasonally repeated measurements**			
Authors: Keigo Saeki, Kenji Obayashi, Junko Iwamoto, Nobuhiro Tone, Nozomi Okamoto, Kimiko Tomioka, Norio Kurumatani					
Study type	**Setting**	**Inclusion criteria**	**Definition of functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cohort study	Nara, Kansai Region, Japan September 2010–April 2012	Adults >60 years living at home	N/A	Not described	Not fully described; non-random sampling

Samples	Exposure	Outcome measures	Results	Quality (GRADE) and limitations
N=880 n=868 met inclusion criteria n=subgroup measured in winter N= 215 measured in winter and spring/autumn	Indoor temperature at home	Average BP 2h after rising (morning BP); lowest in bed BP (lowest BP); average BP 2h before rising (pre-waking BP)	A 1^{o}C lower indoor temperature was significantly associated with a 0.22mmHg higher daytime systolic blood pressure (95% CI: 0.003–0.43), a 0.18% higher nocturnal blood pressure fall (95% CI: 0.04, 0.32), a 0.33mmHg higher sleep-trough morning blood pressure surge (95% CI: 0.11, 0.55), and a 0.31mmHg higher pre-waking morning blood pressure surge (95% CI: 0.10, 0.52) independent of age, sex, BMI, smoking, habitual drinking, diabetes, administration of CCB, ACE/ARB, other antihypertensive medication, evening administration of antihypertensive medication, and physical activity at BP measurements.	High Low risk of bias, consistent, direct precise. Participants were recruited by non-random sampling which limits the generalizability of this study.

7.	Study: Saeki et al 2013	Title: Influence of room heating on ambulatory blood pressure in winter: a randomized controlled study			
Authors: Keigo Saeki, Kenji Obayashi, Junko Iwamoto, Yuu Tanaka, Noriyuki Tanaka, Shota Takata, Hiroko Kubo, Nozomi Okamoto, Kimiko Tomioka, Satoko Nezu, Norio Kurumatani					
Study type	**Setting**	**Inclusion criteria**	**Definition of functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Parallel group, assessor blinded, simple randomized controlled study 1:1 allocation	Nara prefecture, Japan (winter temperatures average 3 to 5^{o}C November 2009 – March 2010	Adults 18-60 years living at home	N/A	Chronic cardiovascular illness, diabetes or kidney disease excluded	Not described

Samples	Exposure	Outcome measures	Results	Quality (GRADE) and limitations
N=146	Intensive heating group: 11h overnight at 22°C; weak heating group 11h overnight at 12°C	BP 2h prior to going to bed (evening BP); mean BP in bed (night BP); BP 2h after rising (morning BP)	Morning and evening BP measurements were found to be lower in those in an intensively heated room (22°C) compared to those in a room heated to only 12°C. Morning systolic was lower by 5.8mmHg (95% CI 2.4–9.3mmHg p=<0.01) and diastolic by 5.1mmHg (95% CI 2.3–7.9mmHg p=<0.01). Morning BP surge was suppressed to two thirds of that observed in the colder room (sleep trough BP surge 14.3 (SD 8.7) vs. 21.9 (SD 10.9) mmHg p=<0.01); pre-waking BP surge, 9.7 (SD 8.4) vs. 14.9 mmHg (SD 9.6) p=<0.01). No statistically significant difference in night-time BP and authors suggest this is due to the increased use of bedclothes and blankets. Authors suggest that intensive heating to 22°C may reduce clinical stroke by 25.5% and haemorrhagic stroke by 12.4% and all-cause mortality by 12.4% in the elderly, although the sample were adults aged 18–60.	High Low risk of bias, consistent, direct precise. No control for alcohol consumption or other medication use such as those for thyroid.

8.	**Study: Shiue 2015**	**Title: Cold homes are associated with poor biomarkers and less blood pressure check-up: English Longitudinal Study of Ageing, 2012–2013**			
Authors: :Shiue, Ivy					
Study type	**Setting**	**Inclusion criteria**	**Definition of specific functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cross-sectional	England, the United Kingdom 2012–2013	Adults (>50 years), in English Longitudinal Study of Ageing	n/a		Selected from existing data

Samples	Exposure measure	Outcome measures	Results	Quality (GRADE) and limitations
7997 with valid indoor temperatures, with 1301 (16.3 %) in cold homes	Cold homes, threshold 18°C	Biomarkers present in the blood and lung	Participants in cold homes had higher blood pressure readings, higher cholesterol levels, higher insulin-like growth factor levels, higher haemoglobin levels, and lower level of white blood cell count. The values in these biomarkers also showed linear associations with room temperature. For ≥18 °C vs <18 °C, Beta (95% CI) sBP: -0.67 (-0.85 – -0.48) dBP: -0.61 (-0.72 – -0.50) Mean arterial pressure: – 0.64 (-0.75 – -0.52) Total blood cholesterol: – 0.02 (-0.04 – -0.01) Low-density lipoprotein: – 0.03 (-0.04 – -0.01) Insulin-like growth factor: – 0.10 (-0.15 – -0.04) Blood haemoglobin: – 0.04 (-0.07 – -0.04) White blood cell count: – 0.08 (0.06 – 0.11)	Medium Consistent Direct Some confounding factors not identified

9.	Study: Shiue & Shiue 2014	Title: Indoor temperature below 18°C accounts for 9% population attributable risk for high blood pressure in Scotland			
Authors: Ivy Shiue, Mercedes Shiue					
Study type	**Setting**	**Inclusion criteria**	**Definition of functional impairment**	**Exclusion criteria**	**Recruitment procedures**
Cross-sectional analysis of existing data set of the Scottish Health Survey	Scotland 2010	Adults 16-95 years, survey data available on blood pressure and indoor temperature	N/A	Chronic cardiovascular illness, diabetes or kidney disease excluded	Sample selected from Postcode Address File recruited by post[8]

Samples	Exposure	Outcome measures	Results	Quality (GRADE) and limitations
Original cohort N=17 253 n=13 710 aged 16+ n= 2047 with data available for study	Single temperature measurement in subject's home. Mean room temperature 20.1°C, range 0°C–28.2°C	Systolic and diastolic blood pressure	Households heated to below 18°C had a higher risk of high BP (OR 2.08, 95% CI 1.12-3.43, P=0.004) and a further increase in risk if heated to below 16°C (OR 4.92, 95% CI 1.97–12.24, P=0.001). Population attributable risk of hypertension due to an indoor temperature of less than 18°C was 9.3% and 16°C a further 4.5% risk. Authors concluded that 9% of hypertension can be prevented as a result of low indoor temperatures of below 18°C.	Medium Consistent and direct, but a number of confounders not controlled for, and wide confidence intervals for temperatures below 16°C

10.	Study: Bruce et al 1991	Title: The contribution of environmental temperature and humidity to geographical variations in blood pressure.
Authors: Nigel Bruce, Jonathan Elford, Goya Wannamethee, A. Gerald Shaper		

Study type	Setting	Inclusion criteria	Definition of functional impairment	Exclusion criteria	Recruitment procedures
Analysis of existing British Regional Heart Study (BHRS) and Nine Towns Study (NTS) data. Smaller cross-sectional sub-study	BHRS: 24 British towns, 1978–80 NTS: subset of 9 of those towns, 1987	BHRS males 50–59 years NTS: Adults 25–29, 40–44 and 55–59	N/A	Not described	Sampled from age-sex registers in general practice, invited to participate. 78% response rate (BHRS); 68% response rate (NTS)

Samples	Exposure	Outcome measures	Results	Quality (GRADE) and limitations
N=7735 (BHRS) N=2610 (Nine Towns Study)	Single room temperature measurement	Systolic and diastolic BP; mean arterial pressure	Evidence of negative association for systolic blood pressure and diastolic blood pressure with room temperature.(British regional Heart Study: 21.1±1.89°C) (Nine Towns Study males: 19.8 ± 1.58°C females: 19.9 ± 1.76°C). Adjusting for age, on an individual level for each rise in room temperature of 1°C an effect equivalent to 0.5mmHg decrease in sBP and dBP is seen and these findings are significant for both (p=<0.001). However, this reduction in BP is no longer significant when town is adjusted for. Authors suggest indoor temperatures cannot account for regional differences in blood pressure.	Medium Consistent, direct, precise. Some risk of selection bias; external validity questioned, some confounders not accounted for.

Appendix 4 Risk of bias assessment of studies included during the update in 2018

Study	Did the study address a clearly focused issue?	Was the cohort recruited in an acceptable way?	Was the exposure accurately measured to minimize bias?	Was the outcome accurately measured to minimize bias?	Have the authors identified all important confounding factors?	Were confounders taken into account in the analysis?	Was the follow up of subjects complete enough?	Was the follow up of subjects long enough?	Are the results reliable?	Can the results be applied to the local population?	Was there a description of how study size was arrived at?	Was there an adequate description of the statistical analysis?	Is there an adequate description of the study participants?
Mu 2017	+	+	unclear	+	-	+	+	+	unclear	unclear	+	+	+
Saeki 2015	+	-	+	+	+	+	+	+	+	unclear	+	+	+
Shiue 2016	+	+	+	+	-	-	N/A	N/A	unclear	unclear	+	+	-