Defining indoor heat thresholds for health in the UK

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Abstract

Introduction: It has been recognised that as outdoor ambient temperatures increase past a particular threshold, so do mortality/morbidity rates. However, similar thresholds for indoor temperatures have not yet been identified. Due to a warming climate, the non-sustainability of air conditioning as a solution, and the desire for more energy-efficient airtight homes, thresholds for indoor temperature should be defined as a public health issue.

Aims: The aim of this paper is to outline the need for indoor heat thresholds and to establish if they can be identified. Our objectives include: describing how indoor temperature is measured; highlighting threshold measurements and indices; describing adaptation to heat; summary of the risk of susceptible groups to heat; reviewing the current evidence on the link between sleep, heat and health; exploring current heat and health warning systems and thresholds; exploring the built environment and the risk of overheating; and identifying the gaps in current knowledge and research.

Methods: A global literature search of key databases was conducted using a pre-defined set of keywords to retrieve peer-reviewed and grey literature. The paper will apply the findings to the context of the UK.

Results: A summary of 96 articles, reports, government documents and textbooks were analysed and a gap analysis was conducted. Evidence on the effects of indoor heat on health implies that buildings are modifiers of the effect of climate on health outcomes. Personal exposure and place-based heat studies showed the most significant correlations between indoor heat and health outcomes. However, the data are sparse and inconclusive in terms of identifying evidence-based definitions for thresholds. Further research needs to be conducted in order to provide an evidence base for threshold determination.

Conclusions: Indoor and outdoor heat are related but are different in terms of language and measurement. Future collaboration between the health and building sectors is needed to develop a common language and an index for indoor heat and health thresholds in a changing climate.

INTRODUCTION

Healthy individuals with a balanced regulatory system maintain a core temperature within a safe range of around 37°C. Adjustment to the surrounding temperatures is achieved through conduction, convection, radiation and evaporation.[1] However, increases in temperature have the potential to compromise the human body's ability to maintain thermoregulation and consequently, can adversely affect health.[1] Physiological damage from overheating follows a continuum from heat stress, strain, stroke, and eventually to death.[2] Certain groups are at increased risk of heat-related illness for a number of reasons.[3]

In their paper on health and thermal comfort, Ormandy and Ezratty[4] reviewed the historical background of the universally applied World Health Organization (WHO) thermal comfort guidelines on indoor temperatures.[4] They highlight that thermal comfort, by its very nature, is linked directly to health and such guidance is necessary for the protection of those most susceptible to extremes of temperatures.

The Intergovernmental Panel on Climate Change (IPCC) has projected that it is *very likely* that an increase in the frequency, duration and/or intensity of heatwaves will occur in the urban areas of Europe as a result of climate change.[5] As

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a positive response to reducing carbon emissions to mitigate climate change, there has been a drive towards building more energy-efficient buildings. However, this has raised concerns about the potential for these dwellings to overheat due to the increasing levels of thermal insulation and airtightness reducing the potential to reject heat gains from a building without positive intervention.

In addition to warmer temperatures, the issues of increased urbanisation and an ageing population contribute to the impact of possible future scenarios. In the past 50 years there has been an increase of 30% in the ratio of those living in urban-to-rural areas, with a significant rising trend for the future.[6] The Urban Heat Island (UHI) effect is a phenomenon affecting built-up areas and can be defined as the variation between urban and rural temperatures due to atmospheric and surface impacts.[7] As a result of increased urbanisation more people will be exposed to the UHI effect and consequently any adverse health outcomes from rising temperatures.

Current building regulations in the UK do not provide or enforce indoor temperature thresholds for health. As building regulations in the UK are expected to be revised in 2013 and the development agenda is strongly emphasising more airtight, energy-efficient homes, it is important to look at the potential of homes being hotter and the effect of this on health.

There are concerns that air conditioning will be the first line of defence in maintaining the indoor health and well-being of the population.[8] The use of air conditioning alone creates a positive feedback loop in which the goal of building energy-efficient houses to offset carbon emissions is compromised by creating airtight spaces that may require air conditioning to keep cool enough for healthy living, therefore increasing emissions. There is also the emerging concern of fuel poverty and the increasing difficulty that certain groups may face in paying for the energy needed to maintain cool indoor temperatures.[4]

Bone *et al.*[9] recently addressed the question of the health of occupants in energy-efficient homes in the UK and also emphasised the use of passive cooling techniques as an alternative to air conditioning. The main implications for health identified from their paper were the potential for poor indoor air quality and overheating as a result of insufficient ventilation.[9] As a result of the limited evidence base, they called for further research to be undertaken in this field. This paper aims to build on this work and will focus on the development of thresholds for new domestic buildings. Although the problems of existing dwellings is acknowledged by the authors as an important area of work, full discussion of this is outside the scope of the paper. The findings of this research will be of interest to the UK building regulations, the Health and Safety at Work Act and the Housing Health and Safety Rating System.

AIMS

The aim of this paper is to outline the need for indoor heat thresholds and to establish if they can be identified. Our objectives are as follows:

- Describing how indoor temperature is measured.
- Highlighting threshold measurements and indices.
- Describing adaptation to heat.
- Summarising the risk of susceptible groups to heat.
- Reviewing the current evidence on the link between sleep, heat and health.
- Exploring current heat and health warning systems and thresholds.
- Exploring the built environment and the risk of overheating.
- Identifying the gaps in current knowledge and research.

METHODS

The Cochrane Library was initially checked for any previous review on indoor heat thresholds; none was found.

The following step-by-step process was then undertaken to gather the available scientific evidence on the subject:

- Databases searched for peer-reviewed literature included SCOPUS, Web of Knowledge, PubMed and Medline from 2000 to the present.
- Textbooks relevant to the academic areas of climate change housing, and health were reviewed.
- Google Scholar and the WHO, United Nations (UN), Health Protection Agency (HPA), Environmental Protection Agency (EPA) and Centers for Disease Control and Prevention (CDC) websites were searched for grey literature. These organisations were identified for their instruction in climate change, heat and public health policy.
- Key opinion and thought leaders in the fields of public health, engineering and building research were contacted for suggestions and input.

The following search terms and similar words were used:

- Indoor: inside, house, dwelling, building, residence, home, internal
- Heat: hot*, thermal, temperature, heat wave, overheating, overheat*, heat*, warmth
- Health: human, well-being, hazards, mortality, death, health*, ill*, morbidity, stress, condition, complications, sick*
- Thresholds: limits, index, comfort, safety, extremes, stress, max*

Truncation and Boolean operators AND/OR were used in the search to retrieve a narrower field of results. Prospective and retrospective searches were conducted through citations and references to find relevant papers, and duplicate references were removed.

Documents in non-English languages, those involving non-human studies, those focusing exclusively on cold temperatures and editorials were excluded from the search results.

RESULTS

Measurement of indoor temperature and their effects

The majority of people worldwide spend most of their time indoors, yet the epidemiologic studies found on the relationship between heat and health used outdoor temperature as a predictor.[10] The WHO highlighted in 2009 the lack of evidence on how indoor temperatures influence the risk of heat-related morbidity and mortality.[11]

There are several ways to present temperature measurements. This is of considerable importance, as heat-related mortality cannot be compared when exposure is derived using different measurements. Studies reviewed have used mean temperature (an average daily, monthly or yearly figure), minimum, maximum or apparent temperature (which combines temperature and humidity). All have particular advantages.[12] However, it has been suggested that all measurements had similar levels of predictive accuracy.[12] In their recent review, Ormandy and Ezratty[4] outlined an alternative method of measurement in place of traditional ambient temperature measuring techniques.[4] They highlight the discrepancies of ambient temperature within a room (vertical and horizontal gradients), at different times of the day, between different rooms of the house and between rooms that are occupied and used for different reasons.[4] With this in mind, they describe the perception approach as a proxy for thermal comfort, which relies on occupant feedback.[4] Despite limitations relating to those at the extremes of age, studies such as the WHO Large Analysis and Review of European Housing and Health Status have explored this technique and been able to utilise the findings to aid in the understanding of the relationships between indoor temperatures and certain clinical indicators of morbidity.[4] Initial results indicate that the perception approach is a very promising technique that has the potential to add value to housing and health studies.[4]

A rise in temperature leading to an increase in morbidity and mortality is not the only predictor of heat-related health outcomes. Diurnal variations, which can be defined as the variation in temperature between day and night or the 'within day temperature range' are important to consider, yet have been given very little attention.[13,14] Sheridan and Kalkstein[15] suggest that a lack of night-time relief from heat is a significant contributing factor to heat-related mortality.[15] They hypothesise this due to the strong association between high morning temperatures and deaths secondary to heat exposure.[15] As diurnal temperature range is an environmental indicator that has been associated with climate change, it is an important measurement to include in future temperature/mortality models.

In addition to diurnal variations, there is data to support the effects of changes in temperature between days as having an effect on risk of mortality.[15] Guo *et al.*[16] found that regardless of the actual temperature, a change of more than 3°C in either direction had a significant negative effect on health outcomes. Both diurnal variation and large changes in temperature between days are of relevance as they are separate drivers of mortality that require thresholds to determine risk.[16] This is important to recognise as we discuss indoor heat thresholds as determinants of morbidity/mortality.

Threshold measurement and indices

Several studies have shown that heat-related mortality begins when outdoor temperatures exceed a local or regional minimum figure.[10] Arriving at any particular threshold requires use of an index to describe temperature and its effects on health. Establishing indoor temperature thresholds would also require the development of an appropriate index.

There are simple and complex indices. Simple methods are based on measurements of a combination of air temperature and humidity, sometimes including a duration variable.[17] Complex indices with relevant meteorological and physiological variables that assess the heat load for a particular place or area have also been developed.[17] For example, heat budget models, which are widely used in indoor thermal comfort assessments, take into account the physiological mechanisms of heat exchange in order to determine real and modelled individual experiences.[17]

An exposure study done in 2002 by Basu and Samet looked at personal exposure to ambient temperature and found a positive correlation between ambient temperature and body temperature.[18] The researchers monitored ambient temperature using temperature probes attached to participant clothing and by recording Baltimore temperatures. The median body temperature, heart rate and activity level of subjects was also measured and compared. This is of particular interest as physiological measures such as core body and skin temperature can be correlated with both high indoor and high outdoor temperatures as a result of individual monitoring.[18] Developing an index that could directly measure the health effects of indoor heat is therefore important and development of such a tool should be encouraged. The framework developed in 2001 by Chan *et al.*[19] developed a physiologically based mechanism to assess the key risk factors for health correlated with heatwaves.[19] Within this framework, called the heat-related health effects index (HEI), there is flexibility to include place-based assessments on the health effects of localised heat. This study looked at indoor exposure specifically and found that a healthy person in an indoor unventilated building was 3.8 times more likely to have an adverse health effect due to heat than a healthy individual outdoors.[19]

Thermal comfort guidance on the range of temperatures within which there is a minimal risk to health is defined by WHO as between 18°C and 24°C.[4,20] Although this guidance is based on revisions made from earlier WHO thresholds, there is little in the way of literature to explain what the reasons for the changes were.[4] Nevertheless, the current range of temperatures has been based on evidence that has been followed up by further research and is largely accepted as the range within which health is optimally protected. However, there are numerous variables associated with thermal comfort that would differ between individuals and their environment.[4] These need to be taken into account when developing threshold standards as often, assumptions will need to be made.[4]

Other thresholds for indoor heat are based on thermal comfort models derived from the building and engineering industries.[21] These figures result from the creation of an 80% occupant acceptability standard through Fanger's heat balance model, and have mainly been defined on the basis of data from office buildings.[22] These standards also assume that indoor climatic conditions physiologically affect all groups in the same way, regardless of age or medical condition.[23] However, Fanger's model uses the theories of heat balance, stress and thermoregulation to describe thresholds for comfort, not for health.[24]

Both the traditional heat balance model and the newer adaptive model of thermal comfort have temperature thresholds for air-conditioned and naturally ventilated buildings.[25] Because these thresholds are what determine the criteria for human occupancy, it is important to note that they assume people will be able to adapt, and that the outdoor climate will stay within the necessary range to allow this adaptation. Crime, urbanisation, noise, pollution and power failure are not taken into account in their modelling.[26] This is problematic as the adaptive thermal comfort model specifically allows higher indoor temperatures as a result of an occupant's ability to change or alter their environment (e.g. opening windows or using electric fans) regardless of their physical or environmental circumstances.

No other study was found that has built on Basu's work on individual exposure to indoor temperatures.[18] It is important that the scientific evidence base on the relationship between indoor and outdoor temperature is researched further and tools are developed with which to measure it.

Adaptation to heat

Although the evidence suggests that populations acclimatise to higher temperatures, no studies were identified in this search on the effect of behavioural thermoregulation and acclimatisation. This reflects the results found by Malony and Forbes[27] who also found no studies on behavioural thermoregulation.[27] This is particularly relevant in the context of industrialised countries, as air conditioning is a predominant adaptive intervention. In terms of sustainability and the use of air conditioning, research has shown that for every one degree increase in outdoor temperatures, there is a jump from 5% to 20% demand for cooling energy; this translates into a 120% increase in energy use by 2100.[28] This indicates that in terms of energy conservation and reducing carbon emissions, alternative forms of maintaining indoor temperatures beneath a certain threshold must be sought.

Table 1

Groups at increased risk of heat-related illness

Pre-existing health conditions	Obesity, poor existing health, pre-existing dehydration, cardiovascular conditions, respiratory conditions, chronic fatigue, sleep deprivation, low fitness or physical disabilities, uncontrolled diabetes, medications affecting thermoregulation, long-term high-level exercise, gastrointestinal conditions, psychiatric illness, hyper/hypotension, renal complications, previous heatstroke, alcohol and/or drug abuse, certain neurological disorders, pre-existing electrolyte imbalances, peripheral vascular disease, eating disorders, dermatological disease or damage, fever
Extremes of age	Older people (particularly over 65 years), children and infants
Inability to adapt behaviours	Alzheimer's, confinement to bed, disabilities, those at extremes of age
Environment	Residing in upper floors of buildings, south-facing flats, lack of adequate ventilation in home or air conditioning, living alone, socially isolated, lack of acclimatisation, urban dwelling, care home residents

Source: Adapted from 30, 31, 32, 33, 34

Groups susceptible to heat

Although anyone can be at risk from indoor heat, there are several groups of individuals who are at increased risk of mortality or morbidity to increased temperatures. Those at risk include urban dwellers who may be less acclimatised to warmer temperatures through the use of air conditioning or living in traditionally temperate areas.[6] During the 1995 heatwave in Chicago, those most at risk were those who lived alone, lived in a building with few rooms, or occupied buildings with flat roofs.[10] The researchers found that having a functioning air conditioner was associated with an 80% reduction in mortality risk.[10]

The elderly are particularly at risk from increased heat as they can often be socially isolated, confined to bed, taking certain kinds of medications, have limited respiratory and cardiovascular function, or reside in nursing or long-term care homes.[18] However, it is not only the physiological characteristics of being elderly that increase risk. A separate study found that it was the *least* physically fragile patients in a nursing home during the 2003 heatwave in France that were the most susceptible.[29] It has been suggested that this is because carers may have spent time with the most dependant residents during episodes of severe heat. Those who were perceived to be independent were therefore left to self-care and may not have recognised in themselves the onset of heat-related illness.

Susceptible groups to heat highlighted in the literature are summarised in Table 1.

Nocturnal temperatures and health

It has been postulated that night-time temperatures may impact negatively on health due to the consequences of a lack of overnight relief from heat experienced during the day.[32] In urban areas it is possible that there will be higher night-time temperatures during hot weather than in the surrounding rural areas due to the UHI effect. This is of particular relevance to those who reside in towns and cities and who are then consequently exposed to higher night-time temperatures than their rural counterparts.

Physiologically, the key differentiating factor between day and night is the ability of the human body to thermoregulate while asleep.[35] Being awake, or 'wakefulness', has been hypothesised as potentially the only state that allows for the management of increased thermal loads.[36]

Several studies have examined the effect of temperature, quality of sleep, the bedroom environment and mortality. In their study, Okamoto-Mizuno and Tsuzuki[35] found a significant relationship between bedroom temperatures and poor sleep episodes only in summer. They suggest that this is due to a warmer bedroom climate.[35] Another study on sleep patterns and mortality in the elderly showed that there is an increased risk for mortality with night-time insomnia and sleep-onset delay.[37] While the variable of temperature was not an element in this study, it does establish the link between poor sleep and increased mortality. Another study has shown a direct link between the risk of mortality, living on the top floor of a dwelling and the duration of sunlight entering the bedroom.[38]

Heat and health warning systems and thresholds

Indoor heat and thresholds were not identified within the widely accepted framework for heat and health warning systems (HHWSs). However, there are specific HHWSs in Philadelphia and the UK that integrate protective actions for the elderly and the hospitalised.[15] In addition, most warning issuances (including the UK) are linked to national systems.[39]

The Heatwave Plan for England (2011) has a provision for indoor temperature monitoring to ensure that temperatures do not rise above 26°C, but this is only recommended for spaces in residential or nursing homes and in rooms where susceptible groups spend their time.[31] As the generally accepted public health measure implemented through an HHWS is to suggest cooling areas for at-risk populations, adapting large spaces like nursing homes in an increasingly warm climate necessarily revisits the question of air conditioning.

The evidence shows that acute responses of the kind that HHWSs are designed to elicit only address late-stage issues for the detection and prevention of heat-related mortality.[39] More long-term interventions are needed, including the consideration of domestic housing as a risk area.

There are also complex social consequences for certain preventative aspects of an HHWS, like centralised cooling areas for the elderly and other susceptible groups. Having concrete thresholds (outdoor or indoor) would trigger action in some cases involving movement of people from one location to another, possibly increasing the risk of exacerbating existing medical conditions and/or mental conditions due to displacement or separation from family members.[40]

Buildings and the risk of overheating

There have been case studies completed by the Chartered Institution of Building Services Engineers (CIBSE) as well as a study from University College London that examined the likelihood of overheating in certain types of dwellings, day versus night cooling and bedroom temperatures.[11] However, these studies are not directly linked to health through time-series or case-control data. Another study from 2005 focused on nine UK dwellings during the August 2003 heatwave, measuring indoor versus outdoor temperatures and comfort metrics, but not risk for morbidity or mortality.[41] A recent study evaluated the indoor/outdoor temperature relationship by addressing 'exposure misclassification' in personal exposure studies. The researchers found increased mortality rates beyond a threshold of 26°C and considered that indoor variables like orientation of a room or solar gain can exacerbate the effects of outdoor ambient temperatures.[42] It is therefore evident that buildings are, to some extent and with variability, modifiers of the effect of climate on health,[43] and it is suggested that this level of modification, towards hotter temperatures, will increase as we move to more energy-efficient houses.

The Department for Communities and Local Government (DCLG) recently identified several necessary aspects of a home built to the Code for Sustainable Homes, one of which requires the living environment to be comfortable in terms of temperature, taking future climatic scenarios into account.[44]

DISCUSSION

Because indoor heat thresholds are currently linked to comfort and outdoor thresholds are linked to morbidity and mortality, the language in which each is described is not comparable. In addition, using outdoor indices to predict the possible health effects of indoor heat is problematic as there are several variables and possible modifiers that may significantly impact on the validity of an index, such as adaptive behaviour, indoor heat gains, solar gain and density of occupants. Given this wide range of variables, a national system enforcing indoor heat thresholds would be problematic. If indoor heat thresholds are to be established, they require a separate and unique measurement index as well as further research and evidence linking indoor heat directly to morbidity and mortality data.

Factors such as minimum night-time temperatures and diurnal variation require further research and should be heavily weighted in an indoor heat model, given the currently available evidence on bedroom temperatures and sleep. As a result of the data on temperature and sleep disturbances, many building and design standards already include provisions for lower temperature thresholds for bedrooms.[45]

Within the literature, air conditioning was highlighted to be unsustainable, not widely affordable, with the opening of windows seldom feasible due to pollution, crime, noise or keeping a home airtight. Therefore it would appear that preventative indoor temperature thresholds should be implemented in the design stage as a means of protecting health.

In respect to vulnerability, it is of interest to note the response of care homes to heatwaves. Recent research concluded that because care home staff viewed patients with the most complex health conditions as having the greatest need when it came to addressing their care requirements during a period of severe heat, prioritising their care may have occurred above that of more independent residents. As a result, they suffered fewer health impacts than their independent counterparts. This suggests that the ability to protect oneself or a group of people from the health effects of heat decreases vulnerability. Therefore, creating standards for action through setting indoor heat thresholds for health might further increase the capacity for preventative measures and action.

Although various protocols exist on indoor temperatures, to date no universal measurement has been agreed. It is also noted that the current thresholds cited by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and CIBSE are based on a working environment and therefore take into account a healthy workforce only. This population is not fully representative of the wider, more general population who occupy domestic settings and have a range of vulnerabilities that make them more susceptible to heat-related illness. An environment will differ depending on its use (e.g. care home or office), occupant density (e.g. individual or overcrowded) or individual characteristics (e.g. elderly or workforce). Such characteristics need to be taken into account when considering any development of thresholds.

Strengths and limitations

This paper was limited to English-language papers only and the authors recognise that a broader search inclusive of other languages could enrich the findings. It was also appreciated that certain studies conducted in countries outside the UK have inherent limitations when extrapolating results to a UK population. The results also revealed the lack of studies using indoor temperature as the unit of measurement and therefore this paper depends on studies using outdoor temperature. However, despite such limitations, the paper benefited from the collaboration between the HPA and the Building Research Establishment, thus combining knowledge and experience from both the built environment and health sectors.

Future research needs

The important gaps identified in the current knowledge on indoor heat and health highlighted by this paper include:

- The relationship between sleep, temperature and health outcomes.
- Longitudinal studies on indoor heat and health.
- Improving the predictive ability and widespread agreement of key modelling techniques – most importantly indoor/outdoor temperature relationships.
- Studies on the effect of behavioural thermoregulation and acclimatisation.
- Cost–benefit analysis of preventing heat-related deaths.
- Vulnerability mapping on the national, regional and local level.
- Understanding vulnerability management through everyday exposure to heat.
- Indoor heat integration into HHWSs.

CONCLUSION

The results from this literature review highlight the need for indoor heat thresholds for health as a preventative measure against increasing morbidity and mortality in a warming climate. This paper also highlights the gaps within the research that make it very difficult to define an index or measure and compare outcomes between health and dwellings. Local, dwelling-based thresholds that can be effectively monitored and enforced should be a priority. Given the current literature and data available on indoor heat and health, indoor thresholds are not considered feasible on a widespread or national basis. The variability that comes with different types of dwellings, human adaptive behaviour, high-risk groups, social policy and epidemiological identification of threshold figures makes it challenging to identify a comprehensive risk model. However, given the rapidly warming climate, urbanisation, demographic changes and concern with increasing carbon emissions, there is a need for further research in order to link these variables together to attempt to define indoor heat as a public health concern.

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