DEFINING OVERHEATING

EVIDENCE REVIEW

ZERO
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HUB

The Zero Carbon Hub was established in 2008, as a non-profit organisation, to take day-to-day operational responsibility for achieving the government's target of delivering zero carbon homes in England from 2016. The Hub reports directly to the 2016 Taskforce.

To find out more, or if you would like to contribute to the work of the Zero Carbon Hub, please contact: info@zerocarbonhub.org.

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01

INTRODUCTION

The purpose of this Evidence Review is to set out the different ways the term 'overheating' is understood. We summarise:

- existing technical overheating thresholds for thermal comfort, health and wellbeing, productivity and infrastructure resilience;
- assess the level of evidence on which each threshold is based; and
- comment on their practical implementation to date.

Similar to other reviews in the Zero Carbon Hub's series, our focus is on the residential sector, including care homes and student accommodation. This Review links closely to the Assessing Overheating Risk Evidence Review as the outputs from models, i.e. the assessment of whether overheating may occur in a property is partially determined by the definition or criteria being used. There will naturally be overlap with other reviews too.

This Review summarises current UK, EU and US thermal comfort standards, current research and public health advice, and also complements and further builds on the London Climate Change Partnership's Heat Thresholds Project publication (LCCP 2012).

This Evidence Review forms part of a wider evidence gathering exercise being conducted by the Zero Carbon Hub for our *Tackling Overheating in Homes* project. It provides a summary of relevant evidence and concepts relevant to the theme: defining overheating.

Key Points

- A key issue highlighted in this Review is that evidence-based 'overheating' thresholds related to different sectors have been developed on the basis of different environmental variables, quite often by researchers from different disciplines. As a result, they are commonly expressed in different metrics and are therefore not directly comparable with each other.
- Indoor health-related thresholds are less well defined in comparison to thermal comfort-based thresholds, despite the well-characterised epidemiological relationships between outdoor ambient temperature and heat-related morbidity and mortality. This is partly due to the methodological complexity of linking indoor environments with health outcomes.
- Future research should aim to establish an integrated approach towards defining overheating thresholds that cuts across comfort, wellbeing and health impacts.

02

CATEGORISING DEFINITIONS OF OVERHEATING

Overheating can be assessed with respect to:

- Thermal comfort;
- Health; or
- Productivity.

Of the three forms of definition, the most commonly applied in the design of buildings is thermal comfort. Thermal comfort itself has been defined in a number of ways. The International Organization for Standardization (ISO) Standard 7730:2005 defines thermal comfort as *'that condition of mind that expresses satisfaction with the thermal environment'* (ISO 2005).

While this qualitative definition of comfort reflects more than ('dry bulb air') temperature alone, design criteria for avoiding overheating tend to focus on the assessment of temperature profiles under typical outdoor temperature conditions, and specifically the frequency, duration and magnitude of temperatures above specified thresholds.

Box 1. **Dry Bulb Temperature (DBT)**

The Dry Bulb Temperature (DBT) is the temperature of air measured by a thermometer freely exposed to the air but shielded from radiation and moisture. DBT is the temperature usually thought of as air temperature.

Environmental factors affecting a person's thermal comfort include air temperature, radiant temperature, air speed and humidity. Personal factors include age, gender, state of health, clothing, and activity levels (Fanger 1970). Due to these multiple influences, any definition of overheating in terms of thermal comfort needs to make reference to the circumstances and target groups to which that definition is applied. For example, an environment which is comfortable for someone who is physically inactive may be too hot for someone engaged in sustained physical activity. Typically, the assumption is made that the thermal conditions inside the home should be appropriate for a sedentary adult occupant wearing relatively light clothing. Section 4 sets out the guidance and criteria for assessing thermal comfort in more detail.

For the purposes of the Tackling Overheating in Homes project, the Zero Carbon Hub adopted the following working definition to cover all three categories of definition:

'The phenomenon of a person experiencing excessive or prolonged high temperatures within their home, resulting from internal and/or external heat gains, and which leads to adverse effects on their comfort, health or productivity.'

Health effects

In more extreme situations, 'excess' heat exposure can impact on health and even lead to fatalities.

Excess heat-related mortality is broadly defined as the short-term rise in mortality above the mean baseline for that region and period of the year (Basu 2002). Heat-related morbidity includes a continuum of illnesses resulting from the body's inability to cope with excess heat exposure. Heat vulnerable groups include the elderly (above 65 years old), the very young, the chronically ill (e.g. people suffering from cardiovascular or respiratory diseases, or mental illness) and socially deprived population groups (Kovats & Hajat 2008a).

Whilst the present-day incidence of cold-related deaths is markedly higher than that of heat-related deaths by almost an order of magnitude (DCLG 2012b), heat-related deaths are expected to rise as a result of climate change induced increases in the frequency and severity of heatwave events and higher average temperatures. See the Impacts of Overheating Evidence Review for more discussion on this subject.

Definitions of what constitutes a heatwave tend to vary. The World Health Organization (WHO) definition defines a heatwave as *‘when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5°C, the normal period being 1961-1990’*.

In the UK, according to the Met Office (2014), the term heatwave usually refers to a period of prolonged hot weather, often combined with high levels of humidity. The Heatwave Plan for England 2014 recommends that heatwave action should be taken when:

- Trigger temperatures are reached on one day and the following night in one or more Met Office National Severe Weather Warning Service (NSWWS) regions; and
- It is very likely (90% confidence) that temperatures on the next day will lie above the daytime threshold.

The heatwave thresholds vary by region . The average threshold temperature is 30°C in the daytime and 15°C overnight. Section 5 sets out health and wellbeing thresholds.

A death is characterised as heat-related if individual excess heat exposure either caused or contributed to it (Kovats & Hajat 2008a), although in practice it is challenging to record which are heat-related.

Productivity levels

High temperatures can also have adverse effects on sleep. Although there is no well established definition of sleep quality (Krystal & Edinger 2008), the term usually refers to total sleep time, sleep onset latency (the time taken to fall asleep), and sleep efficiency (the proportion of time spent sleeping during the sleep period). Sleep disruption may refer to the occurrence of sleep disruptive events, for instance apnoea and spontaneous arousals.

An adverse effect of heat stress and compromised sleep quality is the reduction in work productivity levels.

Box 2. **Work capacity**

The 'work capacity' for a given combination of direct heat exposure levels and work intensity levels expresses the percentage of a working hour a worker can perform their intended tasks after subtracting the time needed to rest so as to maintain a core body temperature below 38°C (Kjellstrom 2000; Kjellstrom et al. 2009; Holmér 2010).

A newer issue is that there is an increasing number of professionals who tend to work from home, and a significant proportion of individuals who work in domestic settings, e.g. those supporting vulnerable people in the community or home care services. Taking this into consideration, direct heat exposure during the daytime is increasingly likely to have an impact on work capacity for certain segments of the population. Section 6 provides more detail on productivity-related thresholds.

03

BUILDINGS AS MODIFIERS OF EXPOSURE TO THE EXTERNAL CLIMATE

It has been estimated that individuals in the UK, a heating-dominated country, spend more than 90% of their time in indoor spaces (Schweizer et al. 2007). Another study of the lifestyle patterns of the adult urban population (19-60 years old) in Oxford found that people spend on average 66% of their time at home, with this percentage rising to 89% for individuals not in employment (Lader et al. 2006). It is also likely that heat vulnerable groups, such as young children, the elderly, and individuals of low mobility and/or poor health may spend an even larger proportion of their time at home.

The fact that people in the UK spend a large proportion of their time indoors is of considerable importance because the building envelope acts as a modifier of human exposure to the external climate, and associated health impacts. This ability of the building to modify temperatures means that the relationship between outdoor temperature and mortality, for example, cannot be simply extrapolated to indoor temperature.

Researchers expect that, for a given external ambient temperature recorded at a single weather station, there will be a wide distribution of internal temperatures across the entire building stock, with internal temperatures potentially both lower and higher than the external.

The people inhabiting these indoor spaces are also likely to demonstrate a wide distribution of individual heat vulnerability, with certain groups being disproportionately affected by excess temperature exposure. These three elements - location, building and occupant vulnerability - have been identified as 'triple jeopardy' factors (MoL 2011).

Depending on its characteristics, a building could offer refuge from outdoor heat or exacerbate occupant excess heat exposure. For example, an analysis of data from the Chicago 1995 heatwave found that healthy individuals in unventilated indoor spaces were 3.8 times more likely to experience heat-related adverse health impacts compared to people outdoors (Chan et al. 2001).

A further example demonstrating the importance of a building's characteristics as a modifier of internal temperatures is provided by (Vandentorren et al. 2006). The team conducted a detailed case-control study on the impacts of housing characteristics on heat-related mortality during the 2003 heatwave in France and found large variations in risk across different building types.

The temperature profile of a particular indoor space will be a function of site microclimatic conditions (including potential urban heat island effects) and the building characteristics.

An investigation into the home environments of persons aged 65 and over who died between 8 August and 13 August 2003 in selected communities in four different areas severely affected by the heatwave, indicated that:

- Individuals in top floor flats were 2.33 times (95% C.I. 1.33–4.09) as likely to die of heat compared to people living in other types of buildings; and
- The risk of heat-related death was 2.16 (95% C.I. 1.26–3.69) higher for people sleeping in a bedroom directly under the roof.

Unfortunately, the lack of indoor temperature monitoring in these studies does not allow us to directly link indoor temperature with health effects. There are a number of challenges in collecting high resolution indoor temperature data, such as: capturing a statistically representative housing sample, monitoring occupant behaviour (use of windows and shading) etc.

Currently, the interrelationship between indoor temperature and health impacts can be explored further only through the use of building simulation. For example, a dynamic thermal modelling study of a theoretical London housing stock (Oikonomou et al. 2012) using two different weather files (one in the centre and one in the outskirts of London) found significant differences in indoor air temperature, and hence occupant heat exposure, between various dwelling types located in the same site (Figure 1). Higher indoor temperatures were also observed in the top floor flats of this notional stock, in agreement with the 2003 epidemiological studies (Semenza et al. 1996; Vandentorren et al. 2006).

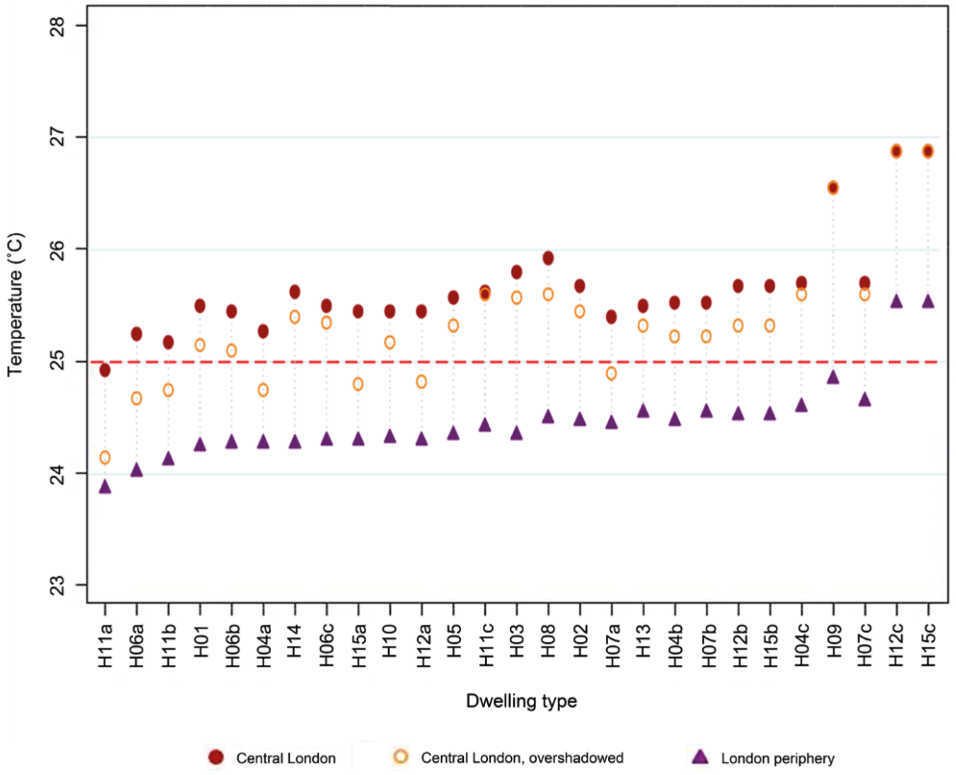
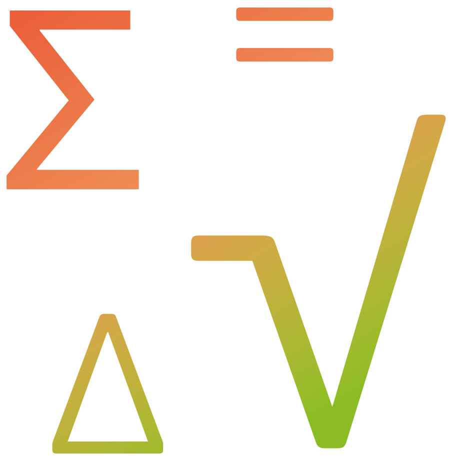


Figure 1. Mean indoor temperatures in naturally ventilated London dwellings by dwelling type and location, with and without overshadowing in central London. With night ventilation. Temperatures are averaged results across the four dwelling orientations during the five-day period with the highest moving mean outdoor temperatures in the 2050s Medium-High emissions scenario weather file used in the study. The dashed line signifies the summer upper thermal comfort threshold for living rooms according to CIBSE Guide A, Source: Oikonomou et al. (2012)

04
THERMAL COMFORT THRESHOLDS FOR FREE RUNNING BUILDINGS



Most published guidance on thermal comfort uses either:

- Simple internal/external air temperature (technically dry bulb temperature); or
- One of two different methods of defining thermal comfort – the use of deterministic models or adaptive models.

Deterministic thermal comfort models are based on data from controlled climate chamber studies under steady state conditions. Their most recognised form is the Predicted Mean Vote (PMV), developed by Danish researcher Povl Ole Fanger (1970). This represents the expressed thermal comfort for particular combinations of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation.

This method has been used as the basis for the description of thermal comfort in a number of Standards related to mechanically heated/cooled spaces.[1] This Review focuses on the standards that apply to 'free running' buildings - i.e. buildings that are naturally ventilated and do not use mechanical cooling. We assume that most existing homes will still, at present, depend on natural ventilation for their summer cooling.

In contrast, adaptive thermal comfort models are based on the principle that an individual's thermal expectations and preferences are determined by their experience of recent (outdoor) temperatures and a range of contextual factors, such as their access to environmental controls. In short, a person's comfort 'threshold' or limit is affected by, for example, how well they adapt to recent outdoor temperatures and how easily they can adapt their own living environment.

Adaptive thermal comfort models are informed by a series of field studies[2] which observed occupant behaviour and how individuals tend to adapt their environment and behaviour in response to environmental changes (Nicol & Humphreys 2002). The field studies were undertaken in the natural environment of the participants and recorded information over extended periods. The mean air or operative temperatures were measured, and their neutral (or comfort) temperatures were calculated. In many of the studies, the level of activity and clothing were also recorded. In all studies the two temperatures were consistently highly correlated and ranged between about 12°C and 35°C depending on the climate.

Box 3. The Running Mean

A key measure of the adaptive model is the exponentially weighted 'running mean' of the daily mean outdoor temperature, Trm, or 'running mean' for short.

The running mean takes into consideration the fact that days in the more remote past will have less effect on occupant comfort than more recent days. This is reflected by attaching decreasing weight in the mean daily outdoor temperatures furthest from the day under consideration.

Although adaptive models provide some options for adjustments of the comfort 'limits' based on different air speeds, they do not take into consideration humidity levels, or the different preferences of occupants who cannot change their circumstances, adapt their clothing and do not have direct access to operable windows (e.g. the case with open plan office spaces, or when there are security concerns or noise issues).

Also important is the fact that an increasing number of buildings, including a number of new houses use Mechanical Ventilation with Heat Recovery (MVHR) systems and employ various combinations of natural and mechanical ventilation to condition their spaces. This makes the use of the adaptive model less straightforward.

Most UK and international standards have now adopted the adaptive thermal comfort model for the calculation of thermal comfort limits of free running buildings.

Design standards of thermal comfort in free running buildings

In this section, we describe recent sets of guidance on indoor thermal environments. Two based on absolute temperature thresholds:

- CIBSE Guide A (2006): Environmental design; and
- Standard Assessment Procedure, SAP: Appendix P, 2012 edition.

Three are based on the adaptive thermal comfort approach:

- BS EN 15251:2007;
- CIBSE TM52; and
- ANSI/ASHRAE Standard 55-2013.

CIBSE Guide A (2006): Environmental design (now superseded by TM52)

The 2006 edition of the Chartered Institution of Building Services Engineers (CIBSE) Guide A, Chapter 1 (CIBSE 2006) defined overheating in terms of specific absolute design operative temperatures.

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[1] Including the British Standard European Norm (BS EN) Standard 15251:2007, International Organisation of Standardisation (ISO) 7730:2005 and the American National Standards Institute (ANSI), American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 55-2013 (ASHRAE 2013).

[2] Many different field studies were undertaken between 1936 – 1976 consisting of 200,000 observations made in offices, schools, homes, hospitals, boats, in a variety of climates and are described in Humphreys (1976a; 1976b). More recently, an additional study using a similar number of more recent data has shown very similar results (Humphreys et al. 2013).

Specifically, for free running buildings in the UK climate, the comfort temperatures in Table 1 are:

Table 1. **Comfort temperatures based on building type, recreated from CIBSE Guide A Environmental design (2006) (with permission)**

Building type	Acceptable summer comfort temperature (°C)
Offices	25°C
Schools	25°C
Homes - living areas	25°C
Homes - bedrooms	23°C

CIBSE 'Guide A' (2006) also suggested 28°C as the maximum threshold above which the majority of people in a building will start feeling uncomfortable.

Guide A then sets 'design' thresholds for the same building types and overheating criteria to be used (Table 2). These had been published previously in CIBSE TM36, *Climate change and the indoor environment: Impacts and adaptation (CIBSE 2005).*

Specifically, the design criteria are based on 'hourly exceedance', i.e. the number of hours a given temperature is exceeded for, and are used with the Design Summer Years (DSY) in simulation tools (see the Assessing Overheating Risk Evidence Review for a more detailed description).

Table 2. **Peak temperatures and overheating criteria for the design of buildings, recreated from CIBSE Guide A Environmental design (2006) (with permission)**

Building type	Peak temperature (°C)	Overheating criterion
Offices	28°C	1% annual occupied hours over peak temperature
Schools	28°C	1% annual occupied hours over peak temperature
Homes - living areas	28°C	1% annual occupied hours over peak temperature
Homes - bedrooms	26°C	1% annual occupied hours over peak temperature

Night time temperatures in particular are critical, as they may offer relief or cause continuing thermal discomfort for individuals who have been exposed to excess heat throughout the day (Koppe et al. 2004, Luber & McGeehin 2008, Lindley et al. 2011, WHO 2008, Hajat et al. 2006).

Sleep quality has been found to reduce during the summer, an effect that is commonly attributed to high night time temperatures (Okamoto-Mizuno & Tsuzuki 2010). This is very likely to be the case during prolonged heat episodes characterised by consecutive hot days and warmer than average nights that inhibit the recovery from daytime heat (Fischer & Schär 2010) as, for example, during the 2003 heatwave (Black et al. 2004; Beniston & Diaz 2004; Poumadère et al. 2005).

This effect is likely to be most pronounced in locations with strong heat island effects, such as core urban areas, which experience significantly higher night time temperatures compared to their rural surroundings (Sailor 2014, Hajat et al. 2007, Milojevic et al. 2011, GLA 2006, Hajat & Kosatky 2010).

Many studies have highlighted the significance of diurnal temperature difference on comfort (Gosling et al. 2008, Guo et al. 2011).

Due to the changes in the thermoregulatory ability of the human body during sleep,[1] thresholds for sleep discomfort or disruption are deemed to be lower than the corresponding daytime comfort thresholds. CIBSE Guide A, for example, suggests that sleep quality may be compromised when the indoor operative temperature lies above 24°C - which is 2°C and 4°C lower than the general overheating threshold for bedrooms and living rooms, respectively (CIBSE 2006).

The threshold of 24°C was, however, based on a study from the 1970s of a very small sample of twenty one adults (11 women and 10 men), fairly homogeneous from a socio-economic point of view, in which bedroom temperature monitoring was combined with an occupant questionnaire survey including information about bed clothing, sleep quality and thermal discomfort (Humphreys 1979). Furthermore, the study was based on traditional English bedding, i.e. blankets and eiderdowns, which are no longer in common use. The minority of respondents who used continental duvets were specifically excluded, whereas this form of bedding is now the norm in the UK.

Absolute thresholds, such as those provided in CIBSE Guide A, although simple to use with most simulation tools and relatively simple to communicate and address within the design team, do not take into consideration the fact that occupant comfort temperatures in free running buildings vary with outdoor temperature. Occupants tend to adapt to higher temperatures experienced over an extended period.

Furthermore, a single temperature threshold is sensitive to the method of estimating temperatures used in different simulation tools and the way they are used. For example, different assumptions about the number of hours a building is occupied, and when, could have a substantial bearing on the assessment of overheating and the effectiveness of natural ventilation. This is particularly problematic in the design of homes that do not have a standard occupancy pattern, in a way that offices have, for example.

A single temperature threshold does not provide a measure of the severity of overheating. This means that it would not distinguish between a building that exceeds a threshold by 1°C and a building that exceeds the threshold by 4°C for the same amount of time.

Standard Assessment Procedure (SAP): Appendix P (2012 edition)

The Standard Assessment Procedure (SAP) (BRE 2012) is the Government's procedure for rating the energy performance of homes.

Designers and developers in the UK need to show compliance with SAP for each of the domestic units they are designing. SAP is not a design tool, but rather a compliance tool and is designed to produce an energy rating for the unit under consideration. As such, the treatment of its thermal performance is under steady state conditions.

For the assessment of overheating, SAP (Appendix P) offers such a steady state calculation method that takes into consideration heat gains and fabric characteristics of the building to calculate monthly mean summer internal air temperatures that are then compared to a threshold temperature in Table 3 (over the page).

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1. See Okamoto-Mizuno & Tsuzuki (2010), Parmegianni & Velluti (2005); and Parmeggiani (2003).

Table 3. **Levels of threshold temperature corresponding to likelihood of high internal temperature during hot weather, recreated from SAP 2012 (Appendix P)**

Threshold temperatures (°C) [1]	Likelihood of high internal temperatures during hot weather
< 20.5°C	Not significant
≥ 20.5°C and < 22.0°C	Slight
≥ 22.0°C and < 23.5°C	Medium
≥ 23.5°C	High

Appendix P of SAP provides a simplified check of whether the home will have an overheating problem. Following Table 3, if the calculation shows monthly mean internal temperatures lower than 20.5°C the risk of the home overheating is predicted to be 'not significant'. If the calculation estimates internal temperatures between 20.5°C and 22°C, then there is predicted to be a 'slight risk' of overheating, etc.

The SAP methodology does not predict the severity of the overheating risk and the effectiveness of remedial solutions. The thermal performance of a building is a dynamic function of multiple variables and changes during the day. The use of a steady state approach that is using monthly average temperatures can mask severe hot events, their intensity and duration. The impact of the urban heat island effect and future changes in climate are also not included, due to the use of monthly mean regional temperatures.

BS EN 15251:2007: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

The British Standard European Norm (BS EN) 15251:2007 Standard (BSI 2007) introduces the concept of 'acceptable' indoor comfort temperatures for four categories of buildings, described in Table 4 (over the page). The classifications relate to the ability of the occupants to modify their environments. Figure 2 then shows the acceptable summer indoor temperatures for these categories of free running buildings.

This Standard has been developed from the adaptive thermal comfort approach (described above), based on field studies as part of the Smart Controls and Thermal Comfort (SCATs) project undertaken in five EU countries and in a total of 25 office buildings (McCartney & Nicol 2002). A total of 27,000 responses to questionnaires, completed during extended periods, were collected on the participants' comfort, clothing, activity and controls in order to develop the adaptive control algorithm to be used in the design of free running buildings throughout Europe.

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[1] These temperatures are indicative of the house as a whole. Appendix P treats the whole house as a single zone. The split between zones is only used for the main SAP heating calculation.

Table 4. **Description of building types recreated from BS EN 15251:2007 (with kind permission from the British Standards Institute)**

Category	Explanation	Suggested acceptable range (K)
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	**± 2K**
II	Normal expectation (for new buildings and renovations)	**± 3K**
III	A moderate expectation (used for existing buildings)	**± 4K**
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)	**>4K**

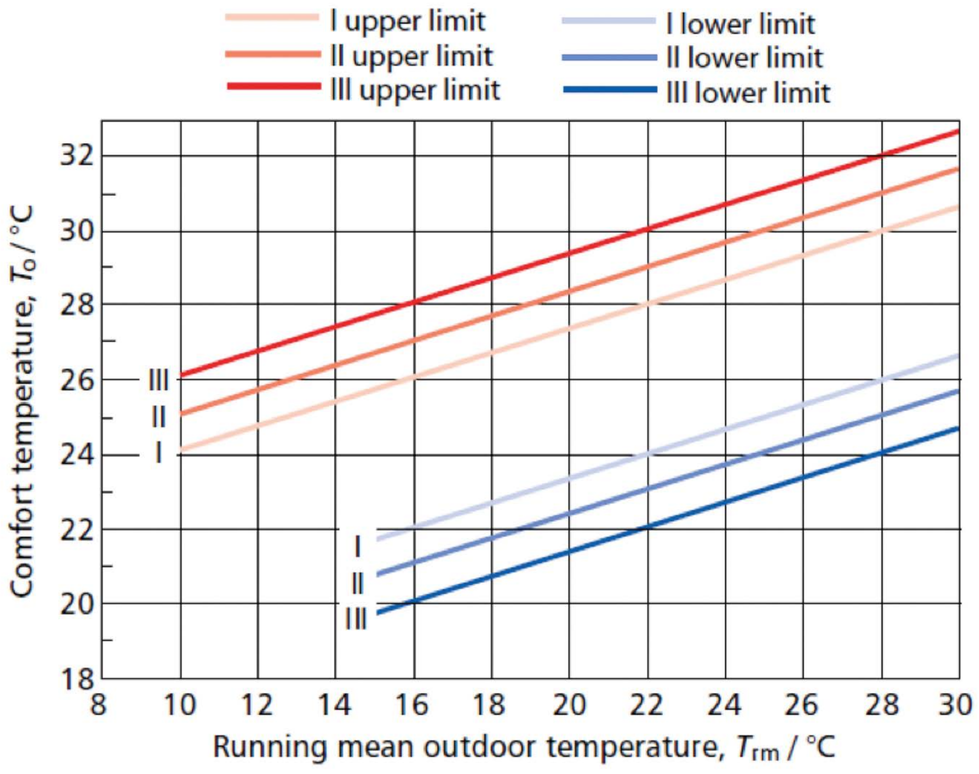

Figure 2. Indoor comfort temperatures for free running buildings as a function of the running mean outdoor temperature, for the three building types. Used with kind permission from the British Standards Institute.

The Standard states that *'these comfort temperatures are valid for office buildings, and other buildings of similar type, and dwellings, used for human occupancy with sedentary activities, and with easy access to operable windows and occupants that could freely adapt their clothing to the indoor/outdoor thermal conditions'*. It suggests that the criteria for free running buildings could also be used for spaces that are mechanically ventilated but with unconditioned air, and for spaces that use other cooling means such as fans, shutters, and night time ventilation.

The comfort temperatures in existing standards are primarily based on studies in office buildings. There is limited evidence on occupant comfort at home and almost no evidence on their comfort preferences during sleep.

Based on the fact that human physiology stays the same at work and at home, it seems reasonable to assume that the adaptive model, based on evidence from non-domestic settings, also broadly applies in residential buildings. The ability to adapt the surrounding environment and clothing is more flexible at home than in the office and so could allow for a wider range of comfort temperatures bands (although this assumption might not apply to occupants that are vulnerable to heat). Further research is needed to investigate the relevance of the adaptive thermal algorithm to the domestic sector and how it can be adapted for use in the design of homes. Researchers will also need to investigate how the adaptive thermal algorithm could be applied to buildings that house vulnerable occupants with varied heath conditions, such as hospitals and care homes.

CIBSE TM52: Criteria for defining overheating in free running buildings

The three new CIBSE criteria in Technical Memorandum (TM) 52 (CIBSE 2013) are defined based on the BS EN 15251:2007. Together, they provide a more in-depth method for the assessment of overheating risk in UK and European buildings. A room or a building that fails any two of the three criteria is described as being likely to overheat. Full details of these criteria are set out in Annex 1 of this report.

Box 4. Which building classification should be used?

CIBSE's recommendation in TM52 is that new buildings, major refurbishments and adaptation strategies should conform to Category II (see Table 4 on page 13) of BS EN 15251:2007, which sets a maximum acceptable temperature of 3°C above the 'comfort' temperature for buildings in free running mode.

For buildings occupied by sensitive and fragile persons, TM52 suggests the more demanding standard for Category I buildings may be appropriate. The approach presented in TM52 is recommended in the new edition of the CIBSE Guide A (CIBSE 2015).

ANSI/ASHRAE Standard 55-2013: Thermal environmental conditions for human occupancy

ASHRAE advice on the design of free running buildings is similar to the BS EN 15251:2007. The ANSI/ASHRAE Standard 55-2013 (ASHRAE 2013) uses BS EN 15251:2007 to relate indoor comfort temperatures in free running spaces to running mean outdoor temperatures, measured for no less than seven and no more than thirty days prior to the day under consideration.

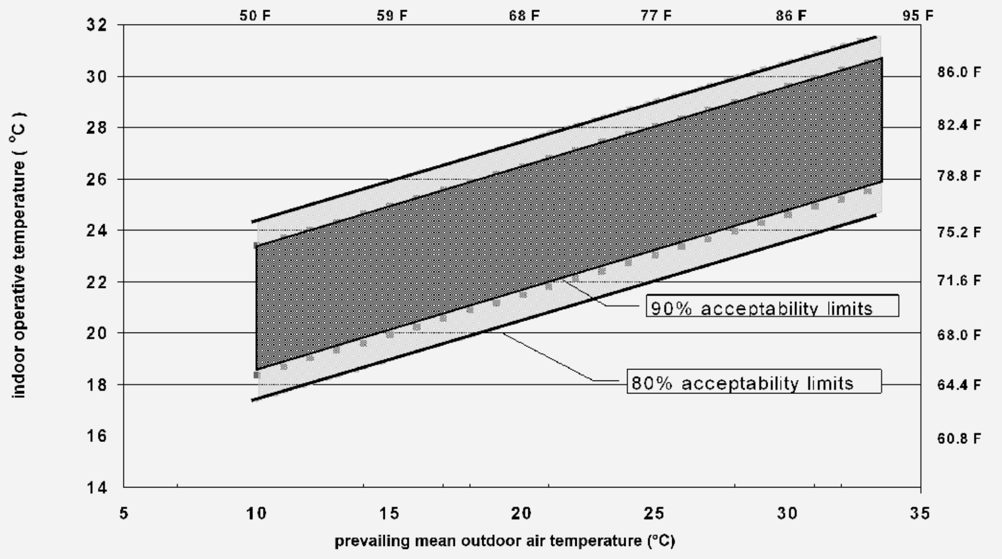

Figure 3. **Acceptable indoor temperatures for free running buildings. Used with kind permission from ASHRAE.**

Although two ranges are presented, 90% and 80% acceptability, the Standard states that acceptable indoor temperatures should be calculated using the 80% acceptability limits, while the 90% acceptability limits are to be used when a higher standard of thermal comfort is required.

The Standard sets a range of no less that 10°C and no greater than 33.5°C for the prevailing mean outdoor air temperature where this method should be applied. The comfort temperatures can be taken as constant if the running mean temperature is outside those limits (McCartney & Nicol 2002).

Other industry standards

Other industry standards used in the UK include the Building Research Establishment Environmental Assessment Methodology (BREEAM) Code for Sustainable Homes (BREEAM 2014), and Passivhaus (Passivhaus 2014).

The BREEAM Code, although it includes a chapter on health and wellbeing, does not refer to the summer thermal performance of homes. This is not surprising as it goes hand-in-hand with SAP and draws on the SAP analysis to inform the energy credits. Because of the air-tight nature of the Passivhaus homes, overheating is identified as a risk and the Standard introduces the threshold of 25°C which should not occur in a building for more than 10% of the occupied year.[1] The Standard also recommends that the frequency of overheating does not exceed 5% in order to guarantee high summer comfort.

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[1] For a Passivhaus dwelling the occupied year is considered to be 365 days.

05

HEALTH AND WELLBEING THRESHOLDS

Physiological effects of heat exposure

The various sets of guidance described in the preceding section were largely based on definitions of thermal comfort. Equally important, but more difficult to practically define, are thresholds for health.

There are several mechanisms by which increased heat exposure can impair health. A healthy individual's core body temperature is maintained within a safe range of around 37°C as a result of homeostatic mechanisms that include the loss of heat from the skin through convection, conduction, radiation, and evaporative processes. Adverse effects on health can arise if the temperature of the brain and other vital organs rises or if the attempt to maintain normal body temperature leads to decompensation of the circulatory and other systems.

The physiological responses to heat are continuous functions (DCLG 2012b) and there is a multi-stage transition from thermal discomfort to heat stress (D'Ambrosio Alfano et al. 2013). Moreover, a large burden of adverse heat-related effects on health may occur in the absence of clearly identifiable heat stress and affect a wide range of clinical conditions. Thus, heat-related illness consists of a spectrum that includes heat rash, heat oedema, heat cramps, heat syncope, heat exhaustion, heat stroke and even death (Kilbourne 1999; Bouchama & Knochel 2002). It is often identifiable epidemiologically through a statistical increase in the occurrence of multiple causes of morbidity and mortality (especially from cardiorespiratory illnesses) with increasing ambient temperature (Kovats & Hajat 2008a; Kilbourne 1999). See the Impacts of Overheating Evidence Review for further discussion.

The following sections set out a number of wellbeing and health-based thresholds found in the current literature and offer an overview of existing knowledge gaps and suggestions for further research.

Box 5. **Acclimatisation**

Humans can adapt/acclimatise to a wide range of climatic conditions through biological, behavioural and socio-cultural processes. Some authors call this 'temperature training/fine-tuning' (van Marken Lichtenbelt & Kingma 2013).

Although the initial physiological acclimatisation to hot weather could potentially occur within a few days, complete acclimatisation of a population to a warmer climate may take several years (Kovats & Akhtar 2008). But beyond certain limits, the ability of the human body to maintain thermoregulation through physiological processes becomes increasingly difficult and eventually impossible with continuing thermal exposure (Parsons 2003).

Impacts of high ambient temperature on morbidity and mortality

Epidemiological evidence on the relationship between high ambient temperatures and mortality/morbidity is largely based on time-series studies that examine the frequency of adverse health events occurring in defined geographical populations in relation to daily outdoor temperature usually recorded at one or more weather stations.

Well-established U-shaped relationships exist for cold and heat-related mortality and morbidity (Basu 2002, Kovats & Hajat 2008a, Armstrong et al. 2011, Gasparrini et al. 2012). Maximum daytime outdoor temperature is a strong predictor of mortality, and in general, relatively limited additional explanatory power is obtained by the addition of, for example, the daily minimum temperature in regression models (DCLG 2012b, Hajat et al. 2006).

Temperature-mortality curves have been characterised for a number of locations and populations worldwide (Armstrong et al. 2011, Baccini et al. 2008, Ishigami et al. 2008, Vandentorren et al. 2004, McMichael et al. 2008 and D'Ippoliti et al. 2010). Those developed for various regions in England and Wales are illustrated in Table 5 and Figure 4 below.

Lower heat-related mortality thresholds are observed as we move from south to north. For example, the corresponding mortality thresholds are 23.5°C for the South East and 20.9°C for the North East. In addition, the shape of the curves indicates that mortality rates are higher towards the upper end of the observed temperature distributions.

A similar relationship is observed between outdoor temperature and morbidity. Proxies for the latter include hospital admissions (Guirguis et al. 2014), ambulance calls or other forms of reported communication with health professionals (DCLG 2012b). It is worth noting, however, that these curves are truncated at the lower end and do not fully capture cold-related mortality effects.

Some of the adverse effects of high outdoor temperatures may arise as a result of increases in the atmospheric concentration of ozone, the levels of which tend to rise through photochemical processes during periods of warm sunny weather (DCLG 2012b).

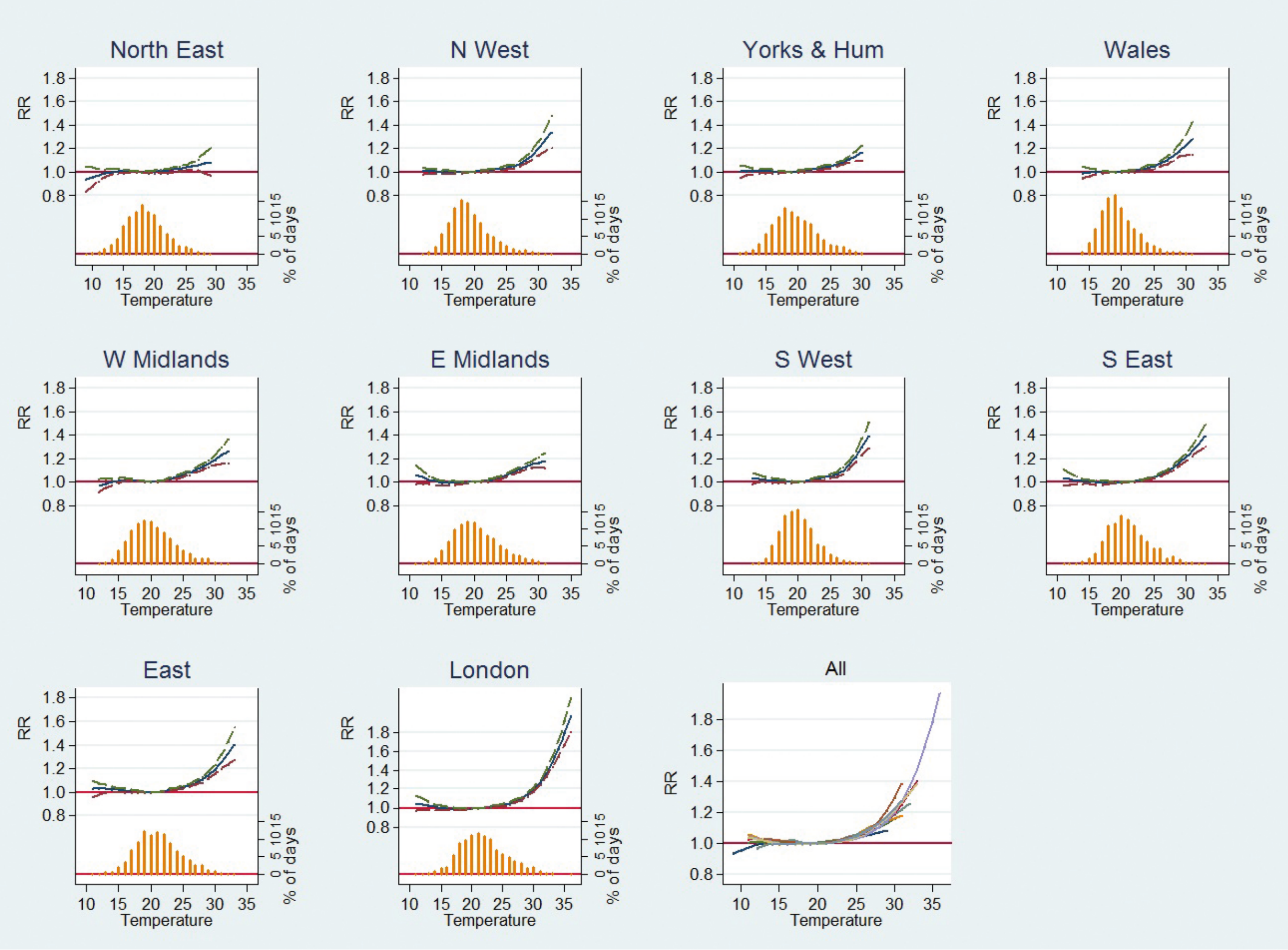
In London, mortality appears to rise when the maximum daily air temperature goes above 24.7°C, with approximately a 3.33% increase in mortality for every 1°C increase in external temperature (DCLG 2012b).

Table 5. **Summer daily maximum temperature and heat-related mortality thresholds across regions in England and Wales between 1993 and 2006 (recreated from Armstrong et al. 2011)**

Region	Mean (°C)	(Min, max,°C)	93rd centile* (threshold,°C)
North East	18.4°C	(8.8°C, 29.4°C)	20.9°C
North West	19.3°C	(11.5°C, 32.0°C)	21.7°C
Yorkshire & Humberside	19.5°C	(10.5°C, 30.3°C)	22.2°C
Wales	19.6°C	(12.4°C, 31.6°C)	21.6°C
West Midlands	20.3°C	(9.9°C, 33.8°C)	23.0°C
East Midlands	20.3°C	(9.7°C, 32.3°C)	23.0°C
South West	20.1°C	(12.3°C, 30.9°C)	22.3°C
South East	21.0°C	(10.2°C, 34.0°C)	23.5°C
East	21.2°C	(10.5°C, 34.5°C)	23.9°C
London	21.8°C	(10.7°C, 37.3°C)	24.7°C

**93rd centile of year-round 2-day mean temperature distribution*

Figure 4. **Temperature-mortality associations in each region in England and Wales, Source: Armstrong et al. (2011), (RR: Relative Risk)**



The epidemiological evidence presented above forms the basis of public health response systems. The Heatwave Plan for England (PHE & NHS 2014) is a document developed collaboratively between Public Health England (PHE), the National Health Service (NHS) England and the Local Government Association (LGA). It is supported by the Department of Health and the Met Office, who operate a Heat-Health Watch System (HHWS) for England. It consists of five levels of response on the basis of region-specific maximum daytime and minimum night time temperature thresholds, which are outlined in the Heatwave Plan for England 2014. The trigger levels and response levels are set out at Annex 2.

Importantly, however, heat-related deaths also occur outside heatwave events, i.e. when the external temperature lies below heat wave thresholds (Armstrong et al. 2011). The reason trigger temperatures are set at the level they are is to seek a balance between encouraging action and avoiding alert fatigue (alerts being raised multiple times throughout the season).

It is also worth noting that there is large variation of thermal discomfort and heat stress risk within population groups, and as a result it is expected that there will be different thresholds for different people based on their age, health and socioeconomic status (Hajat et al. 2010). Heat vulnerability is expected to be widely distributed across the population.

A growing body of epidemiological literature has investigated the individual determinants of heat vulnerability but a detailed review of such studies is beyond the scope of the present report. In brief, the very young and the elderly (above 65 years old), chronically ill (in particular individuals suffering from cardiovascular, cerebrovascular, renal and respiratory diseases, as well as mental health disorders), low-mobility (e.g. confined to bed), socially isolated, socially deprived individuals and urban dwellers are likely to be affected the most during extreme heat episodes (Kovats & Hajat 2008b; Hajat et al. 2007; Hajat & Kosatky 2010).

Despite the wealth of epidemiological studies that demonstrate a strong relationship between external ambient temperature and excess heat-related morbidity and mortality, and various theoretical frameworks aiming to define internal temperature thresholds for comfort, there are currently no established, universally accepted upper internal temperature thresholds for health.

Box 6. Acclimatisation

The lack of a universally accepted upper internal temperature thresholds for health has been identified by many (Koppe et al. 2004, DCLG 2012b, DCLG 2012a, LCCP 2012, Anderson et al. 2013, White-Newsome et al. 2012) and has been partly attributed to a number of factors:

- Large scale, longitudinal indoor temperature measurements of high spatial and temporal resolution across representative UK dwelling types are generally sparse. In addition, there appears to be a lack of consistency as to how indoor overheating metrics are reported, thus not allowing the cross comparison and meta-analysis of results of various studies.
- There is a high level of complexity arising from the heterogeneity of indoor environments, both as regards to physical characteristics as well as in relation to the modifying effect of human behaviour and associated adaptive capacity actions aiming to reduce indoor overheating risk (Chan et al. 2001, Mavrogianni et al. 2014).
- Occupants will tend to have different degrees of vulnerability to heat depending on their age, health, social contacts etc., which makes it challenging to specify a single threshold.
- The lack of a shared vocabulary between built environment and health researchers has resulted in monitoring studies of indoor thermal environments not being directly linked to health outcomes.

A recent review led by the UK's Health Protection Agency (HPA), now Public Health England (PHE) (HPA 2011, Anderson et al. 2013) outlined the urgent need for collection of evidence in this area and suggested that the determination of such thresholds and the development of an appropriate indoor heat vulnerability index is a public health issue.

Only a small number of attempts have been made to date a) to specify upper indoor temperature thresholds for health and b) to develop indoor overheating risk indices. Some of the health-based indoor temperature thresholds found in the current literature are briefly summarised below:

- According to WHO guidance, the air temperature below which heat-related health effects for sedentary people, such as the elderly, are minimised is 24°C (WHO 1987). It should be noted that this limit is slightly lower than the CIBSE Guide A static upper thermal comfort indoor operative temperature thresholds and potentially the comfort temperature thresholds that may be calculated using the CIBSE TM52 adaptive approach. In addition, it does not factor in individual behavioural responses and adaptive capacity that are likely to result in a wider range of temperatures that would be considered optimal for different people.
- Although indoor temperature levels are not commonly included in the UK HHWS, the Heatwave Plan for England 2014 recommends that 'cool areas' (i.e. spaces with temperatures below 26°C) are provided in hospitals, care/nursing homes and residential environments occupied by vulnerable individuals. It is also suggested that the indoor temperature is monitored regularly in spaces occupied by vulnerable individuals during hot periods and, if needed, reduced through passive cooling measures (shading, switching off appliances, night ventilation, use of fans provided internal temperatures are beneath 35°C etc.). However, it does not specify what would constitute a dangerous threshold of indoor temperature.

Box 7. Regulation

The UK Building Regulations and Housing Health and Safety Rating System (HHSRS) (Office of the Deputy Prime Minister 2004) do not currently incorporate any guidance on healthy indoor temperature ranges to be enforced at the design or retrofit stage of a building's lifetime, although the HHSRS mentions that adverse health effects increase when (external) temperatures rise above 25°C.

In the long term, it is suggested that detailed housing surveys and high resolution indoor temperature measurements connected to health outcomes through time-series or case-control data are conducted in order to determine how housing characteristics and resulting indoor temperatures affect heat-related health risk.

As regards the development of an indoor heat vulnerability index, two distinct methodological approaches have been identified in the literature: a) the physiological evidence approach, and b) the epidemiological evidence approach. The fundamental differences of these two approaches have been discussed in detail elsewhere (DCLG 2012b). In brief:

- The physiological evidence approach is commonly based on the bottom-up study of the biological responses of healthy individuals to heat, often in laboratory conditions. The observed relationships are subsequently extrapolated to larger populations; and
- The epidemiological evidence approach which relies on macro-level analysis of events, such as summertime mortality, that allows the derivation of thresholds for adverse health effects at the aggregate population level.

An example of the former approach is the Heat-related health Effects Index (HEI), a physiologically-based modelling framework developed by Chan et al. (2001) following the 1995 Chicago heatwave. The index is able to calculate core body temperature and assess associated adverse health impacts during periods of heat stress based on information about site-specific environmental conditions and behavioural responses.

An epidemiological evidence-based framework has been developed as part of the ongoing NERC-funded research project 'Air Pollution and Weather-related Health Impacts: Methodological Study based On spatio-temporally disaggregated Multi-pollutant models for present day and futurE' (AWESOME) (LSHTM 2014). One of the project aims is to assess the modifying effect of housing characteristics on the variation of heat-related health impacts across the UK, in line with other simplified indoor temperature prediction modelling tools developed in the US (White-Newsome et al. 2012) and Canada (Smargiassi et al. 2008), which rely on the extraction of reduced data from Geographic Information Systems (GIS) databases.

06
PRODUCTIVITY THRESHOLDS

Whilst a review of comfort and health-based thresholds for non-domestic buildings is beyond the scope of this paper, a summary of thresholds found in the literature related to the resilience of workplace environments related to housing is summarised in this section.

People's experiences of thermal conditions in residential and work settings are closely intertwined. It is likely, for example, that the cumulative effects of night time discomfort, sleep disruption and sleep deprivation, in combination with sustained heat exposure in the workplace during the day will have an impact on the ability of individuals to concentrate and perform both physical (Kerslake 1972, Bridger 2008) and mental (Ramsey 1995) activities.

It is likely that the percentage of people working from home may increase during prolonged heatwave periods following public health guidance to stay in the shade and out of the sun during the daytime. People may, as a result, choose to stay at home, thus blurring the divide between home and work environment. In this case, domestic indoor overheating risk is likely to impact upon work productivity levels.

Adverse heat stress effects could range from a reduction in work productivity levels (Kjellstrom et al. 2009) to risks in health and safety (Ramsey & Burford 1983). Regarding health and safety, research indicates that the incidence of occupational injuries and accidents either in the workplace or at home is likely to increase as external temperatures rise, however, further research is needed to identify clear thresholds for this effect (Ishigami et al. 2008).

Box 8. Heat exposure and productivity loss

The majority of studies carried out to date that examine the relationship between direct heat exposure and work productivity loss focus on manual labour capacity in low- and middle-income, hot, tropical and sub-tropical countries due to the fact that working populations in these countries already experience thermal conditions beyond the thresholds that human physiological mechanisms can cope with and are, thus, expected to be disproportionately affected by a warming climate (Kjellstrom et al. 2009; Kjellstrom, Sawada, et al. 2013).

The relevant metrics and thresholds have, therefore, been primarily developed to assess the impact of exposure to outdoor, rather than indoor, environments and should, thus, be applied to residential settings with a certain degree of caution.

People may increasingly work from home in the future. According to recent estimates (ONS 2015) around 14% of people at work in the UK are home workers, a percentage that has been increasing at a 2.8% rate since records began in 1998.

The most commonly used occupational heat stress index is the Wet Bulb Globe Temperature (WBGT) (Kjellstrom et al. 2009).[1] The WBGT was initially developed to control outbreaks of heat illness in US army training camps. It is an empirical index that quantifies the levels of physiological stress associated with prolonged heat exposure. It factors in the integrated effect of air temperature, radiant temperature, humidity and air speed on human thermal discomfort and potential heat stress.

Resilience to heat depends on metabolic activity levels. The thresholds of WBGT above which preventive action should be sought to reduce heat exposure risks levels for working people are presented in ISO Standard 7243:1989 (ISO 1989) and, for Britain, in BS EN Standard 27243:199 4 (BSI 1994) for various levels of work intensity.

Figure 5 illustrates the estimated work/rest regime ratios for different values of WBGT and work intensity levels for an acclimatised, healthy, physically fit, lightly clothed person with sufficient water intake, assuming no sensible air movement (Kjellstrom et al. 2009; Holmér 2010; ISO 1989). According to existing guidelines, work activity should not be continued without heat protective clothing if these thresholds are exceeded. Lower thresholds will apply for workers wearing heavier clothing. According to Kjellstrom et al. (2009) the WBGT thresholds above which an average acclimatised worker wearing light clothing would not be able to continue working are:

- 39°C (light work)
- 37°C (medium work)
- 36°C (intense work)
- 34°C (very intense work)

With regard to cognitive performance, nevertheless, the ability of an individual to perform complex mental tasks has been found to drop within the range of 30–33°C WBGT (Hancock & Vasmatzidis 2003).

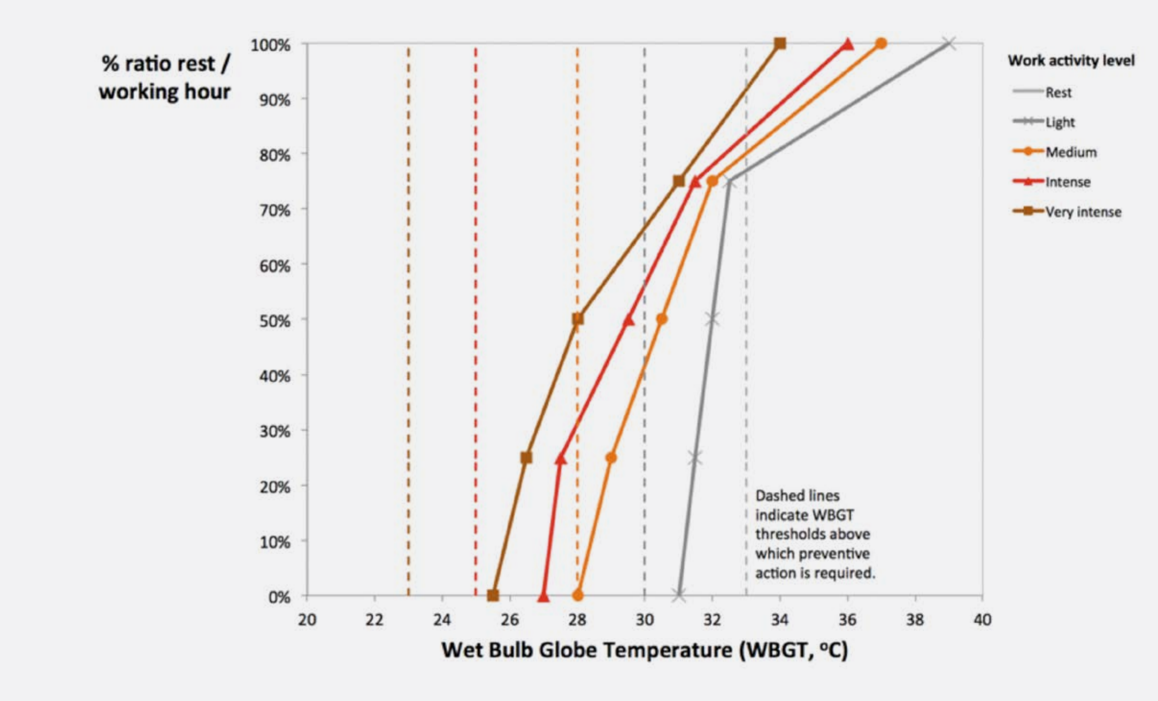


Figure 5. Approximate estimates of limiting WBGT thresholds for the percentage of a working hour needed for rest due to heat exposure for different activity levels for an average acclimatised worker wearing light clothing assuming no sensible air movement, Source: ISO Standard 7243:1989 (ISO 1989), DCLG (2012b)

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[1] WBGT has a number of limitations, which have been addressed through the development of alternative heat stress risk indices often based on physiological models, such as, for example, the Universal Thermal Climate Index (UTCI), the Predicted Heat Strain Index (PHSI), the Required Sweat Rate Index (RSRI) and the Thermal Work Limit (TWL) (Kjellstrom et al. 2009). Their detailed presentation is, however, beyond the scope of the present report and, therefore, only WBGT thresholds are presented due to its wide implementation in the field of occupational health, e.g. studies that output WBGT from meteorological data to map regional work productivity loss risk worldwide (Lemke & Kjellstrom 2012; Kjellstrom, Lemke, et al. 2013).

Heat stress risk may be higher than indicated by the WBGT index inside buildings characterised by low thermal mass or high radiant heat emitted by internal processes or equipment. Furthermore, the WBGT index should be adjusted to take into account work duration levels, the clothing levels (protective clothing, in particular), potential acclimatisation levels of a given population or the adaptive capacity and other personal behavioural factors that might affect an individual's levels of heat stress (Budd 2008, Parsons 2006, Ashley et al. 2008).

It is also recommended that individual differences, including the effects of ethnic origin, cultural differences and human behaviour are taken into account when translating the WBGT index into a health risk function for a given region (Parsons 2006).

Notably, in contrast with other indices that adopt a physiological perspective, the WBGT index was derived from empirical relationships in non-domestic environments, primarily industrial settings, where individuals are likely to have limited adaptive capacity. It is likely, therefore, that it overestimates work capacity loss occurring as a result of heat stress in home environments, where individuals may have access to a wider range of adaptive thermal comfort options (clothing adjustment, use of ventilation and shading, breaks, consumption of cold beverages, cold showers etc.). Further research is, therefore, needed before the WBGT index can be applied to estimate heat stress experienced by people working from home.

Box 9. **Threshold temperature guidelines for workplaces**

A number of threshold temperature guidelines for workplaces are also provided in other industry health and safety best practice documents:

- The Health and Safety Executive (HSE) publication 'Thermal Comfort in the Workplace, Guidance for employers' (HSE 1999) suggests that an acceptable thermal comfort zone in the UK lies between around 13°C and 30°C, with acceptable temperatures for more strenuous work activities concentrated towards the bottom end, and more sedentary activities towards the higher end of the range.
- In CIBSE TM40 (CIBSE 2014), the threshold for maximum surface temperature, including heating radiators, is 43°C.
- Also in CIBSE TM40, for extreme environments in the UK it is recommended that medical supervision of working people is provided for work in extreme environments with air temperatures up to 50°C (BSI 2001).

07

INFRASTRUCTURE RESILIENCE THRESHOLDS

According to recent data from the English Housing Survey (EHS) Energy Follow-Up Survey (EFUS) (BRE 2013), the penetration of air conditioning is currently very low across the residential sector; less than 3% of English households were found to use a fixed or portable air conditioning unit during the summer. Nevertheless, the projected rises in summer air temperatures are likely to increase the demand for cooling (Day et al. 2009). A study of domestic air conditioning usage found, for example, that the indoor air temperature thresholds above which people tended to switch on their unit was 24-25°C (Pathan et al. 2008).

As electricity use increases to cover cooling needs, increased peak demand could put a strain on the grid. Blackout risk temperature thresholds are largely context-specific and given the lack of historical data, it is particularly challenging to provide an estimate of external air temperature thresholds above which the likelihood of power outages may increase in the UK. It has, however, been suggested that for air temperatures above 30°C overhead power lines have reduced rating factors and power and refrigeration networks lose capacity for every 1°C of increase in external temperatures (LCCP 2012).

08

OBSERVATIONS

The aim of this Review was to present existing overheating thresholds for thermal comfort, health, wellbeing, productivity and infrastructure resilience, assess the level of evidence on which each threshold is based on and comment on their practical implementation to date.

Adaptive comfort models

In summary, the indoor thermal comfort thresholds are an area in which considerable research has been carried out in recent years, primarily revolving around the two theoretical approaches, the static and adaptive thermal comfort model.

Research in this field has resulted in a number of thresholds that are described in detail in a series of standards. Whilst the absolute/single temperature exceedance, static threshold approach was until recently widely adopted by industry professionals, following the update of UK, EU and US comfort standards such as the CIBSE TM52, the BS EN 15251 and the ASHRAE 55-2013, there is now a requirement by the industry to apply the adaptive approach. This approach aims to increase awareness of the importance of microclimatic, psychological, behavioural and cultural factors on thermal comfort.

Although primarily based on studies in office buildings, based on the fact that human physiology stays the same at work and at home, it seems reasonable to assume that adaptive comfort models broadly apply in residential buildings as well where the ability to adapt the surrounding environment and clothing is more flexible than in the office and so could allow a wider range of comfort temperatures.

Further research will be needed to investigate the relevance of the adaptive thermal algorithm to the domestic sector and how it can be adapted for use in the design of homes. More investigation is also needed in the application of the adaptive thermal algorithm to buildings that house vulnerable occupants with varied health conditions such as hospitals and care homes.

The SAP methodology is currently widely used by practitioners in design to check whether a home is likely to overheat. SAP is a compliance tool rather than a design tool and, as such, provides a basic calculation of overheating risk. A more dynamic approach is necessary to determine the severity of the overheating risk and the effectiveness of various remedial solutions. However, because of the resource intensity of dynamic simulation design methods, they do not currently represent a standard design approach in the domestic sector.

A comprehensive methodology for the design of homes would be needed to enable the annual and seasonal performance of homes to be assessed without adding considerable resource requirement to existing industry practices.

Health-related thresholds

Indoor environmental health-related thresholds are less well defined in comparison to thermal comfort-based thresholds, despite the well-characterised epidemiological relationships between outdoor ambient temperature and heat-related morbidity and mortality. This is partly attributed to the methodological complexity of linking indoor environments with health outcomes and the lack of research work in this area to date.

Heat-related adverse health impacts also largely depend on individual characteristics and levels of exposure, which adds another layer of complexity to the specification of health-related indoor environment thresholds.

This Review also briefly touched upon other thresholds that may apply to people working from home, such as, for example, heat stress thresholds related to work capacity and cognitive performance. Such thresholds, albeit well established and widely used, are accompanied by the caveat that they have been developed for industrial settings. Caution is advised when they are applied to residential environments.

The main temperature-related thresholds discussed in this Review that apply to the UK context are summarised in Table 8 (mainly outdoor temperature thresholds identified in epidemiological studies) and Table 9 (mainly indoor temperature guidance thresholds) below.

A key limitation that has arisen from this Review is that evidence-based thresholds related to different sectors have been developed on the basis of different environmental variables, quite often by researchers from different disciplines. As a result, they are commonly expressed in different metrics and are therefore not directly comparable with each other.

Future research should establish an integrated approach towards the definition of overheating thresholds that cuts across comfort, wellbeing and health impacts. This should be underpinned by a large-scale, high-resolution, inter-disciplinary monitoring study of a statistically representative sample of the UK housing stock, including the consideration of occupants with a range of health statuses.

Table 6. Summary of outdoor temperature thresholds

Upper threshold or range	Variable	Outcome when values exceed threshold or fall outside the range	Source
15.0°C	Night time maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the North East region	Heatwave Plan for England 2014
15.0°C	Night time maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the North West region	Heatwave Plan for England 2014
15.0°C	Night time maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the Yorkshire & Humberside region	Heatwave Plan for England 2014
15.0°C	Night time maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the West Midlands region	Heatwave Plan for England 2014
15.0°C	Night time maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the East Midlands region	Heatwave Plan for England 2014
15.0°C	Night time maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the South West region	Heatwave Plan for England 2014
16.0°C	Night time maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the South East region	Heatwave Plan for England 2014
18.0°C	Night time maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the London region	Heatwave Plan for England 2014
20.9°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the North East region	Armstrong et al. 2011
21.6°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the Wales region	Armstrong et al. 2011
21.7°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the North West region	Armstrong et al. 2011
22.2°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the Yorkshire & Humberside region	Armstrong et al. 2011
22.3°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the South West region	Armstrong et al. 2011
23.0°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the West Midlands region	Armstrong et al. 2011
23.0°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the East Midlands region	Armstrong et al. 2011
23.5°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the South East region	Armstrong et al. 2011
23.9°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the East region	Armstrong et al. 2011
24.7°C	Daily maximum outdoor air temperature (°C)	Excess heat-related mortality for the London region	Armstrong et al. 2011
28.0°C	Daytime maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the North East region	Heatwave Plan for England 2014
29.0°C	Daytime maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the Yorkshire & Humberside region	Heatwave Plan for England 2014
30.0°C	Daytime maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the North West region	Heatwave Plan for England 2014
30.0°C	Daytime maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the West Midlands region	Heatwave Plan for England 2014
30.0°C	Daytime maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the East Midlands region	Heatwave Plan for England 2014
30.0°C	Daytime maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the South West region	Heatwave Plan for England 2014
31.0°C	Daytime maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the South East region	Heatwave Plan for England 2014
32.0°C	Daytime maximum outdoor air temperature (°C)	Heat-Health Warning Level 3 trigger for the London region	Heatwave Plan for England 2014

Table 7. Summary of indoor temperature thresholds (please note that, although rank-ordered, the thresholds express different metrics and cannot be directly compared)

Upper threshold or range	Variable	Outcome when values exceed threshold or fall outside the range	Source
20.5 – 22.0°C	Monthly mean summer indoor temperature (°C) as modelled in SAP Appendix P	Slight likelihood of high internal temperatures during hot weather	Standard Assessment Procedure (SAP): Appendix P
22.0 - 23.5°C	Monthly mean summer indoor temperature (°C) as modelled in SAP Appendix P	Medium likelihood of high internal temperatures during hot weather	Standard Assessment Procedure (SAP): Appendix P
23.0 - 25.0°C	Indoor operative temperature (°C)	Summertime thermal comfort in living rooms and bedrooms in air-conditioned dwellings	CIBSE Guide A (2006 edition)
23.0°C	Indoor operative temperature (°C)	Summertime thermal discomfort in bedrooms in free running dwellings	CIBSE Guide A (2006 edition)
23.5°C	Monthly mean summer indoor temperature (°C) as modelled in SAP Appendix P	High likelihood of high internal temperatures during hot weather	Standard Assessment Procedure (SAP): Appendix P
24.0°C	Indoor operative temperature (°C)	Sleep impairment in bedrooms in free running dwellings	CIBSE Guide A (2006 edition)
24.0°C	Indoor air temperature (°C)	Heat-related health effects for dwellings	WHO Guidance
24.0 - 25.0°C	Indoor air temperature (°C)	Switching-on of air-conditioning (if installed) in dwellings	Pathan et al. 2008
25.0°C	Indoor operative temperature (°C)	Thermal discomfort in living rooms in free running dwellings	CIBSE Guide A (2006 edition) [1]
26.0°C	Indoor operative temperature (°C)	Overheating in bedrooms in free running dwellings	CIBSE Guide A (2006 edition)
26.0°C	Indoor air temperature (°C)	Room would not function as a 'cool spaces'	Heatwave Plan for England 2014
28.0°C	Indoor operative temperature (°C)	Overheating in living rooms in free running dwellings	CIBSE Guide A(2006 edition)
30.0°C	Indoor air temperature (°C)	Heat-related health effects for workplaces	HSE Guidance
35.0°C	Indoor air temperature (°C)	Use of fans should be avoided	Heatwave Plan for England 2014
43.0°C	Surface temperature (°C)	Safety limit, including heating radiators, for institutional buildings	CIBSE TM40
50.0°C	Indoor air temperature (°C)	Medical supervision requirement for workplaces (extreme environments)	CIBSE TM40

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1. Note that the CIBSE Guide A (2006) thresholds have now been superseded by the adaptive overheating criteria as published in TM52.

09
BIBLIOGRAPHY

Anderson, C.A., 2001. Heat and violence. Current Directions in Psychological Science, 10(1), pp.33–38. Available at: http://cdp.sagepub.com/lookup/doi/10.1111/1467-8721.00109 [Accessed October 8, 2014].

Anderson, M. et al., 2013. Defining indoor heat thresholds for health in the UK. Perspectives in Public Health, 133(3), pp.158–164. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22833542 [Accessed October 6, 2014].

Armstrong, B.G. et al., 2011. Association of mortality with high temperatures in a temperate climate: England and Wales. Journal of Epidemiology and Community Health, 65(4), pp.340–345. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20439353 [Accessed October 6, 2014].

Ashley, C.D. et al., 2008. Heat strain at the critical WBGT and the effects of gender, clothing and metabolic rate. International Journal of Industrial Ergonomics, 38(7-8), pp.640–644. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0169814108000255 [Accessed October 12, 2014].

ASHRAE, 2013. ANSI/ASHRAE Standard 55-2013 - Thermal environmental conditions for human occupancy, Atlanta, USA: American National Standards Institute (ANSI), American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE).

Baccini, M. et al., 2008. Heat effects on mortality in 15 European cities. Epidemiology, 19(5), pp.711–719.

Basu, R., 2002. Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence. Epidemiologic Reviews, 24(2), pp.190–202. Available at: http://epirev.oupjournals.org/cgi/doi/10.1093/epirev/mxf007 [Accessed August 22, 2014].

Bell, P.A., 1981. Physiological, comfort, performance and social effects of heat stress. Journal of Social Issues, 37(1), pp.71–94. Available at: http://doi.wiley.com/10.1111/j.1540-4560.1981.tb01058.x.

Beniston, M. & Diaz, H.F., 2004. The 2003 heat wave as an example of summers in a greenhouse climate? Observations and climate model simulations for Basel, Switzerland. Global and Planetary Change, 44(1-4), pp.73–81. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0921818104000980 [Accessed October 10, 2014].

Black, E. et al., 2004. Factors contributing to the summer 2003 European heatwave. Weather, 59(8), pp.217–223. Available at: http://doi.wiley.com/10.1256/wea.74.04.

Bouchama, A. & Knochel, J.P., 2002. Heat stroke. The New England Journal of Medicine, 346(25), pp.1978–1988.

BRE, 2013. Energy Follow-Up Survey 2011, Report 9, Domestic appliances, cooking & cooling equipment, Watford, UK: Prepared by BRE on behalf of the Department of Energy and Climate Change.

BRE, 2012. The Government's Standard Assessment Procedure for Energy Rating of Dwellings, SAP 2009, Watford, UK: Building Research Establishment (BRE).

BREEAM, 2014. Code for Sustainable Homes (CSH). Building Research Establishment Environmental Assessment Methodology (BREEAM). Available at: http://www.breeam.org/page.jsp?id=86.

Bridger, R.S., 2008. Introduction to ergonomics, Third edition, Boca Raton, USA: CRC Press, Taylor & Francis.

BSI, 2007. BS EN 15251: 2007, Indoor environmental input parameters for design and assessment of energy performance of buildings - addressing indoor air quality, thermal environment, lighting and acoustics, London, UK.

BSI, 2001. BS EN ISO 12894:2001: Ergonomics of the thermal environment, Medical supervision of individuals exposed to extreme hot or cold environments, London, UK: British Standards Institution (BSI).

BSI, 1994. BS EN ISO 27243:1994: Hot environments, Estimation of the heat stress on working man, based on the WBGT index, London, UK: British Standards Institution (BSI).

Budd, G.M., 2008. Wet-bulb globe temperature (WBGT)—its history and its limitations. Journal of Science and Medicine in Sport, 11(1), pp.20–32. Available at: http://www.ncbi.nlm.nih.gov/pubmed/17765661 [Accessed July 30, 2014].

Bushman, B.J., Wang, M.C. & Anderson, C.A., 2005. Is the curve relating temperature to aggression linear or curvilinear? Assaults and temperature in Minneapolis reexamined. Journal of Personality and Social Psychology, 89(1), pp.62–66. Available at: http://www.ncbi.nlm.nih.gov/pubmed/16060743 [Accessed October 13, 2014].

CBE, 2014. CBE Thermal Comfort Tool. Center for the Built Environment (CBE), University of California, Berkeley.

Chan, N.Y. et al., 2001. An empirical mechanistic framework for heat-related illness. Climate Research, 16, pp.133–143.

CIBSE, 2006. CIBSE Guide A, Environmental design, London, UK: Chartered Institution of Building Services Engineers (CIBSE).

CIBSE, 2005. TM36, Climate change and the indoor environment: impacts and adaptation. In London, UK: Chartered Institution of Building Services Engineers (CIBSE).

CIBSE, 2014. TM40, Health issues in building services, London, UK: Chartered Institution of Building Services Engineers (CIBSE).

CIBSE, 2013. TM52, The limits of thermal comfort: Avoiding overheating in European buildings, London, UK.

Cohn, E.G. & Rotton, J., 1997. Assault as a function of time and temperature: A moderator-variable time-series analysis. Journal of Personality and Social Psychology, 72(6), pp.1322–1334. Available at: http://doi.apa.org/getdoi.cfm?doi=10.1037/0022-3514.72.6.1322.

D'Ambrosio Alfano, F.R., Palella, B.I. & Riccio, G., 2013. On the transition thermal discomfort to heat stress as a function of the PMV value. Industrial Health, 51(3), pp.285–296. Available at: http://jlc.jst.go.jp/DN/JST.JSTAGE/indhealth/2012-0163?lang=en&from=CrossRef&type=abstract.

D'Ippoliti, D. et al., 2010. The impact of heat waves on mortality in 9 European cities: Results from the EuroHEAT project. Environmental Health, 9(37). Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2914717&tool=pmcentrez&rendertype=abstract.

Day, A.R., Jones, P.G. & Maidment, G.G., 2009. Forecasting future cooling demand in London. Energy and Buildings, 41(9), pp.942–948. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778809000838 [Accessed October 13, 2014].

DCLG, 2012a. Investigation into overheating in homes, Analysis of gaps and recommendations, London, UK: Department for Communities and Local Government (DCLG).

DCLG, 2012b. Investigation into overheating in homes, Literature review, London, UK: Department for Communities and Local Government (DCLG).

EC, 2004. How Europeans spend their time, Everyday life of women and men, Data 1998-2002, Luxembourg City, Luxembourg: European Commission (EC), Office for Official Publications of the European Communities.

Fanger, P.O., 1970. Thermal comfort: Analysis and applications in environmental engineering, New York, USA: McGraw-Hill.

Farrow, A., Taylor, H. & Golding, J., 1997. Time spent in the home by different family members. Environmental Technology, 18(6), pp.605–613. Available at: http://www.tandfonline.com/doi/abs/10.1080/09593331808616578 [Accessed October 7, 2014].

Fischer, E.M. & Schär, C., 2010. Consistent geographical patterns of changes in high-impact European heatwaves. Nature Geoscience, 3(6), pp.398–403. Available at: http://www.nature.com/doifinder/10.1038/ngeo866 [Accessed September 7, 2014].

Gamble, J.L. & Hess, J.J., 2012. Temperature and violent crime in Dallas, Texas: Relationships and implications of climate change. The Western Journal of Emergency Medicine, 13(3), pp.239–246. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3415828&tool=pmcentrez&rendertype=abstract [Accessed October 13, 2014].

Gasparrini, A. et al., 2012. The effect of high temperatures on cause-specific mortality in England and Wales. Occupational and Environmental Medicine, 69(1), pp.56–61. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21389012 [Accessed October 6, 2014].

GLA, 2006. London's urban heat island, A summary for decision makers, London, UK: Greater London Authority (GLA).

Gosling, S.N. et al., 2008. Associations between elevated atmospheric temperature and human mortality: A critical review of the literature. Climatic Change, 92(3-4), pp.299–341. Available at: http://link.springer.com/10.1007/s10584-008-9441-x [Accessed September 21, 2014].

Guirguis, K. et al., 2014. The impact of recent heat waves on human health in California. Journal of Applied Meteorology and Climatology, 53(1), pp.3–19. Available at: http://journals.ametsoc.org/doi/abs/10.1175/JAMC-D-13-0130.1 [Accessed October 6, 2014].

Guo, Y. et al., 2011. A large change in temperature between neighbouring days increases the risk of mortality. PLoS One, 6(2), p.e16511.

Hajat, S. et al., 2006. Impact of high temperatures on mortality: Is there an added heat wave effect? Epidemiology, 17(6), pp.632–638. Available at: http://www.ncbi.nlm.nih.gov/pubmed/17003686 [Accessed September 24, 2014].

Hajat, S. & Kosatky, T., 2010. Heat-related mortality: a review and exploration of heterogeneity. Journal of Epidemiology and Community Health, 64(9), pp.753–760. Available at: http://www.ncbi.nlm.nih.gov/pubmed/19692725 [Accessed August 26, 2014].

Hajat, S., Kovats, S. & Lachowycz, K., 2007. Heat-related and cold-related deaths in England and Wales: Who is at risk? Occupational and Environmental Medicine, 64(2), pp.93–100. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2078436&tool=pmcentrez&rendertype=abstract [Accessed September 25, 2014].

Hajat, S., O'Connor, M. & Kosatsky, T., 2010. Health effects of hot weather: From awareness of risk factors to effective health protection. Lancet, 375(9717), pp.856–863. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20153519 [Accessed October 7, 2014].

Hancock, P.A. & Vasmatzidis, I., 2003. Effects of heat stress on cognitive performance: The current state of knowledge. International Journal of Hyperthermia, 19(3), pp.355–372. Available at: http://www.ncbi.nlm.nih.gov/pubmed/12745975 [Accessed October 12, 2014].

Holmér, I., 2010. Climate change and occupational heat stress: Methods for assessment. Global Health Action, 3(5719). Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2997731&tool=pmcentrez&rendertype=abstract [Accessed October 12, 2014].

HPA, 2011. Overheating and health: A review into the physiological response to heat and identification of indoor heat thresholds, London, UK.

HSE, 1999. Thermal comfort in the workplace, Guidance for employers, HSG194, Sheffield, UK: Health and Safety Executive (HSE).

Humphreys, M.A., 1976a. Field studies of thermal comfort compared and applied. Journal of the Institution of Heating and Ventilating Engineers, 44, pp.5–27.

Humphreys, M.A., 1976b. Outdoor temperatures and comfort indoors. Building Research and Practice, 6(2), pp.92–105.

Humphreys, M.A., 1979. The influence of season and ambient temperature on human clothing behaviour. In P. O. Fanger & O. Valbjørn, eds. 1st International Indoor Climate Symposium, Indoor climate: Effects on human comfort, performance and health in residential, commercial and light-industry buildings. Copenhagen, Denmark: Danish Building Research Institute.

Humphreys, M.A., Rijal, H.B. & Nicol, J.F., 2013. Updating the adaptive relation between climate and comfort indoors; new insights and an extended database. Building and Environment, 63, pp.40–55. Available at: http://dx.doi.org/10.1016/j.buildenv.2013.01.024.

Ishigami, A. et al., 2008. An ecological time-series study of heat-related mortality in three European cities. Environmental Health, 7(5). Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2266730&tool=pmcentrez&rendertype=abstract [Accessed September 29, 2014].

ISO, 1989. ISO Standard 7243:1989, Hot environments - Estimation of the heat stress on working man, based on the WBGT-index (Wet Bulb Globe Temperature), Geneva, Switzerland: International Standards Organization (ISO).

ISO, 2005. ISO Standard 7730:2005, Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, Geneva, Switzerland: International Standards Organization (ISO).

Kaiser, R. et al., 2001. Heat-related death and mental illness during the 1999 Cincinnati heat wave. The American Journal of Forensic Medicine and Pathology, 22(3), pp.303–307.

Kerslake, D.M., 1972. The stress of hot environments, Cambridge, UK: Cambridge University Press.

Kilbourne, E.M., 1999. The spectrum of illness during heat waves. American Journal of Preventive Medicine, 16(4), pp.359–360.

Kjellstrom, T., Sawada, S.-I., et al., 2013. Climate change and occupational heat problems. Industrial Health, 51(1), pp.1–2. Available at: http://www.ncbi.nlm.nih.gov/pubmed/23411751.

Kjellstrom, T., 2000. Climate change, heat exposure and labour productivity. Epidemiology, 11(4), p.S144.

Kjellstrom, T., Holmer, I. & Lemke, B., 2009. Workplace heat stress, health and productivity - an increasing challenge for low and middle-income countries during climate change. Global Health Action, 2. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2799237&tool=pmcentrez&rendertype=abstract [Accessed August 10, 2014].

Kjellstrom, T., Lemke, B. & Otto, M., 2013. Mapping occupational heat exposure and effects in South-East Asia: Ongoing time trends 1980-2011 and future estimates to 2050. Industrial Health, 51, pp.56–67. Available at: https://www.jstage.jst.go.jp/article/indhealth/51/1/51_2012-0174/_article.

Koppe, C. et al., 2004. Heat-waves: Risks and responses, Health and Global Environmental Change Series, No. 2, Copenhagen, Denmark: World Health Orgnanization (WHO) Europe.

Kovats, S. & Akhtar, R., 2008. Climate, climate change and human health in Asian cities. Environment and Urbanization, 20(1), pp.165–175. Available at: http://eau.sagepub.com/cgi/doi/10.1177/0956247808089154 [Accessed November 29, 2014].

Kovats, S. & Hajat, S., 2008a. Heat stress and public health: A critical review. Annual Review of Public Health, 29, pp.41–55. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18031221 [Accessed September 17, 2014].

Kovats, S. & Hajat, S., 2008b. Heat stress and public health: a critical review. Annual Review of Public Health, 29, pp.41–55. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18031221 [Accessed March 7, 2013].

Krystal, A.D. & Edinger, J.D., 2008. Measuring sleep quality. Sleep Medicine, 9 Suppl 1, pp.S10–S177. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18929313.

Lader, D., Short, S. & Gershuny, J., 2006. The Time Use Survey, 2005, How we spend our time, London, UK: Office for National Statistics (ONS).

LCCP, 2012. Heat Thresholds Project, Final report, London, UK: London Climate Chnage Partnership (LCCP).

Lemke, B. & Kjellstrom, T., 2012. Calculating workplace WBGT from meteorological data: A tool for climate change assessment. Industrial Health, 50(4), pp.267–278. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22673363.

Lindley, S. et al., 2011. Climate change , justice and vulnerability. In London, UK: Joseph Rowntree Foundation (JRF).

LSHTM, 2014. "Air Pollution and WEather-related Health Impacts: Methodological Study based On spatio-temporally disaggregated Multi-pollutant models for present day and futurE" (AWESOME), Available at: http://awesome.lshtm.ac.uk.

Luber, G. & McGeehin, M., 2008. Climate change and extreme heat events. American Journal of Preventive Medicine, 35(5), pp.429–435. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18929969 [Accessed October 6, 2014].

Van Marken Lichtenbelt, W.D. & Kingma, B.R., 2013. Building and occupant energetics: A physiological hypothesis. Architectural Science Review, 56(1), pp.48–53. Available at: http://www.tandfonline.com/doi/abs/10.1080/00038628.2012.759377 [Accessed October 8, 2014].

Mavrogianni, A. et al., 2014. The impact of occupancy patterns, occupant-controlled ventilation and shading on indoor overheating risk in domestic environments. Building and Environment, 78, pp.183–198. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360132314001048 [Accessed September 29, 2014].

McCartney, K.J. & Nicol, J.F., 2002. Developing an adaptive control algorithm for Europe: Results of the SCATs project. Energy and Buildings, 34(6), pp.623–635.

Mcgregor, G.R. et al., 2007. The social impacts of heat waves, Science Report, SC20061/SR6, Bristol, UK: Environment Agency (EA).

McMichael, A.J. et al., 2008. International study of temperature, heat and urban mortality: The "ISOTHURM" project. International journal of epidemiology, 37(5), pp.1121–1131. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18522981 [Accessed October 6, 2014].

MetOffice, 2014. Heatwave. Heatwave. Available at: http://www.metoffice.gov.uk/learning/learn-about-the-weather/weather-phenomena/heatwave.

Milojevic, A. et al., 2011. Impact of London's urban heat island on heat-related mortality. Epidemiology, 22(1), pp.S182–S183.

MoL, 2011. Managing risks and increasing resilience, The Mayor's climate change adaptation strategy, London, UK: Mayor of London (MoL).

Nicol, J.F. & Humphreys, M.A., 2002. Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and Buildings, 34(6), pp.563–572. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778802000063.

Nicol, J.F. & Humphreys, M.A., 2010. Derivation of the adaptive Equations for thermal comfort in free running buildings in European standard EN15251. Building and Environment, 45, pp.11–17.

Office of the Deputy Prime Minister, 2004. Housing Health and Safety Rating System, Operating Guidance, Housing Act 2004, Guidance about inspections and assessment of hazards given under Section 9. In London, UK: Office of the Deputy Prime Minister (ODPM).

Oikonomou, E. et al., 2012. Modelling the relative importance of the urban heat island and the thermal quality of dwellings for overheating in London. Building and Environment, 57, pp.223–238. Available at: http://www.sciencedirect.com/science/article/pii/S0360132312001187.

Okamoto-Mizuno, K. & Tsuzuki, K., 2010. Effects of season on sleep and skin temperature in the elderly. International Journal of Biometeorology, 54(4), pp.401–409. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20041336 [Accessed October 7, 2014].

ONS, 2015. Record proportion of people in employment are home workers. Available at: http://www.ons.gov.uk/ons/rel/lmac/characteristics-of-home-workers/2014/sty-home-workers.html.

Page, L.A. et al., 2012. Temperature-related deaths in people with psychosis, dementia and substance misuse. The British Journal of Psychiatry, 200(6), pp.485–490. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22661680 [Accessed September 26, 2014].

Parmeggiani, P.L., 2003. Thermoregulation and sleep. Frontiers in Bioscience, 8, pp.557–567.

Parmegianni, P.L. & Velluti, R.A., 2005. The physiologic nature of sleep, London, UK: Imperial College Press.

Parsons, K., 2006. Heat stress standard ISO 7243 and its global application. Industrial Health, 44(3), pp.368–379. Available at: http://joi.jlc.jst.go.jp/JST.JSTAGE/indhealth/44.368?from=CrossRef.

Parsons, K., 2003. Human thermal environments: The effects of hot, moderate, and cold environments on human health, comfort and performance, Second edition, New York, USA: Taylor & Francis.

Passivhaus, 2014. The Passivhaus Standard. Passivhaus. Available at: http://www.passivhaus.org.uk/standard.jsp?id=122.

Pathan, A., Young, A. & Oreszczyn, T., 2008. UK domestic air conditioning: A study of occupant use and energy efficiency. In Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Windsor, UK, 27-29 July 2008. London, UK: Network for Comfort and Energy Use in Buildings (NCEUB), pp. 27–29.

PHE & NHS, 2014. Heatwave Plan for England 2014, Protecting health and reducing harm from severe heat and heatwaves, London, UK: Public Health England (PHE), National Health Service (NHS).

Poumadère, M. et al., 2005. The 2003 heat wave in France: Dangerous climate change here and now. Risk Analysis, 25(6), pp.1483–1494. Available at: http://www.ncbi.nlm.nih.gov/pubmed/16506977 [Accessed October 3, 2014].

Ramsey, J.D., 1995. Task performance in heat, A review. Ergonomics, 38(1), pp.6–22.

Ramsey, J.D. & Burford, C.L., 1983. Effects of workplace thermal conditions on safe work behavior. Journal of Safety Research, 14, pp.105–114.

Sailor, D.J., 2014. Risks of summertime extreme thermal conditions in buildings as a result of climate change and exacerbation of urban heat islands. Building and Environment, 78, pp.81–88. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360132314001085 [Accessed August 4, 2014].

Schweizer, C. et al., 2007. Indoor time-microenvironment-activity patterns in seven regions of Europe. Journal of Exposure Science and Environmental Epidemiology, 17(2), pp.170–181. Available at: http://www.ncbi.nlm.nih.gov/pubmed/16721413 [Accessed September 22, 2014].

Semenza, J.C. et al., 1996. Heat-related deaths during the July 1995 heat wave in Chicago. The New England Journal of Medicine, 335, pp.84–90.

Smargiassi, A. et al., 2008. Prediction of the indoor temperatures of an urban area with an in-time regression mapping approach. Journal of Exposure Science & Environmental Epidemiology, 18(3), pp.282–288. Available at: http://www.ncbi.nlm.nih.gov/pubmed/17579651 [Accessed October 6, 2014].

Stafoggia, M. et al., 2006. Vulnerability to heat-related mortality: A multicity, population-based, case-crossover analysis. Epidemiology, 17(3), pp.315–323. Available at: http://www.ncbi.nlm.nih.gov/pubmed/16570026 [Accessed October 6, 2014].

Vandentorren, S. et al., 2006. August 2003 heat wave in France: Risk factors for death of elderly people living at home. European Journal of Public Health, 16(6), pp.583–591. Available at: http://www.ncbi.nlm.nih.gov/pubmed/17028103 [Accessed October 7, 2014].

Vandentorren, S. et al., 2004. Mortality in 13 French cities during the August 2003 heat wave. American Journal of Public Health, 94(9), pp.1518–1520. Available at: http://ajph.aphapublications.org/doi/abs/10.2105/AJPH.94.9.1518.

White-Newsome, J.L. et al., 2012. Climate change and health: indoor heat exposure in vulnerable populations. Environmental Research, 112, pp.20–27. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22071034 [Accessed November 8, 2012].

WHO, 1987. Health impact of low indoor temperatures. In Copenhagen, Denmark: World Health Organisation (WHO).

WHO, 2008. Improving public health responses to extreme weather/ heat-waves – EuroHEAT, Meeting Report, Bonn, Germany, 22-23 March, 2007, Copenhagen, Denmark: World Health Organization (WHO) Europe.

ANNEX 1

Adaptive thermal comfort criteria in full, CIBSE TM52:

The three new CIBSE criteria in Technical Memorandum (TM) 52 (CIBSE 2013) are defined based on the BS EN 15251:2007. Together, they provide a more in-depth method for the assessment of overheating risk in UK and European buildings. A room or a building, which fails any two of the three criteria, is described as being likely to overheat.

The criteria are all defined in terms of ΔT, which is the difference between the actual operative temperature (a combination of indoor air temperature and mean radiant temperature) in the room at any time (Top) and the maximum acceptable temperature (Tmax). ΔT is measured in oK rounded to the nearest integer.

Criterion 1: Hours of Exceedance (He)

The number of hours (He) that ΔT is greater than or equal to one Kelvin during the period May to September inclusive shall not be more than 3% of occupied hours. If data are not available for the whole period (or if occupancy is only for a part of the period) then 3% of available hours should be used.

Criterion 2: Daily Weighted Exceedance (We degree-hours)

To allow for the severity of overheating, the weighted Exceedance (We) shall be less than or equal to 6 degree-hours (Kh) in any one day.

$We = \Sigma he \times wf = (he0 \times 0) + (he1 \times 1) + (he2 \times 2) + (he3 \times 3)$

Where the weighting factor $wf = 0$ if $\Delta T \leq 0$, otherwise $wf = \Delta T$, and hey = time in hours when $wf = y$

For example, a room where the temperature is simulated or monitored at half-hourly intervals over 8 occupied hours so we have 16 readings, 10 of them where ΔT is zero or negative ($wf = 0$), 3 readings where $\Delta T = 1$ ($wf = 1$), 2 where $\Delta T = 2$ ($wf = 2$) and one where $\Delta T = 3$ ($wf = 3$) then: $We = (½ (10x0 + 3x1 + 2x2 + 1x3)) = 5$ (i.e. the criterion is fulfilled)

Criterion 3: Upper Limit Temperature (Tupp)

To set an absolute maximum value for the indoor operative temperature the value of ΔT shall not exceed 4 K.

ANNEX 2

Heat-Health Watch System Response Levels and Trigger Temperatures

- Level 0 (blue, long term planning) covers year-round long-term planning and preparedness and encourages longer term actions (e.g. related to spatial planning and housing) that could reduce the harm to health of severe heat when it occurs.
- Level 1 (green, summer preparedness and long-term planning) represents the minimum state of vigilance during the summer.
- Level 2 (yellow, alert and readiness) is triggered when there is a 60% probability that threshold temperatures will be reached or exceeded in one or more regions on at least two consecutive days and the intervening night.
- Level 3 (amber, heatwave action) is triggered when threshold temperatures have been reached in one or more regions on one day and the following night, and it is very likely (90% confidence) that temperatures on the next day will be above the daytime threshold.
- Level 4 (red, emergency) is triggered in the case of a period of hot weather so severe and/or prolonged that it is likely to affect sectors other than health and social care, for example causing power or water shortages.

The trigger local temperature for Heat-Health Warnings are shown in Table 6.

Table 8. **Heat-Health Warning Level 2 and 3 threshold maximum daytime and night time temperatures by region, Source: PHE & NHS (2014)**

Region	Daytime temperature threshold (°C)	Night time temperature threshold (°C)
North East	28°C	15°C
North West	30°C	15°C
Yorkshire & Humberside	29°C	15°C
West Midlands	30°C	15°C
East Midlands	30°C	15°C
South West	30°C	15°C
South East	31°C	16°C
London	32°C	18°C

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