Overheating in new homes

A review of the evidence

Research Review

NHBC Foundation

Housing research in partnership with BRE Trust

ZERO CARBON HUB

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About the NHBC Foundation

The NHBC Foundation was established in 2006 by the NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the Government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy technologies and the earlier investigation of what zero carbon means to homeowners and house builders.

The NHBC Foundation is also involved in a programme of positive engagement with Government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org.

NHBC Foundation Advisory Board

The work of the NHBC Foundation is guided by the NHBC Foundation Advisory Board, which comprises:

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Professor Steve Wilcox, Centre for Housing Policy, University of York

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About the Zero Carbon Hub

The Zero Carbon Hub was established in the summer of 2008 to support the delivery of zero carbon homes from 2016. It is a public/private partnership drawing support from both Government and the industry and reports directly to the 2016 Taskforce.

The Zero Carbon Hub has developed five workstreams to provide a focus for industry engagement with key issues and challenges:

- Energy efficiency
- Energy supply
- Examples and scale up
- Skills and training
- Consumer engagement.

To find out more about these workstreams, please visit **www.zerocarbonhub.org**. If you would like to contribute to the work of the Zero Carbon Hub, please contact **info@zerocarbonhub.org.**

Foreword

As new homes are built with more thermal insulation and to improved standards of airtightness, the NHBC Foundation's Advisory Board is conscious of the increased risk of overheating that appears to be emerging. Our concerns are echoed by a growing number of industry colleagues. Alongside the key issue of indoor air quality, overheating ranks amongst our greatest concerns that need to be addressed as a priority.

This report documents a wide-ranging review of existing information and evidence on overheating, supplemented by outcomes from two industry workshops.

The first, run in association with the Health Protection Agency, concentrated on health issues and identified that, especially for vulnerable groups such as the elderly, the impact of overheating is extremely serious. An example of this is the heat wave that occurred in northern France in August 2003 for a period of three weeks and resulted in 15,000 excess deaths.

The second, involved practitioners from the house-building and housing sectors together with a range of other professionals. This workshop considered definitions and incidences of overheating in occupied homes. These incidences were examined in detail to see what lessons could be learned and how they could influence future housing design.

I am very grateful for the excellent contributions made by the delegates who attended these workshops and for the support of the Health Protection Agency throughout this research.

The report identifies good practice that should be observed in the design of new homes, from the earliest stages of outline planning through to the detail of services installation. It also provides a useful overview in the form of case studies. To begin to disseminate this good practice guidance to the wider industry, the NHBC Foundation has already published *Understanding overheating – where to start: An introduction for house builders and designers* (NF 44), which explains simply the key principles of good design.

Clearly, overheating is a risk that needs to be managed carefully as we move further towards the aim of zero carbon new homes. I hope that this report helps you to understand the issues associated with overheating and the steps that we can take to minimise its impact.

Rt. Hon. Nick Raynsford MP
Chairman, NHBC Foundation

Executive summary

This report presents and reviews evidence of overheating in dwellings, its causes and the consequences of overheating for the health of occupants. A number of recent BRE investigations into overheating in dwellings are presented and analysed as case studies. The report also discusses what parameters might be used in the definition of overheating including possible threshold temperature levels. Guidance on the requirements for reducing overheating is also presented and discussed.

There is increasing evidence that new and refurbished properties are at risk of overheating, especially small dwellings and flats and predominantly single-sided properties where cross ventilation is not possible. However, there is also evidence that prototype houses built to zero carbon standards are suffering from overheating, which shows that overheating may also become an issue where cross ventilation is not achievable in lightweight, airtight houses with little or no solar shading.

In many cases the lack of ability to reject the heat build-up from normal occupant activities means that a risk of overheating exists in summer. However, in some instances the gains are such that the overheating occurs for most of the year and is therefore independent of the external temperature.

A review of existing overheating criteria suggests that they are based on the upper limit of thermal comfort, rather than the threshold for long-term temperatures that may cause serious health problems for vulnerable groups. The medical evidence shows that although the health effects of exposure to excessive heat can be mild, if left untreated symptoms have the potential to develop quickly into severe, often fatal heat illness. With global climate change, increasing episodes of extremes in heat, an ageing population and urbanisation, this risk is expected to increase. However, at present the evidence base with which to inform policy and guidance is limited.

A significant risk factor is night-time temperature because higher night-time temperatures are thought to increase the risk to health due to the inability to recover from daytime heat stress and the interruption to sleep. Some of the case study evidence shows that the ability to cool dwellings down overnight is severely limited in some urban locations and property types.

The mechanisms of heat gain within buildings are all very well understood. However, existing guidance and modelling tools appear unable to predict overheating in all cases, and more work is needed to develop them based on robust practically proven research. This should include a practical assessment of the effectiveness of inclusion of thermal mass and night-time ventilation in new dwellings. Robust solutions are also needed for minimising heat gains in all future designs, and adaptation of such solutions for application to the existing stock, including reducing heat gains from communal heating systems.

The report concludes that there is still a pressing need to develop a universally accepted definition of overheating in dwellings, and that the development of robust national thresholds for use by planners, designers, builders and authorities is vital for dealing with overheating. The extent to which such thresholds could or should be regulated, for instance through the Building Regulations, is also a key issue for debate and action. At a more detailed level, agreement is needed on whether to base temperature criteria entirely on health or simply base them on thermal preferences (as has often been the case historically). Further research is also needed on how thresholds should take account of a changing outdoor climate, human adaptation and the effect of minimum night-time temperatures and diurnal variation.

1 Background

At present there is no rigorous definition of what constitutes overheating in dwellings. However, there is documented evidence that temperatures currently being reached in some existing dwellings are harmful to occupant health and well-being. It is also evident that some dwelling designs currently passing planning and building control, exhibit the same design and construction characteristics as existing dwellings where high temperatures are known to have caused harm to health and well-being. An accepted definition of what constitutes overheating is needed, so that designers, assessors and surveyors can predict and mitigate against the risk of overheating. It would also alert and inform policy makers and the whole construction industry to the importance of this issue.

The factors that contribute to overheating in dwellings include urbanisation, occupant behaviour and interventions, orientation, aspect, glazing, internal gains, thermal mass, changes in building design (including the drive for energy efficiency, leading to highly insulated and airtight dwellings), pollution, noise and security[1]. Many previous assessments and existing research into the subject have tended to make the assumption that window opening is an available option when occupants become hot but, particularly in urban locations, window opening is not always appropriate or safe for occupants, or is limited in its effectiveness. The Government's Standard assessment procedure (SAP) currently makes simplistic assumptions about ventilation, and is applied uniformly across the housing stock and throughout the UK. Alternative means of assessing overheating risk are required in order to capture factors such as a building's microclimate and actual occupant use of the means of ventilation provided.

At the present time, reported cases of overheating in existing dwellings are still relatively low in the context of the size of the housing stock, although three major factors are contributing to widespread concerns that the problem of overheating will increase in future years.

Firstly, the energy efficiency and zero carbon agendas have resulted in a drive for more highly insulated and airtight dwellings, in both new build and retrofit. Historically in the UK the use of heavyweight construction materials and limited amounts of thermal insulation, allied with high levels of infiltration through gaps in the building fabric, have contributed to minimise overheating. Highly insulated and airtight low and zero carbon homes, often designed with large areas of glazing, mechanical ventilation and/or communal heating systems have the potential to overheat throughout the year, not just in the summer months or in heatwaves. In rural and suburban locations it may be easy to use natural ventilation (eg window opening) to help cool dwellings, but in urban and deep-urban locations it is often not possible to do this. For example, in some cases windows cannot be opened to a great enough extent or occupants are not willing to do so for any length of time on the grounds of noise, pollution or security concerns.

Secondly, it is widely predicted that climate change will lead to further increases in temperatures in the UK, this being especially the case in the South East and in urban locations. Furthermore temperature maxima are expected to be higher and more frequent, as are heatwaves in which high temperatures persist for several days and nights. These meteorological factors will exacerbate the risk of overheating, especially in urban settings where other factors such as the urban heat island (UHI) effect come into play. Recent heatwaves have demonstrated very graphically the risk of overheating for some sections of the population. For example, Donaldson noted that in England and Wales estimated excess mortality associated with the 1995 heatwave (30 July to 3 August) to be 619 deaths (an 8.9% increase)[2]. In Northern France in August 2003 unprecedentedly high day and night-time temperatures for a period of three weeks resulted in 15,000 excess deaths[3]. The IPCC reported that across Europe as a whole it was estimated that the number of excess deaths was in the range of 35,000 in 2003[4]. In addition to heatwaves, it is expected that higher ultraviolet radiation levels and more days with dangerous ozone levels in the air will encourage more people to spend more time indoors[5].

Thirdly, increased urbanisation and an ageing population are expected to contribute to the impact of possible future scenarios. In the past 50 years there has been a 30% increase in the ratio of those living in urban areas to those in rural areas[6]. Due to the UHI effect and the unique microclimate generated by cities, and changes in dwelling design, more people may be affected by adverse health outcomes from rising temperatures. Population demographics are also changing globally, and particularly within the UK. As the UK population ages a greater proportion of the population will be exposed to higher indoor temperatures since the elderly tend to spend more of their time indoors.

Overheating is therefore an important issue which needs to be both understood and dealt with across the UK housing stock. The causes of overheating in dwellings and the effects that it may have on occupants, especially those in vulnerable groups who might be worst affected, need to be better understood. Excess heat is already identified as a significant health problem (eg see the Housing Health and Safety Rating System, HHSRS guidance publication)[7]. Although not on the scale of excess cold, which is thought to be responsible for approximately 25,000 deaths per year in the UK, excess heat due to high outdoor temperatures is already thought to currently cause around 2000 deaths in the UK per year. Projections by climate change scientists indicate that this figure may increase markedly over the next century, and increased overheating in dwellings is very likely to be a major contributory factor in such an increase.

Crucially, although a reasonable body of research exists on outdoor heat and its effect on human beings, there is little published data on the way in which dwellings modify external temperatures and on measurements of coincidental outdoor/indoor temperatures in dwellings. As well as a need for research into the effects of overheating on building occupants it is imperative that policy makers, planners, designers, builders and dwelling occupants are made more aware of the risks associated with overheating, and that measures are put in place to reduce them.

2 Introduction

This report is aimed primarily at policy makers and stakeholders in the house-building industry. It is based on the findings of a review project conducted by BRE for the NHBC Foundation. The review project was initiated following increasing anecdotal evidence of cases of overheating in the UK, and a series of investigations into dwellings where overheating had been reported – a significant number of them being of very recent construction.

The review project involved a desk study of the causes of overheating, a literature review on the effects of excess heat on human health, review of past BRE investigations into cases of overheating, and consultation with a range of stakeholders. In order to gauge the views of stakeholders, two interactive workshops were held in 2011. The first, held at the Health Protection Agency (HPA) in London, concentrated on the medical aspects and involved delegates from central and local government, chartered institutions, consultancies and academia. The 22 attendees were asked to consider the definition of overheating, causes and effects (including emphasis on vulnerable population groups), methods for mitigation or adaptation, and thresholds for intervention. The second workshop was held at BRE in Watford and was attended by 55 delegates from the house-building sector, housing association sector, central and local government, chartered institutions, consultancies and academia. The interactive sessions looked at definitions, causes and effects, thresholds for intervention, treatment or adaptation of existing dwellings, and design of future dwellings. At both workshops the delegates were asked to identify current knowledge gaps.

It is evident that a crucial starting point is to define exactly what the effects of overheating are in medical terms, since without a workable definition designs cannot be properly evaluated and robust benchmarks cannot be determined. It is also recognised that as evidence of overheating in existing dwellings increases, there is a need for a standard definition for use by assessors to determine whether a dwelling is overheating, or whether there is a risk of overheating occurring in future. Based on such a definition, robust thresholds for various levels of intervention should then be established.

Therefore Section 3 of the report initially considers the current definitions of overheating and presents the findings of a literature review of the medical effects of heat and overheating on human beings. The literature review was led by an HPA medical registrar in association with BRE and it is summarised here; the full review is available on the HPA website[8]. In addition, based on this review, Anderson et al have discussed the definition of indoor heat thresholds for health in a separate paper[9].

Section 4 considers the causes of overheating in existing dwellings based on basic building physics principles by considering aspects of building design that may contribute to the problem, and by reference to case studies of overheating investigations carried out by BRE. This section of the report is informed by the desk study, BRE case studies from overheating investigations, and stakeholder consultations.

Section 5 discusses the ways in which overheating may be reduced, again based on the desk study, findings from BRE case studies and consultation with stakeholders. Key to this is the consideration of lessons which can be learnt from planning, design and construction practices which have contributed to overheating. It is important to look forward and find ways in which all parts of the house-building supply chain can lessen the risk of building dwellings that have the potential to overheat and cause harm to occupants. The particular challenges presented by occupant behaviour, climate change, the low/zero carbon agenda and urban locations are considered in detail.

Section 6 of the report presents the main conclusions drawn from the review project and provides recommendations for areas of future research.

3 Overheating: definitions and health consequences

3.1 Is overheating thermal comfort?

3.1.1 Thermal comfort

There is no absolutely fixed value for thermal comfort, as evidenced by the range of places on Earth man has inhabited – from near polar to tropical. However, an internationally accepted definition of thermal comfort in ISO 7330[10] is 'that condition of mind which expresses satisfaction with the thermal environment'. Therefore, from a designer's point of view, the aim is to produce a design that, when constructed, allows the occupants to be thermally comfortable.

ISO 7330 is based on experiments studying the responses of individuals in tightly controlled environments. The result of this experimentation was the concept of PMV (predicted mean vote). The thermal comfort conditions are considered to approach optimum when the PMV indicates that the percentage dissatisfied (ie occupants who feel that the temperature is too hot or cold) is at a minimum.

A consequence of this approach to defining thermal comfort, which is based on an energy balance model, is that the results are the same almost regardless of the climatic conditions being considered. Also the model was developed from laboratory studies, and the effects of building type and its surroundings were not considered. Therefore considering these limitations the Chartered Institution of Building Services Engineers (CIBSE)[11] notes that, although this approach may be appropriate for fully air conditioned buildings where the occupants' ability to control their own environment through direct access to outside is minimal, it may not be appropriate for 'free running' buildings where openable windows allow internal conditions to be more closely linked to the outside conditions.

Work by Nicol et al assessing the thermal comfort of occupants who have a high degree of control over their internal environment has led to the development of the concept of 'adaptive thermal comfort'[12]. This approach is based on the findings of extensive field surveys which have shown that building occupants are more tolerant to temperature changes than the energy balance model would suggest. The adaptive approach to thermal comfort reflects the fact that people in daily life are not passive in relation to their environment, but tend to make themselves comfortable – by making adjustments (adaptations) to their clothing, activity and posture, as well as to their thermal environment. Over time people tend to become well adapted to thermal environments they are used to, and therefore tend to find them to be comfortable.

It must be noted that nearly all of the work on thermal comfort has been undertaken in office/commercial-type buildings. However, the concept of a 'free running' building, without mechanical cooling, describes most of the dwellings in the UK. Very few UK dwellings have air conditioning, and it has been noted that Fanger considered that in such buildings the adaptive approach may well be more appropriate[13].

CIBSE presents both approaches for building designers in its *Environmental Design, Guide A* depending on the nature of the building and the level of user control of the environment[11]. Figure 1 shows a comparison of the predicted comfort temperatures using the two approaches.

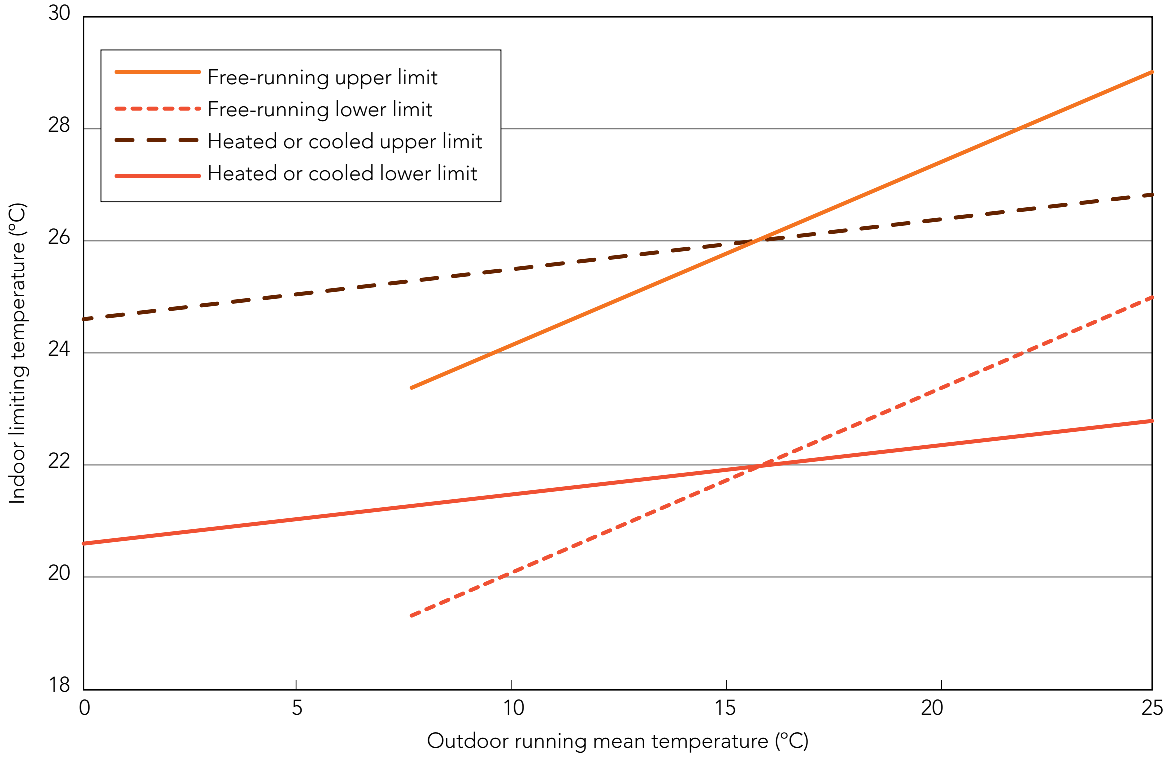


Figure 1 Comfort temperatures as a function of outdoor running mean temperature (Reproduced with permission from CIBSE *Environmental Design, Guide A*)[11]

3.1.2 Overheating

There is no precise or accepted definition of overheating, but based on the concept of thermal comfort, BS EN 15251 suggests that there is a maximum allowable difference from comfort temperature[14]. *Environmental Design, Guide A* suggests that a benchmark approach be used where the summertime thermal performance of the building is measured against a temperature that should not be exceeded for a defined number of hours or percentage of the occupied hours[11]. Therefore:

> *When the benchmark temperature is exceeded the building is said to have 'overheated' and if this occurs for more than the designated amount of time the building is said to suffer from 'overheating'.*[11]

For dwellings in the UK, which are mainly not air conditioned, the maximum allowable difference from the comfort temperature is suggested to be 3 or 4°C. The difference is based on an assumption of expectations for four different categories of building, graded I to IV. For air-conditioned buildings, BS EN 15251 suggests that the maximum operating temperature in the summer season for categories II (normal expectation, used for new buildings/renovations) and III (moderate expectation, used for existing buildings), is 26 and 27°C respectively. This corresponds to a running mean outdoor temperature of approximately 13°C for a building without mechanical cooling (Figure 2). This implies a very high level of heat gains within a building to produce such a large difference between the inside and outdoor air temperatures.

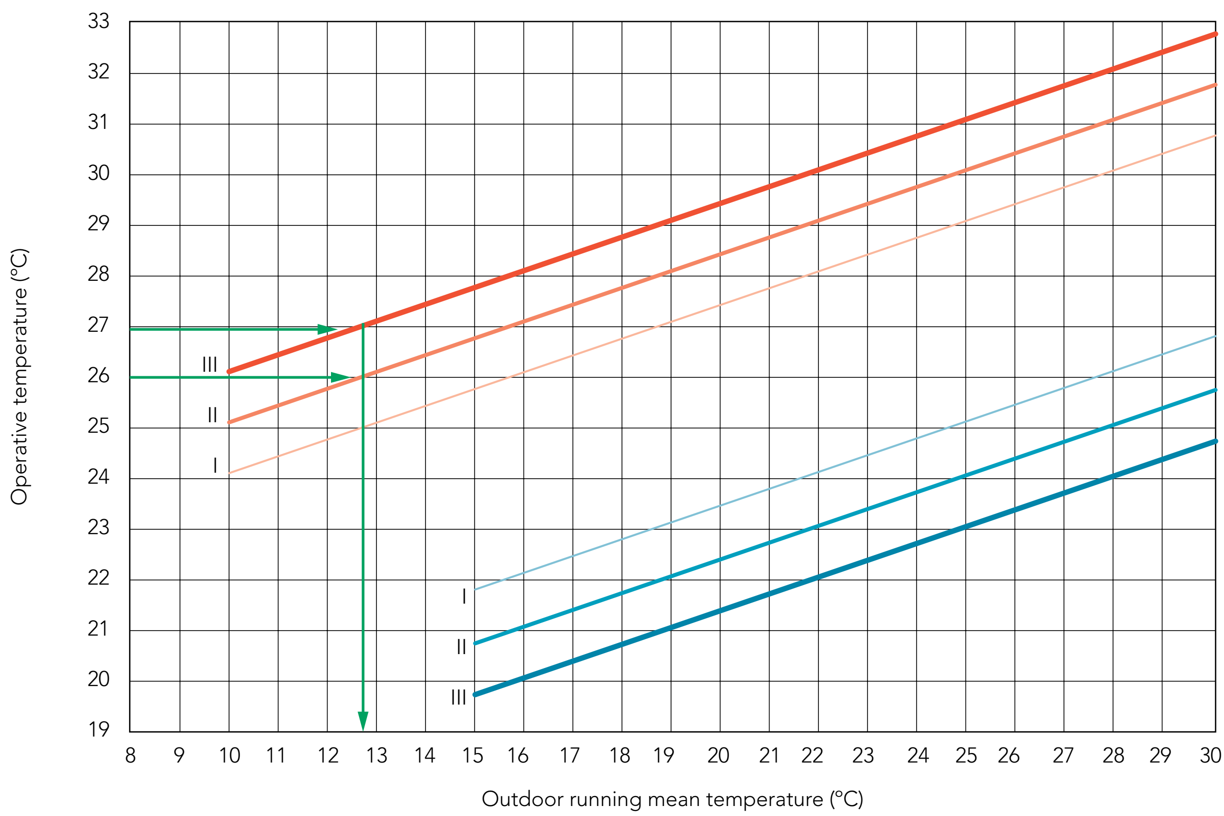


Figure 2 Design values for indoor operative temperature for free-running buildings as a function of running mean outdoor temperature. © British Standards Institution (BSI). Based on Figure A1 from BS EN 15251:2007 *Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics*. Reproduced with permission. All rights reserved.

CIBSE suggests values for overheating criteria for a range of building types[11]; the criterion values for dwellings are given in Table 1.

Table 1 Benchmark summer peak temperatures and overheating criteria. Data taken from CIBSE *Environmental Design, Guide A*[11]

Location	Benchmark summer peak temperature	Overheating criterion
Living areas	28°C	1% of annual occupied hours over comfort temperature of 28°C
Bedrooms	26°C	1% of annual occupied hours over comfort temperature of 26°C

CIBSE, in their publication *Climate Change and the Indoor Environment: Impacts and Adaptation*[15], present the results of a detailed investigation into the impact of climate change on indoor environments. CIBSE notes that there has been less work undertaken on thermal comfort in dwellings, but in the course of the investigation assumed that in living areas the temperatures that would cause discomfort would be similar to other buildings. However, for bedrooms a benchmark summer peak temperature of 25°C was used, ie the overheating criterion was modified to 1% of annual occupied hours over a comfort temperature of 25°C. It was noted that people generally expect temperatures to be lower at night than during the day and find sleeping in warm conditions difficult.

For summer design conditions the *Environmental Design, Guide A* suggests that indoor comfort temperatures for non-air conditioned buildings should be 25°C for living areas and 23°C for bedrooms. It is then noted that sleep may be impaired above 24°C. This is reinforced by results from an investigation that demonstrated changes in quality of sleep compared to a range of bedroom temperatures.

The UK Government introduced the Housing Health and Safety Rating System (HHSRS)[7] as a defined approach for the evaluation of the potential risks to health and safety from any deficiencies in dwellings. The underlying principle of the HHSRS is that 'any residential premises should provide a safe and healthy environment for any potential occupier or visitor'. The HHSRS is in itself not a standard, however since it was introduced under the Housing Act 1985, s604, as amended by the Local Government and Housing Act 1989, judgements about the lack of safety of a dwelling are enforceable under the Act. The HHSRS covers those matters which can be considered the responsibility of the owner or landlord.

Assessments using the HHSRS are based on the logical evaluation of both the likelihood of an occurrence that could cause harm, and the probable severity of the outcomes of such an occurrence. Overheating in dwellings, expressed as 'excess heat', is included as one of the defined hazards and covers threats from excessively high indoor air temperatures.

Defining the health effects of heat, the HHSRS states:

> *As temperatures rise, thermal stress increases, initially triggering the body's defence mechanisms such as sweating. High temperatures can increase cardiovascular strain and trauma, and where temperatures exceed 25°C, mortality increases and there is an increase in strokes. Dehydration is a problem primarily for the elderly and the very young.*[7]

Based on this and the fact that the most vulnerable age group is noted as being all persons aged 65 years or over, the identified statistical risks are presented according to dwelling type and different classes of health outcomes to give average HHSRS scores.

3.2 Discussion

Design guidance for indoor temperatures has been developed based on the concept of thermal comfort, and then extended to define the upper and lower limits of comfort, ie the point at which occupants experience discomfort. The upper limit has been referred to as 'overheating', however the basis for the criterion was not entirely health based; rather it was based on thermal preference.

The HHSRS notes that:

> *Dwellings, as well as providing protection from the environment, should be capable of being occupied safely and healthily by a range of households with a spectrum of lifestyles. Also, dwellings should meet the needs of a wide range of households whose members may include the elderly or the very young.*

It is suggested that this point may be another reason for the difference between the design guidance provided by, for example, the *Environmental Design, Guide A*, and the risk assessment criteria set out in the HHSRS. Commercial buildings are rarely occupied overnight, and the occupants are awake during the day. As a consequence of this there is a transitory nature to the perception and feelings of thermal comfort, whereas in a dwelling the occupants, especially the risk groups noted in the HHSRS, may not leave (or be able to leave) the building for long periods of time. This may also serve to address the apparent conflict between the findings of increased mortality as average outside air temperatures increase and the upper levels of thermal comfort which may be derived for a running mean outdoor air temperature. Thermal comfort for the working day needs to be considered differently to the temperature levels at which some members of the population may be at risk due to overheating in their homes.

3.3 What are the health consequences of overheating?

There is increasing evidence that some existing dwellings are overheating for very significant periods of the year, and the effects for some residents range from discomfort and reduced performance to serious health effects. For most of the population overheating is a matter of thermal comfort, but for certain vulnerable sections of the population, excess heat can have significant health implications.

At the outset of the review project it was perceived that much of the research on the effects of heat on people had been carried out using external temperature levels, and that knowledge gaps exist regarding the relationship between external and indoor temperature. The importance of prolonged exposure to high levels of heat indoors, and in particular during the night, was also seen as critical in assessing the potential health and well-being effects of overheating, therefore these factors were considered in the medical review carried out by the HPA.

3.3.1 Introduction

A range of health effects from mild to severe can result from exposure to high ambient temperatures. Vulnerable groups, which include infants, the elderly, those socially isolated, urban dwellers, the obese and chronic disease sufferers, are particularly at risk from increased heat due to a number of physiological, social and behavioural reasons. These are also the groups which are more likely to spend a higher proportion of their time indoors when compared with the general population. There is currently much debate surrounding the identification of temperature thresholds when applied to the indoor environment. With an ageing population, urbanisation and climate change, the need to address indoor heat, health and thresholds is apparent.

3.3.2 Normal thermoregulation

The normal, healthy human body has a core temperature range of between 36.1˚C and 37.8˚C and can cope with this temporarily increasing up to 38˚C or 39˚C without causing damage to health[16,17,18]. Regulation and maintenance of core body temperature within these parameters is managed by a part of the brain called the hypothalamus through a careful and precise balance of heat generation and loss[16,17]. Maintaining this balance is known as thermoregulation. The heat remaining within the body is the difference between the heat generated and the heat lost[18]. Consequently, core body temperature will rise if generation exceeds loss and will drop if loss exceeds gain[17].

The human body loses heat via a number of routes which include convection, conduction, radiation, sweating, cutaneous vasodilation, respiration and increased heart rate[19]. These mechanisms are summarised and explained in Table 2.

Table 2 Mechanisms for the loss of body heat

Route	Mechanism
Convection	When air or water passes over the skin
Conduction	Contact with cooler objects on the skin
Radiation	Electromagnetic waves in the form of infrared rays
Sweating	Heat is released through the evaporation of sweat
Increased heart rate	Enables blood to be brought to the skin surface
Cutaneous vasodilation	Increased blood flow to allow heat to escape from the skin surface
Respiration	Heat loss through exhaled breath

It is important to note that individuals will all respond differently to heat and the development of signs and symptoms of heat illness. This is due to physiological, anatomical, vulnerability, behavioural, economic, social and cultural reasons. In the following sections a general summary of heat-related illness is given, but it should be noted that presentation of symptoms may often differ between individuals.

3.3.3 Increasing heat and thermoregulation

When the surrounding air temperature is higher than body temperature, heat loss via the convection route can be impaired and heat will be gained from the environment to skin. This will result in a raised core body temperature, following which the body will initiate physiological responses such as sweating to aid in cooling. Sweating is the most effective mechanism through which the body can lose heat and maintain thermo neutrality; the human body can produce up to two litres of sweat per hour, which can lead to dehydration if these substances are not replaced quickly enough[18, 20, 21]. Sweating can be compromised by use of certain medications, or in humid environments with high vapour pressure when water cannot leave the skin into the environment[18, 20, 21]. When sweating is inhibited the core body temperature is at risk from increasing and this may lead to potentially severe heat illness[17].

3.3.4 Influencing factors and adaptation

Temperature, humidity, air movement and radiant energy exchange all influence the ability to thermoregulate. The mechanisms to maintain thermoregulation through the exchange of heat between the human body and the environment can all be modified by the built environment and influenced by clothing, economic situations, context and the behavioural practices an individual adopts[18,19]. Such factors therefore need to be taken into account when assessing and preventing heat stress.

Due to differing climates across the world, people have adapted differently over thousands of years both in their physiology and in the behavioural, cultural and social practices they adopt to cope with heat[18]. However, although this concept of adaptation is generally accepted in the scientific literature and there is evidence to suggest adaptation can occur as early as three days after exposure[22], it can take a number of years to develop fully[18]. Of particular significance is the hypothesis that adaptation will occur, but perhaps not at the speed of global warming[23]. A component of adapting to warmer temperatures is that people typically acclimatise to warmer temperatures over the course of a summer. Therefore, heat events occurring at the beginning of a summer pose a greater risk of morbidity (incidence of ill health) and mortality (incidence of death)[24].

3.3.5 Mild heat-related health effects

Mild heat-related health effects include dehydration, prickly heat, heat cramps, heat oedema (swelling due to build-up of fluid), heat syncope (fainting) and heat rash. Dehydration can be especially dangerous since the body can already be severely deficient in water at the time that appreciable thirst is first experienced. Reduced productivity, efficiency and mental concentration have also been cited as being related to excessive heat exposure. A reduction in mental concentration can lead to an increase in accidents.

3.3.6 Severe heat illness

Potentially severe health effects include mental health consequences, heat exhaustion and heat stroke. Two types of heat exhaustion can occur as a consequence of excessive sweating[25]. Firstly reduction in the circulatory blood volume due to fluid loss which is not replaced orally. Secondly due to reduction of sodium levels in the body due to replacement with fluids which are too low in salt content.

If an individual suffering from heat exhaustion is not removed from the environmental heat source and given treatment then heat stroke can develop; this is the rarest but most serious of all the heat-related illnesses and occurs as a result of a failure of the thermoregulatory system. It has a high fatality rate and requires rapid clinical treatment to cool the body[25]. Risk factors for heat stroke include advanced age, any illness which compromises the thermoregulatory system, chronic disease, medication use, social isolation and residing in dwellings which overheat, ie those that are poorly ventilated homes without air conditioning[16, 20]. However, significant exposure to heat will also put healthy people at risk[19]. It is well documented in the literature that heatstroke deaths are often under-reported because of their similarity to fatalities due to strokes, heart attacks and respiratory illnesses, the lag time between developing heat stroke and attendance at hospital, and the difficulty in measuring sudden death[17, 26]. Studies have shown that while data indicates a rise in mortality during periods of excess heat (heatwaves), the data on hospital admissions does not show the same degree of increase. This indicates that people are dying before coming to the attention of health services[15].

3.3.7 Vulnerable groups

Although all humans are at risk of heat illness if subjected to excessive environmental heat exposure, some people are more vulnerable than others. Vulnerabilities to heat include those at the extremes of age, those with chronic illness, the obese, those on medications and urban dwellers. These groups will be discussed briefly in turn below. Those at an increased risk of heat-related illness are generally also those more likely to spend more time indoors than the average population.

Children are at increased risk of exposure to heat as their metabolism differs from that of adults and they are less able to thermoregulate. They are also more at risk from dehydration and are more dependent on others to regulate their environment[17].

The elderly are at an increased risk from heat-related illness for a number of physical, physiological and social reasons. These underlying risk factors predispose them to an accelerated rise in body temperatures and susceptibility to dehydration which can lead to heat illness[18]. Ability to deal with imbalances of salt and water is much reduced in elderly people; in those above 75 years old sweating is reduced or possibly absent. Having an awareness of and understanding of the reasons the elderly are at increased risk is of significant importance as the UK population is ageing and more people are moving into this vulnerable age category[16, 17, 18]. Often, the elderly reside in nursing or long-term care homes. It has been found that it was the *least* physically fragile patients in a particular nursing home during the 2003 heatwave in France that were the most vulnerable. It is possible that because the staff viewed patients in the worst health conditions as having the greatest need, other groups were neglected[27]. Therefore, the ability to protect oneself or a group of people from the health effects of heat by use of preventative measures may decrease vulnerability. These findings are of particular relevance to the private setting, as they show that the elderly living alone may be at particular risk from the effects of high indoor temperatures.

The literature states that almost all chronic illnesses have the potential to affect the body's ability to react to an increase in temperature, due to physiological, anatomical and behavioural consequences[16, 17]. There are several medications and drugs that can increase an individual's vulnerability to heat illness, since they can affect mechanisms of thermoregulation[16]. Of course the elderly are more likely to have chronic illnesses and to be taking medications.

Obese individuals generate more heat during activity when compared with leaner individuals and require less heat to be produced before their core temperature begins to rise. As the body seeks to dissipate heat, a strain is put on the cardiovascular system of obese individuals who already have a decreased cardiac output due to an increase in body weight[18, 20].

Urban dwellers are at an increased risk of heat illness due to the UHI effect. In London during the 2003 heatwave, temperature differences between London and the surrounding rural areas at times exceeded 9°C[21]. The UHI effect is defined as a variation between urban and rural temperatures in which urban temperatures are significantly higher due to both atmospheric and surface impacts such as the lack of vegetation and the thermal storage of urban structures such as roads and buildings[28].

3.3.8 Resilience measures

The most important protective measure to combat high indoor heat is to stay cool or to leave the hot environment for a cooler one, as detailed in the Department of Health's *Heat Wave Plan*[25]. Those who are exposed to high temperatures should be encouraged to have plenty of cool drinks, avoid excessive alcohol and caffeine intake, and to take cool showers or sprinkle cold water on their clothes and bodies as required. People are advised to wear light, loose fitting clothing, keep bedrooms cool for sleeping and stay alert to weather forecasts so they can plan supplies. Other resilience measures include use of shading to reduce the effect of sunlight, turning off electrical equipment and opening of those windows in direct sunlight only at night. The latter response is often compromised when crime, noise, pollution or design of the windows themselves makes it difficult for people to keep them open at night.

Depending on the nature of their vulnerability, certain groups may not be able to respond effectively to increasing temperatures or be aware that they are in danger, and subsequently may not initiate preventative behaviours. Therefore, people are encouraged to look out for relatives, friends and neighbours who may be vulnerable and to alert the health services if such people feel unwell.

3.3.9 Importance of night-time temperatures

Higher night-time temperatures are thought to increase the risk to health due to the inability to recover from daytime heat stress[16] and due to the interruption to sleep[29, 30]. Mortality in urban areas is thought to be higher than rural areas because of the role of the UHI effect in elevating these night-time temperatures[16]. As body temperature increases, the mechanisms used to regulate temperature and cool the body (eg sweating) can cause a disturbance to sleep. The literature suggests that a change of as little as 1°C in skin temperature can affect the quality of sleep obtained, particularly in the elderly[29, 31]. Awakenings and increased sleep fragmentation have been linked to poor health, poorer quality of life and reduced work productivity[32]. It is important to recognise that sleep fragmentation, duration and quality can also be related to individual characteristics and behaviour, so cannot be attributed to temperature alone.

3.4 Discussion

It has been shown that an increase in heat exposure has the potential to negatively impact upon health. The effects of heat on the human body range from mild to severe and can lead to death. However, the majority of the studies considered in the medical review carried out have used external temperature as the main measurement. Using outdoor indices to predict the possible health effects of indoor heat is problematic as there are several variables and possible modifiers of ambient temperature such as adaptive behaviour, indoor heat gains, solar gain and density of occupation. Therefore, if indoor heat thresholds are to be established, they require a separate and unique measurement index, as well as further research and evidence linking indoor heat directly to morbidity and mortality data. No other study was found that has built on Basu's work on individual exposure to indoor temperatures (in that case research carried out in an elderly population in Baltimore, USA)[33]. If undertaken, further work of this type could be used to develop a future tool to measure the indoor/outdoor temperature relationship.

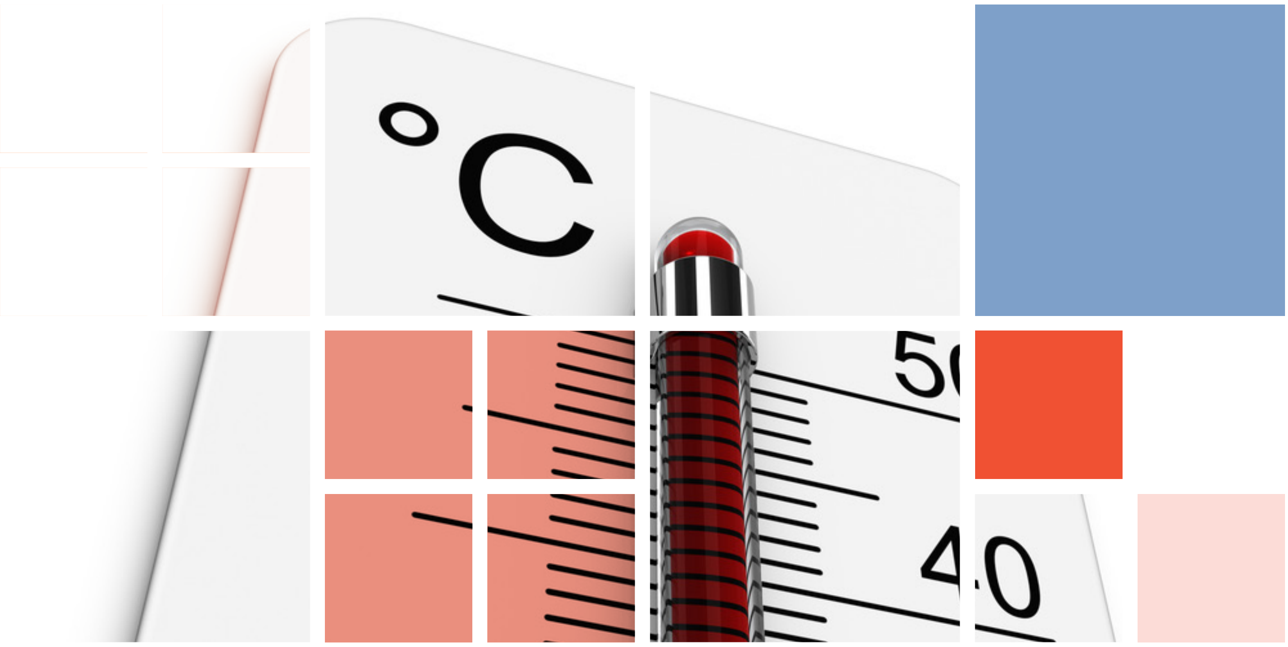
Due to the uncertain nature of the relationship between indoor and outdoor temperatures, establishing indoor heat thresholds based on a changing outdoor climate also necessitates further discussion and research. Factors such as minimum night-time temperatures and diurnal variation (the variation in temperature that occurs between the highs of daytime and the lows of night-time) should be heavily weighted in an indoor heat model given the evidence available on bedroom temperatures and sleep effects.

From the review undertaken, it is apparent that one single threshold would be very difficult to establish and enforce due to the wide range of adaptive modifiers of heat risk and individual adaptation factors. It has been shown that people adapt to heat over the summer and that morbidity and mortality is higher earlier in this period. This has obvious implications for the development of a threshold, as the evidence indicates that any threshold may potentially alter depending on the time of year.

The health effects of exposure to excessive heat can be mild but if left untreated can quickly develop into severe, often fatal heat illness. With global climate change, increasing episodes of extremes in heat, an ageing population and urbanisation there is a pressing need for research to be conducted into specific indoor environments, health of occupants and identification of thresholds. At present the evidence base with which to inform policy and guidance is limited.

Other specific areas which have been identified as requiring further research include the undertaking of longitudinal studies (studies which involve repeated observation of certain variables over a long period of time) on indoor heat and health, the relationship of mental health to increased heat, research into the types of housing inhabited by those who most suffer heat related illness, the long term consequences of heat exposure, the effect of behavioural thermoregulation and acclimatisation, and the relationship between heat and interrupted sleep and health. While the effects of increased temperatures on quality of sleep and wakeful episodes have been demonstrated, less attention has been placed on the cumulative effect of several consecutive warmer sleepless nights on health[34].

4 What causes overheating?



4.1 Sources of heat

Overheating is caused by a build-up of heat within a dwelling, resulting in the temperature exceeding a safe limit for the occupants. To assess means of minimising the occurrence of overheating it is vital that the sources of the heat are identified. A dwelling that is not being heated intentionally by a heating system will gain heat from some, or all, of the following sources, which may be classed as either internal or external.

4.1.1 Internal sources of heat

Occupants

The rate of heat emission from the human body is dependent on the level of activity, and a range of values for both the sensible heat gain (increases in air temperature) and latent heat gain (increases in moisture content of the air) are discussed in *Environmental Design, Guide A*[11]. No data are given specifically for dwellings, but, for a range of activity levels (ranging from sedentary to light work) the rate of sensible heat emission for a mixture of male and female occupants is given as between 65 to 80 W, increasing as the level of activity increases.

Occupant activities

Occupant activities such as cooking and bathing all release heat and therefore give rise to internal heat gains. The level of heat from each of these activities is highly variable, and data provided in *Environmental Design, Guide A* is based mainly on restaurant-sized appliances.

Domestic hot water systems

There are two basic categories of domestic hot water system: combination systems, where water is heated instantaneously on demand, and storage, where hot water is stored in a cylinder until it is required.

- **Combination systems:** These systems do not have any significant level of hot water storage, and so heat gains to a building are mainly from the distribution pipework, which inside a dwelling is generally not insulated.
- **Storage systems:** Cylinders used to store hot water must be insulated, and modern cylinder heat loss is relatively small, but the losses are still typically between 1 and 2 kWh per day. In addition to this the primary distribution pipework may not be insulated in existing dwellings. If this is the case, whenever the boiler is heating up the cylinder there are losses from this pipework, in addition to the losses from the distribution pipework. Solar hot water system pipes may also not be highly insulated within a dwelling and this will add to unwanted heat gains during the summer.

Electrical appliances

Almost all of the electricity used in a dwelling is converted into heat. The amount of heat gains to a dwelling can therefore be estimated from meter readings. The efficiency of electrical goods is increasing as energy efficiency is recognised by manufacturers as a marketable feature, eg fridges. Some highly inefficient devices are being phased out through legislation, eg high-power incandescent light bulbs. Of particular importance is the standby power of many devices that are now routinely left switched on. This has been addressed at a European level for new products, but older products may liberate a small, but significant, level of heat continuously.

Communal heating systems

Communal heating systems are common in large blocks of flats and are also starting to be seen in houses on some developments. A communal system has a central heat generator from which heat is then piped to all of the dwellings served by the system. The interface between the individual dwellings and the central system is a heat exchanger. The heat exchangers are usually placed within a dwelling and allow both heating and domestic hot water to be drawn at any time. The primary system is therefore always running hot. To minimise heat losses from the system the primary pipework distributing the hot water around the dwellings is usually very well insulated as losses from this pipework are not metered. However, the heat exchanger itself and the local primary pipework within a dwelling may not be so well insulated and therefore heat gains from these elements, which are often at temperatures of between 60 and 80°C, can be very significant. As the system is running 24 hours a day, this can represent a very significant heat gain to a small dwelling.

4.1.2 External sources of heat

Solar gains through the fabric of a building

The magnitude of heat conducted through the opaque elements of the building fabric, due to the external surface of the fabric being at a higher temperature than that internally, is relatively small in modern buildings (U-Values of walls and roofs generally being less than 0.4 W/m^{2}K). This may not be the case for older buildings, especially where attics have been converted and the loft insulation has not been upgraded sufficiently. In situations such as this the heat gains can be very significant.

Solar gains through windows

The direct gains that occur through glazing can be very significant in dwellings. The actual transmission of heat is a complex function of the type of glazing unit, orientation, degree of over-shading, time of day, and season. Manufacturers publish technical data on transmission of solar gains through glass which is usually expressed as the g value. The g value is the ratio between the solar energy which is transmitted, conducted and emitted into the interior and the total incident energy. For a single sheet of float glass, g = 0.87. Using this data along with incident solar data on respective façades, and accounting for shading, will allow the gains to be estimated. If blinds or curtains are drawn, some solar radiation may be reflected back through the window, but the balance will heat the blind or curtain and this heat will be liberated immediately, warming the room air. If blinds and curtains are not in place the solar radiation will be absorbed by the internal structure of the room. Depending on the thermal capacity of the materials within the room this heat may be liberated quickly (eg by carpets and other lightweight materials), or it may be absorbed and liberated a matter of hours later (eg by exposed concrete and brick).

High external air temperature

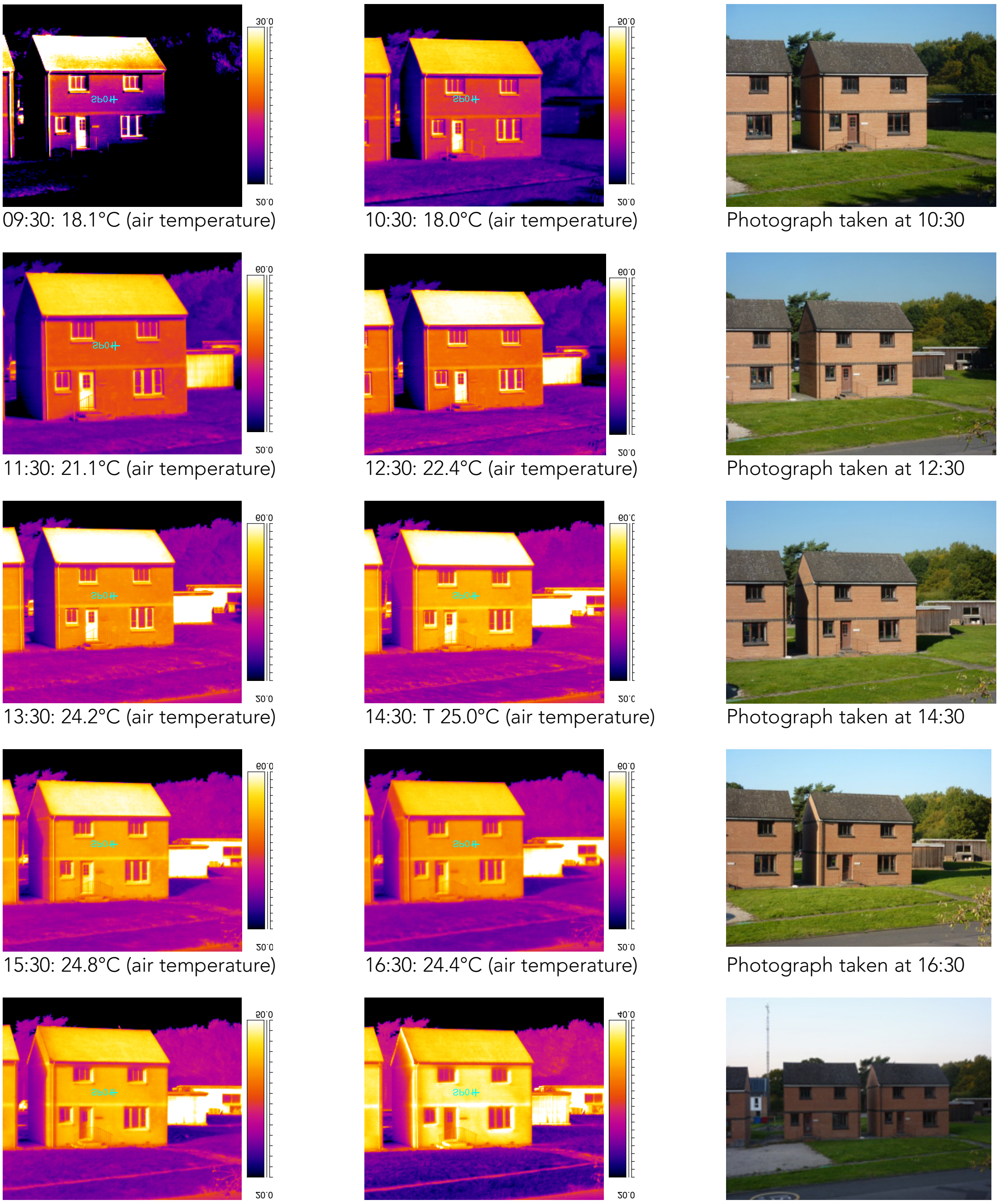
If the air temperature outside is higher than that present internally, any air brought into the dwelling for ventilation purposes will increase the temperature of the air in the dwelling. There are occasions when the external air temperature does exceed that internally, although the occurrence of this in the UK generally is currently low. However, in cities and large urban locations the local heating of the air creates a local environment that may be several degrees warmer than that in a rural location a relatively short distance away. This is referred to as the UHI effect and has been extensively studied recently as the impact of this elevation of temperatures has become apparent. Graves et al undertook a very detailed assessment of the UHI effect in London during the summers of 1999 and 2000[35]. Temperature data loggers were placed in up to 80 locations, radiating out from the centre of London, to measure hourly temperatures and to allow spatial variations to be assessed. The findings of this investigation demonstrated very clearly how night-time temperatures are kept higher in urban areas and also how the effect of this varies with distance from central London.

Building micro-environment

Investigations into the causes of overheating in a range of buildings over the past ten years has highlighted a potentially very significant source of heat that has, to date, not traditionally been considered or accounted for: that is the building's own micro-environment. In passive solar design the micro-environment was taken to be the surrounding area, often taken as being up to several tens of metres from the building. This concept was used as passive solar designs often looked to create local modification of the climate conditions through planting trees or by addition of other features such as ponds. The use of deciduous trees allowed winter gains to reach a building, but the leaves shaded a building in summer, minimising the risk of overheating. However, it is proposed here that the term micro-environment refers to the boundary layer of air adjacent to the fabric of the building. This boundary layer is the air that is either drawn in through vents into a building when it is ventilated by mechanical means, or is drawn into a building through windows when they are opened to provide natural ventilation.

The solar gains absorbed by the external surfaces of a building and surrounding hard standing are liberated over a period of time that is dependent on the prevailing weather conditions and the nature of the materials. Materials with a high thermal mass (ie high density and thermal heat capacity), such as concrete and brick, may retain the heat absorbed during sunny periods for a significant time, remain warmer than the surrounding air, and liberate heat late into the night. The effect of this is that the walls will have a warm convective boundary layer close to the surface. This may mean that air drawn into a building, for ventilation or due to infiltration, will be warmer than the free air in that general location. The magnitude of this mode of heat gain has not been studied in detail, and advice to building designers about location of supply vents for mechanical ventilation systems does not explicitly consider it for domestic buildings.

A series of infrared pictures of the test houses at the BRE site in Garston (Figure 3) demonstrates the temperatures that are typically reached by building fabrics on a warm sunny day. The infrared images show clearly that the surface of a dwelling can reach 60°C in direct sunlight, and that the heat of the day is only slowly released as the sun sets. If the supply air is drawn through vents in the wall or roof it is clear that for periods of the day it may be very hot, but more importantly, as the outside temperature falls in the evening, the fresh air drawn into the house may continue to be warmed, limiting and delaying the cooling potential of ventilation.



09:30: 18.1°C (air temperature) | 10:30: 18.0°C (air temperature) | Photograph taken at 10:30

11:30: 21.1°C (air temperature) | 12:30: 22.4°C (air temperature) | Photograph taken at 12:30

13:30: 24.2°C (air temperature) | 14:30: T 25.0°C (air temperature) | Photograph taken at 14:30

15:30: 24.8°C (air temperature) | 16:30: 24.4°C (air temperature) | Photograph taken at 16:30

17:30: 22.8°C (air temperature) | 18:30: 21.3°C (air temperature) | Photograph taken at 18:30

Figure 3 Infrared images and actual photographs of one of the BRE test houses taken over the course of a sunny September day (please note that temperature scales vary)

4.2 Changes to Building Regulations

The HHSRS provides details of the risks of overheating at the time of its introduction in 1995:

> *The major dwelling factors are solar heat gain, ventilation rates, and thermal capacity and insulation of the structure. Smaller, more compact dwellings, and particularly attic flats, are more prone to overheating than are large dwellings.*[7]

A key piece of evidence to support this assertion was the finding that in the 2003 heatwave a very significant level of overheating was identified in small flats and rooms under the roofs of predominantly zinc-roofed Paris buildings. Salagnac noted that such rooms under roofs are generally rather small and quite difficult to insulate thermally using conventional techniques[4]. It was concluded that thermal insulation of the roof structure played a significant role as a risk-reduction factor. It was suggested that the risk of death was decreased by a factor of five between non-insulated and insulated dwellings, and that location of a bedroom under the roof led to an increase in the risk of death by a factor of four or more.

This therefore suggests very strongly that risk is predominantly an issue for older properties, where lofts have been converted into flats or bedsits. In these situations there is a strong likelihood that adequate thermal insulation has not been installed, leading not only to the potential risk of excess heat, but also to a risk of excess cold. A preventative measure suggested in the HHSRS, and noted by Salagnac[4], is the introduction of adequate thermal insulation.

There is, however, a growing body of evidence that modern energy efficient, ie well insulated, airtight, dwellings are suffering from overheating, and that in some cases this is resulting in adverse health effects for the occupants of these properties. During a stakeholder workshop held as part of this NHBC Foundation project, social housing providers put forward the premise that the problems appeared to have started following the 2006 changes to Approved Document L1A *Conservation of Fuel and Power in New Dwellings* (AD L1A) of the Building Regulations 2000 (England and Wales)[36], ie the fabric became more insulated and, possibly more critically, the level of airtightness of dwellings increased very significantly. There was no definitive evidence put forward to back up these anecdotal comments; however, by looking at what has occurred as a result of recent changes to the Building Regulations it is possible to point to a potential combination of factors that may have resulted in cases of overheating in certain airtight modern dwellings.

The changes in AD L1A from 2002 to 2006 were not significant. However, the Code for Sustainable Homes was implemented in April 2007, and from April 2008 all new homes built with public finance (eg social housing) or on ex-public land were required to meet Code Level 3. This represented a target of 25% energy reduction against that achieved according to AD L1A[36]. As a result this led developers to seek means of reducing energy use to below that required by the current Building Regulations.

One key effect of the changes to AD L1A[36] was that very quickly the airtightness of buildings made a near step change from generally leaky (air permeability of > 10 $m^3/h/m^2$) to most buildings being close to 5 to 6 $m^3/h/m^2$, and many buildings being below 5 $m^3/h/m^2$ (Figure 4)[37].

When Approved Document F (AD F) *Ventilation* of the Building Regulations 2000 (England and Wales)[38] was amended in 2006, the means and rate of ventilating buildings remained the same. However, the amendment noted that buildings may well achieve levels of air permeability down to around 3 to 4 $m^3/h/m^2$ of envelope at 50 Pa pressure difference. Based on this assumption, it was stated that the ventilation provisions in the 2006 edition of AD F were appropriate for buildings with air permeability at these levels or worse. If special measures were undertaken to achieve better levels of airtightness, it was stated that additional ventilation provisions may be required. However, there were no details of what these additional provisions should be.

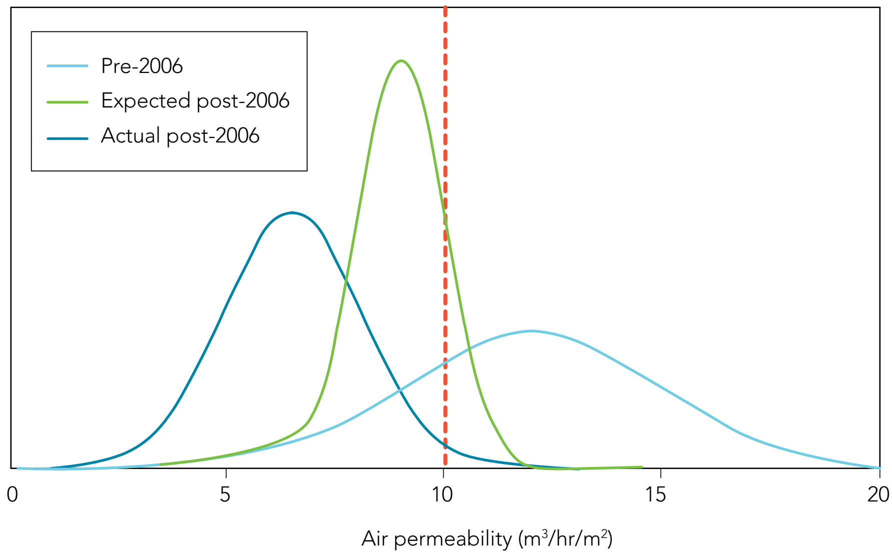


Figure 4 Changes in airtightness predicted and achieved across the 2006 changes to AD L1A[36]

The implication of ventilation provisions in AD F was that the level of infiltration was key to achieving an adequate ventilation rate; if infiltration fell too low, the ventilation provisions were inadequate. In addition to this, the size of openable windows specified was 1/20th floor area, if the window opens 30° or more. For windows that opened less than 30° the required size of openable windows was 1/10th floor area. This was amended in the 2010 edition of AD F[39] noting that if a window did not open more than 15° then it would not be suitable for providing purge ventilation and that other means must be sought. Therefore according to the 2006 edition of AD F a window could open fractionally, remain within the window reveal (and therefore provide a free opening measurable in millimetres) and, provided it met the 1/10th floor area rule, it was deemed suitable for the provision of purge ventilation. The note included in the 2006 edition that 'Purge ventilation provisions may also be used to improve thermal comfort and/or overheating of buildings in summer' could therefore be seen in some cases to be wishful thinking. This is confirmed in Appendix P of SAP 2005[40], where it is noted that for windows that open up to 50 mm the effective ventilation rate is up to 1 ach (air changes per hour) where cross ventilation is possible, and only up to 0.6 ach where no cross ventilation is possible.

Reviewing the most recent changes to the Building Regulations it is clear that there has been a step change in the requirements for performance of the building envelope. This has been driven by the need to minimise energy use, however it is not clear that the implications of the changes on the overall performance of dwellings have been fully assessed. Roaf et al note that 'modern buildings' appear to pay no attention to the traditional means of achieving comfortable internal environments, eg inclusion of thermal mass, shading, openable windows for natural ventilation[41]. While this comment is aimed mainly at the non-domestic sector and the fascination of modern architects with the 'highly glazed box', the same is true, to a large extent, of many recent urban housing developments. Overall, it is suggested that the long-learnt lessons of warmer regions of the world, especially Southern Europe, were not reflected in the recent changes to the UK Building Regulations. This has led to a potential default assumption that mechanical cooling systems will be required to prevent overheating as global warming raises summer temperatures over the lifetime of many of the buildings recently constructed.

4.3 Effect of thermal mass

The thermal mass of a building may be defined as the materials within that building, fabric and contents which absorb and store heat from, and release heat to, the interior spaces over a period of time. The most effective thermal storage materials are the dense structural elements that form part of the fabric of many buildings, eg materials such as concrete, bricks and stone used in walls, floors, ceilings. One of the key issues with many buildings is that they may be structurally very heavy, but thermally they are lightweight. The reason for this is that the thermal mass is not exposed to the internal spaces due to the installation of carpets, lightweight plasterboard internal walls, etc., and therefore the heat storage capacity does not in practice significantly influence the temperature of the internal space.

A good way of understanding the effect of thermal mass and the need to remove the heat that is stored in the thermal mass of a building is by considering the simplified cases presented in BRE Digest 454-1[42]. While this publication considers office buildings, the theory regarding how thermal mass attenuates and delays temperature swings is true for all buildings. There are also several books available covering the various aspects of how thermal mass can be integrated into a building.

In 2001, Barnard et al undertook a project looking at the potential for modelling the performance of thermal mass to allow its true effectiveness to be determined[43]. Basic guidelines are given for the use of models; however, no real comparative results for the different approaches to modelling are presented, leaving the designer with the need to undertake detailed dynamic thermal modelling.

Orme et al undertook a wide-ranging investigation of the means of minimising overheating in future housing in 2003 across a range of dwelling types[44]. Acknowledging the influence increases in thermal insulation will have on the potential for overheating, the investigation initially modelled a dwelling to Approved Document L1A (AD L1A) 2002[45], and then a house to a proposed future performance standard. The elemental U-Values used for this future standard are shown in Table 3.

Table 3 Elemental U-Values of proposed future performance standard[44]

Element	U-Value (W/m^2 °C)
Walls	0.25
Roof	0.16
Floor	0.22
Windows	1.3

The results of this initial investigation demonstrated very clearly that although both dwellings overheated, increasing the level of insulation resulted in higher levels of overheating. The investigation also assessed the effect of a range of adaption techniques on the two dwelling types. The results of this more detailed investigation showed very clearly that to achieve any significant level of reduction in the overheating a combined approach would have to be adopted, including high thermal mass, night cooling with natural ventilation, solar shading and a reduction in the internal gains. The reductions predicted were of the order of 70 to 80% in degree hours above 27°C. As an assessment of the potential to retrofit a solution to a thermally lightweight dwelling, the semi-detached house was modelled including night cooling and the addition of solar shading. The results of this investigation predicted reductions in degree hours above 27°C of between 50 and 60%.

In 2005 Arup and Bill Dunster Architects investigated the question of constructing low or high thermal mass dwellings as a means of coping with predicted climate change[46]. This investigation was undertaken using full dynamic thermal modelling, and considered the base case of an unadapted house and then the impact of a range of adaptations to minimise the occurrence of overheating. Each of these houses was investigated with three levels of thermal mass ranging from low to high. The base case house was assumed to have natural ventilation, controlled very closely by the occupants, based on internal air temperature. In the modelling all windows were deemed suitable for opening; however it was acknowledged that in some locations, eg urban, leaving windows open at night may not be appropriate for security reasons. The degree of overheating in the bedrooms for the base case showed little difference between high and low thermal mass models.

The adaption measures undertaken were to provide solar shading and to provide a mechanical ventilation system allowing very closely controlled ventilation based on a detailed control strategy. The ventilation rate for the mechanical ventilation system was assumed to be 6 ach. No details of how these air flow rates were to be achieved, or exactly what type of system was assumed to have been installed, were provided. The results of the modelling show very clearly that when controlled ventilation designed to achieve maximum night cooling and 90% solar shading are implemented, a high thermal mass building fabric performs better than a low thermal mass fabric.

Also in 2005, Faber Maunsell undertook a detailed investigation of the effects of thermal mass on the risk of overheating in a dwelling. The basis of the investigation was in part to assess the effectiveness of the simple SAP overheating test which was proposed at that time. Three levels of thermal mass were investigated, ranging from lightweight to high thermal mass, and three natural ventilation strategies were adopted achieving rates of 1, 2 and 3 ach respectively. The ventilation strategies relied on the occupants varying the degree of window opening, based on internal air temperatures, from 10 to 50% open. The investigation then assessed two different ‘typical’ dwelling types to study a wide range of adaption methods in order to evaluate their effectiveness at reducing the occurrence of overheating.

The investigation into the effectiveness of the simple SAP 2005 overheating test highlighted the very limited value of this test in showing and discriminating between a wide range of adaption measures. Based on the presence of thermal mass, and potential for ventilation, the overheating test predicted that increased thermal mass and higher ventilation rates were both beneficial to minimising the occurrence of overheating.

The detailed assessment of the effectiveness of a wide range of adaption measures predicted very high levels of overheating in both summer and winter for the base case high and low thermal mass models. The adaption measures included:

- rotating the main axis of the building
- reduction of south facing glazing and installation of light shelves for solar shading
- reduction of internal gains
- addition of thermal mass to the low thermal mass model
- adoption of a user-based ventilation strategy (opening the windows based on internal air temperatures).

The results of this modelling investigation showed very clearly that although the addition of thermal mass into the model of a dwelling did reduce the occurrence of overheating, introducing night cooling resulted in a significant further reduction. However, under the 'Normal Ventilation' strategy the windows were closed at 22:00 and opened again at 07:30. Under the 'Night Cooling Ventilation' strategy the windows were opened quarter way between these hours. This makes the very big assumption that the local environment is appropriate for such a strategy, ie the openings are secure and there are no pollution or noise issues that would limit window opening.

4.4 Discussion

The mechanisms of heat gain within buildings are all very well understood, although the effect of the microclimate, as defined here, may in some locations significantly compound local climate modifications ie the UHI effect. The means of minimising heat gains are also well understood, and simple techniques are used routinely in warmer climates to provide comfortable internal environments.

The means of rejecting heat are very limited. Ventilation is effective, but the required volumes of air to remove even a small heat load are significant. This limits the potential of natural ventilation in many dwellings, as leaving windows open in urban locations may not be appropriate. The use of thermal mass has been demonstrated to be highly effective in reducing the diurnal variation of internal air temperatures; however, unless linked with very effective night-time ventilation with cooler night air, it can result in overheating being exacerbated as heat is retained within a dwelling as outdoor temperatures fall.

All of the very detailed thermal modelling investigations undertaken into overheating have demonstrated the sensitivity of the internal temperature to a relatively small imbalance between gains and losses in highly insulated and airtight dwellings. It is therefore vital that robust solutions are adopted to minimise heat gains in all future designs and that these are developed to apply to the existing stock. If this work is not undertaken there will be a very significant number of dwellings where a thermal balance through mechanical means, ie comfort cooling or full air conditioning, is the only means of preventing overheating.

4.5 Case studies

The HHSRS risk assessment suggests that the risk of overheating is greatest in older properties. The evidence for this was that loft conversions, and the upper floors of older properties, were known to be more prone to overheat than were the lower floors of such properties. It had been assumed that as the level of insulation increased in modern dwellings, the occurrence of overheating in such properties would reduce. There are many examples of upper floor flats, or loft conversions in older properties, that tend to overheat and the causes of the overheating are generally the same – lack of roof insulation and lack of adequate ventilation. Two examples investigated by BRE are typical of this situation.

The first is a one bedroom flat in the top floor of a Victorian terrace with windows on one (north east) façade only (see Figure 5). Here overheating had occurred due to the combination of lack of thermal insulation in the roof space, the high thermal mass of the building fabric, and low levels of single-sided ventilation, in part due to the small area of openable window. The second is a flat located within a mansard roof of a development where the original Victorian façade had been retained but all other fabric elements had been replaced (see Figure 6). The occupants complained of year-round overheating and stuffiness. Ventilation provision met the requirements of AD F (2010 edition) for mechanical extract ventilation from wet rooms (intermittent fans in the kitchen and bathroom) and heat gains were assessed to be typical for the occupancy. However, the nature and position of the

Figure 5 Top floor flat in Victorian Terrace

Figure 6 Flat within mansard roof

window in the bedroom meant that insufficient air exchange was achievable in the flat, leading to overheating. This was demonstrated by monitoring of the internal air temperatures with the window both open and closed, which showed that the temperature within the bedroom varied only marginally when the window was opened, and showed very little diurnal variation.

The following case studies (all of which have been investigated by BRE over the past few years involving new homes) demonstrate some of the primary causes of overheating. In each case the following are considered: general description of property, sources of heat gain, means of rejecting the heat and main causes of overheating.

4.5.1 Modern development of flats with high solar gains

Property description: Two bedroom flat located on the north corner of a development constructed in the early 2000s in an urban location near an elevated roadway. The development has retail on the ground floor and 11 storeys of flats above. The building has generally low thermal mass. Significant areas of glazed floor-to-ceiling panels are present. There are intermittent extract fans in the wet rooms and ducted vents in the ceiling for background ventilation. Overheating has been reported in several flats within the development.

Figure 7 Corner flats, showing large area of glazing

Occupancy: Family group (two adults and two children).

Sources of heat gain: Internal gains are typical for the level of occupancy. Though predicted to be low based on orientation, significant solar gains are experienced in daytime due to the large overall area of glazing in the living room. Heating is provided by electric wall-mounted heaters; the domestic hot water (DHW) is also electric, with a mains pressure cylinder in an airing cupboard.

Means of rejecting heat: The only means of heat rejection is through the windows since intermittent extract fans installed in the kitchen and bathroom are not intended for continuous operation (being noisy when running). Restrictors on the windows are required for safety, however location of the windows in reveals where actual open area is significantly restricted results in limited potential for purge ventilation. Due to the proximity of the flat to an elevated roadway, windows cannot reasonably be left open at night time, so that the only means of ventilation overnight is via the background ventilation ducted terminals. With all of these located in the ceiling, and evidence of a poorly installed flexible duct, it is likely that the background air exchange rate is very low.

Causes of overheating: The lack of background ventilation is evident in winter, with condensation and mould reported to be a problem in the flat, and this problem is coupled with the very small openable area of the windows – which means that the heat built up in the flat is very hard to reject. The need to keep windows shut at night and the very significant solar gains mean that this flat will always be at temperatures significantly above those existing externally. In summer this means that the daytime temperatures may be very high, but also that at night there is very little opportunity to follow the natural diurnal variation of temperature. As a result temperature will vary very little across each 24 hour period.

4.5.2 Modern development of flats with high solar gains and local microclimate

Property description: One bedroom single-sided flat located on the south-west elevation of an eight storey development of flats constructed in the early 2000s in a deep urban location near a major city centre road. The building is generally low thermal mass, with an envelope of brick and block on a structural steel frame. The windows are side hung with restrictors (approx.100 mm). There are intermittent extract fans in the wet rooms, and trickle vents in window frames for background ventilation.

Figure 8 Air temperature and temperatures of building components and surroundings on a warm day

Occupancy: Single person

Sources of heat gain: Internal gains are very small. Heating is provided by electric wall-mounted heaters; the DHW is also electric, with a mains pressure cylinder in an airing cupboard. Solar gains are significantly high due to the orientation of the flat (facing south west across a wide road) and the large glazed area without shading of any form. The flat has a micro-environment driven by the expanse of hard standing immediately in front of the elevation. Figure 8 shows results of a temperature survey of the building fabric, which demonstrates the high temperatures such structures reach when subject to direct solar radiation. For this flat therefore, opening the window at any time while the sun is shining onto this elevation, or for a significant period after the sunset, will introduce air that is very significantly warmer than that of the local environment as a whole, and which is potentially unsuitable for thermal comfort.

Means of rejecting heat: The only means of heat rejection is through the windows (extract fans in the wet rooms are noisy and not designed for continuous use). Window restrictors are in place for security as the windows open outwards and are set back only a small distance from a busy pavement. The location of the flat makes it unreasonable to open windows at night, meaning that only the trickle vents can provide background ventilation, which will not be at the level required to facilitate heat rejection.

Causes of overheating: The combination of direct solar gains and the inherent micro-environment leads to high external heat gains and means that there is little access to 'free air' that follows the diurnal variations of the local environment. The lack of any means of providing night-time ventilation or in reality daytime purge ventilation – due to the noise, pollution and security risks of the location – dictates that there is no real means of heat rejection other than that through building fabric. The internal temperatures in the flat will therefore always be significantly above those experienced externally, and at night the high daytime temperatures will be maintained, with little diurnal variation of temperature possible.

4.5.3 Modern development of flats with high internal gains from communal heating system

Property description: Flats within a modern 11 storey block in an urban location overlooking a busy mainline railway. Building façade is clad with anodised aluminium panels and is generally of low thermal mass. Ventilation is by mechanical ventilation with heat recovery (MVHR), with purge ventilation provided by single elevation windows. Overheating is reported in some flats within the development, mainly on the east elevation overlooking the railway.

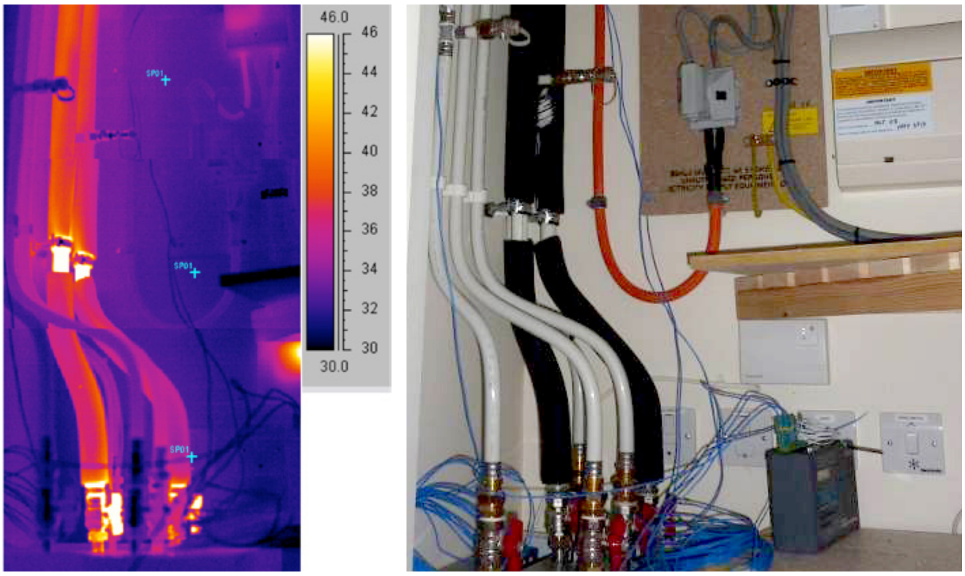


Figure 9 Communal pipes feeding heat exchanger box (located at the bottom of the photograph) and corresponding thermal image

Sources of heat gain: Internal gains are typical and not worthy of concern. Solar gains are significant, but not considered to be a prime cause of overheating. Heating and DHW are provided by a central boiler system, distributed through pipes in the common area. Local heat exchangers are located in each flat's airing cupboard. Figure 9 shows communal pipes feeding a heat exchanger box in an airing cupboard. Based on monitored temperature data and IR images it was concluded that the heat exchanger and associated pipework act as a small but 'permanently on' heater. The airing cupboard walls maintain temperatures in the upper 20s (°C), which maintains the flat at temperatures in the mid-20s (°C). Fresh air being supplied to the flat is warmed in the ceiling void by pipes snaking around the MVHR unit itself.

Means of rejecting heat: Lack of a summer by-pass facility and limited air flow rates on boost mean that the MVHR unit offers little potential to provide cooling in the summer. The amount of purge ventilation offered by openable windows is compromised by the noise from the adjacent railway line, and the fact that the windows are very large and without stays (meaning that they can only be fully open or shut).

Causes of overheating: Solar gains are significant, but of more impact are the continuous heat gains from communal heating system distribution pipes that enter the property and serve the local heat exchanger. The effect of this heat gain appears to be to maintain the flats at a minimum temperature of around 25°C. Lack of summer by-pass on the MVHR limits the potential to reject heat through the ventilation system, and it is noisy at boost speed, making it unlikely that occupants would run the MVHR in this mode overnight. Significant noise nuisance caused by the railway line means that leaving windows open at night is not realistic. The lack of effective means of rejection of the heat gained externally and internally prevents the flats being cooled at night to a comfortable temperature.

4.5.4 1990s flat conversion: flats with high internal gains from local boiler room

Property description: One bedroom ground floor flat on the south-east elevation of a 1950s office block which was converted into flats in the 1990s. The flat is single-sided with outlook on to a small paved garden area. The building envelope and internal structure are all concrete providing a very high thermal mass. Ventilation is by a continuous central extract system (rate not controllable), with fresh air supplied to the building through trickle vents at the head of the windows. Purge ventilation is provided through opening windows in the living room and bedroom.

Figure 10 Bedroom window and patio doors looking onto paved garden area

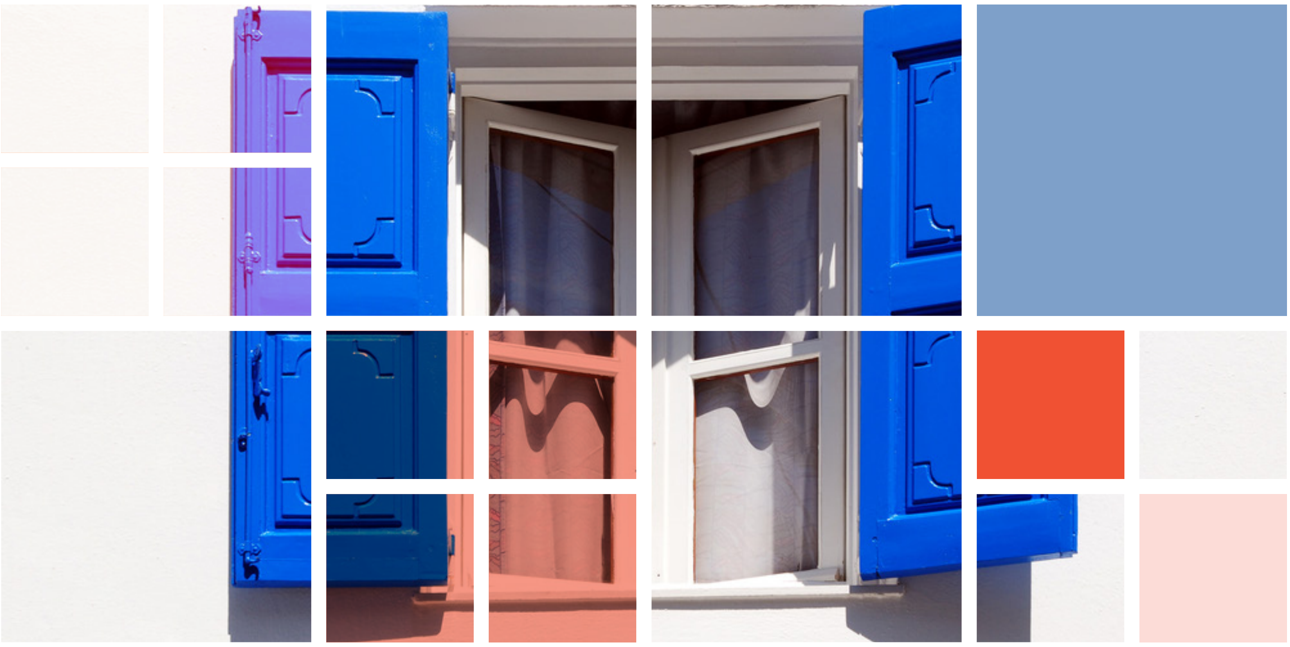
Occupancy: Two adults.

Sources of heat gain: Internal gains are typical for the level of occupancy. Orientation of the flat and the size of the windows would suggest that solar gains may be significant, but the shading by an elevated road and pedestrian walkway limit the duration of direct solar access. The flat is located above the main heating plant room for the development; a survey of the temperature of internal surfaces of walls and floor in the kitchen, bathroom and hall areas of the flat revealed that they were all at temperatures between 28 and 30°C. The plant room is a very hot space and is only partially insulated: some of the exposed and un-insulated areas of wall are directly below the flat being investigated.

Means of rejecting heat: The continuous extract ventilation system is sufficient to provide background ventilation, with air quality within the flat noted as being satisfactory by the occupants. The large bedroom windows and patio doors are not left open, except in the daytime or when the occupants are at home, due to security reasons. In order to remove the heat gains the occupants have installed two 3.3 kW room air conditioning units, one in the bedroom and the other in the living room. It was noted that they run all day every day and are never turned off, showing little variation in operation across the year.

Causes of overheating: The source of the heat gains is the large boiler room located below the flat. There appears to be little insulation of the building fabric in the plant room to minimise heat gains to the structure of the building and this has resulted in the walls and floor of much of this flat attaining temperatures approaching 30°C. The continuous mechanical extract system is not sufficient to remove the heat gains and due to security risks the windows cannot be left open when the flat is unoccupied, or overnight. Therefore, with no effective means of heat removal it is suggested that the flat would reach a steady state temperature in the low 30s or higher, and that this would vary little across the day or seasonally, since the boilers provide the heating and DHW for the whole building (which includes leisure facilities).

5 Reducing overheating



5.1 Heat gains – design guidance and lessons

5.1.1 Internal heat gains

CIBSE *Environmental Design Guide A* provides no specific guidance on heat gains for building designers to undertake overheating analyses of dwellings[11]. CIBSE notes that most of the published surveys on heat gains are for offices, with few published surveys of measured internal heat gains for other types of building. However, CIBSE TM 37[48] provides values for standard casual gains in dwellings based on the Simplified Building Energy Model (SBEM), the standard tool for assessing compliance with the Building Regulations Approved Document L2A[49]. Based on average UK dwelling floor areas and the occupant, equipment and lighting casual heat gain values given in TM 37, it is estimated that heat gains range from 600 W for a two-bedroom flat to 1000 W for a detached house. SAP uses assumptions about internal gains to assess the reduction in space heating required, and also to make a basic assessment of overheating risk.

A range of investigations have been undertaken into electricity use in dwellings and these give a feel for the magnitude of the gains that can be taken as typical in UK dwellings. The Electricity Association has presented data for a range of periods throughout the year (eg winter and spring) and also split data into week days, Saturdays and Sundays. The data are from 1997 and so may not reflect recent changes in appliance efficiency or lifestyle changes, but they do indicate the range of heat gains that can be expected in dwellings in summer. For instance, a typical evening load of 500 W is seen in summer (compared with around 800 W for winter evenings). A more detailed study has been undertaken by Richardson et al[50], who have produced a model of domestic electricity demand that can be used to look at typical demands for a range of scenarios.

Although the model does not consider all the heat gains in a dwelling, ie occupancy, gas based heating, etc., it allows the true magnitude of heat gains from electrical appliances in UK dwellings to be assessed.

5.1.2 External heat gains

Solar gains through the fabric of a building

Due to the highly transitory nature of heat exchange through the fabric of a building, even one which contains a small level of thermal mass, accurate assessment of the solar gains passing through the fabric of a building can only be reliably undertaken using full dynamic thermal models. At the early design stage of a dwelling, such an approach may not be appropriate and a simplified approach may be sufficient to allow overheating risk to be assessed. *Environmental Design, Guide A*[11] provides details of an admittance (cyclic) method of performing simple dynamic thermal modelling. The admittance method is limited by the fact that it is based on steady state cyclic weather and thermal gains, and it is assumed that the building has reached a steady cycling response to these gains.

The admittance method uses the concept of 'sol-air' temperature to predict heat transfer through opaque building fabric materials, defined in CIBSE's *Guide J: Weather, Solar and Illuminance Data*[51]. The sol-air temperature is a means of combining the short-wave solar radiation on a surface, the long-wave radiation exchange with the surface, external air temperature and the wind speed into a single temperature. CIBSE concludes that if time-temperature relationships are required then full dynamic thermal modelling is the only reliable method of obtaining this data. The CIBSE *Applications Manual AM 11: Building Energy and Environmental Modelling* provides details of appropriate dynamic thermal models[52].

Solar gains through windows

There is an extensive body of work covering solar gains through glazing, and the effectiveness of a wide range of solar shading devices. *Environmental Design, Guide A*[11] details how solar gains are used to estimate peak summer internal temperatures through the admittance method, and provides details of cooling loads for a range of glazing combinations. CIBSE TM 37[48] and BR 364[53] provide detailed guidance on the types of solar shading devices that are appropriate for buildings and the advantages and limitations of each.

High external air temperature

A very significant amount of work has been undertaken into the effect of the UHI on energy use and mitigation strategies for cities as global warming starts to occur. However, information about how to account for the UHI effect in evaluating the thermal performance of buildings in sufficient detail for overheating risk studies is covered less well. Graves et al produced a set of data that could be used to modify the temperature data for Bracknell, the local weather data site for London, to account for the UHI effect[35]. The modification to the temperature is based on monitored data from a large array of measurements made over the summer months of 1999 and 2000, and the results of this are presented based on post codes. *Environmental Design, Guide A*[11] provides less detailed modification data based on the distance from the centre of London, taken as being at the British Museum. From this data it is evident that, within 10 km of the centre of London, the night-time temperatures are elevated a minimum of 3°C above that of Bracknell. Mavrogiannia et al reported on recent developments in the LUCID project (Local Urban Climate Model and its Application to the Intelligent Design of Cities), looking to use GIS to model domestic space heating demand within London's UHI[54]. Work in this area does offer the potential to map, and therefore predict, levels of urban heat gain at a relatively small scale.

Building micro-environment

There is currently no detailed advice on location of ventilation intakes, or the effects of a building's micro-environment, on the effectiveness of ventilation as a means of minimising the occurrence of overheating. Graves et al noted work in Athens which highlighted the effect of solar radiation in making surfaces hot, effectively adding to the cooling load of a building, concluding with the advice that air conditioning inlets should be placed away from areas experiencing high surface temperatures[35]. CIBSE's *Minimising Air Pollution at Air Intakes*[55] provides details of ventilation system air intake locations to minimise pollution ingress, but does not specifically consider heat pick-up, only mentioning that heat rejection plant can have an impact on ventilation system performance by elevating the temperature of the inlet air.

5.1.3 Removal of heat

To prevent internal temperatures becoming too high, heat gains must be removed. The means of achieving this without recourse to mechanical cooling are the conduction of heat through the fabric of a building and ventilation.

Conduction through the fabric of a building

At night in the UK the external air temperature is generally lower than that internally. Therefore there is potential for heat to be transferred out through the fabric of the building. However, the reality is that with the low U-Values of most fabric elements, and the relatively small temperature difference between the inside and outside air, the rate of heat transfer is very low. The rate of heat transfer is also complicated by the thermal mass of the fabric elements, which delays the transfer of heat. This may mean for example that during the night the internal surface of a wall is warmer than the room air, ie heat is being gained by the room. This is a result of the previous day's daytime gains on the external surface being transmitted slowly through the building's fabric.

Ventilation

The mechanism of removing heat via ventilation is straightforward. However, due to the low density and the low thermal capacity of air, the practicalities of achieving any meaningful rate of heat removal are challenging. As an example, for an internal/external air temperature difference of 2°C and an internal heat gain of 120 W, the air flow rate required to remove that amount of heat would be approximately 50 l/s. Considering the continuous air flow rates required to meet AD F 2006 and 2010, such an air flow rate would be in excess of that required (and in most cases achievable) by the mechanical ventilation systems installed in modern small apartments which are designed to provide background ventilation. Considering the level of heat gains that occur in dwellings and typical ventilation rates it is clear that, during periods of low temperature difference between inside and outside, the internal air temperature must increase significantly for an energy balance to be achieved. This may result in the internal air becoming excessively hot.

Table 4 Summary of Building Regulations AD F ventilation provision requirements

Version	High ventilation rate terminology	Suggested ventilation rates achieved and reasons for needing such rates
AD F 2000	Rapid ventilation	Rapid ventilation rates are not defined, nor the possibility that these may be required for heat removal
AD F 2006	Purge ventilation	A minimum of 4 ach in each habitable room. Purge ventilation may also be used to improve thermal comfort and/or overheating in buildings in summer
AD F 2010	Purge ventilation	A minimum of 4 ach for habitable rooms. Purge ventilation is required only intermittently and for short periods to dilute high concentrations of pollutants and water vapour Ventilation may also provide a means of controlling thermal comfort but this is not controlled under the Building Regulations. Part L (2010 edition) addresses minimising energy use due to the effects of solar gain in summer

5.1.4 Design guidance

The Building Regulations, over the past few iterations, have begun to acknowledge the need for ventilation as a means of heat removal (Table 4).

Approved Document L (2010 edition) of the Building Regulations 2010 addresses minimising the solar gains in summer as a means of minimising the need for mechanical cooling energy use.

When assessing windows for suitability of meeting the requirements of AD F for purge ventilation, AD F 2010 notes:

> *For habitable rooms, measure the opened area of windows and doors opening to the outside and then add them together to ensure a minimum provision of 5% of the floor area of each room. The usable opened area of hinged and pivot windows should be taken as half the actual area if the window does not open more than 30°; if the window opens less than 15° it is not suitable for purge ventilation, so other arrangements should be made.*[39]

AD F 2010 notes that the ventilation rates have been sized for the winter period. Additional ventilation may be required during summer months and it has been assumed that the provisions for purge ventilation (eg openable windows) could be used. Overall therefore, Part F of the Building Regulations acknowledges that ventilation is a means of controlling thermal comfort and that in summer the ventilation rates may need to increase to the purge ventilation rates, but the requirements for achieving this are that there should be suitable openable windows to achieve 4 ach. Appendix P of SAP 2005 provides details of the likely ventilation rates that can be achieved by trickle vents and various levels of window opening[40, 56].

'Slightly open' refers to windows that can be securely locked with a gap of about 50 mm; however it is stated that this option will not give sufficient ventilation to control overheating. This therefore represents a significant problem in dwellings with windows above ground floor level, where RoSPA recommends that restrictors are used on windows to prevent falls. RoSPA acknowledges that there is a conflict between security, unlawful entry, and means of escape from fire, cleaning windows, ventilation and the prevention of falling from a window located at first floor level or above, but with 4000 children (aged 0 to 15) injured falling from windows per year, the advice to restrict window opening is compelling.

SAP acknowledges that windows on ground floors cannot be left open all night because of security issues, though suggests that windows on other floors can be. 'Fully open' therefore refers to dwellings where security is not an issue (eg an upper floor flat) or where there is secure night-time ventilation (eg by means of grilles, shutters with vents, or purpose made ventilators). In most cases where there are ground and upper floor windows, 'windows open half the time' would be an effective night-time ventilation strategy, ie ground floor windows open in the evening only, upper floor windows open all night.

SAP notes that if there is a mechanical ventilation system providing a specified air change rate, that rate can be used instead in the assessment of overheating risk. However, achieving ventilation rates of at least 4 ach for a whole dwelling with a mechanical ventilation system would be difficult as this is approximately eight times the normal background ventilation rate of 0.5 ach. To achieve such high air flow rates would require significantly larger fans than are currently installed in mechanical ventilation systems. The ducts would also need to be increased in size and the room supply and extract grilles would need to be capable of handling such an increase in flow rate without creating a noise nuisance. However, purge ventilation applies to a single habitable room in AD F, so there is the potential to consider zoning of a dwelling for the purpose of ventilation to minimise overheating. As noted above, this is currently not an option with mechanical ventilation systems available on the UK market, and would require use of additional hardware and controlling software.

Environmental Design, Guide A[11] provides guidance on the potential for using windows to achieve effective ventilation in summer for a range of window opening strategies. CIBSE notes that where natural ventilation is to be used a maximum of 10 ach is not unreasonable, although this figure will depend upon the ventilation opening configuration. This rate of ventilation is significantly higher than that considered to be achieved in SAP, and suggests that it is aimed at non-domestic buildings, although BRE notes that reference has been made to this ventilation rate figure by house designers during conversations regarding modelling of overheating risk.

As heating systems and means of ventilation in dwellings change in nature, for example with the advent of MVHR and community heating systems, it is important that inadvertent heat gains which can arise from such systems are understood and mitigated against. MVHR systems, especially those not equipped with a summer bypass, will distribute heat gains throughout a dwelling, so that the ventilation system can itself reduce the potential of some areas of a dwelling, such as bedrooms, to remain cool.

5.2 Meeting urban challenges

During the day in urban areas buildings and hard surface materials such as brick, concrete and tarmac absorb heat which is re-emitted back into the air when the outdoor temperature drops at night time. Additional heat gains arise from outlet vents from air conditioning systems and chiller plant of surrounding buildings. The cumulative effect of these factors is known as the UHI effect, which can lead to elevated temperatures at night, especially in heatwaves. High nocturnal ambient temperatures present challenges when ventilating dwellings and clearly represent a major potential cause of overheating.

The proportion of people living in cities and other urban areas is constantly increasing, and at the same time demographic factors dictate that more of the elderly and infirm, ie those people most vulnerable to the effects of excess heat, will live in urban areas. Therefore it is important that steps are taken when planning and designing residential developments in such settings. Over and above the need for designs to include ways to minimise heat gains and measures to remove heat from dwellings as discussed above, there is a need for careful master planning so that contributory causes of overheating are negated.

UHI effects may be reduced by the inclusion of parks, other green spaces, ponds and lakes in an urban development. Even the inclusion of small garden areas adjacent to buildings rather than tarmac can have a significant effect. Orientation of dwellings is an important factor for consideration, since useful heat gains from sunlight during winter may be offset by unwanted gains in the summer months which could contribute to overheating. Occupants of single aspect dwellings do not benefit from the ability to cross-ventilate by natural means, so special care is needed in the orientation of such dwellings. Since it is often not possible to open windows or doors in certain urban dwellings located near to roads or railways due to noise, poor air quality or security concerns, the number of dwellings in such locations should be minimised.

In urban locations it is also important for local government and the appropriate agencies to set up effective support mechanisms for vulnerable people who are susceptible to the effects of excess heat, especially when heatwaves are forecast and occur. Those most vulnerable to the effects of heat may live in isolation, have limited access to health and social care and be unable to move to cooler locations for respite without assistance. It is also important that people are educated regarding the importance of taking actions to reduce overheating and regarding what resilience measures and responses can be deployed.

5.3 Development and implementation of thresholds

To reduce the risk of overheating clear thresholds are required for designers to work to and for the appropriate authorities to use for intervention. These thresholds need to be robust and underpinned by a strong evidence base. However, there are considerable challenges associated with establishing and defining thresholds for excess heat in dwellings.

Basu and Samet offer the basic definition of a medical-based threshold as the point at which mortality effects due to heat begin, and defined as a local or regional temperature threshold[57]. Ormandy and Esratty have recently reviewed the historical background of the universally applied World Health Organisation (WHO) thermal comfort guidelines on indoor temperatures[58]. This review concludes that thermal comfort is directly linked to health and that guidance is required for the protection of those most vulnerable to extremes of temperature. Defining heat-related mortality is difficult since often only deaths due to extreme heat are reported to public agencies, when in fact shorter and less severe stretches of warm weather have a significant impact on morbidity and mortality rates. Heat-related deaths are also commonly under or misdiagnosed[24]. When defining temperature thresholds agreement is needed on how to present temperature data since *mean temperature* (an average daily, monthly or yearly figure), *minimum*, *maximum* or *apparent temperature* (which combines temperature and humidity) have all been used and all have particular advantages.

There is also a need for an *index* to describe temperature and its effects on health. Complex indices with relevant meteorological and physiological variables that assess the heat load for a particular place or area have been developed. They take into account the physiological mechanisms of heat exchange in order to determine real and modelled individual experiences[59]. Different comfort zones within a dwelling are based on the physiological interaction between the human body and its environment. For example the neutral temperature zone for sleep is different from the neutral zone for resting or eating. As the difference in comfort thresholds can be up to several degrees, indoor thresholds for health would have to start at a much lower limit to cover the greatest range of risk.

Guidance is needed on the range of temperature over which there is a minimal risk to health. WHO currently defines this as between 18˚C to 24˚C[58, 60]. This is different to earlier WHO thresholds, but there is little in the literature to explain why the changes were made[61]. While general guidelines exist, it is not universally accepted that safe temperatures can be predicted, as there are wide individual variations[59]. Within the UK's current heatwave plan, 26°C is considered to be the safe limit in residential or nursing homes and in rooms where vulnerable groups spend their time[24].

In the UK current guidance for the assessment of overheating consists of *Environmental Design, Guide A*[11] and the HHSRS[7]. *Environmental Design, Guide A* states that the peak indoor temperature during the day should never be more than 3°C above the design temperature and that bedrooms should have lower thresholds due to probable sleep disruption above 24°C. The HHSRS is a ratings-based framework and is the attempt to evaluate evidence-based risks to health from any UK dwelling. While some heat and morbidity/mortality data are mentioned as being used in determining the risk of overheating to health, they are not widely available or published. In addition, as stated in the HHSRS guidance, there are currently no direct indicators for overheating dwellings and health.

6 Conclusions

6.1 Findings

The project undertaken has presented and reviewed evidence of overheating which shows that new properties and refurbished properties are most at risk, especially small dwellings and flats and predominantly single-sided properties where cross-ventilation is not possible. However, there is also evidence that prototype houses built to zero carbon standards are suffering from overheating – which shows overheating may also become an issue where cross ventilation is achievable in lightweight, airtight houses with little or no solar shading.

In many cases the lack of ability to reject the heat build-up from normal occupant activities means that a risk of overheating exists in summer. However, in some instances the gains are such that the overheating occurs for most of the year and is therefore independent of the external temperature.

A review of existing overheating criteria suggested that these are currently based on the upper limit of thermal comfort, rather than the threshold for long-term temperatures that may cause serious health problems for vulnerable groups.

The findings of several investigations show that the mortality rate increases significantly at average or running mean outdoor temperatures of 25°C and above, which suggests that the HHSRS limit of 25°C may be an appropriate value to consider as the start of the onset of overheating risk. However, the relationship between internal and outdoor temperature needs to be assessed because it is suggested that it is no longer appropriate to use outdoor temperature as a variable in the definition of overheating risk in modern, highly insulated airtight dwellings. It was also noted that *Environmental Design, Guide A*[11] states that sleep may be impaired above 24°C.

The mechanisms of heat gain within buildings are all very well understood; however, in some 'deep urban' locations a building's microclimate may compound the UHI effect. Therefore:

- Design guidance must consider inlet location for ventilation systems since sourcing air from south-west façades will exacerbate overheating, regardless of the ability to undertake effective night-time ventilation.
- The means of rejecting heat, without recourse to mechanical cooling, are very limited. To effectively use ventilation requires secure, acoustically treated openings, which are able to draw air from a pollution-free location. Night-time ventilation needs to be automated to minimise the potential for over cooling. Systems need to be developed that can achieve this in existing dwellings, and this needs to become a requirement for new urban dwellings.
- A practical assessment of the effectiveness of inclusion of thermal mass and night-time ventilation in new dwellings must be undertaken. Much of the modelling suggests that this may be very effective, but models often make assumptions of perfect control, and the sensitivity of the effectiveness of thermal mass to the night-time ventilation needs to be determined in order to deliver robust designs.

There is also evidence of increased overheating in dwellings served by communal heating systems which suggests that the design and installation of these systems needs to be reviewed. It appears that the levels of pipework insulation required by the Building Regulations may be insufficient to effectively minimise heat gains and that the lack of effective ventilation of communal areas and service voids is causing these areas to overheat and contribute to overheating in the dwellings.

The recent NHBC Foundation publication NF 44 *Understanding Overheating – Where to Start*[1] provides a guide for house builders and designers with respect to key factors which can lead to high indoor temperatures, and describes some of the measures which should be considered during planning and design in order to mitigate against overheating.

A significant element of this project was an investigation and detailed literature review of the medical aspects of overheating. The conclusions from this are:

- The health effects of exposure to excessive heat can be mild, but if left untreated can quickly develop into severe, often fatal heat illness. With global climate change, increasing episodes of extremes in heat, an ageing population and urbanisation the risk of exposure to excess heat is expected to increase. However, at present the evidence base with which to inform policy and guidance is limited.
- Night-time temperatures are important because higher night-time temperatures are thought to increase the risk to health due to the inability to recover from daytime heat stress and the interruption to sleep.
- Indoor thresholds for health are needed as a protective measure against preventable morbidity and mortality. Local, dwelling-based approaches should be a priority. Given the current literature and data currently available on indoor temperatures and health, it is concluded that it is not feasible to define a single indoor temperature based threshold and it would be challenging to identify a comprehensive risk model. The epidemiological studies on the relationship between heat and health use outdoor, not indoor, temperatures as a predictor. This makes it difficult to extrapolate results to the indoor setting and requires further research.

6.2 Recommendations for future research

6.2.1 Health and well-being

Comprehensive studies are required on *indoor* heat and health. Further research is also required into the types of housing inhabited by those who have suffered heat-related illness (such as fainting, heat stroke and more serious effects), using existing data on hospital admissions and housing stock data. Long-term consequences of heat exposure, the effect of behavioural thermoregulation and acclimatisation, and the relationship between heat and interrupted sleep and health also need further research.

6.2.2 Internal environments

More study of the relationship between external and indoor temperature is required. Study of the health of occupants in relation to exposure to excess heat experienced when indoors is needed to inform the identification of thresholds for internal temperatures; for this, cross disciplinary research will be required, including evidence gathering and monitoring on a large scale.

6.2.3 Temperature thresholds

There is a pressing need to develop a universally accepted definition of overheating in dwellings and the development of robust national thresholds for use by planners, designers, builders and authorities is vital for dealing with overheating. The extent to which such thresholds could or should be regulated, for instance through the Building Regulations, is also a key issue for debate and action. At a more detailed level agreement is needed on whether to base temperature criteria entirely on health, or simply base them on thermal preferences (as has often been the case historically). Further research is also needed on how thresholds should take account of a changing outdoor climate and the effect of minimum night-time temperatures and diurnal variation.

6.2.4 Building design, construction and systems

It is important to establish how we may learn from the experience learnt in the warmer regions of the world, and how to incorporate this knowledge into UK Building Regulations and construction practice. The effectiveness of traditional means of achieving comfortable internal environments (including thermal mass, shading, openable windows) for modern buildings also needs to be investigated. Work is needed to develop, trial and introduce systems which are capable of rejecting heat from existing dwellings, and to determine whether such systems should become a requirement for new urban dwellings. Robust solutions must be sought for minimisation of heat gains in all future designs, and work carried out on potential adaptation of such solutions for application to the existing stock. Evidence based, clear and authoritative design guidance is required for practitioners on the required techniques including use of thermal mass, shading and effective inlet location for ventilation systems. Tools are required with which to assess the practical effectiveness of thermal mass and night-time ventilation in new dwellings. There should also be a review of the design and installation of community heating systems.

6.2.5 Modelling

Building energy models, including SAP, need to be reviewed and modified to take account of overheating using data from building monitoring and case studies. Factors that must be considered in any modelling tool include: effectiveness of night-time ventilation and thermal mass, the influence of real building microenvironments and the boundary layers around building façades, realistic heat gains and the influence of occupants. However, it is also important that modelling tools are affordable, not overly complex to use and widely applicable.

6.2.6 Regulations

Further work is required on the assessment of the implications that recent step changes in the requirements for the building envelope performance (Building Regulations) have had on the overall post-occupancy performance of dwellings. An evidence base is required with which to establish whether control of the risks of overheating should be a regulatory or non-regulatory matter (or a blend of both).

6.2.7 The occupant

Effective means of educating occupants (and their support network in the case of the vulnerable) are required. Behaviour adaptation and the effective use of buildings and their systems are required in order to minimise the effects of overheating.

7 References

1 NHBC Foundation. Understanding overheating – where to start: An introduction for house builders and designers. NF 44. Milton Keynes, NHBC Foundation, 2012.

2 Donaldson G, Kovat R, Keatinge W and McMichael A. Overview of climate change impacts on human health in the UK, Health effects of climate change in the UK, 2001. London, Department of Health, 2001.

3 Intergovernmental Panel on Climate Change (IPCC). Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry ML, Cansiani OF, Palutikof JP, van der Linden PJ and Hanson CE (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

4 Salagnac J-L. Lessons from the 2003 heat wave: a French perspective. Building Research & Information, 2007, 35 (4) 450–457.

5 Mudarri D. Public health consequences and cost of climate change impacts on indoor environments. Arlington, VA, The Cadmus Group, Inc., 2010.

6 Meehl GA and Tebaldi C. More intense, more frequent, and longer lasting heat waves in the 21st century. Science 305 (5686) 994–997, 2004.

7 Office of the Deputy Prime Minister (ODPM). Housing Health and Safety Rating System (HHSRS): Operating guidance. London, ODPM, 2006.

8 Anderson M, Carmichael C and Murray V. Overheating and health: a review into the physiological response to heat and identification of indoor heat thresholds. London, Health Protection Agency, 2012. www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1317133912939 (accessed 7 August 2012).

9 Anderson M, Carmichael C, Murray V, Dengel A and Swainson M. Defining indoor heat thresholds for health in the UK. Perspectives in Public Health. First published on July 25, 2012 as doi:10.1177/1757913912453411.

10 British Standards Institution (BSI). BS EN ISO 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. London, BSI, 2005.

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

12 Humphreys M, Sykes O and Roaf S (eds). Standards for thermal comfort, Indoor air temperature standards for the 21st century. Nicol F, Abingdon, Spon Press, 1995.

13 Schumacher R, Wortel W and Wieringa P. Human factors in thermal indoor climate and thermal comfort. 20th European annual conference on human decision making and manual control, June 25–27, 2001.

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

15 CIBSE. Technical memorandum 36. Climate change and the indoor environment: impacts and adaptation. London, CIBSE, 2005.

16 Kovats S and Hajat S. Heat stress and public health: A critical review. Annual Review of Public Health, 2008, 29 (9)1–9.15.

17 World Health Organisation (WHO) (Regional Office for Europe). Heat health action plans. Copenhagen, WHO, 2008.

18 WHO (Regional Office for Europe). Heat-waves; risks and responses. Health and global environmental change. Series 2, 2004. www.euro.who.int/__data/assets/pdf_file/0008/96965/E82629.pdf (accessed 17 September 2012).

19 Havenith G. Interaction of clothing and thermoregulation. Exogenous Dermatology, 2002 (1) 221–268.

20 Allen A and Segal-Gidan F. Heat related illness in the elderly. Clinical Geriatrics, 2009, 37–45.

21 Health Protection Agency (HPA). Heat wave questions and answers. 2011. www.hpa.org.uk/Topics/EmergencyResponse/ExtremeWeatherEventsAndNaturalDisasters/Heatwaves/HeatwaveQuestionsAndAnswers (accessed 17 September 2012).

22 Parsons K. Maintaining health, comfort and productivity in heat waves. Glob Health Action, 2009, 2.

23 Page LA and Hajat S. Relationship between daily suicide counts and temperature in England and Wales. The British Journal of Psychiatry, 2007,191 (2) 106-112.

24 Luber G and McGeehin M. Climate change and extreme heat events. American Journal of Preventive Medicine, 2008, 35 (5) 429–435.

25 Department of Health. Heat wave plan for England, 2011. www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/documents/digitalasset/dh_127235.pdf (accessed 17 September 2012).

26 WHO (Regional Office for Europe). Improving public health responses to extreme weather/heat-waves: EuroHEAT, report on a WHO meeting EuroHEAT, 2008.

27 Brown S and Walker G. Understanding heat wave vulnerability in nursing and residential homes. Building Research and Information, 2008, 36(4) 363–372.

28 Environmental Protection Agency. Reducing urban heat islands: compendium of strategies, 2008. www.epa.gov/heatisld/resources/pdf/BasicsCompendium.pdf (accessed 17 September 2012).

29 Aries MBC and Bluyssen PM. Climate change consequences for the indoor environment. HERON, 2009, 54 (1). http://heron.tudelft.nl/54-1/3.pdf (accessed 17 September 2012).

30 Libert JP and Bach V. Thermoregulation and sleep in the human, 2005. Chapter 19 in Parmeggiani PL and Velluti RA. The physiologic nature of sleep. London, Imperial College Press, 2009.

31 Raymann RJEM, Swaab DF and Van Someren EJW. Skin deep: enhanced sleep depth by cutaneous temperature manipulation. Brain, 2008, 131(2) 500–513.

32 Buysse DJ, Grunstein R, Horne J and Lavie P. Can an improvement in sleep positively impact on health? Sleep Medicine Reviews, 2010. pp 405–410.

33 Basu R. An exposure assessment study of ambient heat exposure in an elderly population in Baltimore, Maryland. Environmental Health Perspectives; Supplements, 2002, 110 (2) 1219.

34 Bach V, Tellie F et al. The interaction between sleep and thermoregulation in adults and neonates. Sleep Medicine Reviews, 2002, 6 (6) 481–492.

35 Graves H, Watkins R, Westbury P and Littlefair P. Cooling buildings in London: overcoming the heat island. BR 431. Bracknell, IHS BRE Press, 2006.

36 Department of Communities and Local Government (DCLG). The Building Regulations 2000. Approved Document L1A: Conservation of fuel and power – New dwellings (2006 edn). London, DCLG, 2006.

37 Ross D. Condensation, ventilation and indoor air quality. London, Aecom, 2011. www.goodhomes.org.uk/downloads/members/david-ross-aecom.pdf (accessed 17 September 2012).

38 DCLG. The Building Regulations 2000. Approved Document F: Means of ventilation (2006 edn). London, DCLG, 2006.

39 DCLG. The Building Regulations 2000. Approved Document F: Means of ventilation (2010 edn). London, DCLG, 2010.

40 Department of Environment, Food and Rural Affairs (Defra). SAP 2005. The Government's Standard Assessment Procedure for Energy Rating of Dwellings (2005 edn). London, Defra, revision 1, 2008.

41 Roaf S, Crichton D and Nicol F. Adapting buildings and cities for climate change. A 21st Century survival guide (2nd edn), 2009.

42 Braham D, Barnard N and Jaunsens D. Thermal mass in office buildings: an introduction. Digest 454-1. Bracknell, IHS BRE Press, 2001.

43 Barnard N, Concannon P and Jaunsens D. Modelling the performance of thermal mass. IP 6/01. Bracknell, IHS BRE Press, 2001.

44 Orme M and Palmer J. Control of overheating in future housing – Design guidance for low energy strategies. St Albans, Faber Maunsell, 2003.

45 DCLG. The Building Regulations 2000. Approved Document L1A – Conservation of fuel and power in new dwellings (2002 edn). London, DCLG, 2002.

46 Arup R & D, Bill Dunster Architects. UK housing and climate change, heavyweight vs. lightweight construction. London, Ove Arup & Partners Ltd, 2005.

47 Faber Maunsell. Thermal mass and overheating. Providing modelling support to guidance on overheating in dwellings. St Albans, Faber Maunsell, 2005.

48 CIBSE. Design for improved solar shading control. Technical memorandum TM 37. London, CIBSE, 2006.

49 DCLG. The Building Regulations 2000. Approved Document L2A: Conservation of fuel and power – New buildings other than dwellings (2010 edn). London, DCLG, 2010.

50 Richardson I, Thomson M, Infield D and Clifford C. Domestic electricity use: A high-resolution energy demand model. Energy and Buildings, 2010, 42 (10) 1878–1887.

51 CIBSE. Guide J: Weather, solar and illuminance data. London, CIBSE, 2002.

52 CIBSE. Applications manual AM 11: Building energy and environmental modelling. London, CIBSE, 1998.

53 Littlefair P. Solar shading of buildings. BR 364. Bracknell, IHS BRE Press, 1999.

54 Mavrogiannia A, Davies M and Kolokotroni M. Using GIS to model domestic space heating demand within London's urban heat island. AGI, 2011. www.agi.org.uk/storage/events/20110323-Env/AnnaMavroGianni.pdf (accessed 17 September 2012).

55 CIBSE. Minimising air pollution at air intakes. Technical memorandum TM 21. London, CIBSE, 1999.

56 BRE. Standard Assessment Procedure (SAP) 2009. For more information visit: www.bre.co.uk/sap2009/page.jsp?id=1642.

57 Basu R and Samet JM. Relationship between elevated ambient temperature and mortality: A review of the epidemiologic evidence. Epidemiologic Reviews, 2002, 24 (2) 190–202.

58 Ormandy D and Esratty V. Health and thermal comfort: from WHO guidance to housing strategies. Energy Policy, 2011, doi:10.1016/j.enpol.2011.09.003.

59 Koppe CK, Jendritsky G and Menne B. Heat-waves: risks and responses. Copenhagen, WHO Regional Office for Europe. Health and Global Environmental Change Series 3, 2004.

60 WHO (Regional Office for Europe). Health impact of low indoor temperatures: report on a WHO meeting. Copenhagen, WHO Regional Office for Europe, 1987.

61 Burridge ROD. Unhealthy housing: research, remedies and reform. London, E&FN Spon, 1993.

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Overheating in new homes

There is increasing evidence that new and refurbished properties are at risk of overheating, especially small dwellings and flats and predominantly single-sided properties where cross ventilation is not possible. However, there is also evidence that prototype houses built to zero carbon standards are suffering from overheating, which indicates that overheating may also become an issue where cross ventilation is not achievable in lightweight, airtight houses with little or no solar shading.

This report reviews evidence of overheating in dwellings, its causes and the consequences of overheating for the health of occupants. A number of recent BRE investigations into overheating in dwellings are presented and analysed as case studies. The report also discusses what parameters might be used in the definition of overheating, including possible threshold temperature levels, and gives guidance on reducing overheating. It concludes that there is an urgent need to develop a universally accepted definition of overheating in dwellings, and that the development of robust national thresholds for use by planners, designers, builders and authorities is vital for dealing with overheating.

The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the UK's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.

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