IMPACTS OF OVERHEATING

EVIDENCE REVIEW

ZERO CARBON HUB

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

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CONTENTS

01 INTRODUCTION

The Review

This Review summarises recent research and evidence on some of the more common impacts and consequences of overheating in residential buildings, primarily focussing on:

- The health and wellbeing of people; and
- The downstream impacts on businesses, the health service and the economy.

Section 2 of the Review describes the range of impacts on health. Section 3 then examines some of the factors which can influence how severely an individual may experience the effects of overheating, for example, their ability to follow advice given during a heat wave. Section 4 describes some of the behaviours and actions people take when experiencing overheating in their homes to reduce their discomfort. These behaviours may exacerbate the problem or have other knock-on effects such increasing the demand for energy in their homes.

Section 5 reviews evidence on some of the downstream impacts of overheating in homes on the health service, businesses and the economy. Section 6 highlights a number of the evidence gaps which would need to be addressed in order to more fully understand the links between overheating and the resulting impacts. Lastly, Section 7 draws out some of the main observations and conclusions from the Review.

We have conceptualised the 'impact' of overheating in the following way: 'what happens to people when their home overheats?' The Review does not attempt to provide a comprehensive description of the causes of overheating.

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

Accompanying reports

This Review forms part of a larger evidence gathering exercise on overheating being conducted by the Zero Carbon Hub designed to assist industry and government decision makers in managing current and potential future overheating risk in England and Wales. There will naturally be overlap with other Reviews in the series. The Review covers research and evidence relating to the impacts of overheating in residential dwellings including homes, care homes and student accommodation.

An accompanying report by AECOM for the Zero Carbon Hub entitled 'Overheating Risk Mapping' showcases examples of where risk-mapping has been used to highlight particular risk 'hot spots'. This kind of approach can help decision-makers, such as local authorities, understand where to target limited resources. The Zero Carbon Hub's Baseline Report (to be published in June 2015) will use these reports, and the wider evidence base, to summarise which locations, buildings and people are considered to be more 'at risk'.

> As would be expected, observed overheating in homes is more prevalent in certain parts of England and Wales, in certain built environment contexts and in certain types of dwellings. It therefore follows that any impacts will be experienced more severely in certain locations.

Methodology

The information presented is based on a review of the most up-to-date literature.

The literature to be reviewed was collected by AECOM and the Zero Carbon Hub, based on published English language documents potentially of relevance to the impacts of overheating in homes, with a focus on health impacts and on the UK (but with some studies included from other countries where particularly relevant).

Sources of literature include the previous review undertaken by AECOM for the Department for Communities and Local Government (DCLG) (AECOM 2012a) and sources referenced within this, and studies found through searches for key terms. In total, just over 60 reports have been included. The majority of these are peer-reviewed formally published studies, though some are from other sources such as consultancy reports and research and guidance from government agencies.

During the review of literature, we have used the following working definition of overheating, provided by the Zero Carbon Hub:

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

There are various ways of defining overheating; some of these are discussed in Section 2 and also in the Defining Overheating Evidence Review.

Key points

- Heat-related illnesses and mortality can occur when the human body's ability to thermoregulate is impaired. This ability is influenced by temperature, humidity, air movement, radiant energy exchange, the built environment and behaviour.
- Studies agree that the number of heat-related 'excess deaths' are expected to increase in the future. A number of estimates have been made, but the most recent suggests a tripling of current levels, from approximately 2,000 to 7,000 heat-related deaths per year by the 2050s, as a result of climate change, and a growing and ageing population.
- There is limited and indirect epidemiological evidence about the indoor temperature exposure conditions which would cause adverse health impacts. The evidence base is considered to be insufficient to define an indoor overheating threshold for health risk.
- Studies are starting to link external thresholds more explicitly to internal temperatures in homes, for example (Mavrogianni et al. 2012) which investigates the impacts of individual building characteristics on indoor temperatures using dynamic thermal modelling.

02 HEALTH-RELATED IMPACTS OF OVERHEATING

Introduction

In this section the impacts and consequences of overheating in residential buildings on health have been divided into two themes:

1. Heat-related mortality (deaths) and morbidity (illnesses); and
2. Sleep deprivation caused by people being too hot at night.

Box 1. **Key terms**

Mortality
Mortality is another term for death. A mortality rate is the number of deaths during a certain period due to a disease divided by the total population. Figures on mortality are usually assessed in terms of 'excess deaths' – mortality above what would be expected based on 'non-crisis' rates.

Morbidity
Morbidity is another term for illness. Prevalence is a measure often used to determine the level of morbidity in a population – it measures the proportion of a population with a particular condition. Morbidity due to heat-related illness is sometimes measured in terms of increases of annual 'patient-days' in hospital.

There is a significant amount of literature relating to the effects of overheating on comfort and health. Thermal discomfort is a negative impact in its own right, and over prolonged periods, and may lead to more serious health impacts for individuals. Overheating can also cause sleep loss which may contribute to health risks for the person concerned and for others, for example through a loss of productivity at work.

Heat-related Mortality and Morbidity

This section summarises the findings from the literature review on the impact of overheating on mortality and morbidity rates.

Why does heat-related mortality and morbidity occur?

Heat-related illnesses and mortality can occur when the human body's ability to thermoregulate is impaired. This ability is influenced by temperature, humidity, air movement, radiant energy exchange, the built environment and behaviour. The human body uses thermoregulation to maintain its core body temperature of between 36.1°C and 37.8°C, balancing heat generation and loss. It can cope with temporary increases of up to 38°C or 39°C without causing damage to health.

Heat loss mechanisms used by the body include (World Health Organization 2004a; Carmichael, Anderson, and Murray 2011):

- **Convection** – air or water passing over the skin. However, when the surrounding air temperature is higher than the body temperature, heat will be gained rather than lost, as would be the case if the water passing over the skin is warmer;
- **Conduction** – contact with cooler objects;
- **Radiation** – heat loss through the air via electromagnetic waves. This can also be a mechanism of heat gain;
- **Evaporation (sweating)** – this is the most effective mechanism. However it can lead to dehydration and heat exhaustion if fluids and salt are not replaced quickly enough, and it can be inhibited by humidity (high vapour pressure leading to water being unable to leave the skin); and
- **Respiration** – through exhalation.

Increased heart rate and cutaneous vasodilation (blood vessel expansion) can increase the body's ability to lose heat by bringing blood flow to the skin surface. However, redirecting flow from other systems and increasing the heart rate can impact on underlying cardiovascular conditions.

These mechanisms are not fully understood but illness and death may be caused by additional strain on the cardiovascular system, with dehydration, increased blood viscosity and other changes taking place. Any illness compromising thermoregulation will increase the risk (Kovats and Hajat 2008).

When thermoregulation is put under stress or in extreme cases fails, due to high temperatures, this can lead to heat stress, illness and death (Carmichael, Anderson, and Murray 2011), (Dengel, Andy 2012).

What are the health risks?

As noted in an earlier literature review undertaken by AECOM in 2012 (AECOM 2012a), severe overheating in dwellings is a significant health risk.

The literature identifies several specific health risks associated with overheating. A key report is the review of physiological responses to heat undertaken by the Health Protection Agency (HPA)[1] and the Building Research Establishment (BRE) (Carmichael, Anderson, and Murray 2011). It identifies mild effects of exposure to high temperatures including dehydration, prickly heat, heat cramps, heat oedema (fluid retention often in the ankles and feet), heat syncope (dizziness and fainting) and heat rash, as well as reduced productivity and concentration. It also identifies potentially more severe effects, ranging from mental health consequences including increased suicide risk, to heat exhaustion due to excessive sweating and heat stroke.

1. The HPA (Health Protection Agency) was restructured and renamed Public Health England (PHE) in 2013. We will refer to HPA as PHE throughout this document.

Heat stroke is currently rare – but may be under-reported due to similarities to other illnesses. It occurs when core body temperatures reach 40.5°C or above, which leads to damage to the thermoregulatory system and to cellular structures and has a high case-fatality ratio (World Health Organization 2004a).

Although there is a large body of evidence on heat-related health effects, the relationship between heat exposure and mental well being is less well understood. A link has been established between existing mental illness and heatwave vulnerability, but it is also likely that there are cumulative implications on the mental state of people during long periods of hot weather. High temperatures have long been related to an increase in aggressive behaviour and violence (McGregor et al. 2007). However, it is difficult to attribute incidents of aggression to heat exposure due to the large number of confounding factors in play (Anderson 2001).

There is also some evidence of indirect impacts of excess heat on health, for example, the effectiveness of drugs can be affected at temperatures over 25°C (Carmichael, Anderson, and Murray 2011); and, it is estimated that a 1°C rise in temperature would result in an increase of food borne illnesses of approximately 4.5% across the population (Scottish Government, Health and Wellbeing Sector Actions Plan, 2011, cited in (London Climate Change Partnership and Environment Agency 2012)).[1] These two impacts – change in drug effectiveness and food-borne diseases – were rated as lower risks than heat-related mortality and morbidity in the Government's Climate Change Risk Assessment for the Health Sector and were not selected for more detailed assessment (Hames and Vardoulakis 2012).

Another, indirect issue is that high outdoor/indoor temperatures may increase accidents such as falls from open windows (AECOM 2012a). A wider range of health impacts related to other impacts of climate change are covered in the literature but this study focuses on those directly related to overheating in homes as opposed to the wider environment.

What are the 'thresholds' for heat-related mortality and morbidities?

The literature suggests that normally people can cope with their body temperatures increasing to 38°C or 39°C during exercise without damaging health, with a resting temperature of 37°C (World Health Organization 2004a). However, as noted by several studies such as (Dengel, Andy 2012), (AECOM 2012a), (Nicol, F. 2012), different individuals respond to heat in different ways. This makes it difficult to define acceptable thresholds for physiological response functions, which may also depend on environmental and other factors (AECOM 2012a).[2]

There is currently no formal cross-sectoral agreement on the temperature thresholds for 'overheating' in homes above which adverse health impacts occur. Most definitions and thresholds have been developed with thermal comfort in mind rather than identifying specific health impact trigger points. Definitions to date have also focussed more on non-domestic buildings.

1. *The Food Standards Agency, Guidance on Temperature Control Legislation in the UK, EC Regulation 852/2004, 2006, states that temperatures between 4-60°C encourage bacterial growth.*

2. *It should be noted that hyperthermia (elevated body temperatures due to failed thermoregulation) induced by exercise is different to that experienced by those not exercising, so care should be taken when using results of studies of people exercising, as these may not always be directly transferable to an indoor population.*

High temperatures increase the risk of various other causes of mortality including cardiovascular and respiratory diseases which account for the majority of heat-related deaths.

When overheating in homes occurs the severity of health effects is influenced by various factors, including:

- **The susceptibility of the individual and their level of activity;**
- **Occupancy patterns; and**
- **The occupant's ability and willingness to act on advice.**

These risk factors are discussed in more detail in Section 3.

CIBSE Guide A (2006) provides summer indoor comfort temperature thresholds for non-air conditioned dwellings, stating that people start to feel increasingly uncomfortable when living area operative temperatures rise above 25ºC and when bedroom operative temperatures rise above 23ºC. It notes that sleep may be impaired above an operative temperature of 24ºC.[1]

Researchers are concerned with how such definitions take into account continuous duration or severity over set limits, sensitivity to assessment methods, variation in individuals' responses and perception and their applicability to naturally ventilated buildings (Nicol, F. 2012). This type of definition is also based on the assumption that the occupants are healthy adults of working age and not more vulnerable individuals.

In addition to defining thermal comfort by the duration of exposure to temperatures over maximum values, the ability of occupants to interact with and control their indoor environment is also taken into account in more recent models and definitions ('adaptive thermal comfort'). Recently, CIBSE TM52 has provided a summary of existing definitions (primarily derived from data in non-domestic settings), including those taking into account adaptive thermal comfort. They proposed a definition which is based on BS EN 15251 (CIBSE 2013, 52). A lack of research on defining night-time thermal comfort is noted in TM52.

Evidence gaps

A key finding of AECOM's Literature Review (2012) is that there was limited and indirect epidemiological evidence about the indoor temperature exposure conditions which would cause adverse health impacts, and concluded that the evidence was insufficient to define an indoor overheating threshold for health risk.

A recent report by Public Health England (PHE) confirms that the difficulties of defining thresholds are still current.[2] PHE investigated evidence for cold-related health effects, noting that various factors made assessing indoor temperature thresholds challenging, including the difficulties of measuring exposure (e.g. duration of exposure, temperature gradients within rooms/homes, ensuring temperatures measured are representative, accounting for variables), and of assessing outcomes. Limited robust evidence was found to support a threshold.

An evidence review carried out for the NHBC Foundation by BRE with input from PHE (Dengel, Andy 2012) investigated possible threshold temperatures for overheating and drew upon recent investigations by BRE. It noted that whilst existing overheating criteria reviewed in the study were found to be based on upper thermal comfort limits, medical evidence suggested that in the short term health effects can be mild (within these limits), but that longer-term exposure to high temperatures can cause more serious problems and fatalities, particularly for vulnerable groups. It was concluded that more evidence was required on the impact of exposure times and that this is taken into account in policy development, there is an urgent need to develop robust overheating thresholds.

1. *The operative temperature is based on a combination of air temperature and mean radiant temperature.*

2. *PHE, Minimum home temperature thresholds for health in winter – a systematic literature review, 2014.*

Design guidance on thermal comfort includes CIBSE's Environmental Design Guide A (CIBSE 2006), which proposes that the operating temperature should not exceed a benchmark temperature for more than a set amount of time.

The CIBSE Guide A definition for dwellings is that operative temperatures should not exceed 28°C for 1% of annual occupied hours in living areas, and 26°C for 1% of annual occupied hours in bedrooms.

The Government's Housing Health and Safety Rating System guidance suggests that where temperatures (presumed to be indoor temperatures given the focus of the guidance) exceed 25°C, this can lead to an increase in strokes and mortality (HHSRS Guidance for Landlords and Property-Related Professionals, 2006).

Box 2. The Housing Health and Safety Rating System (HHSRS) 2006

The Housing Health and Safety Rating System (HHSRS) is a risk-based evaluation tool to help local authorities, landlords and property-related professionals identify and protect against potential risks and hazards to health and safety from any deficiencies identified in dwellings. It was introduced under the Housing Act 2004 and applies to residential properties in England and Wales.

The HHSRS assesses 29 categories of housing hazard. Each hazard has a weighting which will help determine whether the property is rated as having category 1 (serious) or category 2 (other) hazard. Two of the 29 hazards are Excess Cold and Excess Heat.

This threshold is consistent with the WHO's guidance (1982, readopted 1987 and 1990) which defines the internal air temperature range between 18-24°C as that at which there is a minimal risk to the health of sedentary people in housing (Ormandy and Ezratty 2012). Research by Armstrong found that external air temperatures over 24.7°C in London over a two-day average lead to higher mortality and morbidity rates and hospital admissions (Armstrong et al. 2011).

The Heatwave Plan 2014, which was first implemented in response to the 2003 heatwave in Europe, also sets out risk thresholds (day and night external temperatures) for different areas of England (Public Health England 2014), as summarised in Box 3. It is important to note that overheating can occur outside of 'official' heatwave periods.

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Box 3. The Heatwave Plan for England

The Heatwave Plan for England (Public Health England 2014) defines regional day and night temperature thresholds that trigger four escalating alert levels. In connection with this, a 'Heat-Health Watch' system operates in England from 1st June to 15th September each year. The Plan gives the following explanation of the thresholds:

"Although excess seasonal deaths start to occur at approximately 25°C, for practical reasons the health heatwave alert system is based upon temperature thresholds where the odds ratio is above 1.15 – 1.2 (a 15 – 20% increased risk). The different trigger temperatures are summarised below, with regional variations due to the relative assumed adaptation to heat. However, a significant proportion of excess summer deaths occur before the health heatwave alert is triggered, which emphasises the importance of long-term planning actions by local authorities and the health sector."

Region	Day	Night
London	32°C	18°C
South East	31°C	16°C
South West	30°C	15°C
Eastern	30°C	15°C
West Midlands	30°C	15°C
East Midlands	30°C	15°C
North West	30°C	15°C
Yorkshire and Humber	29°C	15°C
North East	28°C	15°C

Alert Level 2 (alert and readiness) is triggered when the Met Office forecasts a 60% chance of thresholds being exceeded on at least two consecutive days. Alert Level 3 (heatwave action) is triggered as soon as the Met Office confirms that threshold temperatures have been reached in any region.

Studies are starting to link external thresholds more explicitly to internal temperatures in homes, for example (Mavrogianni et al. 2012) which investigates the impacts of individual building characteristics on indoor temperatures using dynamic thermal modelling. Generally, impacts on mortality and morbidity have often been assessed based on threshold outdoor temperatures, however some guidance exists on indoor temperature thresholds.

A key question for the sector is whether it is necessary to define a single threshold. An alternative approach may to be to focus efforts on understanding the effectiveness, benefits and pitfalls of measures designed to keep homes cool.

External temperatures cannot simply be translated to indoor temperature due to various factors including the effect of different building envelopes and site microclimatic conditions.

Jenkins et al (2014) carried out a modelling study which, for the 2050s, shows that if adaptation measures were effective at reducing internal temperatures by 1-2°C, heat-related mortality could be reduced by 32%-69% (compared to the no adaptation scenario).

What is the nature of the evidence and how strong is it?

The strength of the evidence on heat-related mortality is noted in the Government's Climate Change Risk Assessment (CCRA) for the health sector (Hames and Vardoulakis 2012), which states that of all the risks assessed, the strongest evidence was for heat-related mortality in terms of future exposure levels and exposure-response relationships. However the report also notes that evidence on heat-related morbidity is weaker due to inherent uncertainties in defining morbidity outcomes. This issue is discussed in AECOM's 2012 literature review for DCLG: *"the body of evidence on heat-related morbidity, as reflected by hospital admissions, general practice consultations, ambulance calls and communication with the health service, is less extensive than for mortality, but it shows broadly similar patterns (though some analyses suggest that hospital admissions have a weaker association with high temperature than mortality)."*

The CCRA for the health sector, for example, notes that assessments of the scale of heat-related mortality are very sensitive to assumptions about temperature thresholds at which excess deaths and hospitalisation are caused (Hames and Vardoulakis 2012).

Most of the evidence on the relationship between temperature and health effects (both mortality and morbidity) is from 'epidemiological' studies – studies of the distribution and causes of health-related events. Daily or weekly counts of health events have been related to outdoor temperatures measured at weather monitoring stations in time-series analyses, and their influence on health event frequency for a certain population, allowing for other risk factors, for example air pollution and seasonal infections.

Such studies have shown a strong relationship between temperature levels and duration of high temperatures, and increases in mortality and morbidity. Examples include (Ishigami et al. 2008), (Vandentorren et al. 2004), (McMichael et al. 2008). A significant amount of work specifically focusing on heat-related mortality in England and Wales has been undertaken by the London School of Hygiene and Tropical Medicine (LSHTM), including time-series analyses of regions in England and Wales over the summers of 1993-2006 (Gasparrini et al. 2012), (B. G. Armstrong et al. 2011).

Physiological evidence can provide an indication of responses to particular temperature levels for an individual, but the relationship between physiological responses and adverse health effects is often unclear and it is difficult to aggregate results to the population level (in contrast with epidemiological studies). One of the factors influencing physiological responses is humidity, however some studies found little evidence to link humidity to mortality (B. G. Armstrong et al. 2011). AECOM's 2012 literature review concluded that for most practical purposes humidity does not need to be taken into account for epidemiological analyses, although the 'apparent temperature' (taking into account vapour pressure of water) may have physiological impacts.

Box 4. Climate Change Risk Assessment (CCRA)

The UK's Climate Change Risk Assessment 2012 reviewed the evidence for over 700 potential impacts of climate change in a UK context. Detailed analysis was undertaken for over 100 of these impacts across 11 key sectors, including the health sector, on the basis of their likelihood, the scale of their potential consequences and the urgency with which action may be needed to address them.

Estimates of heat-related mortality and morbidity, in particular future projections, can be sensitive to the assumptions underlying them.

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The current situation

The London School of Hygiene and Tropical Medicine (LSHTM) investigated the causes of deaths related to heat during the period 1993-2006 in England and Wales (Gasparrini et al. 2012), (B. G. Armstrong et al. 2011). The study concluded that the risk of mortality is distributed widely across contributing causes: 34% of heat deaths were attributable to cardiovascular causes, 25% to respiratory causes and 41% to other causes.

A London School of Hygiene and Tropical Medicine study found an increase in mortality risk during summer of 2.1% for a 1°C increase in temperature above region-specific thresholds (which allow for partial adaptation to regional climates).

The steepest increase in risk was for respiratory mortality, and there were high increases in risk for certain cardiovascular causes (pulmonary heart disease, arrhythmias and atrial fibrillation), and lower increases for other cardiovascular causes (myocardial infarction, ischaemic heart diseases) – but it was noted that these have large absolute risks. Among other non-respiratory or cardiovascular causes, the most significant increases in risk were for genitourinary and nervous system disorders, but it was found that there were significant heat-related risks for most conditions including endocrinal, nutritional and metabolic disorders, and mental and behavioural disorders.

The study noted that the findings were broadly compatible with other UK studies, (Hajat, Kovats, and Lachowycz 2007) (Hajat et al. 2002), as well as European and US ones which for example also found a 1% – 7.3% mortality risk increase in over 75s for a 1°C increase in the daily maximum temperature e.g. (Baccini et al. 2011).

A separate similar study found that relative risks of heat-related mortality were higher for certain regions and in urban areas, with London showing the highest risk; and Wales one of the lowest (Hajat, Kovats, and Lachowycz 2007). These findings are supported by another more recent study by Imperial College London investigating the risk of heat-related deaths from cardiorespiratory causes in England and Wales (Bennett et al. 2014).

Box 5. Estimates on the annual number of heat-related deaths

A LSHTM study suggests that there was an average of just under 1,700 heat-related excess deaths per year in England and Wales over the 14 year period studied (Armstrong et al. 2011). The study notes that this accounts for around 1% of all overall mortality during the summer months of the period.

The CCRA 2012 has lower figures, using a baseline of 1,100 excess deaths per year for the UK as a whole (based on the period 1993-2006), and noted that significantly higher figures occurred in exceptionally hot years.

The most recent estimates are that there are approximately 2,000 excess heat-related deaths per year (Vardoulakis and Heaviside 2012), (Hajat et al. 2014) based on data for 1993-2006, and projected for 2000-2009. This figure was the baseline used in the Committee on Climate Change Adaptation Sub-Committee's recent report (Adaptation Sub-Committee 2014).

Clearly, estimates vary depending on a range of underlying factors including the baseline population and temperature thresholds, and the method used to estimate 'expected' baseline mortality rates.

Various studies have also looked specifically at increases in mortality over 'heat wave' periods in the UK, Europe and elsewhere – though heat waves account for only a fraction of the overall health impacts as they are at present relatively infrequent (Smith and Woodward 2013).

Just under a 9% increase in mortality rates in England and Wales was estimated during the 1995 heat wave from 30th July – 3rd August, a total of 619 excess deaths (Department of Health 2001), and a 16% increase was estimated in London over the same period, a total of 137 excess deaths.[1]

A 16% increase in mortality rates was estimated for the August 2003 heat wave in England, a total of 2,091 excess deaths,[2] with a 42% increase in the London region – a total of 616 excess deaths (Kovats and Hajat 2008).

Estimates of excess mortality rates depend on various factors including magnitude of the heat wave, timing in the season, population experience/acclimatisation and public health responses (Koppe et al. 2004).

Box 6. The Urban Heat Island effect

The Urban Heat Island Effect (UHI) describes the effect that cities and urban areas can have on air temperature, whereby cities can be around 5 to 9°C warmer than the surrounding countryside.

The UHI effect is predominantly a night-time phenomenon. The heat absorbed in materials during the day is released at night, reducing the temperature differential between internal and external temperatures and compromising heat release from buildings.

Around 40% of the heat-related deaths during the May-June 2006 heat wave in London have been attributed to the UHI effect (Davies and Mavrogianni). However it should be noted that urban temperatures are not always higher than those in surrounding rural areas.

Displaced mortality

The LSHTM recently described the difficulty of robustly accounting for what is sometimes termed 'displaced' mortality – the effect of a proportion of deaths being brought forward by overheating by a short time. They note the unreliability of attempts to estimate this and conclude that the problem has not been resolved (B. Armstrong, Gasparrini, and Hajat 2014). An earlier critical review of the evidence on heat stress impacts on public health explained that assessments are complicated as the ability to consider reductions in expected deaths in the period following an initial hot day may be masked by an opposing increased risk from subsequent hot days. However, it has been suggested that during the 2003 heat wave in France and during the Chicago 1995 heat wave, a very low proportion of the attributable deaths were due to short-term displacement (Kovats and Ebi 2006) and (Kovats and Hajat 2008). In contrast, a study on the heat wave in Belgium in 1994 estimated the displacement effect at 15% (R Sari Kovats 2006).

The Kovats and Ebi study notes that more research is needed to understand the extent to which heat-related deaths are preventable, though noting that it should be assumed that this is a sufficient number to develop preventative measures and that heatstroke is easily preventable.

1. Rooney et al., 'Excess mortality in England and Wales, and in Greater London, during the 1995 heat wave', J Epidemiol Community Health 1998; 52:482-86, cited in Kovats and Ebi 2006.

2. Johnson H. et al., 'The impact of the 2003 heat wave on mortality and hospital admissions in England, Health Stat Q 2005; Spring:6-11, cited in Kovats and Ebi 2006.

Hospital admissions

An epidemiological study was undertaken in 2004 into the effects of high ambient temperatures on emergency hospital admissions in Greater London over the period April 1994 to March 2000, based on the three-day average of daily mean temperatures (Kovats, Hajat, and Wilkinson 2004). It concluded that the study did not find evidence for a similar magnitude of increases in hospital admissions as for mortality increases, and that this supported the hypothesis that many heat-related deaths occur before issues have come to medical attention.

The findings of the study above are similar to a study on the 1995 Chicago heat wave which found that mortality increased by nearly 150% but emergency hospital admissions increased by just over 10%.[1] It did find evidence for increases in hospital admissions for heat-related respiratory and renal disease in children under 5 and for respiratory disease in adults over 75, but not for cardiovascular disease, which accounts for the highest proportion of excess deaths.

It is unfortunate that the evidence for changes in patient days statistics is limited as it is one of the few available indicators of heat-related morbidity (Hames and Vardoulakis 2012). As noted in the Adaptation Sub-Committee's 2014 report, using mortality estimates has limitations: it does not measure the number of years of life lost, the economic cost of disease, or wider impacts on health such as well-being (Adaptation Sub-Committee 2014).

Future projections

Future projections are informed by climate change scenario projections. The NHBC Foundation (Dengel, Andy 2012) identifies a number of key factors that are likely to increase the magnitude of heat-related impacts now and in the future, including:

- **Climate change** – the increased occurrence of more extreme weather events is predicted, including hotter drier summers, longer and more frequent heat waves, higher and more frequent maximum temperatures, higher UV radiation levels and dangerous ozone levels, which are likely to lead to greater health impacts as well as to people spending more time indoors.
- **Increased urbanisation** – more occupants may live within an UHI. The UHI itself may intensify due to larger urban populations and greater density of development.
- **An ageing population** – a greater proportion of the population is likely to be vulnerable to the effects of overheating.
- **Changes to new and existing dwelling design** – the drive for carbon reduction is leading to better insulated and more airtight dwellings, which may lead to an increased overheating risk and a greater need to focus on ensuring good levels of ventilation are provided.

The CCRA for the health sector highlights other factors likely to exacerbate the impacts of overheating. These include the prevalence of some conditions which increase vulnerability to overheating such as obesity, health care inequalities, social inequalities, drug abuse, risk from infectious disease outbreaks, health staff shortages, and new technology/environmental hazard risks (Hames and Vardoulakis 2012).

1. Semenza, JC et al., 'Excess hospital admissions during July 1995 heat wave in Chicago', Am J Prev Med 1999; 16:269-77, cited in Kovats, Hajat, and Wilkinson 2004.

2. Fouillet A et al., 'Excess mortality related to the August 2003 heat wave in France', Int Arch Occup Environ Health, 2006, 80:16-24, and New York City Department of Health and Mental Hygiene, New York City Community Health Survey Public Use Data, 2007, cited in Quinn et al. 2014.

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Evidence on non-fatal effects of heat are usually based on reported increases in emergency hospital admissions or ambulance call-outs during times of high temperatures.

The Department of Health estimated in 2001 that there are around 80,000 additional patient-days per year due to heat-related illness (Department of Health 2001).

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The Climate Change Risk Assessment 2012 assumes that each heat-related death is equal to 102 patient-days in hospital, thus representing an estimation of heat-related morbidity and potential for strain on the health service.

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During the 2003 European heat wave, one study suggested that 50% of heat-related deaths in France occurred in homes. Over 80% of heat strokes in New York City have been attributed to exposure in the home. [2]

Generally, the literature has focussed on the impact of a changing climate and projections do not always take the other factors listed above into account.

Box 7. Future health risks

This section focuses on reviewing some of the literature which attempts to predict what the impacts of some of these factors may be on future mortality rates. It does not review the evidence for the factors themselves.

A report by the Department of Health has noted that there are broadly three methods used in the assessment of future climate change impacts on the health of the population. These include:

- Qualitative/quantitative analogue studies on the impact of a past or current extreme event such as a heat wave;
- Empirical early effects studies that analyse relationships between climate trends and health status such as heat-related mortalities; and
- Predictive models that might for example be based on an extrapolation of climate/disease relationships over time (Department of Health 2001).

The report notes a need for monitoring systems to record the early impacts of climate change on health, for example changes in the magnitude of impacts associated with heat waves. It notes issues to be aware of when considering future projections, such as the limited possibilities for data-based validation, high levels of aggregation, limits of existing knowledge, need to account for other factors and necessary simplifications.

This uncertainty is reflected in the CCRA for the health sector, which, as discussed, notes that the scale of heat-related mortality is very sensitive to assumptions on temperature thresholds at which excess deaths and hospitalisation is caused (Hames and Vardoulakis 2012). Variations in figures between studies can be seen in the examples given below. The variation may also be due to a range of other factors including use of different climate projections, inclusion/exclusion of population change, etc. (Department of Health 2001).

Studies agree that the number of heat-related excess deaths will increase in the future. A number of estimates have been made, with the more recent estimates found in the literature being higher than earlier estimates:

- The Department of Health in their original 'Health Effects of Climate Change in the UK' study in 2001 estimated there could be around 2,800 excess heat-related deaths in summer by 2050 in the UK; an increase of around 2,000 cases per annum (c.350%) compared to their baseline.[1] It also estimates a proportional increase to 280,000 additional days of NHS hospitalisation. This report is largely based on the UKCIP98 medium-high scenario (Department of Health 2001).

1. Based on excess deaths defined as all deaths occurring on days with mean temperatures over 18.6˚C, on future climate projections (medium-high scenario, UKCP 98), and on the 1996 UK population.

- Updated figures in the Climayte Change Risk Assessment (CCRA), which used UKCP09 projections to assess future risks, used a higher baseline of 1,142 excess deaths per year (1,055 in England and Wales only) based on the period 1993-2006. It was noted that significantly higher figures are seen in major heatwave years, 18% to 33% higher, though heatwave effects were not explicitly accounted for in projections. It projected a c.60% increase in heat-related mortality and morbidity by the 2020s (c.1,860 UK deaths, 1,720 England and Wales) and c.300% by the 2050s (c.3,370 UK deaths, 3,150 England and Wales), based on the central estimate of the medium emissions scenario. These figures assume a constant population size and also age distribution and no adaptation – it was noted that a more realistic assumption of a larger, older population would increase the estimates whereas measures to adapt and acclimatise would reduce the estimates (Hames and Vardoulakis 2012).[1]
- Higher estimates of baseline deaths and higher long-term projections for the UK were given in PHE's 2012 update of the 'Health Effects of the Climate Change in the UK'. This report projected an increase of approximately 70% in heat-related deaths in the 2020s, 260% in the 2050s and 540% in the 2080s, compared with a mortality baseline of around 2,000 premature deaths per year. The study took into account population increases and changing demographics, but did not assume any physiological or behavioural adaptation of the population to higher temperatures. The projections were based on the use of the 93rd percentile threshold and accounted for additional heat wave deaths (only seen to have an effect in London) – meaning there may be around 12,538 deaths per year by the 2080s (Vardoulakis and Heaviside 2012) also presented in (Hajat et al. 2013).[2]
- In July 2014, the Committee on Climate Change's Adaptation Sub-Committee Progress Report gave a still higher projection from a similar baseline of around 2,000 deaths per year. This also took into account the anticipated growth in the aged population as well as climate change. It updated the work previously undertaken in the CCRA and PHE's study. The ASC estimated that excess deaths in the UK from high temperatures are projected to increase to 7,000 per year on average as early as the 2050s – a similar proportion of increase as in the CCRA and Health Effects reports but with higher absolute figures (Adaptation Sub-Committee 2014). This report used data from the 2013 study by Hajat et al. (Hajat et al. 2013) – lower than those in the CCRA.

The PHE (Vardoulakis and Heaviside 2012) identifies the South East, London, East and West Midlands, East of England and the South West as the most vulnerable regions currently and in the future.

1. The CCRA also considered changes in the population size, but not age distribution.

2. The baseline differences from the CCRA estimates were attributed to the use of lower thresholds (thresholds from around 16.6˚C in the North-East to 19.6˚C in London reported in the 2013 study (Hajat et al. 2013)) and the inclusion of all-cause deaths including external causes.

Sleep deprivation

Overheating in homes during the night can be particularly problematic as it limits the body's ability to recover from daytime heat stress, which can increase the risk of the health-related impacts. Without relief from high temperatures during the night, heat-related mortalities have been shown to increase (Kovats and Hajat 2008). Heat can also lead to disturbed sleep due to interruptions in the mechanisms which regulate the body temperature such as sweating.

The NHBC Foundation's 2012 evidence review notes that the relationship needs further investigation. Whilst it is clear that high temperatures have an effect on the quality and continuity of sleep, more research is particularly needed on the effect of consecutive nights of high temperatures and poor sleep on health (Dengel, Andy 2012). Studies have also noted that there is no widely accepted definition of sleep thermal comfort e.g. (Leung and Ge 2013) and that there is limited quantitative research on this (Lan et al. 2014).

However, the literature does point to heat-related sleep loss being a cause for concern. Studies such as the Good Homes Alliance's (GHA) investigation into overheating in homes in England (Taylor, Melissa 2014) reported that some residents found it difficult to sleep at night when temperatures were high.

The effect of temperature on sleep has been researched in a number of studies. A note from a World Health Organisation technical meeting on sleep and health in 2004 at which 21 international specialists on sleep discussed the health impacts of sleep disturbance set out several indicators which can be used to describe sleep disturbance or disorders (World Health Organization 2004):

- Total sleep time;
- Number and duration of nocturnal awakenings;
- Sleep onset latency (the length of time taken to transition from full wakefulness to sleep);
- Changes to the amount or rhythms of particular sleep stages, e.g. slow wave ('deep') sleep;
- Rapid Eye Movement (REM) sleep and changes in heart rate, blood pressure, vasoconstriction and respiratory rate; and
- Consecutive nights of sleep disruption in a single week or month.

Studies in Japan have shown the impact of slow decreases in body temperature on a good night's sleep (Setokawa, Hayashi, and Hori 2007). A study of the sleeping patterns and skin temperatures of around 20 older adults showed increased wakefulness during summer nights (Okamoto-Mizuno and Tsuzuki 2010) which it has been suggested is related to an increased ability to thermoregulate when awake (Okamoto-Mizuno and Tsuzuki 2010).

Another study (Okamoto-Mizuno and Mizuno 2012) showed that heat exposure and the need to thermoregulate also decreases REM and slow wave sleep under study conditions (the latter was found to be more likely in real life conditions as ambient temperatures of 32°C at relative humidity of 80% was found to effect only slow wave sleep). Normally peripheral skin temperatures decrease during sleep, decreasing core body temperatures. The study noted that humidity further increases wakefulness and decreases REM and slow wave sleep, probably as it inhibits the ability for sweat to evaporate. It suggested that in the elderly, even mild heat exposure can affect wakefulness and REM (this age group already have decreased slow wave sleep).

A US study based on scans of brain activity in 17 young healthy male adults deprived of sleep over a 24 hour period found that short-term sleep deprivation decreases activity in certain regions of the brain, particularly the cortico-thalamic network which mediates attention and higher-order cognitive processes, reducing alertness and cognitive performance, including increasing the time required to perform tasks.

Increases in skin temperature of just 1°C can affect sleep quality (Dengel, Andy 2012).

At increased temperatures, thermoregulatory mechanisms such as sweating or blood vessel expansion can cause a disturbance to sleep. The time taken to get to sleep is longer, sleep is more interrupted and total sleep time is reduced (Carmichael, Anderson, and Murray 2011).

These brain areas may have a relatively greater need for recuperation during sleep than others (Thomas et al. 2000). Research cited in this study found that performance deficits could occur after only one night without sleep and were amplified after two or three nights, but they did not seem to have examined the impact of sleep disturbance where some sleep may be had in a night.

The WHO has noted that even a single night of abnormal or poor sleep can lead to a disturbed day (feeling tired, risks of falling asleep, reduced concentration and alertness, memory blanks, irritability, frustration) (World Health Organization 2004b). Reductions in mental concentration can also lead to an increase in accidents (Thomas et al. 2000) (World Health Organization 2004b).

Sleep disturbance has also been linked to poor physical health, the ability to maintain a healthy immune system, poor mental health, poor quality of life and low productivity at work.[1] A paper summarised in the WHO meeting notes suggested that there is an increased mortality risk but noted the lack of accurate data on this and suggested it may be linked to work-related accidents rather than intrinsic health conditions (World Health Organization 2004b). More recent studies have suggested that sleep disturbance may increase the risk of various adverse health problems including cardiovascular disease (Lan et al. 2014).

High night-time temperatures are projected to occur more frequently in the future, and changes to diurnal temperature variations are also expected which may limit the ability to undertake night purge ventilation (AECOM 2012a). However, the literature review did not find studies specifically quantifying the current or future prevalence of heat-related sleep problems. Evidence limitations are noted in the review by PHE and BRE (Carmichael, Anderson, and Murray 2011) finding that sleep impacts cannot be attributed to temperature alone, many laboratory studies look at the bed microclimate and not the room, and have not been performed on a representative cross-section of the population, limiting the ability to robustly extrapolate results.

1. *Thomas et al. 2000, Kovats and Hajat 2008, Carmichael, Anderson, and Murray 2011, Buysse DJ et al., 'Can an improvement in sleep positively impact on health?', Sleep Medicine Reviews, 2010, 405-10, cited in Dengel, Andy 2012, Okamoto-Mizuno and Tsuzuki 2010, World Health Organization 2004b.*

A Chinese study of 19 young healthy adults showed that participants' subjective assessments of sleep reported decreases in quality at internal temperatures of 30°C as compared to 26°C. Physiological measurements supported this and found that the duration of sleep onset latency was longer and the duration of slow wave sleep was lower at 30°C (Lan et al. 2014).

There is a greater risk of high night-time temperatures in urban areas experiencing the UHI effect, which contributes to higher rates of excess mortality in these areas (Davies and Mavrogianni) (Kovats and Hajat 2008) (Hajat, Kovats, and Lachowycz 2007) (Laaidi et al. 2012) (Dousset et al. 2011).

03
RISK FACTORS

Introduction

The risk of a dwelling overheating is influenced by many factors including location (very broadly the East and South East currently appear to be more affected), the presence of the UHI effect, and dwelling design, age, type and tenure which may influence an individual's ability to adapt their home.[1]

Box 8. Overheating risk factors for dwellings

- The external temperature and other climate variables, such as relative humidity – which vary from year to year, both across the UK and between urban and rural locations.
- How the building moderates the external climate – this includes:
  - How unwanted solar heat gains are avoided, for example through shading, solar coatings on glazing and/or the size and orientation of the glazed elements;
  - How external heat ingress is reduced, which depends for example on the extent of insulation and where the insulation is located in the construction build-ups;
  - How the dwelling stores heat, its thermal mass; and
  - The ability to reduce internal temperatures for example through ventilation measures, through flow of air, and cooling systems.
- The level of heat gains within the dwelling – external and internal including solar gains, gains from services and appliances, and from people.

NB: This list does not include the susceptibility of the individuals themselves.

1. Data on dwelling characteristics can, for example, be found in the English Housing Survey, the National Survey for Wales, and ONS 2011 Census data.

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AECOM's 2012 evidence review noted that small dwellings and flats, in particular single aspect properties and properties with a large proportion of external surfaces exposed such as top floor flats, and airtight, un-shaded houses, are at an increased risk of overheating. However, these factors are not the core focus of the current evidence review.

Rather than looking at risk factors which might influence whether a dwelling overheats, this paper seeks to provide a brief review of a number of factors that may increase the risk and severity of health impacts when overheating in homes does occur.

Box 9. People-related risk factors

- **The susceptibility of the individual:** linked to age, social isolation level, socio-economic status, and existing health issues such as obesity and chronic disease, as well as an individual's level of adaptation to heat and level of activity.
- **Occupancy patterns:** whether people are in the dwelling at the time when the property has the highest internal temperatures, or after the peak has passed.
- **People's ability and willingness to act on advice.**

Risk factors

Individual susceptibility

Social, behavioural, demographic and clinical factors mean that the temperature thresholds for health impacts may be lower for vulnerable groups or individuals. With increasing external temperatures, an increasingly large proportion of the population becomes more vulnerable to the effects of excess heat, including even relatively fit young adults.

Significant research has been undertaken investigating which groups may be most at risk of heat-related illnesses and fatalities. As noted in other reports, there is a need to regularly review the emerging evidence to inform the advice on targeting prevention strategies at certain groups (Kovats and Hajat 2008).

The elderly population

Increased vulnerability in the elderly is particularly well-established in the literature. Older people have a decreased ability to thermoregulate due to a reduced ability to sweat, decreased blood flow to the skin and extremities, and a decreased plasma volume and cardiac output (Kenny et al. 2010). NHS heatwave guidance for care home managers and staff advises that care, nursing and residential homes should include a room or area which maintains a temperature at 26°C or below (Public Health England 2014). Older people are also particularly at risk of interruption to sleep due to high night-time temperatures (Dengel, Andy 2012).

The definition of vulnerable age groups varies in different reports. A more comprehensive summary of reasons for the particular vulnerability of older people to the effects of heat is given in the PHE/BRE review (Carmichael, Anderson, and Murray 2011).

Vulnerability risk factors include age, health conditions which limit mobility, and pre-existing psychiatric, cardiovascular, pulmonary and other illness which can limit the body's ability to react to temperature increases (AECOM 2012a).

The Government's Housing Health and Safety Rating System (2006) identifies people aged 65 and over as the most vulnerable age group.

75 and over is the age group referred to in the Heatwave Plan as at particular risk, and a recent epidemiological study of the vulnerability of different groups in different areas of England and Wales to heat-related mortality found that the risks are highest for those over 85 (Bennett et al. 2014).

Medical conditions
Other risk factors include the use of drugs that interfere with thermoregulatory processes (including phenothiazines, antidepressants, alcohol and diuretics), increased levels of dependency, and the increased prevalence of other pre-existing physical conditions; cardiovascular conditions (congestive heart failure, ischaemic heart disease); neurological conditions (cerebrovascular disease, autonomic impairment, head injury, cerebral tumour or abscess); endocrine disorders (diabetes, hyperthyroidism, hyperpituitarism); skin disorders impairing sweating, and infections (respiratory, gastrointestinal, septicaemia); or mental conditions (dementia, confusional states) (Department of Health 2001).

The Heatwave Plan for England also identifies people with serious chronic health conditions (particularly heart or breathing problems), mobility problems, and serious mental health problems as particularly at risk, along with those on certain medications and those who misuse drugs (PHE 2014).

Armstrong et al. however noted that there is limited evidence on the degree to which risk is focused on these groups or whether targeting these groups would prevent a significant number of heat-related deaths (B. G. Armstrong et al. 2011).

Another example of a physical condition which increases the risk of heat-related health impacts is obesity. Individuals who are obese generate more heat when active and need less heat to be produced before their core temperature rises. Strain is placed on the cardiovascular system in order to keep the individual cool, which increases the existing strain on the system, which is already increased due to increased body weight. These individuals are therefore more susceptible to heat illness. However, evidence has shown that once the air temperature exceeds skin temperature, the difference in heat strain between lean and obese individuals decreases (Koppe et al. 2004).

Nursing and residential homes
People living in nursing and residential homes may be particularly vulnerable to the effects of overheating. One study showed that the most significant increases in excess deaths during the 2003 heat wave in southern England occurred in such homes, with higher risks for those in nursing homes as opposed to care homes (R Sari Kovats 2006). The Kovats study suggested that these observations are likely to be more strongly related to other factors (e.g. age, health of individuals) rather than the condition of the homes.

There is variation in findings within the studies focussing on this population. A European study of nearly 100,000 nursing home residents in South West Germany from 2001 to 2005 found increased mortality risks in all sub-groups of nursing home population (all ages, sexes, levels of functional ability) (Klenk, Becker, and Rapp 2010).

However, a study investigating vulnerability in nursing and residential homes during the 2003 heat wave in France suggested that those with the worst health conditions were less badly affected than those less apparently physically vulnerable. This may be because staff prioritised the former, showing the risks of prioritising a particular group over another and suggesting that those unable to take preventative measures for themselves (including those living alone in private homes) may be at an elevated level of risk (Holstein, J et al., 'Were less disabled patients the most affected by 2003 heat wave in nursing homes in Paris, France?', Journal of Public Health, 27(4), 359-365, reported in (Brown and Walker 2008).

A study of the 1995 Chicago heat wave indicated that heat-related deaths occurred most commonly in those already ill, isolated, or with limited mobility and ability to care for themselves.[1]

1. Semenza JC et al., 'Heat-related deaths during the July 1995 heat wave in Chicago', New Engl J Med 1996 335:84-90, cited in (Department of Health 2001).

Children
Young children are also at increased risk of some health impacts (PHE 2014). The Government's Housing Health and Safety Rating System guidance identifies dehydration as a particular problem for the elderly and the very young (HHSRS Guidance for Landlords and Property-Related Professionals, 2006).

The Heatwave Plan states that those under 4, who are overweight, taking medication or with disabilities or complex health needs may be at increased risk and advises that children should not take part in vigorous physical activity during external temperatures over 30°C (Public Health England 2014). As well as having a limited ability to thermoregulate, children are more at risk of dehydration than adults and are more dependent on others.

Some evidence of excess mortality in children due to heat waves was found in studies of the 1981 and 1991 heat waves in Portugal, and children were found to have died of heat stroke in France during the 2003 and 2006 heat waves (Kovats and Hajat 2008). However a study investigating heat-related mortality in three cities including London did not find strong evidence of increased mortality in children, though it noted their relatively limited ability to thermoregulate, and suggested that more research is needed on the effects of heat-related mortality and morbidity in the young (Ishigami et al. 2008).

Gender
European studies have found that women are generally more vulnerable to the effects of heat waves than men, even after accounting for age (Hajat, Kovats, and Lachowycz 2007). However some studies have only found this to be the case for women aged 65 and over, and have suggested that this might relate to a negative effect of the menopause on thermoregulation as well as on cardiovascular fitness (Hajat, Kovats, and Lachowycz 2007).

The risks vary for different mortality causes – for example, research in the US has found that heatstroke is of a higher risk for men due to relative activity levels during hot weather. Similarly, research into the Paris heat wave in 2003 found that there were more excess deaths among working age men than working age women, possibly due to different levels of heat exposure and activity in different occupations (Smith and Woodward 2013).

Socio-economic status
Those of lower socio-economic status and with lower levels of education may be more vulnerable. Although this effect is not fully understood and appears to vary in different geographies (Brown and Walker 2008), with the effect not commonly found in European studies e.g. (Ishigami et al. 2008), (Hajat, Kovats, and Lachowycz 2007), (Bennett et al. 2014).

Ability to acclimatise
Acclimatisation or adaptation can help to reduce the risk of health impacts, and therefore means that heat thresholds vary for different people and also that heat events occurring towards the start of a summer tend to incur greater risks. For example, heat-related mortality occurs at higher temperatures in hotter regions of Europe and does not account for significantly more deaths there than in colder areas (Keatinge et al. 2000). However, the research is not conclusive on this, for example a recent study of heat-related cardiorespiratory deaths in England and Wales suggested that people living in warmer areas had not typically adapted physiologically or behaviourally to their local temperatures (Bennett et al. 2014).

Some research suggests that physiological acclimatisation can occur only three days after exposure, but other work suggests it can take years to develop. Additional research is needed on physiological as well as behavioural acclimatisation (Vardoulakis and Heaviside 2012), (Carmichael, Anderson, and Murray 2011). The capacity for either type of acclimatisation may be limited by those with higher levels of dependency due to existing health conditions, disabilities or age.

Acclimatisation includes physiological adaptation (e.g. reduction of the salt lost in sweat which is associated with thrombotic deaths), as well as behavioural responses (e.g. drinking more water) and cultural adaptation.

Occupancy patterns

The risk of heat exposure to an individual in the home is affected by their occupancy patterns. Maximum external temperature and peak solar gains are more likely to occur in the early afternoon. The dwelling's ability to moderate heat and reject heat is influenced by factors including design and location. If the dwelling has cooled by the evening, indoor temperatures are more likely to be acceptable for those out during the day and returning in the evening. Individuals in their homes during the daytime are more likely to be inside at the times of highest external and internal temperatures, and they may add to internal heat gains, e.g. from using appliances.

Furthermore, those most likely to occupy a dwelling in the daytime (the sick, elderly people and young children) are also most likely to be vulnerable to the effects of overheating for other reasons – so this risk interacts with others described above.

It is also particularly important for the most commonly occupied rooms not to overheat. This is particularly an issue in homes where residents are limited in their choice of rooms they can move to. The recent Good Homes Alliance study (Taylor, Melissa 2014) found that in some cases residents found it 'difficult to use certain rooms or sleep at night', and in some cases avoided being inside their homes at certain times when they anticipated hot weather. One tenant in a block of low-rise new build flats reported that she avoided taking her children home after school in summer until the evening when internal temperatures began to fall. In other cases, there were reports from residents that they did not use certain rooms at all during the summer months.

It is however difficult for occupants to avoid using their bedrooms. Another study into internal bedroom and living room temperatures in 207 homes in England during the summer of 2007 found that, despite the fact that it was a relatively cool summer, 21% of bedrooms still had temperatures over 26°C for over 5% of night-time hours (Beizaee, Lomas and Firth 2013).

Other post-occupancy monitoring studies have also found evidence of overheating in bedrooms. For example a study of five apartments found that, on average, bedroom temperatures exceeded 25°C for just over 60% of the time, and exceeded 26°C for nearly 15% of the time, despite their coastal location (Capon 2014). Overheating in bedrooms at night can be exacerbated by the UHI effect as this limits the ability for heat to be lost to the outside environment.

Ability and willingness to act on advice

Whilst advice exists on how people can themselves reduce the risk of health-related impacts from overheating, the Climate Change Risk Assessment for the Health Sector found that residents are still, on the whole, unaware of where to go for advice. The report also notes a lack of knowledge, skills or experience in the supply chain on the most effective and appropriate cooling for different types of dwellings (Frontier Economics, Irbaris, and Ecofys 2013a).

An evaluation of the 2006 Heatwave Plan also found that 34% of Primary Care Trusts reported lists of vulnerable people to contact during a heatwave were incomplete or missing, and reported logistical issues associated with the large number of people classed as vulnerable. Failures to reach vulnerable people early enough during a heatwave increases the chance that a case of overheating escalates and emergency measures such as installing portable air conditioning units are taken (Adaptation Sub-Committee 2014).

A Good Homes Alliance study into the common causes of overheating in England (Taylor, Melissa 2014) based on surveys of environmental health officers, local authorities, and housing owners/managers, found that of the instances of overheating reported, 89% came from dwellings occupied during the day.

Box 10. Examples of sources of advice

- The Heatwave Plan and associated NHS guidance (Supporting Vulnerable People Before and During a Heatwave);
- Advice for Health and Social Care Professionals' (Supporting Vulnerable People Before and During a Heatwave – Advice for Care Home Managers and Staff) (AECOM 2012a);
- The Housing Health and Safety Rating System; and
- The Heatwave Plan for Wales.

Another issue influencing the likelihood of residents taking action concerns a lack of awareness of the potential risks of overheating. One study (Wolf et al. 2010) has shown that many elderly people and their social contacts do not perceive heat waves as 'risky' and therefore do not communicate or act on these risks.

Studies have shown that groups of residents can report viewing future 'overheating' as welcome. They didn't consider the prospect of overheating in the future to be a threat but more a welcome occurrence. One resident in the Suburban Neighbourhood Adaptation for a Changing Climate (SNACC) project was recorded as saying 'As far as I'm concerned at the moment, bring it on!'. Other residents in the SNACC report expressed that they were willing to cope with the impacts of occasional extremely hot days, saying 'That's life isn't it? Enjoy them while you can because the rest of the time it's going to be cold'.

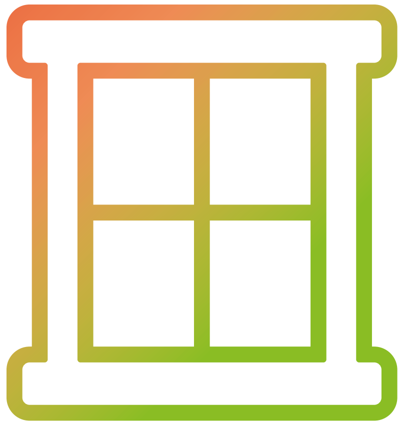
Similarly, on a wider scale, the 2014 Adaptation Sub-Committee report found that the general public appears to perceive that heatwaves and hot weather have become less common over time (Adaptation Sub-Committee 2014). The Department of Health also reported a lack of awareness of the negative health impacts of climate change; the report suggested that the health impact is generally only seen in terms of an increase in skin cancer (Department of Health 2001). The CCRA flags that there is a lack of awareness of overheating as a specific risk and that it is perceived as a future issue (Frontier Economics, Irbaris, and Ecofys 2013).

The Community Resilience to Extreme Weather (CREW) study suggests that more advice on behavioural adaptations should be given when hot weather is forecast in addition to the Heatwave Plan (Community Resilience to Extreme Weather – the CREW Project: Final Report. 2013).

Heat is not always perceived as a bad thing. For example the SNACC report (Williams et al. 2012) gathered feedback from small groups of residents at workshops in six suburbs in three English cities, and found that most residents were sceptical of the extent of climate change and wanted summer temperatures to increase.

Lack of awareness of the potential impacts of overheating means that individuals may not take action to protect their health until the symptoms are quite severe. (London Climate Change Partnership and Environment Agency 2012).

04 ACTIONS PEOPLE TAKE IN RESPONSE TO OVERHEATING



Introduction

This section describes some of the behaviours and actions researchers have observed being taken by people in their homes when experiencing overheating. It focuses on those behaviours which can exacerbate the problem, or have other knock-on effects, such as increasing the demand for energy. Behavioural 'solutions' which would reduce the risk of overheating occurring are considered separately in a Review being undertaken by the BRE due to be published in June 2015. In this section we are referring to actions people take to avoid 'discomfort', rather than severe heat-related health effects which can require medical attention. The actions included are:

- Window opening;
- Use of mechanical ventilation; and
- Use of air conditioning and portable fans.

Previous literature reviews have noted the limited evidence base on these behaviours (Carmichael, Anderson, and Murray 2011), however the sections below summarise what has been found in the current review.

Behaviours

Seek to ventilate the property – window/door opening

One of the most obvious and in-built responses when people become too warm in their homes is to seek to ventilate the property; to 'purge' the hot air. People cool down more quickly by evaporation when air change rates are higher.

Opening windows when it is hotter outside than inside can however result in making the overheating problem worse. The advice is to keep windows in direct sunlight shut during the day if temperatures are high, but open them at night if safe to do so (Public Health England 2014).

A recent literature review (Fabi et al. 2012) on drivers for window opening patterns in homes and offices found that behaviour is more complex than might at first be assumed. The focus was on the relationship between indoor air quality, window use and energy use, rather than overheating. As might be expected, it was reported that various studies found that windows are opened more often and for longer periods in sunny weather

Often opening windows is a useful response, but in some cases it may not relieve the problem or may create security or safety issues. In some cases people may not be able to open the windows in their home sufficiently to purge the hot air, due to lack of sufficient openable windows or window restrictors, or to concerns about security, noise, or outdoor pollution (Taylor, Melissa 2014) (Capon 2014) (Zero Carbon Hub and NHBC Foundation 2013).

because of residents' perceptions of the need to ventilate rooms. However, one study investigating window opening in 21 offices in Germany found that window opening peaked at 20ºC (Herkel 2008).

Fabi et al's literature review noted that some studies suggest that once windows are opened they tend to stay open until another 'crisis of discomfort' is caused, including for night-time ventilation. The review concluded that there is disagreement about whether indoor or outdoor temperatures are the best predictors of window opening behaviour, that occupant behaviour towards night-time ventilation is generally not well understood, and that the degree of window opening (although important information) is ignored in most studies (Fabi et al. 2012).

Box 11. **Window opening**

A report by the Good Homes Alliance (Taylor, Melissa 2014) looked at specific instances of overheating and window opening patterns. In a new build high-rise flat, one tenant overrode the restrictors on the windows in order to open them wider in an attempt to reduce internal temperatures. This was however ineffective (in the occupant's view) and also created a health and safety risk.

Other examples were also presented of tenants attempting to address overheating by leaving the ground floor windows open, potentially causing security issues.

Use of mechanical ventilation and air conditioning

In AECOM's 2012 review, one overheating related issue associated with MVHR systems suggested in stakeholder discussions was the correct use of the summer bypass mode in mechanical systems (AECOM 2012a).

Anecdotal evidence suggests that poor operation of mechanical ventilation systems may contribute to overheating problems in homes – for example due to a failure to run ventilation systems continuously or to use summer bypass, and the need to also use windows to purge hot air (e.g. NHBCF, ZCH and Richards Partington Architects 2012).

The Good Homes Alliance's study also documented a range of actions taken by residents when faced with overheating (Taylor, Melissa 2014). These included the use of electric fans (these may be portable, mounted or hand-held). However, as fans do not cool the air, but draw in cool air from the outside when available, they were found to be less effective when the outdoor air temperature was higher than indoors.

A recent review of international evidence on the use of electric fans as a means of reducing adverse effects in heatwaves (Gupta S et al. 2012) found that fans help people cool down by increasing the efficacy of usual methods of heat loss, in particular evaporation and convection.

The Review found that there are significant gaps in knowledge about the appropriate use of fans. No literature matching the research criteria was found (studies of various types which compared the use of fans to the use of no fans during a heatwave). The study did find retrospective observational studies investigating the association of the use of fans and health outcomes, but the results were mixed. For example fan use can increase sweating which can lead to dehydration and electrolyte imbalances. It was concluded that more research is needed in this area. The study also suggested that at temperatures above 35°C fans might contribute to heat gain and that fans should not be aimed directly at people. Data was not found in the current review on the current or projected uptake of domestic electric fans.

Similarly, there is a limited evidence base on the uptake of air conditioning as noted in other reports (Carmichael, Anderson, and Murray 2011). Studies in the US have found that the use of air conditioning has decreased the risk of mortality significantly reported in (Carmichael, Anderson, and Murray 2011). On the other hand the use of air conditioning may reduce physiological acclimatisation, potentially increasing an individual's susceptibility to heat-related health risks. The evidence is unclear (O'Neill M, 2003, 'Air conditioning and heat-related health effects', Appl. Environ. Sci. Public Health 1:9-12, cited in (Kovats and Hajat 2008)).

Box 12. **The use of air conditioning**

The PHE/BRE review (Anderson et al. 2013) cited research suggesting that there could be a 5-20% increase in cooling energy demand for every 1°C rise in outdoor temperatures, leading to an estimated 120% increase in energy use by 2100. However, evidence on predicted cooling demand for the future varies (Pathan, Young, and Oreszczyn 2008).

Another suggests that cooling demand could triple between 2010 and 2050 for London and the West Midlands (Frontier Economics, Irbaris, and Ecofys 2013a), based on a continuation of current trends of low uptake. If 50% of households installed air conditioning, cooling energy demand would be 37 times higher than the low uptake case and could potentially offset decreases in heating energy use.

Lastly, there is already evidence in newspaper articles suggesting that residents are considering air conditioning as an option (The Guardian 2014).

Increased demand for air conditioning could increase vulnerability to power cuts when external air temperatures are high and puts a strain on the electricity grid (Walsh, B., 'How the heat wave is stressing the electricity grid', Time Magazine, 2011, cited in (London Climate Change Partnership and Environment Agency 2012)), (Kovats and Hajat 2008), (Public Health England 2014), and the heat expelled would be expected to contribute to the UHI effect (Salamanca et al. 2014) (Adaptation Sub-Committee 2014).

05 PUBLIC POLICY IMPACTS

Impact on the health service, businesses and the economy

This section provides a brief overview of some of the impacts of overheating in dwellings in relation to the consequences for the health service, for businesses as a result of productivity losses, and the potential impacts on infrastructure (energy, water and construction materials).

NHS costs

Overheating can damage residents' health and wellbeing, increase social care costs, reduce economic activity, increase NHS costs and lower quality of life (Sustainable Homes on behalf of London Climate Change Partnership 2013).

A number of studies have attempted to quantify the impacts of overheating, including in terms of hospital admission costs and patient-days. However, the scope of the different studies mean that they are not always comparable, and the difficulties of estimating the impacts should not be underestimated. The studies tend not to separate out the impacts which could be attributed specifically to overheating in homes.

As discussed in Section 2, a Department of Health report in 2001 estimated that 800 heat-related deaths were occurring per year in the UK, and that there are around 100 additional patient-days per year of NHS hospitalisation due to heat-related illness for every death: equating to a total of 80,000 patient-days per year. The report projected an increase of heat-related deaths to 2,800 per year in the 2050s, with a proportional increase to around 280,000 additional days of NHS hospitalisation. The study highlights that these admissions would be concentrated within a relatively small number of days per year, potentially putting healthcare facilities under strain at these times (Department of Health 2001).

This cost estimate was based on climate change medium emissions scenarios and the 'principal' scenario of population growth (assuming no acclimatisation). Higher costs were associated with high emissions and growth scenarios. The projections were based on a Value of a Life Year figure of £60,000 as suggested by the Interdepartmental Group on Costs and Benefits. It was assumed that each death resulted in a loss of four months life (Frontier Economics, Irbaris, and Ecofys 2013b). The £183 million per year morbidity cost was monetised using the Interdepartmental Group on Costs and Benefits willingness to pay for a hospital admission patient-day figure of £625 (Frontier Economics, Irbaris, and Ecofys 2013b).

The UK CCRA estimated that heat-related mortality and morbidity costs could potentially increase from the current level by around £84m to £183m (respectively, in 2010 prices) per year by 2050 (Hames and Vardoulakis, 2012).

As noted, a study focusing on Greater London found that emergency hospital admissions did not increase during past periods of high temperatures in line with mortality rates, possibly because people died before they could be treated. It was suggested that this indicates a need to take preventative action in communities to help those who are more isolated and vulnerable (Kovats, Hajat, and Wilkinson 2004).

Productivity losses

Research into productivity losses due to overheating has been a focus of several studies, for example, (Kjellstrom, Holmer, and Lemke 2009), (Nicol, F. 2012) assessing, for example, temperatures at which certain physical activities are affected by heat or where increased periods of rest are needed to avoid core body temperatures exceeding dangerous limits, or to optimise performance.

For example, a study investigating workplace heat exposure and productivity in Central America suggested that continuous light work is possible for an average person at a Wet-Bulb Globe Temperature (WBGT) of around 31°C. Very approximately, at 50% relative humidity the WBGT of 31°C corresponds to an air temperature of around 29°C, although this is an approximation that includes assumptions about sunshine and wind speed.[1]

This light activity threshold suggested by Kjellstrom is several degrees higher than the thresholds used in the UK for when mortality increases, and is also higher than the 25°C figure set in the HHSRS as a threshold over which there is an increase in strokes and mortality (HHSRS Guidance for Landlords and Property-Related Professionals, 2006). See the Defining Overheating Evidence Review for more discussion on this topic.

Box 13. Wet Bulb Globe Temperature (WBGT)

The Wet Bulb Globe Temperature (WBGT) is used as a measure of temperature in some studies because it takes into account effects other than simple shade temperature.

It is a weighted average of three forms of temperature measurement: the so-called black globe thermometer temperature (Tg), which represents the integrated effects of radiation and wind; the natural wet-bulb temperature (Tnwb), which represents the effect of humidity, wind and radiation; and the (shade) air temperature (Ta). For indoor conditions where solar radiation is negligible, the formula for WBGT reduces to 0.7Tnwb + 0.3Tg. (as explained in (AECOM 2012a)).

1. Kjellstrom T, Crowe J. Climate change, workplace heat exposure, and occupational health and productivity in Central America. Int J Occup Environ Health 2011;17(3):270-81, reported in (AECOM 2012a

The study also notes that the findings are focussed on healthy acclimatised individuals and therefore the figures 'severely underestimate' heat stress impacts on productivity for less well acclimatised or less healthy individuals.

The literature on productivity loss to date focusses on workplace temperatures rather than specifically on the impact of overheating in the home. There are some relevant findings, for example the ability of an individual to control their working conditions has been shown to impact upon perceptions of comfort (Bordass and Leaman, 2007, 'Are users more tolerant of 'green' buildings?', Building Research and Information, 35(6), 662-673, cited in (Nicol, F. 2012)).

Clear relationships have also been demonstrated between temperature with productivity, ventilation with productivity, perceived indoor air quality with productivity, and ventilation with sickness absenteeism,[1] which could reasonably be assumed to apply to tasks undertaken in a domestic environment as well. However, evidence was not found specifically quantifying the impacts of overheating in homes on subsequent performance in the workplace.

Impacts on infrastructure

This section provides a brief overview of some of the potential knock-on impacts which overheating within homes may have on the wider infrastructure.

Box 14. LCCP literature review

The London Climate Change Partnership (LCCP) undertook a literature review of research on heat thresholds, including those related to infrastructure (London Climate Change Partnership and Environment Agency 2012).

It cited research finding that buildings' vulnerability to power cuts increases when external air temperatures are high (over 30°C in the reference cited), due to increased demand for air conditioning (Walsh, B., 'How the heat wave is stressing the electricity grid', Time Magazine, 2011); and that power and refrigeration networks lose capacity as temperature rises (IET, Wiring Regulations (BS7671), 2006).

Water stress can also be expected during heat waves due to increased washing (to provide cooling, improve comfort and for hygiene reasons), and use of water for other purposes such as garden watering and paddling pools (Davoudi, Mehmood, and Brooks 2010). The anticipated strain on the water industry through elevated water usage during heat waves could further increase the risk of water shortages (Sustainable Homes on behalf of London Climate Change Partnership 2014) (Public Health England 2014).

Lastly, the Suburban Neighbourhood Adaptation for a Changing Climate report (Williams et al. 2012) noted that higher temperatures and exposure to UV radiation will affect building materials in the future – a risk also presented in TSB's Design for a Future Climate guide (Gething, Bill 2013), potentially leading to increased movement in materials with high thermal expansion coefficients.

1. Leyten and Kurvers, 2010, 'Robust design as a strategy for higher workers' productivity: A reaction to Rehva Guide No. 6', Indoor Climate and Productivity in Offices, Proceedings of Conference on Adapting to Change, London: Network for Comfort and Energy Use in Buildings, cited in Nicol, F. 2012.

06 EVIDENCE GAPS

Suggestions for further research

There are several specific areas where further research would help to develop a better understanding of the direct and indirect impacts of overheating in homes on health:

- **Mortality impacts –** both mortality and morbidity impact estimates are likely to need updating as climate change projections develop, as risk threshold definitions develop, and as the effects of other factors such as increased urbanisation, changes to dwelling design, displaced mortality, air pollution etc. become better understood.
- **Morbidity impacts –** the evidence on heat-related morbidity impacts is weaker than the evidence on mortality (Hames and Vardoulakis 2012), (AECOM 2012a), and further work is needed to understand this, to quantify preventable heat-related morbidity and to evaluate the effectiveness of public health measures (Kovats and Ebi 2006), (Vardoulakis and Heaviside 2012). Further research may enable fuller assessments of the costs of morbidity, for example in terms of years of life lost, economic costs of disease, or wider impacts on health such as well being (Adaptation Sub-Committee 2014). The literature has also noted that the physiological mechanisms which lead to heat-related illness and death are not fully understood (Kovats and Hajat 2008), (Smith and Woodward 2013).
- **Sleep impacts –** the relationship between overheating in homes, interrupted sleep and health as well as productivity requires further research. In particular studies have suggested that the cumulative effect of several consecutive warmer, sleepless nights on health requires more research (Dengel, Andy 2012), and that work is needed to arrive at a widely accepted definition of sleep thermal comfort, e.g. (Leung and Ge 2013), (Lan et al. 2014). In common with previous reviews (Carmichael, Anderson, and Murray 2011), the current literature review did not find studies specifically quantifying the current or future prevalence of heat-related sleep problems or providing a robust evidence base from which results could be extrapolated.

- **Risk factors –** more research is needed to develop a clear picture of the groups at risk in England and Wales in order to inform prevention strategies and plan for the future. This may include further investigation of the impact of gender, socio-economic status, and young age as the evidence on these was mixed. Other specific factors were identified in the literature as requiring further research to understand their impact on heat-related morbidity and mortality, including the ability to acclimatise (Vardoulakis and Heaviside 2012). Limited research was also found on the impact of occupancy patterns and on the efficacy of advice, though this may exist in other sources not covered by the current Review.
- **Adverse impacts of occupant actions –** more research is required to further explore the indicative findings suggested in the current Review, where limited evidence was found. This includes research on window opening behaviour, on the use of mechanical ventilation, electric fans and air conditioning, and on the prevalence of behaviours which may exacerbate overheating. This could include for example behaviour relating to use of shading measures where these include a degree of occupant interaction. This research should be combined with the large-scale monitoring of overheating. Research is also needed on how occupants and other stakeholders are best motivated to take action to reduce the risks of overheating.
- **Productivity impacts –** further research is required to link and quantify the relationship between overheating in homes, sleep deprivation and how this affects performance in the workplace. Much of the literature to date focusses on workplace temperatures and the impact of high temperatures on the productivity of 'healthy' individuals.

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