Thermal Discomfort and Health: Protecting the Susceptible from Excess Cold and Excess Heat in Housing

David Ormandy[1] and Véronique Ezratty[2]

1 Division of Health Sciences, Warwick Medical School, University of Warwick, UK

2 Service des Etudes Médicales (SEM), EDF, Levallois-Perret, France

Corresponding author – David Ormandy, Division of Health Sciences, Warwick Medical School, University of Warwick, Coventry CV4 7AL UK.
david.ormandy@warwick.ac.uk

Thermal Discomfort and Health: Protecting the Susceptible from Excess Cold and Excess Heat in Housing

High on the political and social agenda are the levels of domestic energy use, of carbon emissions, and of fuel poverty. Strategies to reduce these levels should ensure that the health and well-being of residents is protected and improved. Thermal discomfort in housing ranges from being uncomfortable, to serious health impacts. Avoiding thermal discomfort maintains well-being and protects the health of, in particular, the most susceptible members of the population. This position paper defines thermal discomfort, examines how it can be measured, and looks at the health impacts of low and high temperatures. Factors that increase susceptibility to low and to high temperatures, both human and building related, are identified and discussed. This paper shows that there are similarities between some of these factors, and that tackling these together will provide protection for those most at risk from exposure to high and low temperatures. Strategies aimed at reducing susceptibility to both excess heat and excess cold are suggested.

Keywords: thermal discomfort; health; housing; low temperature; high temperature

1 Introduction

The impact of ambient temperature on health is becoming an increasing matter of concern with climate change and ageing of the population. Significant excess mortality is associated with cold and heat waves and there is a significant short-term effect of ambient temperature on morbidity (Ye X et al, 2012). The majority of available studies on the association between ambient temperature and health relate to outdoor climate conditions and, although people spend most of their time indoors in particular the susceptible, studies having assessed the association between indoor thermal comfort and health are scarce, the study methods differ and the quality and consistency of the evidence is variable.

In this position paper, we discuss what constitutes thermal discomfort in housing, ranging from uncomfortable sensations, to the impact on health. We examine how thermal comfort and discomfort can be measured, and what are factors inherent to people, their behaviour, the dwelling and its immediate environment, that can modify the risk associated with temperatures too high or too low. Finally we suggest some strategies aimed at reducing susceptibility to both excess heat and excess cold.

The intention is to provide a summary of some of the evidence and suggest practical solutions that should give protection against the threats from both excess cold and excess heat.

2 Thermal Discomfort – What it is and what influences it

Thermal discomfort is not just a lack of satisfaction with the ambient temperature but reflects a situation where there is a potential threat to health – that is when the temperature falls below 18^{o}C or rises above 24^{o}C for a period of time.

This range is based on the World Health Organization's guidance on thermal comfort for the home environment, which is aimed at protecting health, particularly the health of those most susceptible to low or high temperatures (Ormandy and Ezratty, 2012). The guidance is directed specifically at the housing environment and so differs from the Predicted Mean Vote and Predicted Percentage Dissatisfied, which are geared to the working (office) environment (eg, ASHRAE, 2013) and inappropriate for houses (see Ormandy and Ezratty, 2012). The WHO guidance, followed by most European countries, also recommends that for certain groups, such as the very young and the elderly (65 years and over), the lower limit should be 20^{o}C.

What results in thermal discomfort is influenced by a whole range of environmental and individual objective, and subjective factors (Ormandy and Ezratty, 2012). Environmental factors within the dwelling that could influence the air temperature, include the temperature of the surrounding surfaces, air movement, relative humidity, and the rate of air exchange (ventilation). There are also environmental factors outside the dwelling, and the design and construction of the dwelling will determine how well it protects the occupants.

As well as the activity and the clothing worn by the individual, thermal discomfort will depend on the age, health status, and gender of the individual, their adaptation to the local climate, and the duration of exposure to temperatures outside the comfort range. Crowding and under-occupation of a dwelling will also have an influence. All these factors will vary both for the individual and between members of the household during the day and over time, and will be affected by household activities.

While none of these factors remain stable, and it may not be practical or possible to assess some, it is necessary to make some assumptions and to suggest safe limits. Generally, the main focus to protect health has been to provide guidance on the ambient indoor air temperature.

3 Identifying Thermal Discomfort

Though WHO guidance gives a range of recommended temperatures indoors there are several practical problems associated with physically taking temperature readings. The indoor temperature will depend on a range of factors including the time of year, the time of day, and household activities (see also section 2 above). In addition, there are both horizontal and vertical temperature gradients within rooms and within dwellings.

Contrary to that relating to indoors, data on external ambient temperatures is widely available, and while there may be factors in the immediate outdoor environment that will influence the indoor temperature (for instance, urban heat island effects), there has been limited investigation into the relationship between the external and internal temperatures. A small study in Boston has suggested that the association between indoor and outdoor temperature was good at warm temperature but weak at cooler temperature (Nguyen, et al, 2014). Recognising this relationship, the concept of Heating and Cooling degree days has been developed in the US to assess the influence of temperature change on energy demand by measuring the difference between outdoor temperatures and the temperatures that people generally find comfortable indoors (http://www.epa.gov/climatechange/science/indicators/health-society/heating-cooling.html).

As summarised above (see section 2), the various factors affecting indoor temperatures mean that it is not just difficult, but also impractical to measure or calculate them so that they can be compared within a study and across studies. Recognising this, studies have used occupant perception. For example, the French National Housing Survey (Enquête Nationale Logement), carried out every four or five years, asks whether respondents have suffered from cold during the previous winter. Interestingly, in the last available survey (2006) those who gave a positive answer to this question were different to the households in fuel poverty using the 10% definition (Devalière, 2011). (The 10% definition is based on the work of Boardman, 1991, and is where a household needs to spend 10% of its available income on energy to maintain indoor temperatures within the thermal comfort range.) This suggests that this widely used 10% definition of fuel poverty might not identify those who are not spending too much of their available income on energy but who have adopted restriction behaviour by using less energy than needed for heating (air and water) that could put their health at risk.

Using perception as a proxy for thermal comfort has several advantages such as taking into account the difference of susceptibility and of exposure between members of the same household (Ormandy and Ezratty, 2012). This perception approach was used in the WHO LARES project to assess the relationship between thermal discomfort and health (Ezratty et al, 2009). However, using residents' perception has some limitations, particularly for those age groups more susceptible to health threats from thermal discomfort. The very young may not be able to express their discomfort, and the elderly may be less sensitive, and may not recognise their exposure to low or high temperatures (Abrahamson et al, 2009). Furthermore, those over 65 were found to be more satisfied with worse conditions, like the lack of central heating, in the WHO LARES study (Ezratty et al, 2009).

It also seems that females have a greater need for individual temperature control, and so if females are satisfied with the thermal environment it is highly probable that males will also be satisfied (Karjalainen, 2012).

4 From Discomfort to Health Impacts

There are a considerable number of studies on the health effects of exposure to both low and high temperatures. These have included physio-pathological studies, identifying the mechanisms, and epidemiological studies particularly during cold and heat waves. It is not the purpose of this paper to review the evidence on the health impacts of excess cold and/or heat, and there are many such reviews (including Marmot, 2011; and Carmichael, 2011). Here we provide a brief summary of some of that evidence.

4.1 Low Temperatures

As temperatures fall below 18^{o}C, the potential impact on health increases in severity. The body's reaction to low temperatures includes thickening of the blood, and hypertension (Woodhouse et al, 1993) and an increase risk of cardiovascular or cerebrovascular events (Lan Chang et al., 2004; Howieson, 2005). Respiratory stress starts at around 16^{o}C and cardiovascular stress when the temperature falls below 12^{o}C (Collins, 1993). As the temperature falls, hypothermia (a drop in the body's core temperature), becomes a possibility (Pedley et al, 2002). Also, low indoor temperatures are often associated with other threats to health such as dampness and mould (Marmot, 2011).

Excess winter deaths are seen as the headline for exposure to low temperatures, but what is not clear is whether these deaths are primarily related to low indoor temperatures or other factors such as going from indoors to outside (Keatringe 2002). However, one study found a stronger relationship between indoor temperature with blood pressure than with outdoor temperature (Saeki et al, 2014). The health impact of exposure to low temperatures is delayed (McMichael 2008) and the vast majority of the fatalities are linked to respiratory and cardiovascular conditions, heart attacks and strokes.

It has also been suggested that there is an association between extreme low temperatures and birth defects (van Zutphen et al, 2014).

4.2 High Temperatures

The perception of what constitutes high temperatures, and so personal discomfort, varies depending on local and regional climatic conditions. For instance, a Finnish study found that an ambient temperature of 26^{o}C was considered 'hot', and that discomfort started at around 22^{o}C (Nayha et al, 2013). Such temperatures may be considered normal or even cool in other regions.

Exposure to high temperatures can increase the risk of heat stroke (Bouchama, 2002), and health problems such as respiratory and cardiovascular hospitalizations and deaths (Anderson et al, 2013; and Hoshiko et al, 2010).

There is strong evidence of an association between high temperatures and an increased risk of stillbirths and shortened gestation (Strand, 2011).

Unlike cold, the heat-related health impact can occur relatively soon after exposure (McMichael 2008). These health impacts can vary by region (McGeehin, 2001), by community (Anderson et al, 2013), and can change over time (Davis et al, 2003). It also seems that a population can become more resilient to heat over time (Bobb et al, 2014).

5 Factors Increasing Risks to Health

Susceptibility to exposure to excess heat and excess cold depends on links between individual characteristics (age, health status, etc.), duration of exposure (Rocklöv, 2014), characteristics of the dwelling, and adaptive capacity of the individuals. Location is an additional factor; in urban areas the heat island effect can increase temperatures, and those in difficult to heat dwellings in rural areas may suffer low temperatures (Doick KJ, 2014; Zhao, 2014). In a study on the relationship between temperature and urban mortality in 12 cities with temperate, tropical and subtropical climates, temperature was associated with daily mortality, with increased mortality risk at both extremes (McMichael 2008).

There are some forced or unavoidable responses or circumstances where the occupier has little or no alternatives, and others that may be unintentional where the occupier lacks knowledge to adopt precautionary behaviour to either overheating or exposure to cold.

As well as human factors, the design and construction of a dwelling will influence whether it provides adequate protection for the occupants during heat waves and during cold periods. While it is possible to design new dwellings (those yet to be built) to incorporate protection for either situation, the vast majority of dwellings already exist - in England, 50% of the housing stock is at least 50 years old (DCLG, 2014) and this is probably true for most developed countries. It is this section of the housing stock where it is likely that dwellings do not provide adequate protection.

The relevant factors for low and high temperatures that increase risk are set out in Table 1 and Table 2.

5.1 Low Temperatures

5.1.1 Human Factors

The more obvious, unavoidable circumstances include the elderly, the very young, and those suffering from chronic physical and mental conditions (Marmot, 2011; and Ormandy and Ezratty, 2012)).

The elderly and the very young are more at risk from exposure to low temperatures, both because of their physical state and because they are likely to spend more time in the dwelling. Those over 65, and particularly those over 75 years old are particularly more susceptible. It has also been suggested that older women with a history of respiratory illness may be more susceptible than other older disadvantaged groups per se (Wilkinson, 2004).

The very young, particularly those under five years old, are more at risk primarily because their thermoregulatory system will be immature. Also, both the young and the elderly are likely to be dependent on others.

Another population group at risk is those suffering from chronic physical or mental illnesses, and on particular medication. These include cardio-vascular conditions, respiratory conditions such as asthma, COPD, and diabetes, and arthritis. Those suffering from some mental health conditions, such as dementia, and depression, may mean they are less likely to take appropriate precautions (see Li S et al, 2014; Osman et al, 2008; Li Y et al, 2014; McGeehin and Mirabelli, 2001, and WHO, 2008).

Social isolation can also increase risk, and may be a result of different circumstances. Often the elderly can be isolated, perhaps separated from their relatives, and unable to keep physical contact with friends. Households in cold or damp dwellings may be reluctant to invite friends into their dwelling and so become isolated. Difficulties in heating the whole dwelling can mean heating just one room, which may discourage inviting visitors (social isolation) and can increase the risk of spreading infectious diseases through crowding (Baker et al, 2012). Poor energy efficiency is associated with dampness and mould, conditions of which people may be ashamed.

Lower socio-economic status can result in two circumstances, sometimes in combination. First, those with little disposable income may not be able to afford to live in anything other than old and energy inefficient dwellings. Second, because of the first, or for other reasons the household may not be able to afford sufficient energy needed for normal domestic living. However, the findings on low socio-economic status are inconsistent. One study concluded that socioeconomic factors were not strongly associated with winter death in older people (Wilkinson, 2004), and another found that people in the lowest socio-economic groups do not necessarily live in cooler homes as public sector housing tend to be well heated and well-insulated, compared with large owner-occupied houses which can be harder to heat (Hajat, 2007). Another review found that low income, thermally inefficient dwellings, fuel poverty and smoking contribute to adverse winter health and social outcomes (Tanner et al, 2013).

One study found a significant positive correlation between excess winter mortality and the (Scottish) Index of Multiple Deprivation (Howieson, 2005), and another found socio-economic factors were found to be associated with excess winter mortality across Europe (Healy, 2003).

If inadequate financial resources of the household is a problem (contributing to the heat-or-eat dilemma – see Beatty et al, 2014), it may be that the household is unaware of state benefits that may supplement the resources, or they may be reluctant to accept or apply for available help.

Under-occupation (eg, where parents remaining in a largish dwelling after children have left home) can mean either high heating costs or low indoor temperatures

The UK has higher rates of winter mortality than other European countries that have colder winters, and several studies found that people from regions with warmer winters tended to have cooler homes and took less preventative measures against the cold, such as wearing inadequate clothing (Healy, 2003). Also, it has been argued that much excess winter mortality arises from brief excursions outdoors, rather than low indoor temperatures (Keatinge, 2002). In contrast, another study found that indoor temperatures were strongly associated with blood pressure (Saeki et al, 2014).

5.1.2 Building Factors

The factors involved include the thermal insulation provided by the structure of the dwelling, the efficiency and effectiveness of the means of heating, the rate of air exchange (ventilation), and the location of the dwelling geographically and within the building. In England it has been found that the older the dwelling the greater the risk to the occupants of excess cold (ie, the dwelling wastes heat – is energy inefficient). The risk being greatest in dwellings built before 1850, and lowest in the more energy efficient dwellings built after 1980. It also appears that an absence of central (whole house) heating and dissatisfaction with the heating system also show some association with increased risk of excess winter death (Aylin, 2001).

Similar findings about the link between energy inefficiency and excess winter deaths have been found in a large cross-European study (Healy, 2003). This found that the four countries with the poorest standard of housing, Portugal, Greece, Ireland, and the UK, all scored high for excess winter deaths.

Energy inefficiency depends on whether the dwelling allows too much heat to escape because of poor structural thermal insulation, on type of the fuel used for space and water heating, and the size and design of the means of heating and ventilation.

Disrepair or dampness to the dwelling and any disrepair to the heating system may affect their efficiency. Also relevant are the exposure and orientation of the dwelling – greater exposure increasing the heat loss, and orientation will affect any solar heat gain (even in the colder seasons).

Some forms of insulation, such as glass fibre, will settle over a period and become less effective as a result. In addition, as water readily conducts heat, excess moisture content (dampness) of the structure will reduce the thermal insulation it provides. This means that the effectiveness of some forms of insulating material can be compromised by moisture.

While ventilation is necessary to maintain air quality and remove pollutants, excess and uncontrollable ventilation (rate of air exchange and draughts) wastes heat, reduces air temperatures as warmed air is replaced by cold air from outside. Excess ventilation may be caused by too large or inappropriately sited permanent openings, ill-fitting butt-jointed wooden floor boarding, or ill-fitting doors or windows.

5.2 High Temperatures

5.2.1 Human Factors

Heat-related health impacts can be especially severe for certain population groups. These include the elderly and very young (Kovats and Hajat, 2008), those with chronic physical conditions (such as obesity, diabetes, and cardiovascular disease) and/or mental health conditions, and those on certain medications (Stafoggia, 2006; and IOM, 2011). It is also suggested that women are more likely to be at risk (Fouillet 2006). A lack of mobility or being bed-ridden increases the risk (Vandentorren, 2006).

Individuals who are living alone were found to be more at risk in some studies (Stafoggia, 2006; Fouillet, 2006), but not in a study in Britain (Hajat, 2007). Other at risk groups include those belonging to some specific ethnic groups (White-Newsome et al, 2009), and those isolated of lower socioeconomic background (Hajat, 2010). Studies have found an association between mortality and low socioeconomic status during heat waves, not only in the US where it could be linked to the lack of access to air conditioning, but also in Europe (Stafoggia, 2006), however there is inconsistency in the results from studies, some not finding an association with low socioeconomic status (Ostro, 2009).

5.2.2 Building Factors

Factors affect the risk of exposure to overheating include the location, structural insulation, orientation, and air changes (ventilation)

Location of the dwelling is a factor and risks from high temperatures include those living in urban areas (Fischer et al, 2012), and those in areas with a low prevalence of air conditioning (O'Neill et al, 2005). One study found that there was a higher heat threshold (the temperature above which mortality risk clearly begins to increase) in cities with hotter summers, reflecting the adaptation of the population (McMichael, 2008).

Investigations into the Paris heat wave of 2003 found that elderly residents of dwellings sited immediately under an inadequately insulated roof were more likely to suffer overheating and an increased risk of mortality than those in other apartments (Vandentorren et al, 2006).

The amount of heat conducted through the opaque elements of the building fabric when the temperature of external surfaces is higher than the internal is relatively small in modern buildings. However, this may not be the case for older buildings and in some cases (where dwelling or rooms are directly under the roof) heat gains can be very significant.

The direct heat gains through glazing can also be very significant, particularly where windows face South through to West (Carmichael, 2011). Internal blinds or curtains may reflect some heat, but there will still be heat warming the room air. Solar radiation through windows will heat the internal surfaces and that heat will be given off into dwelling causing internal temperatures to remain high over the following night.

Design and construction practice (both old and new) often means that the same or similar house typography will be adopted irrespective of orientation, so some houses will be more likely to be exposed to overheating than identical houses facing other directions; this is the case for older rows of houses as well as relatively modern estates. In the case of apartment blocks, dwellings on one side may be more prone to overheating than those on the other side.

For modern, highly insulated and relatively air-tight dwellings, the problem is magnified. These energy efficient dwellings limit the heat loss through the fabric and via infiltration, so retaining even more of the internal and solar heat gains within the dwelling.

Ventilation is necessary for indoor air quality, but opening windows when the outside temperature is equal to or above the indoor temperature is at best of no benefit and may be detrimental and increase overheating problems.

In large urban locations there are heat islands, where the local ambient temperature may be several degrees warmer than that in a rural location a relatively short distance away (Kim, 1992; see also www.epa.gov/heatislands). These urban heat island are a result of reflected heat, heat emitted from refrigeration and air condition equipment, heat emitted by people and vehicles, and heat emitted overnight by the thermal mass of buildings and roads that absorbed heat during the day. This is compounded by the lack of protective greenery. The heat island effect can mean that the night-time temperature remain as much as $4^{o}C$ higher than in the rural areas. Even in less dense urban areas with green spaces and trees, the temperature may still be around $2^{o}C$ higher than rural areas at night. This means that there is less variation between day and night temperatures limiting the dwelling, and more importantly the residents, from cooling down.

Moreover, being in a noisy location; adjacent to busy roads, railway lines, or industrial plants, being close to airports or other noise sources, will affect whether occupants open windows at night. Where a dwelling is sited on the ground floor of a block will influence whether occupants open windows at night (for security reasons and to avoid insects attacks).

There are also several sources of heat within dwellings. Depending on activity, the human body will give off between 65 to 80 Watts per person per hour. In addition, activities such as cooking, bathing, etc. all release heat, and almost all of the electricity used in a dwelling is converted into heat. The generation and distribution throughout a dwelling of hot water is also a source of heat liberated into the dwelling, and, depending on the type of system this may be significant.

6 Adaptations to Reduce the Risk

6.1 Human Responses

For both low and high temperatures there are some circumstances and factors that increase the risks but may be unavoidable, and others that could be avoided. Here we consider the human responses or behaviour that can mitigate the risks.

6.1.1 Low Temperature

Many of the factors that may increase susceptibility cannot be avoided, but it is possible to recognise them and take some precautionary measures. Recognising increased susceptibility such as age, serious chronic health conditions, and mobility difficulties, mean that more careful precautions are needed. These can include using a thermometer to give an indication as to whether room temperatures are maintained at a safe level (at least 20^oC), wearing layers of clothing, and preparing warm food and drinks (non-alcoholic).

Preparations for cold weather should include ensuring the heating system is in good working order, and checking if the energy efficiency of the dwelling can be improved. Obviously, these may involve expenditure, and low-income owners should investigate whether financial assistance is available.

Ensuring all grants or benefits the household is entitled to may help towards the cost of sufficient energy, but they may not compensate for other personal and behavioural characteristics (Wilkinson, 2004). There are also some simple general precautions that can be taken, such as closing windows and curtains at night to conserve heat.

6.1.2 High Temperature

Limiting heat gain and reducing indoor temperatures requires the active participation of the occupiers, and this needs awareness and knowledge of precautionary measures.

The behaviour or responses of people is more difficult to assess and to influence but is an important factor. Few studies have evaluated these aspects during extreme heat (in Australia – Nitschke M et al, 2013; and in UK – Abrahamson V et al, 2008). A review on window opening behaviour highlights that while it is possible to identify what drives behaviour, it is difficult to understand how to influence it (Fabi et al, 2012).

Because heat is not necessarily seen as a threat to health, exposure can become especially dangerous for isolated populations who may not hear about heat risks. Some underused methods, including telephone calling and door-to-door campaigns, could be more useful to reach these isolated populations. Given that heat waves are expected to become more frequent and severe under climate change (IPCC, 2012), it is critical to enhance local education and planning for extreme heat events to improve collaborations and reach beyond the more recognised susceptible populations (i.e., the elderly) to other less recognised populations (i.e., those with mobility challenges, the homeless) during heat events (Hajat et al, 2010).

Where possible, any means of shading from the sun to reduce solar heat gain can avoid overheating. Perhaps more important is understanding and controlling appropriate day and night ventilation. Ventilation during the day by opening windows is only useful where the outdoor temperature is lower than the indoor. Purge ventilation at night with high air change rates, to replace warm indoor air with cooler air from outdoors is important to ensure residents can sleep and that heat built up over the preceding day is released (CIBSE, 2006). An alternative is installing and using air conditioning, but this means yet another energy using appliance and one that releases heat back into the outdoors. Installing air conditioning is really a building solution, but using it is a human factor, which may not be an option for those on low income.

As mentioned above, as well as air temperature, the risk from overheating is also affected by other factors, including air movement. Air movement helps the body cool principally by evaporation. There have been studies on this and a recent review on the effectiveness of fans to provide air movement during heat waves (Gupta et al, 2012). Fans can only be useful where the air temperature is low enough to provide cooling and do not replace the need for adequate ventilation.

Relief and cooling can be achieved where there is a cool room (such as a North facing room) or area available in the dwelling or building. Where this is not available, going to a cool (air-conditioned) public space, such as a library or shopping mall, can give relief. However, this is not possible for those who may be the most susceptible including the bed-ridden or with physical impairments.

6.2 Building Responses

For those dwellings yet to be built, there are a range of options – ensuring adequate energy efficiency (thermal insulation, efficient and effective heating system, controllable ventilation, and taking account of orientation). However, dealing with existing dwellings is more problematic.

6.2.1 Low Temperature

The main and sustainable response should be to improve the energy efficiency of the dwelling. This has been shown to improve health, both physical and mental, increased spatial use of the dwelling, and has socioeconomic benefits (Howden-Chapman, 2012; Thomson et al, 2013; Maidment et al, 2014).

Appropriate structural thermal insulation should be provided to minimise heat loss. The level of insulation necessary is in part dependent on geographical location and exposure, position in relation to other dwellings and buildings, and orientation. South facing glazing can be used to increase solar heat gain during daytime and so save energy. It should also ensure that it does not create overheating problems during summer (eg, by providing means of shading or shutters, on which see 6.2.2 below).

Heating should be controllable by the occupants, and safely and properly installed and maintained. It should be appropriate to the design, layout and construction, such that the whole of the dwelling can be adequately and efficiently heated.

There should be means for ensuring low level background ventilation without excessive heat loss or draughts. It should be properly installed and maintained, and should be controllable and understandable by occupiers (Ezratty, 2009). There should be means for rapid ventilation at times of high moisture production in kitchens and bathrooms.

6.2.2 High Temperature

For new (yet to be built) dwellings, building codes can require high levels of thermal insulation and increased air-tightness (while ensuring ventilation is sufficient to maintain indoor air quality). Neighbourhood planning can ensure more green spaces (to reduce the heat-island effect) (WHO, 2011; Doick KJ, 2014).

Increasing the thermal insulation of the structure (external walls and windows, and the loft (roof)) of existing dwellings and buildings will help prevent solar gain through the structure, but will also trap heat inside the dwelling unless there is appropriate means of ventilation. However, external wall insulation is challenging for dwellings of solid wall construction, particularly where the dwelling abuts the pavement (as is the case for many English terraces in urban areas).

There is a range of options to provide shading to limit solar heat gain through windows facing South through to West. Internal shutters can provide some protection, as can curtains, but ideally external shading or shutters will be more effective in preventing the sun radiation entering the dwelling. External shutters can also provide additional security, and, depending on the type, can allow for natural ventilation.

Shading can also be provided by brise-soleil or awning. These are particularly suited for South facing windows and walls, giving protection from high level sun. Vertical shading is more suited to windows facing East or West, giving protection from low level sun. External blinds (e.g., roller blinds) and shutters will provide the most protection, but have the disadvantage of restricting daylight and views of the outdoors (Porritt et al 2011).

Providing a light-coloured finish to flat roofs can reflect sunlight, so reducing solar gain, and it seems likely that some protection is also given by photovoltaic devices fitted to roofs, as these will help reduce the amount of solar gain through the roof.

Ideally, ventilation should be passive, so avoiding the use of additional energy needed for air conditioning (which also emit heat to the immediate outdoors). Fans also use energy and generate heat within the dwelling, and, while they ensure air movement, have limited usefulness when the relative humidity is over 35%, and in high ambient temperatures (over 32.3^{o}C) fail to reduce body temperature (CDC, 1995; Wolfe, 2003; and APHA, 2012). However, for ground floor dwellings and those in apartment blocks with windows opening onto access balconies where there is a need for security and in noisy locations window opening may not be practical or appropriate. In such locations an adequate mechanical ventilation system may be necessary. The system must be capable of achieving the high levels of air change rate required for purge ventilation without impacting the residents i.e. it must be of appropriate size and not noisy. Where security alone is an issue an option on refurbishment is the installation of windows that incorporate fixed secure louvered panels (with protection against insect attack).

7 Conclusion – Protecting the Susceptible

Avoiding Thermal Discomfort within dwellings is not just about residents' satisfaction and comfort, it is about protecting health. Ambient temperatures above 24^{o}C or below 18^{o}C are thresholds beyond which there are threats to health, particularly for those who are susceptible for whatever reason. Although accurate measurement or modeling of indoor temperatures is not really possible, precautions and actions to protect against the likelihood of exposure to excess low or high temperatures are known.

This paper shows that there are some human and some building factors that increase susceptibility and that are common to low and to high temperatures. For the human factors these include age, most of the health related factors, and lack of knowledge of precautionary actions. For the building factors they include inadequate thermal insulation, and inappropriate provision for heating and for ventilation.

The population groups already susceptible will be most at risk where they occupy dwellings that provide inadequate protection exposure to low and/or high temperatures. It is already possible to identify those population groups 'at, and also to identify dwellings which provide little protection and are likely to increase the risk of exposure to those temperatures. By matching these data, local governments and NGOs target the most at risk. Strategies and actions focusing on this most 'at risk' group are necessary for short-term plans, and many countries have Cold Weather, Heat Wave, and/or Extreme Weather Plans that trigger action targeting this most at risk group when a cold or hot event is forecast.

However, long-term solutions, aimed at increasing the protection offered by dwellings, particular the older existing ones, will complement and reduce the strain on reactive interventions. Such building focused solutions provide a more permanent solution as there is no guarantee that the current occupying household (whether at risk or not) will remain in occupation (WHO, 2006).

What seems clear from our summaries of building factors is that there are some common features/factors that mean some dwellings provide inadequate protection to both high and low temperatures (See Tables 1 and 2). This also means that there are some building responses (adaptations) that will reduce the risk of exposure to both (see section 6.2 above). This integrated approach has been pointed out in a recent report to the UK Parliament –

> 'Adapting homes to handle both high and low temperatures – increased insulation alongside passive cooling measures and ventilation – is necessary and readily achievable if considered together.' (CCC), 2014)

References

Abrahamson V, et al (2009). Perceptions of heatwave risks to health: interview-based study of older people in London and Norwich, UK. J Public Health. 31(1):119-26. doi: 10.1093/pubmed/fdn102.

AgeUK (2013). Winter wrapped up: A guide to keeping well and staying warm in winter. Age UK, London

Anderson GB, et al (2013). Heat-related emergency hospitalizations for respiratory diseases in the Medicare population. Am J Respir Crit Care Med 187(10):1098–1103

APHA (2012). Healthy You- Keep cool to prevent heat-related illness. The Nation's Health, American Public Health Association – www.thenationshealth.org

ASHRAE (2013). ASHRAE Handbook – Fundamentals: Chapter 9: Thermal Comfort. American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta <http://www.ashrae.org> (accessed 16 July 2013)

Baker MG, et al (2012). Increasing incidence of serious infectious diseases and inequalities in New Zealand: a national epidemiological study. The Lancet, Vol 379, Issue 9821; 112-119.

Beatty TKM, et al (2014). Is there a 'heat-or-eat' trade-off in the UK. J R Statist A 177, Part 1 pp 281-294.

Boardman B (1991). Fuel Poverty. Belhaven Press, London.

Bobb JF, et al (2014). Heat-Related Mortality and Adaptation to Heat in the United States. Environmental Health Perspectives 122 (8) 811-816

Bouchama A, and Knochel JP (2002). Heat stroke. N Engl J Med 346(25):1978–1988.

Carmichael K, Mindy M, and Murray V (2011). Overheating and health: a review into the physiological response to heat and identification of indoor heat thresholds. Health Protection Agency, London

CCC, (2014). Managing climate risks to well-being and the economy; Adaptation Sub-Committee Progress Report 2014. Committee on Climate Change, London

CDC (1995). Heat-related mortality – Chicago, July 1995. Centers for Disease Control and Prevention. MMWR Morb Mortal Wkly Rep 1995;44;577-9

CIBSE (2006). Guide A: Environmental Design. Chartered Institute of Building Services Engineers, London.

Davis RE, et al (2003). Changing heat-related mortality in the United States. Environ Health Perspect 111:1712–1718; doi: 10.1289/ehp.6336

DCLG (2014). English Housing Survey: Headline Report. Department for Communities and Local Government, London.

Devalière I, et Briant P. (2011) La précarité énergétique : avoir froid ou dépenser trop pour se chauffer : Insee première n°1351. (http://www.insee.fr/fr/ffc/ipweb/ip1351/ip1351.pdf)

Doick KJ, Peace A, and Hutchings TR (2014). The role of one large greenspace in mitigating London's nocturnal urban heat island. Sci. Total Environ. doi: 10.1016/j.scitotenv.2014.06.048.

EPA (2014). Climate Change Indicators in the United States: Heating and Cooling Degree Days. Environmental Protection Agency. http://www.epa.gov/climatechange/science/indicators/health-society/heating-cooling.html (accessed 16 July 2014).

Ezratty V, Duburcq A, Emery C, and Lambrozo J (2009). Liens entre l'efficacité énergétique du logement et la santé des résidents: résultats de l'étude européenne LARES. Environnement, Risques & Santé 2009, 8(6): 497-506

Fabi V, et al (2012). Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and models. Building and Environment 58(2012) 188-198.

Fischer EM, Oleson KW, and Lawrence DM. (2012). Contrasting urban and rural heat stress responses to climate change. Geophys Res Lett 39(3):L03705; doi: 10.1029/2011GL050576

Fouillet A, et al (2006). Excess mortality related to the August 2003 heat wave in France. Int Arch Occup Environ Health 2006;80(1):16-24

Gupta S, et al (2012). Electric fans for reducing adverse health impacts in heatwaves. Cochrane Database Syst Rev 2012 Jul 11;7:CD009888. doi: 10.1002/14651858.CD009888.pub2

Hajat S, Kovats RS, and Lachowycz K (2007). Heat related and cold-related Deaths in England and Wales: who is at risk? Occup Environ Med. 2007; 64(2): 93-100

Hajat S, and Kosatky T (2010). Heat-related mortality: A review and exploration of heterogeneity. J Epidemiol Community Health 64(9):753–760

Hajat S, O'Connor M, and Kosatky T (2010). Heat effects of hot weather: from awareness of risk factors to effect health protection. Lancet, 2010, Vol 375, 857-863

Healy JD (2003) Excess Winter in Europe: a cross country analysis identifying key risk factors. J Epidemiol Community Health 2003;57:784-789

Hoshiko S, English P, Smith D, and Trent R. (2010). A simple method for estimating excess mortality due to heat waves, as applied to the 2006 California heat wave. Int J Public Health 55(2):133–137

Howden-Chapman P, et al (2012). Tackling cold housing and fuel poverty in New Zealand: A review of policies, research, and health impacts. Energy Policy 49 (2012) 134-142

Howieson SG, and Hogan M (2005). Multiple Deprivation and Excess Winter Deaths in Scotland. JRSH2005 125 (1) 18-22

Intergovernmental Panel on Climate Change. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Available: http://ipcc-wg2.gov/SREX/

IOM (2011). Climate Change, the Indoor Environment, and Health. Washington, DC: Institute of Medicine. The National Academies Press.

Jones TS, et al (1982). Morbidity and mortality associated with the July 1980 heat wave in St. Louis and Kansas City, MO. JAMA 247(24):3327–3331

Karajalainen S (2012). Thermal comfort and gender: a literature review. Indoor Air 22(2): 96-109.

Keatinge WR (2002). Winter Mortality and its Causes. International Journal of Circumpolar Health. Invited Review 61: 2992-299

Kim HH (1992). Urban heat island, International Journal of Remote Sensing, 13:12, 2319-2336, DOI: 10.1080/01431169208904271

Kovats RS and Hajat S (2008). Heat Stress and Public Health: A Critical Review. Annual Review of Public Health. DOI: 10.1146/annurev.publhealth.29.020907.090843

Li S, et al (2014). Are children's asthmatic symptoms related to ambient temperature? A panel study in Australia. Enviro Res 113 :239-45

Li Y, et al (2014). Extremely cold or hot temperatures increase the risk of Diabetes mortality in metropolitan areas of two Chinese cities. Environ Res 134C :91-97.

McMichael AJ, Wilkinson P, and Kovats RS, (2008). International study of temperature, heat and urban mortality: the 'ISOTHURM' project. Int J Epidemiol, 2008 Oct;37(5):1121-31. doi: 10.1093/ije/dyn086.

McGeehin M, Mirabelli M. (2001). The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environ Health Perspect 109(suppl 2):185–189

Maidment CD, et al (2014). The impact of household energy efficiency measures on health: A meta-analysis. Energy Policy 6 583-593

Nayha S, et al (2013). Heat-related thermal sensation, comfort and symptoms in a northern population: the National FINRISK 2007 study. European Journal of Public Health. doi:10.1093/eurpub/ckt159

Nitschke M, et al (2013). Risk factors, health effects and behaviour in older people during extreme heat: a survey in South Australia. Int j Environ Res Public Health, 2013 2013 Dec 3;10(12):6721-33. doi: 10.3390/ijerph10126721

Nguyen JL, Schwartz J, and Dockery DW (2014). The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity. Indoor Air 2014; 24: 103–112

O’Neill MS, Zanobetti A, and Schwartz J. (2005). Disparities by race in heat-related mortality in four U.S. cities: the role of air conditioning prevalence. J Urban Health 82(2):191–197

Ormandy D and Ezratty V (2012). Health and thermal comfort: From WHO guidance to housing strategies. Energy Policy Vol.49 . pp. 116-121. (doi:10.1016/j.enpol.2011.09.003)

Osman LM, et al (2008) Home warmth and health status of COPD patients. European Journal of Public Health 18 (4) 399-405.

Ostro BD, et al (2009). Estimating the mortality effect of the July 2006 California heat wave 2009. Environ Res. 109(5):614-9. doi: 10.1016/j.envres.2009.03.010. Epub 2009 Apr 25

Pedley DK, Paterson B, and Morrison W (2002). Hypothermia in elderly patients presenting to Accident & Emergency during the onset of winter. Scott Med J, 2002 Feb:47(1): 10-1

Porritt S, et al (2011). Adapting dwellings for heat wave. Sustainable Cities and Society 2011; 1(2): 81-90 DOI: 10.1016/j.scs.2011.02.004

Rocklöv J, et al (2014). Susceptibility to mortality related to temperature and heat and cold waves duration in the population of Stockholm County, Sweden. Glob. Health Action 2014, 7:22737. http://dx.doi.org/10.3402/gha.v7.22737

Saeki K, et al (2014). The relationship between indoor, outdoor and ambient temperatures and morning BP surges from inter-seasonal repeated measurements. Journal of Human Hypertension 28, 482-488.

Stafoggia M, et al (2006). Vulnerability to heat-related mortality: A multicity, population-based, case-crossover analysis, Epidemiology 2006; 17(3):315-23

Strand LB, Barnett AG, and Tong S (2011). Maternal exposure to ambient temperature and the risks of preterm birth and stillbirth in Brisbane, Australia. AJE DOI: 10.1093/aje/kwr404

Tanner LM, et al (2013). Soicoeconomic and behavioural risk factors for adverse winter health and social outcomes in economically developed countries: a systematic review of quantitative observational studies. J Epidemiol Community Health 67:106-1067.

Thomson H, et al (2013). Housing Improvements for Health ad associated economic outcomes. Cochrane Database Syst. Rev., 2

Vandentorren S, et al (2006). August 2003 Heat Wave in France: Risk Factors for Death of Elderly People Living at Home. European Journal of Public Health 2006 16 (6)" 583-591

Van Zutphen AR, Hsu W-H, and Lin S (2014). Extreme winter temperature and birth defects: A population-based case-control study. Environmental Research 128: 1-8

Ye X, et al (2012). Ambient Temperature and Morbidity: A Review of Epidemiological Evidence. Environ Health Perspect 2012 120(1):19-28. doi: 10.1289/ehp.1003198.

WHO (2006) Housing, Energy and Thermal Comfort: A review of 10 countries within the WHO European Region. World Health Organization for Europe, Copenhagen.

WHO (2011). Public Health Advice on Preventing Health Effects of Heat. World Health Organization for Europe, Copenhagen

WHO (2008). Heat-Health Action Plans. World Health Organization for Europe, Copenhagen.

Wilkinson P, et al (2004). Vulnerability to Winter Mortality in Elderly People in Britain: population based study. BMJ. 2004 Sep 18;329(7467):647. DOI : 10.1136/bmj.38167.589907.55

White-Newsome JL, et al (2009). Climate change, heat waves and environmental justice: advancing knowledge and action. Environ Justice 2(4):197–205

Wolfe R (2003) BMJ. Nov 22, 2003; 327(7425): 1228. doi:10.1136/bmj.327.7425.1228-b

Woodhouse PR, Khaw KT, and Plummer M (1993). Seasonal variation of blood pressure and its relationship to ambient temperature in an elderly population. J Hypertens. 1993;11(11):1267-74

Zhao L, et al (2014) Strong contributions of local background climate to urban heat islands. Nature 10:511 (7508):216-9