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Guidance Document

Overheating in dwellings

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Summary

This guidance document has been produced by the Building Research Establishment during the course of a research project on behalf of the BRE Trust in collaboration with the BRE Centre for Resilience. It defines the characteristics of excess heat, considers the potential for harm arising from excess heat and the associated health impacts. It also identifies the causes of excess heat and potential preventative measures.

An accompanying assessment protocol is available in order to provide a process to be used to determine the seriousness of a potential threat to health from exposure to high temperatures within a dwelling.

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BRE Trust

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The BRE Centre for Resilience

The BRE Centre for Resilience was created to identify the critical issues that need to be addressed as we develop and improve the homes, buildings and structures that underpin our lives into the future. Its mission is to provide a place for the sector to research, learn, develop new standards and create the next generation of resilient materials, products, designs and innovations that will ensure the robustness and longevity of our built infrastructure.

This Briefing Paper has been produced by the Building Research Establishment (BRE) on behalf of the BRE Trust.

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1 Introduction and context

In England and temperate Northern European countries (including France) it is predicted that there will be an increase of extreme weather events, including heat waves. In addition, there are an increasing number of cases where there is a build-up of heat within the dwelling during 'normal' climatic conditions resulting from the characteristics of older existing, rehabilitated, or modern dwellings.

Recognising the increasing possibility of overheating in dwellings, this guidance has been developed to assist in the assessment of dwellings where susceptible individuals will be at risk of exposure to excess high temperatures. The guidance will also inform decisions on preventative measures, both on adaptation of the dwelling and precautionary behaviour. Use of the process will provide data to inform policies locally, nationally, and internationally.

The guidance proposes a means of evaluating the potential of any defects and deficiencies to threaten the health and safety of occupants and visitors, in particular those most susceptible to high temperatures. This guidance is based on that given for the English Housing Health and Safety Rating System, issued by the UK Government (ODPM, 2006).

This guidance gives a profile for the hazard of Excess Heat. This provides a description of the hazard, its potential for harm, the causes including a summary of the relevant matters to take into account in an assessment, and the preventative measures. It also includes guidance on assessing the susceptibility of any occupants, and the precautionary behaviour that should be adopted.

The dwelling assessment methodology involves:

– a whole dwelling survey to identify characteristics that may increase or reduce the likelihood of a hazardous occurrence (i.e. exposure to excess high temperatures);
– assessing the likelihood of a hazardous occurrence (event or period of exposure) during a heat wave or over the next 12 months ignoring the current occupiers, and assuming that the dwelling is (or will be) occupied by a household that includes one or more members of a susceptible group;
– generating a 'Hazard Score' based on this assessment, the higher the Score the greater the risk;
– determining appropriate remedial action to reduce the likelihood and/or severity of the outcome;
– proposing appropriate remedial actions including both dwelling adaptation and advice on precautionary behavioural tactics.

The methodology and process are described in detail in the accompanying Assessment Protocol document

2 Profile for excess heat

2.1 Definition of excess heat/overheating

There is no internationally accepted definition of 'overheating', mainly because it will vary depending on local and regional climatic conditions. However, for temperate zones, the WHO guidance on thermal comfort states that temperatures above 24°C cause discomfort and, in the more fragile and susceptible members of the population, can cause harm (Ormandy and Ezratty, 2011). Although for practical purposes it is generally the air temperature that is used to assess overheating, there are other environmental factors associated with overheating, such as a lack of air movement, relative humidity, radiant heat and the period of exposure.

2.2 Definition of a heat wave

What constitutes a heat wave depends on the usual climate for a particular area or region and is relative to what is considered to be the normal temperature for the season for that area. This means that temperatures that may be normal in one country may be deemed as a heat wave in another, normally cooler, country.

Basically, a heat wave is a period (typically three to five days) when temperatures are higher than normal for the region. The World Meteorological Organization recognised that the definition should be given in terms of the maximum and minimum temperature for area and region.

In England and Wales the Met Office, in association with the Department of Health and the Welsh Assembly, operates a Heat-Health Watch system from 1 June to 15 September each year[1]. This sets temperatures for each region that could have a significant effect on health if reached on at least two consecutive days and the intervening night (see Table 1).

Table 1: Heat wave threshold values for England and Wales

Region	Day max (°C)	Night min (°C)
North East England	28	15
North West England	30	15
Yorkshire & Humber	29	15
East Midlands	30	15
West Midlands	30	15
East of England	30	15
South East England	31	16
London	32	18
South West England	30	15
Wales	30	15

Different definitions have been adopted by other countries and for different regions. For example, the American Meteorological Society has adopted the definition of a 'Hot Wave' proposed in 1900; this is a spell of three or more days on each of which the maximum shade temperature reached or exceeded 90°F (32°C)[2]. In Adelaide, South Australia, a heat wave is defined as five consecutive days at or above 35°C (95°F), or three consecutive days at or over 40°C (104°F).

In France, during summer, alerts of potential heat wave periods are issued by Météo-France (part of the French Ministry of Transportation). These alerts are given when the minimum and maximum temperatures, each averaged over three days, have a high probability of being above the minimum and maximum thresholds for the region. The thresholds vary geographically, and a meteorological station, usually located in the main city of each Département, gives the warning[3]. For example, the thresholds for Paris are a minimum of 21°C and a maximum 31°C.

2.3 Potential for harm

Based on the analyses of English data on health outcomes attributable to overheating matched with housing data, the most susceptible age group is people aged 65 years or over. (However, there are other factors that can increase susceptibility, and these are discussed below.)

1 http://www.metoffice.gov.uk/weather/uk/heathealth/index.html

2 http://glossary.ametsoc.org/wiki/Heat_wave

3 Pascal M, Laaidi K, Ledrans M, Baffert E, Caserio-Schönemann C, Le Tertre A, Manach J, Medina S, Rudant J, Empereur-Bissonnet P. France's heat health watch warning system. Int J Biometeorol. 2006 Jan; 50(3):144-53. Epub 2005 Nov 23. PubMed PMID: 16328399

Table 2: HHSRS likelihoods and outcomes for excess heat (ODPM, 2006)[1]

Excess heat. Average likelihood and health outcomes for all persons ages 65 years or over, 1997–1999							
Dwelling type and age		**Average likelihood 1 in:**	**Spread of health outcomes**				**Average HHSRS scores**
			Class I %	**Class II %**	**Class III %**	**Class IV %**	
Houses	All ages	–	31.0	8.0	25.0	36.0	0 (J)
Flats	Pre 1920	60,000	31.0	8.0	25.0	36.0	5 (J)
	1920-45	90,000	31.0	8.0	25.0	36.0	4 (J)
	1946-79	130,000	31.0	8.0	25.0	36.0	3 (J)
	Post 1979	110,000	31.0	8.0	25.0	36.0	3 (J)
All dwellings		**900,000**	**31.0**	**8.0**	**25.0**	**36.0**	**0 (J)**

1 The calculations were carried out as part of the development work for the UK Government, and have not been updated since then.

The analyses of the 1997-1999 data gave the likelihoods and outcomes shown in Table 2 above.

Details of the bases for the original calculations are given in the HHSRS Operating Guidance (ODPM, 2006).

As there are no direct indicators for heat vulnerable dwellings that can be related to the health statistics, it was originally assumed that the living and sleeping areas of 5% of converted flats are immediately under the roof and suffer from significantly larger temperature rises during heat waves. Until recently, it was also assumed that there was no real risk from overheating associated with houses in the UK. Consequently, there was a weak evidence base for these statistics.

It is predicted that there will be an increase in extreme events, including heat waves, throughout the temperate regions of Northern Europe. Because older dwellings generally provide poor protection against overheating, there is likely to be an increase in morbidity and mortality directly associated with high indoor temperatures. In addition, the need for more energy efficiency is resulting in highly insulated and air-tight dwellings that may also suffer from overheating.

Where overheating does occur it can have serious impacts on the health of the occupiers. It is reported that the 2003 heat wave in Europe resulted in over 20,000 heat related deaths; around 15,000 in France, 2,000 in England, 2,100 in Portugal, and 3,100 in Italy. The important point is that in most cases, overheating is avoidable.

2.4 Health effects

As temperatures rise, so does thermal stress, initially triggering the body's defence mechanisms such as sweating, then increasing cardiovascular strain and trauma that can lead to heat exhaustion, heatstroke and hospitalisation. Where temperatures exceed 25°C, there is an increase in mortality and the incidence of strokes. Dehydration from loss of moisture through sweating can also be a problem, particularly for the elderly and the very young. There is also evidence from Australia of an association between high temperatures and an increased risk of stillbirths.

Evidence from investigations into heat waves and morbidity in other countries shows that there is an increase in genitourinary diseases, and, as air pollutants such as ozone levels rise during heat waves, an increase in respiratory conditions.

The susceptible population groups include the elderly and very young, those with chronic physical conditions (such as obesity, diabetes, and cardiovascular, respiratory, renal disease) and/or mental health conditions, and those on certain medications. A lack of mobility or being bed-ridden increases the risk. It is also suggested that women are more likely to be at risk (Ormandy and Ezratty, 2015).

3 Causes of overheating

3.1 Sources of heat

Solar gains through the building fabric

The magnitude of heat conducted through the opaque elements of the building fabric due to the external surface of the fabric being at a higher temperature than that internally is relatively small in modern buildings. This may not be the case for older buildings, especially where attics have been converted and the loft insulation has not been upgraded sufficiently. In situations like this the heat gains can be very significant.

Solar gains through windows

The direct gains that occur through glazing can be very significant in dwellings. This occurs particularly where windows face South through to West (HPA, 2011). Blinds or curtains may reflect some heat back through the window, but the balance will heat the blind or curtain and this heat will be liberated immediately, warming the room air. If blinds and curtains are not in place, the solar radiation will be absorbed internally. This heat will then be liberated back to the room air over a period of time.

High external air temperature

If the air temperature outside is higher than that indoors, then any air brought into the dwelling through ventilation will increase the temperature of the air within the dwelling. In cities and large urban areas, the local environment may be several degrees warmer than that in a rural location a relatively short distance away. This is referred to as the Urban Heat Island effect. This is where solid dense structures (buildings, roads, etc.) absorb heat during the day and then give it off during the night, added to by the heat discharged by refrigeration plants and chillers in retail premises. The result can mean that the temperature at night can remain as much as 4°C higher in dense urban areas than in rural areas. Even in less dense urban areas, where there are green spaces and trees, the temperature may still be around 2°C higher than rural areas at night. The effect of this is the loss of diurnal variation and therefore the ability to reject heat built up during the day to cool night-time air.

Internal heat gains

The rate of heat emission from the human body is dependent on the level of activity. For a range of activity levels and a mixture of male and females occupants this is between 65W to 80W per person, increasing as the level of activity increases. Activities such as cooking, bathing, etc. all release heat. Almost all of the electricity used in a dwelling is converted into heat. The generation of hot water also liberates heat and, depending on the type of system this may be significant.

3.2 Dwelling characteristics

Both neighbourhood and dwelling characteristics have been found to influence self-reported adverse health effects (Bélanger et al, 2015). Here we discuss some of these characteristics.

Location

There are several different location factors that can increase the likelihood of overheating, including being within a large urban area (the Urban Heat Island effect, see above), and the location (of an apartment) within the building.

The location can also influence whether occupiers are discouraged from taking precautions such as opening windows. This includes being in a noisy location; adjacent to busy roads, railway lines, or industrial plants, being close to airports or to other noise sources.

Dwellings in noisy locations will tend to discourage residents opening windows. Being adjacent to busy roads can discourage residents from opening windows during the day, and night-time traffic may also discourage windows being opened to reject heat. Similarly, while there is likely to be less air pollution, the noise from railway traffic, and from airports may deter residents from leaving windows open for ventilation, especially overnight.

Where the dwelling is sited on the ground floor, adjacent to a pavement or access balcony this may also discourage opening windows because of feelings of insecurity.

Depending on the processes involved, being near industrial plants may make residents reluctant to open windows because of air pollution, and/or noise from the plant or traffic.

For all these situations, high performance double or triple glazed windows may reduce noise transmission levels, but the effect of opening a window may make the difference in noise level seem exaggerated.

Investigations into the Paris heat wave of 2003 found that residents of dwellings sited on the top floors of apartment blocks were more likely to suffer overheating than those in other apartments (Vandentorren et al, 2006). This influence will be affected by the thermal insulation provided by the structure and the ability to achieve good ventilation.

Orientation

Elevations that face from South through to West are more likely to bear the impact of solar heat gain. This is particularly the case for South-West and West facing windows (see above on Causes) when the sun starts to dip from mid-afternoon towards evening and when external temperatures are highest. A sun path diagram is included as an Annex to help assessment of direct solar gains to windows and facades.

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 another side.

Dwelling design and construction

The majority of older houses (i.e. pre-1960) had little thermal insulation, and while this meant they were difficult to heat and were energy inefficient, it also meant that they provided little protection from solar heat gain, particularly through the roof and South through to West facing elevations. This is exacerbated where refurbishment has reduced the natural leaky nature of these houses, i.e. replacement windows and doors, resulting in heat losses being significantly reduced at night.

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 infiltration, so retaining even more of the internal and solar heat gains within the dwelling.

The ability of materials with a high thermal mass can be exploited to minimise diurnal swings. An example of a very high thermal mass building would be an old stone church. The temperature of the internal space changes marginally on a daily basis and almost not at all diurnally. In dwellings, a high thermal mass can help prevent overheating if the heat stored during the day can be effectively rejected at night. This therefore requires continuous high levels of night-time ventilation, which in some locations may not be practical or desirable (NHBC, 2013). A low thermal mass building would be a timber framed building with lightweight floors, ceilings and internal walls. The internal structure assumes the temperature of the air very quickly and so has minimal impact in limiting any change in temperature.

In England, although single aspect houses were prohibited from around 1957 (then known as back-to-back houses, houses sharing a 'back' wall), this prohibition was lifted in 1985 and anyway never seemed to be applied to single aspect apartments (i.e. dwellings in which all the rooms and windows face one direction). The original reason for prohibition was that 'through ventilation' was not possible. Although that problem for indoor air quality and moisture removal can be overcome with mechanical ventilation, there are few systems installed in dwellings that could achieve effectively purge ventilation rates of air change continuously for heat rejection.

Ventilation

While ventilation is necessary for indoor air quality, opening windows when the outside temperature is equal to or above the indoor temperature is at the least of no benefit and may be detrimental and increase overheating problems. Purge ventilation is only really meant as a means of achieving high air change to remove pollutants generated internally. In most dwellings this is achieved by opening windows fully. As noted above, this is often not appropriate. Where it is safe to do so without security being put at risk continuous high ventilation can be effective (CIBSE, 2010; Peacock et al, 2010; Orme et al, 2003).

Mechanical ventilation with heat recovery (MVHR) systems are becoming more common in UK dwellings. These systems recover heat from the exhaust air and return it to the dwelling by raising the temperature of the supply air. In winter this can significantly reduce heating loads. Modern MVHR systems have summer by-passes which reduce or switch off the recovery of heat from the air. Unless specifically designed, MVHR systems will generally not achieve purge ventilation rates as this would require oversizing of all components within the system in order to meet Building Regulation requirements.

Air conditioning is an alternative, but this requires energy and while it may be effective, it increases the dwelling 'running costs' and may not be an option for those on a low income.

4 Preventative measures

These options concentrate on those relevant to existing dwellings rather than the design of new (yet to be built) dwellings (on which see NHBC, 2013). Due to the complexity of heat transfer and dynamics of heat storage, combined with the need to assess a range of different heat rejection measures, no single solution can be considered as solving all cases of excess heat. Added to this the appropriateness of many solutions will differ between different buildings as for example, the cost, planning restrictions, etc. may make some solutions on some buildings inappropriate or prohibitively expensive. The following should be considered:

4.1 Insulation

The provision of additional thermal insulation to the walls and loft (roof) will help prevent solar gain through the structure. However, external wall insulation is problematic for solid wall construction, particularly where the dwelling abuts the pavement (as is the case for many English terraces in urban areas).

Where heat gain is identified as being from communal heating systems, insulation of pipes, reduction of boiler flow temperatures, ventilation of service voids (spaces within the structure for service pipe work, such as gas, electricity, water and drainage) must all be considered.

4.2 Shading, reflection and protection

There are various 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 it is preferable to provide external protection so preventing the sunlight entering the building (Littlefair, 1999).

External protection can be provided by a brise-soleil[4] or an awning. These are most 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 (Capon and Hacker, 2009; Porritt et al, 2011).

It is the practice in the UK to provide windows that open outwards (unlike the practice in many European countries). This tends to make the provision of external shutters impractical. In addition, providing awnings to the front elevation of terraced houses that abut pavements may be problematic.

Providing a light-coloured finish to flat roofs can reflect sunlight, so reducing solar gain. Green roofs also provide protection from solar heat gain, and it is likely that some protection is given by photovoltaic devices fitted to roofs.

4.3 Means of ventilation

Ideally, ventilation should be passive, so avoiding the use of additional energy needed for fans or air conditioning. A disadvantage of reliance on fans or any form of a mechanical system is that they use energy, which may mean that they are not a viable option for dwellings occupied by a household on a low income.

However, for ground floor dwellings and those in apartment blocks with windows opening onto access balconies where there is a need for security, and dwellings in noisy locations, window opening may not be practical or appropriate. In such locations an effective mechanical ventilation system may be necessary. Whatever the system it should be capable of achieving the high levels of air change rate required for purge ventilation without impacting the residents i.e., it must be acoustically attenuated and sized appropriately.

Where security alone is an issue, an option on refurbishment is the installation of windows that incorporate fixed secure louvered panels.

4.4 Occupier behaviour

Limiting heat gain and reducing indoor temperatures requires the active participation of the occupiers. This includes use of any means of shading from the sun, and understanding appropriate day and night ventilation. If possible, occupiers can gain relief and cooling where there is a cool room, such as a North-facing room, within the dwelling (or building). However, influencing behaviour has been found to be difficult (Fabi et al, 2012).

4 A horizontal louvred screen to protect windows and walls from the sun.

4.5 Natural ventilation

Ventilation during the day by opening windows is only useful where the outdoor temperature is lower than the indoor. 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 heat built up over the preceding days is liberated.

Typical background ventilation rates in UK dwellings are approximately 0.5 air changes per hour (ach). Many mechanical ventilation systems have an ability to provide a boost level of ventilation. On site measurements have revealed that this may only be an increase of 25 to 50%. Doubling the ventilation rate to 1 ach would be very unusual for a typical mechanical system. Purge ventilation is considered to be at least 4 ach, i.e. eight times greater than the normal background ventilation rate, which no mechanical system could achieve unless specifically designed to do so. Achieving purge ventilation through opening windows assumes that the windows are wide open.

4.6 Air movement

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, depending on the Relative Humidity. There have been studies and a recent review on the effectiveness of fans to provide air movement during heat waves (Gupta et al, 2012) and, a recent study involving eight healthy males, found fans were effective during hot and humid periods (Ravanelli et al, 2015). However, fans do not replace the requirement for adequate ventilation.

4.7 Comfort cooling

Installing a comfort cooling system is, in terms of solving an overheating problem, a fail-safe solution, in that whatever is the scale of the problem, a system large enough could be installed. However, this solution should only be considered when all measures to minimise the heat gains have been taken and the remaining options for heat rejection can be demonstrated to be insufficient to provide a safe internal environment.

Refrigeration systems are not 100% reliable and the impact on occupants of a failure must be considered. Any mechanical system has an on-going maintenance and running cost. These facts alone may make this option inappropriate for households on a low income.

The wider impact on the local environment must also be considered as heat rejected from one household will tend to increase the air temperature in the local micro-environment, increasing the risk of overheating in adjacent households. These systems may also generate significant noise when running and this may not be acceptable to adjacent households leaving windows open at night to reject heat build-up.

5 Assessing potential effectiveness of remedial measures

There is currently no large body of evidence showing the results of undertaking a variety of remedial measures to overcome cases of excess heat. The number of cases is increasing and remedial measures are being implemented, but it will be some time before a 'catalogue' of solutions is available that can be reviewed for appropriateness for any given case of excess heat.

In the absence of this knowledge base it is suggested that a mix of judgment and mathematical modelling is used to assess the effectiveness of any given combination of remedial measures.

If the source of the heat gains can be very clearly identified, for example; poorly controlled storage heaters and gains from poor thermal insulation of the domestic hot water cylinder, then the remedial measures can be clearly identified without the need for further assessments. However, where the source of heat gains is less clear, and cannot be largely removed, the effectiveness of reducing gains combined with increasing heat rejection must be assessed. This requires that the assessment method captures the dynamics of the thermal processes within the dwelling and its surrounding micro climate. It is suggested that this can only be effectively undertaken through the use of full dynamic modelling.

Great care needs to be exercised when undertaking modelling to ensure that sufficient detail is used to accurately capture the dynamics of the key elements of the building, but it should not become an exercise in modelling every last detail. Over complicating the modelling will significantly increase the time and cost of modelling. The key aim of modelling is to allow the relative effectiveness of a range of remedial solutions to be assessed, both individually and then as a combination. In this way a solution can be identified that is appropriate for a dwelling, which may differ significantly from the appropriate solution for the adjacent dwelling, with for example, a different orientation.

The US Office of Energy Efficiency and Renewable Energy has produced *Guidelines for Home Energy Professionals* which provides useful information on assessing the effectiveness of energy upgrades (Energy.gov).

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Appendix 1: Relevant matters and options for remedial action

Matters relevant to the likelihood of overheating	Result	Options for reducing the likelihood	Comments
Location			
In a dense urban area (heat island)	Heat absorbed by dense materials during the day is given off at night, keeping night-time temperatures relatively high. This is supplemented by heat discharged from refrigerators and chillers, and perhaps air-conditioning units.		
Apartment on the top floor of a building	Inadequate protection from solar heat gain.	Additional insulation over the apartment. Consider reflective finish to the roof.	
Apartment on the ground floor adjacent to a public footpath, or an apartment on the same level as an access balcony	Fear of unauthorised entry (burglary) discourages opening windows for ventilation, particularly at night.		
Adjacent to major road	Noise discourages opening windows for ventilation, depending on the amount of night-time traffic.		
Adjacent to railway line	Noise discourages opening windows for ventilation, depending on the amount of night-time traffic.		
Close to airport and under flight path	Noise discourages opening windows for ventilation, depending on the amount of night-time traffic.		
Orientation			
One or two elevations facing South through to West	Depending on the form of construction, can mean structure absorbs heat and transmits it to the interior.		
Windows facing South through to West	Allows solar heat gain as sunlight passes through the window to be absorbed as heat by internal surfaces.	Awnings, blinds, or shutters to protect from solar heat gain.	Blinds and shutters will be more effective if they can be fitted externally. This may be balanced to some extent by North facing rooms which could provide 'cool' rooms.

Matters relevant to the likelihood of overheating	Result	Options for reducing the likelihood	Comments
Design and Construction			
Poor structural thermal insulation	Depending on the form of construction, can mean structure absorbs heat and transmits it to the interior.	Additional insulation.	Cavity insulation. For solid walls, external insulation is preferable.
High thermal insulation and relatively airtight	Once interior is heated there is little chance of releasing that heat, and little chance of purge ventilation.	Provision of appropriate means for ventilation.	Particularly means for purge ventilation at night. Preferably not air-conditioning.
High thermal mass	Internal structure absorbs heat during the day and gives it off at night.		
Single aspect	Prevents 'through' ventilation, so purge ventilation is not possible.	Provision of appropriate means for ventilation.	Particularly means for purge ventilation at night. This may not be possible without air-conditioning.
Inadequate/inappropriate provision for ventilation	Limited means of releasing any heat.	Provision of appropriate means for ventilation.	Particularly means for purge ventilation at night. Preferably not air-conditioning.

Appendix 2: Sun path diagram

The user should consider themselves at the centre of this diagram looking South. The point at the middle of the diagram is the point in space above the user's head. The outer circle is the horizon.

The sun rises (comes up over the horizon) at 06:00, due East, it is due South at 12:00 with an altitude of approximately 40° (each circle inside the outermost one is 10° elevation up from the horizon – 90° being directly above the user at the centre of the diagram). The sun sets at 18:00 due West of the user.

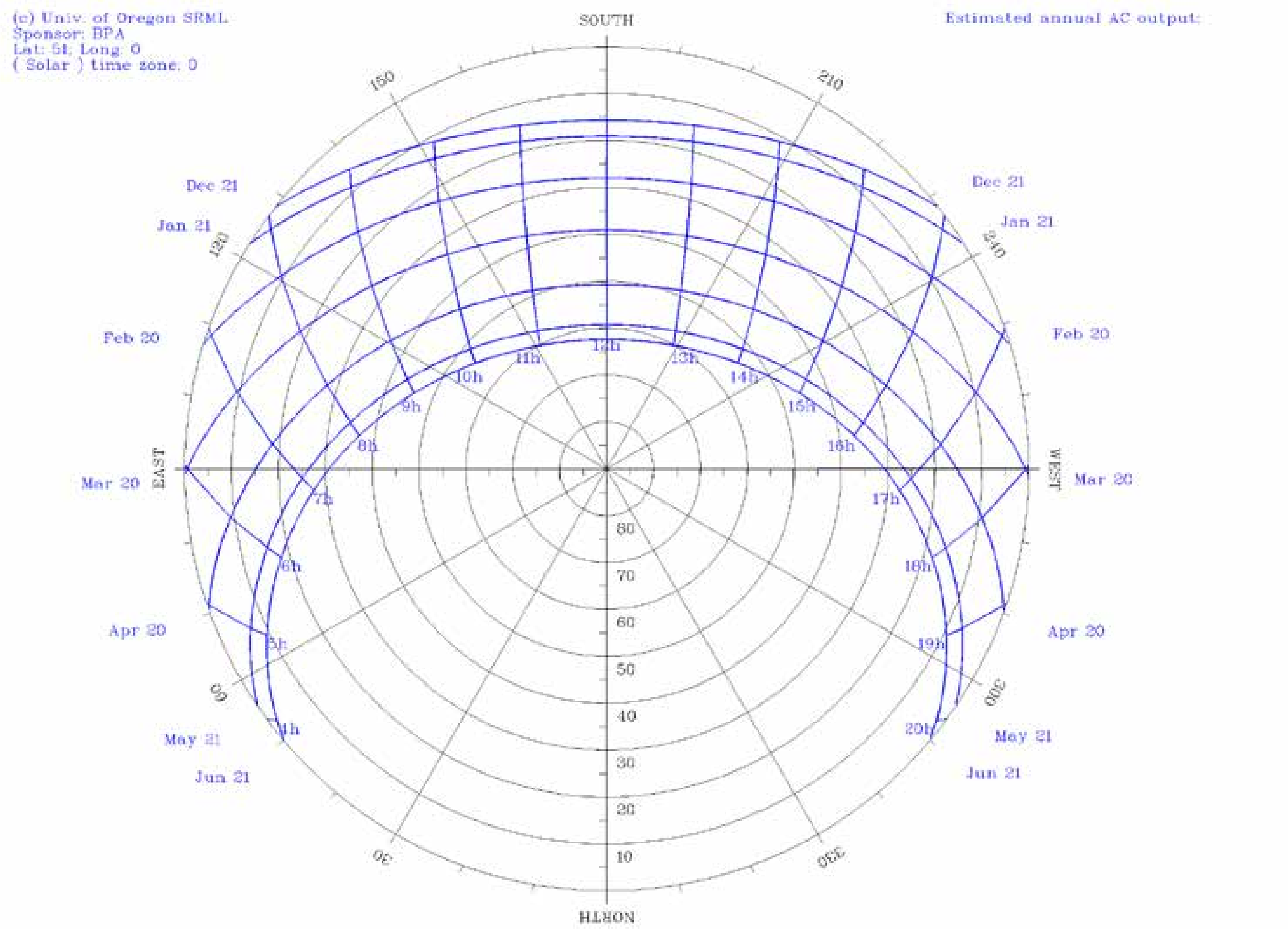


Figure A1: Sun path diagram

Plots are available for any latitude/longitude from:
http://solardat.uoregon.edu/PolarSunChartProgram.html

Appendix 3: Heat transfer process

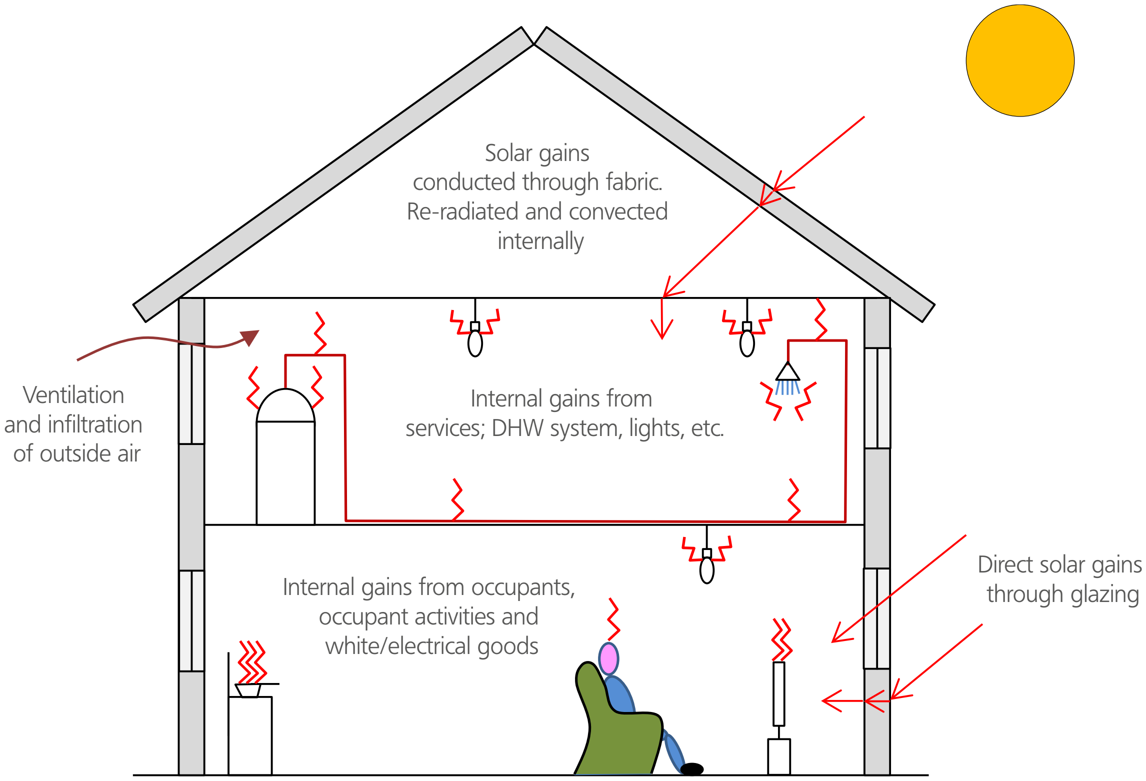


Figure A2: Sources of heat gain

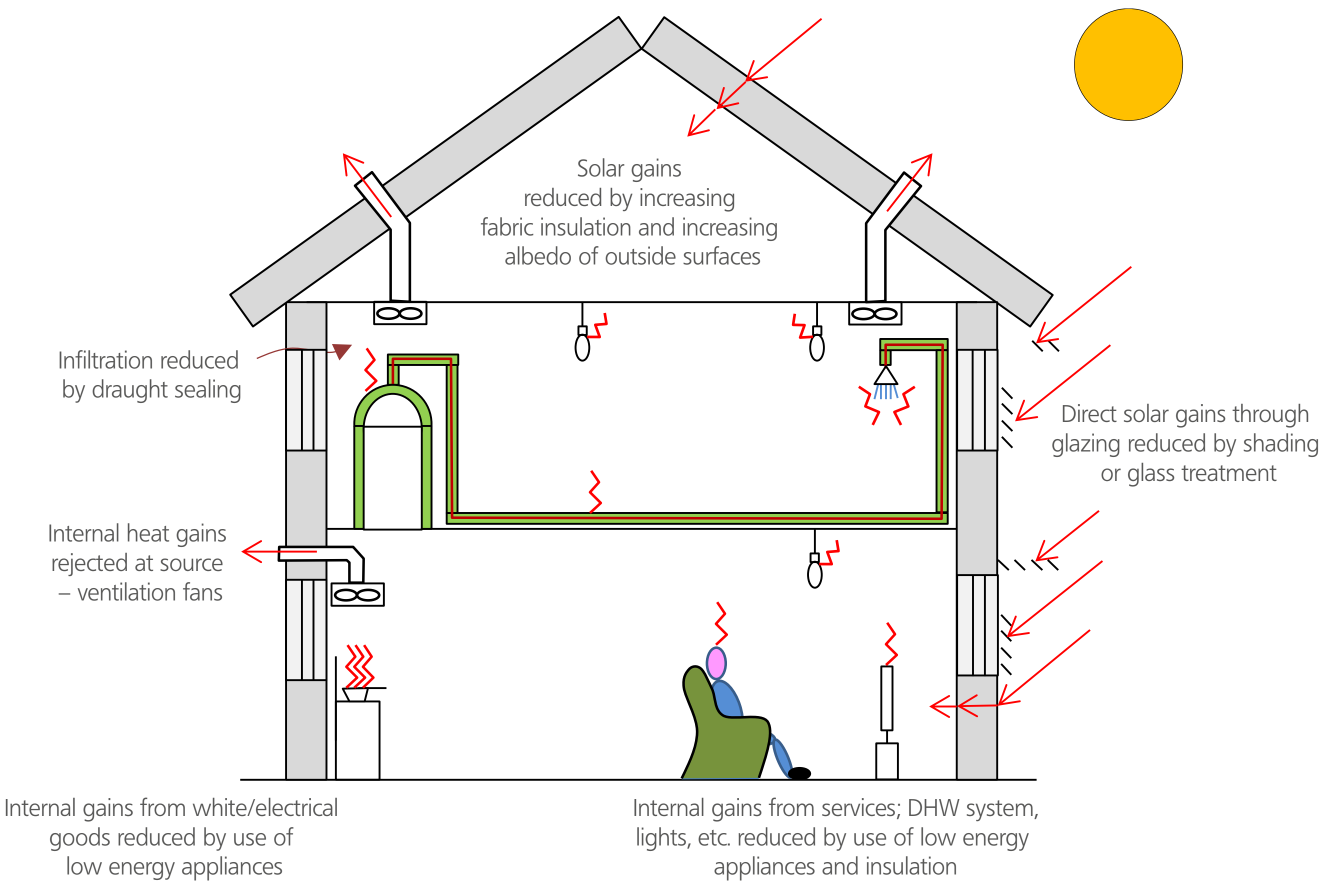
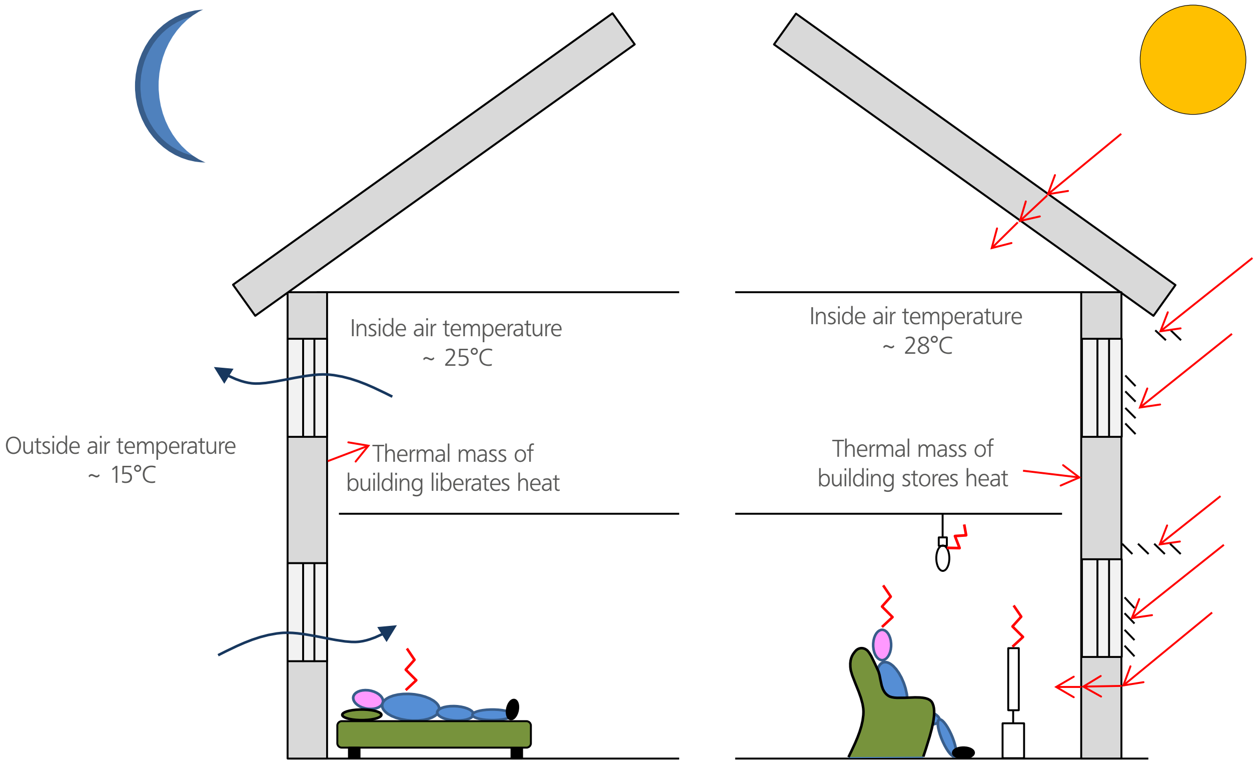


Figure A3: Potential measures to minimise heat gains



If 0.5 ach = 25 l/s and the inside/outside air temperature difference is as above, cooling capacity at night = 300 W. At 4 ach, cooling capacity = 2400 W.

Useful levels of heat rejection only occur when inside/outside air temperature difference is significant. Therefore during the day, gains are not rejected but result in internal air temperature rising above that outside. Heat is also stored in building mass.

Typical internal heat gains:
DHW cylinder 3.0 kWh/day = 125 W (continuous);
Occupants 60-80 W each (continuous);
Fridge/freezer up to 2.0 kWh/day = 83 W (continuous);
Cooking 1.6 kWh/day (intermittent);
ILghts 30-200 W (intermittent);
IT and audio/visual up to 250 W (intermittent).

These figures show clearly that normal background ventilation may at best only reject on-going heat gains, not heat stored in the thermal mass of the building.

Figure A4: Thermal mass and the effectiveness of night ventilation

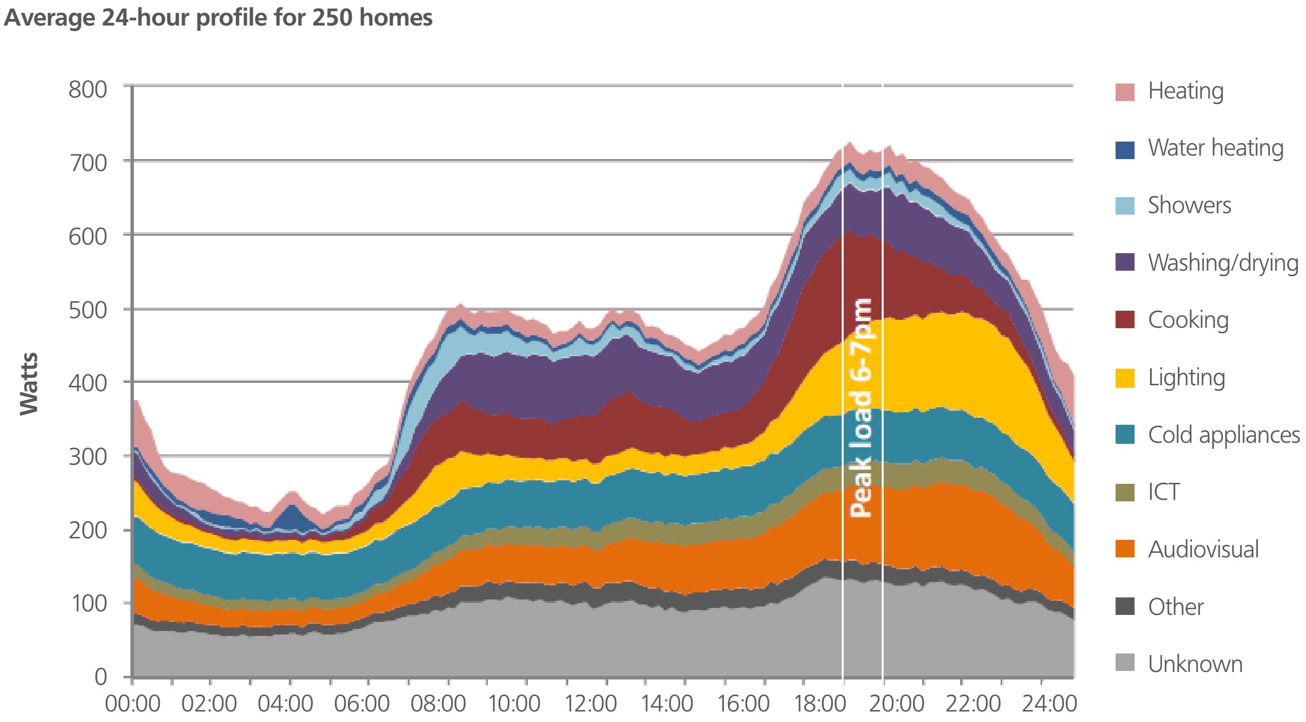


Figure A5: Recent data on internal heat gains for UK dwellings

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BRE Trust
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