SOLUTIONS TO OVERHEATING IN HOMES

EVIDENCE REVIEW

ZERO CARBON HUB

Since our formation in 2008, the Zero Carbon Hub continues to work with Government and industry to identify risks, remove barriers to innovation and help demonstrate that energy efficient, healthy new homes can be delivered by the mainstream house building industry.

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This report is available as a PDF download from:
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SUMMARY

This Evidence Review produced by BRE for the Zero Carbon Hub describes the range of technical and behavioural solutions available to reduce the risk of overheating in UK homes. The review covers a wide range of possible measures from town planning and building positioning, layout and orientation through to building fabric, windows, ventilation, to the actions of individual occupants. As such it covers issues relating to the local environment and neighbourhood as well as to the individual dwellings.

The review is intended for a wide range of people from those involved in town and neighbourhood planning, to those involved in building design and refurbishment, and occupiers.

Throughout the document areas where further research would be useful are highlighted. For example, studies to understand the scale of effects described. It should also be noted that although the terms "solutions" is used throughout the Review, in many cases we mean measures that can mitigate the potential for overheating for certain periods of time.

More than 30 solutions have been considered. These have been categorised according to whether they are based on:

- Limiting heat gains within buildings
- Enhancing heat rejection
- Cooling the space
- Changing occupant behaviour

In many homes a combination of these steps will be sufficient to prevent overheating, though in some cases mechanical cooling with refrigeration may be required some of the time.

The Review is accompanied by a short leaflet summarising the main themes.
See **www.zerocarbonhub.org**

The purpose of this Review is to provide a foundational understanding of the range of solutions available. It is not design guidance or legal advice and the measures described have not been not prioritised. It is likely to be the case that certain measures described will only be appropriate for larger developments.

The cost and practicality of each solution considered can differ substantially depending upon the specifics of the building type and at which stage of the building life-cycle the measure is added. The cost of each solution is therefore indicated (at the end of the document) by a qualitative figure expressed as low/medium/high for comparison.

The building life-cycle stages offer the following opportunity for overheating measures to be applied:

- **New build –** The opportunity to optimise building orientation and built form at minimal cost early in the design stage, and to consider local, district scale technologies.
- **Major refurbishment –** The opportunity to change windows, internal layout, and the means of ventilation, with the cost being amortised alongside scheduled replacement of building materials and equipment.
- **Small-scale retrofit projects –** There is limited opportunity to influence heat gains or heat rejection at this stage. Measures such as internal blinds, certain types of external shading solutions, window films and occupier education are generally low cost. Any other measures are more likely to be relatively high cost at this stage.

In certain circumstances, overheating prevention measures may also incur a 'performance cost' in other areas. There are several design considerations to make holistically e.g. daylighting versus limiting solar radiation gains, summer heat rejection versus winter energy efficiency.

Many sources of heat gains in dwellings are easy to identify and understand when considered individually. However, in overheated dwellings there are usually multiple heat sources and addressing these and identifying the dominant heat source is in many cases not straightforward. Tackling overheating therefore often requires a combination of measures.

Solutions to overheating should be considered following the hierarchy:

1. Reduce heat gains
2. Optimise passive heat rejection
3. Consider mechanical heat rejection
4. Consider mechanical cooling

Each stage should be addressed before moving to the next. It is possible that a combination of solutions is implemented, each addressing an element of the hierarchy above.

There are some key design considerations for combining particular technologies, e.g.:

- In order to be effective, the use of thermal mass must be combined with some effective means of purge ventilation to remove heat absorbed by the thermal mass. See more in Section 04.
- Centralised mechanical ventilation is generally used to maintain good indoor air quality of buildings. It is normally designed to provide both background ventilation and purge ventilation, but not to remove heat due to sizing and noise issues, since purge ventilation rates for heat removal are up to ten times greater than background ventilation.

The wide range of issues outlined in this report implies that a considered, systems approach is essential when undertaking overheating prevention measures.

01
INTRODUCTION

This Evidence Review describes the range of technical and behavioural solutions which can reduce the risk of overheating, and as a result, the need to use energy to provide mechanical cooling in UK homes. This includes considering the characteristics of individual dwellings, but also characteristics of the local environment and neighbourhood. This Review also considers how solutions may be combined to be most effective when applied to various types of building and in various situations, and it seeks to highlight gaps in knowledge where further research may be needed.

The purpose of this Review is not to provide guidance, but to give a good foundation in appreciating and understanding the range of solutions available. It is intended for a wide range of people from Local Authorities, planners, developers, occupiers and as such covers issues ranging from planning decisions relating to building positions, layouts, orientations through issues relating to the building fabric, windows, ventilation, to the actions and behaviour of individual occupants.

As well as their scope to reduce overheating, consideration will be given to the costs and practicalities of implementing each solution.

This Review does not consider the actual resulting internal temperatures within a building due to heat gains; it focuses on heat, the magnitude of which will vary depending on the source. The actual temperature of an internal environment as it affects the occupant of a building, i.e. the operative temperature, is a complex function of the gains and losses in any given space within a building (see Definitions).

Is overheating a problem in the UK? Data gathered over a significant period of time for moderate climates suggests that there is a strong correlation between higher temperatures and increased internal temperatures leading to occupant discomfort. In addition, ill-health and in some cases, mortality, showing a steep rise as external temperatures increase (see Figure 1). A further risk is that overheating may encourage the increased use of mechanical cooling which would lead to increased energy demand and diminish the opportunity or effectiveness of non-mechanical alternatives. The high relative running cost of mechanical cooling also has affordability issues and the associated greenhouse gas emissions will be contributing to climate change.

This Review looks at ways of reducing the occurrence of excessively high temperatures within buildings. Changes to the global climate are outside the scope of this report.

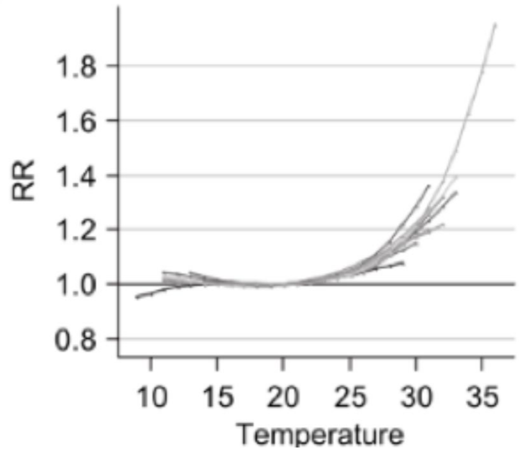

Figure 1. **Temperature-mortality associations in England and Wales (RR means 'relative risk' of mortality, where 1 is the normal risk and Temperature is the mean external summer daily maximum temperature) (Source: Armstrong et al. [1])**

Heat: what is it and where does it come from?

Heat is thermal energy, fundamentally the random motion and vibrations of particles e.g. atoms and molecules, with temperature being a relative measure of the effect of heat on a body. For example adding a kWh of heat to a solid brick wall will result in a very small change in temperature, but add a kWh of heat to the air within a room and there will be a measurable change in temperature of the air. Therefore heat gain will result in a change in temperature, but in a building the resulting change is often a complex function of heat transfer between different parts of the building and the internal air depending on the thermal properties of the materials.

Sources of heat can be inside or outside a building. Sources of heat from outside include:

- Solar radiation
- Direct transfer of heat by conduction
- Air movement to inside when it is hotter outside.

Sources of heat from inside include:

- Occupants
- Electrical equipment including lighting
- Cooking
- Hot water pipes and storage tanks

When heat gains exceed losses this may result in increases in the operative temperature (the temperature 'felt' by occupants, see definitions). This may result in temperatures becoming uncomfortable for occupants, or elevated to levels that result in potential health issues.

When temperatures are constant there is a heat balance:

heat in = heat out or **gains = losses plus rejected heat**

1. Armstrong BG, Chalabi Z, Fenn B, et al., 2011. Association of mortality with high temperatures in a temperate climate: England and Wales. J Epidemiol Community Health. 2011; 65(4): 340–345.

Principles for mitigating against overheating

Reducing unnecessary heat can be achieved through limiting heat gains, for example, by reducing the amount of:

1. Heat from the sun entering the building (solar radiation)
2. Internal heat gains such as from the unnecessary use of electrical equipment (and by switching to energy efficient alternatives) or by limiting gains from other sources such as hot water distribution pipes
3. Warmer outside air entering the building

CIBSE TM36[1] and the Greater London Authority/Westminster Local Authority processes categorize these issues in a similar way.

High internal temperatures may also be managed by increasing the thermal mass of the building. Heavyweight building materials, such as brick, stone or concrete have the capacity to “soak up” and store heat – or cold. This ‘thermal mass’ can be used to maintain more uniform temperatures inside a building. The heat from the day is stored, then released at night when the temperatures are cooler. As a result, internal temperatures should have lower peaks and only reach these peaks once outside temperatures are relatively cool. Thermal mass can be implemented through the selection and incorporation of particular building materials with the aim of reducing the rate of indoor temperature change.

The use of thermal mass must be accompanied by an efficient means of removing the stored heat – i.e. good ventilation or cooling. The use of thermal mass to smooth out temperature changes will also be less effective in locations where the swing between day time and night time is less pronounced e.g. in major cities where an urban heat island exists. See more in Section 04.

Ultimately, once there is excess heat is inside a building, enhancing the heat rejected and/or cooling of the space is required to achieve a reduction of the operative temperature. This can be achieved in three ways:

1. Removal of heat passively or actively through ventilation, i.e. the replacement of internal air with cooler outside air. This is most effective when the internal to external air temperature difference is greatest and thus of limited value during periods of high external air temperatures.
2. Passive or active (e.g. with fans) cooling of the ventilation air or the structure of the building. Drawing air through a cooler space before it enters a building offers the potential to pre-cool warm outside air. Cooling the structure of the building may also be achieved through night ventilation to effectively store ‘coolth’ in the thermal mass of the building to offset the peaks in temperature of the following day.
3. Mechanical cooling using refrigeration based systems. This approach is effective and fail-safe, other than due to plant failure or a loss of electricity supply. Whatever the actual cooling load, a cooling plant could be installed to meet it. However the high relative capital and running cost could create affordability issues. The availability of mechanical cooling may also preclude or discourage the use or effectiveness of simpler and lower energy consuming passive or active methods when these are also provided. The aim of most designers is therefore to prioritise good passive design as a means of controlling temperature, with mechanical cooling as an option if design measures alone cannot address the cooling load.

In the long-run, it is far better to design-in measures to prevent overheating as far as possible than try to address the issue through retrofit if it occurs later.

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

Actions by occupants

This Review covers only the actions taken to prevent heat gains or promote heat rejection. Actions taken by the occupants to safeguard their health, for example drinking water regularly are outside the scope.[1]

Occupant behaviour and use of the property may help to reduce the build-up of heat, for example through timely window opening to purge excess heat. Occupant choices also affect the level of internal gains which can be reduced by the thoughtful use of equipment or the use of very energy efficient equipment. However the design of the building also needs to create the conditions that such actions become intuitive to the occupants. It also helps if occupants have some understanding of the effect of their behaviours on the building's performance. Otherwise uncontrolled additional heat gains will clearly result in increased internal temperatures and increased risk of overheating.

Opportunities to improve summer thermal performance

- **New build –** When a dwelling is designed and built there are very significant opportunities to minimise the propensity for overheating, such as by choice of building orientation and built form; however site or location restrictions may limit scope.
- **Major refurbishment –** At this stage the structure of the building is usually set, but there are significant opportunities to change windows, internal layout, or the means of ventilation and make better use of the building's thermal mass..
- **Small-scale Retrofit projects –** During a simple retrofit there are limited options to significantly change heat gains or the means of heat rejection unless the source of the heat is easily identified.

With all these opportunities, where changes are undertaken which improve the design or energy efficiency of properties during the heating season, care must also be taken to consider the potential effect on summer conditions.

1. *See the Heatwave Plan for England 2015 for further advice.*

02
DEFINITIONS OF TERMS USED

Operative temperature

Temperature is usually the most important environmental variable affecting the thermal comfort of the occupants of a dwelling. As a result of past research about the effect of temperature on dwelling occupants, the CIBSE definition of operative temperature combines air temperature and mean radiant temperature into a single value that accounts for their joint effect. For indoor air speeds below 0.1 m/s:

Equation 1

$$\theta_c = \tfrac{1}{2}\,\theta_{ai} + \tfrac{1}{2}\,\theta_r$$

Where

θ_c = Operative temperature (°C)

θ_{ai} = Air temperature (°C)

θ_r = Mean radiant temperature (°C)

Heat wave

This is a relatively short-term occurrence where temperatures are elevated across a region, possibly as large as the whole UK. There is no official definition of a heat wave in the UK, but the Met Office uses the World Meteorological Organization definition of "when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5°C, the normal period being 1961-1990".

Global climate change

The gradual rise of average outside air temperature as a result of global warming. The rate of change is relatively small from year-to-year, but it is resulting in warmer summers on average and more heat waves as temperature variations become more extreme.

Urban heat island (UHI)

This is a built-up urban area which is significantly warmer than surrounding rural areas due to human activities such as transport and the effect of asphalt, buildings and similar surfaces.

Excess heat

This is the long-term elevation of internal temperature within a building over an extended period of time, i.e. months across a period when the outside air temperature is not excessive and normal diurnal variation occurs.

Diurnal

Relating to a daily 24 hour period

Building microclimate

Boundary layer of air which is adjacent to the structure of a building, for example 100 mm deep.

Local micro climate	Climate that influences the fabric of a building that includes very immediate modifiers, for example shading by trees. Depth assumed to be up to 30 m distance from a building i.e. immediate neighbourhood.
Local climate	The climate that is influenced by modifiers in the local area. This can include the effect of UHI due to the mass of urban structures modifying the local diurnal variations and therefore means the conurbation scale, 5 miles radius.
Regional climate	Assumed to mean the county or possibly the region of the UK, e.g. the south east, 50 miles radius or greater.
Total solar transmittance	The fraction of incoming solar radiation that passes through a window and/or shading system. Commonly referred to as the g value. The total solar transmittance includes both radiation that is transmitted directly through the window, and radiation that is absorbed and then re-radiated, convected or conducted into the room.
Effective g value	This is also expressed as a fraction and allows for the effects of radiation coming in from different angles, throughout a sunny day in summer. So, for example, it can take account of the extra radiation blocked by an overhang or awning above a south facing window, which works best when the sun is high in the sky in summer. Effective g value, Geff, is defined as:

$$g_{eff} = \frac{\textit{Solar gain in period of potential overheating through window with shading device}}{\textit{Solar gain through unshaded,unglazed aperture for the same period}}$$

Albedo	The proportion of the incident light or radiation that is reflected by a surface.
Passive cooling	Cooling by some means that does not require power.
Active cooling	Cooling using equipment that requires power.
Free cooling	For the purpose of this Review and in the context of a dwelling this is used to describe the removal of heat through natural ventilation only.
Mechanical free cooling	For the purpose of this Review and in the context of a dwelling this is used to describe the use of mechanical means, i.e. pumps or fans, to transport 'heat' between a building and a heat sink.
Mechanical cooling	For the purpose of this Review and in the context of a dwelling is used to describe the use of refrigeration based systems.
Coolth	The use of a medium such as air or water that is at a temperature lower than that of the local environment to cool the conditioned space. E.g. ground water in summer can be used to draw heat out of structures and store 'coolth' that offsets the heat gains of the following day.
Single-sided ventilation	A dwelling where openings are only present along one side.
Through ventilation	Ventilation through a dwelling requiring openings on different sides.
Mid-season	Between winter and summer, i.e. spring or autumn.
Emissivity	A measure of the efficiency of a surface in emitting thermal energy, compared to a one which emits the maximum possible ('black body' radiation).
Reflectance	The fraction of incident solar and thermal energy which is reflected by a surface.

03
TECHNICAL AND BEHAVIOURAL SOLUTIONS

The main purpose of this document is to describe the range of possible available options to address overheating within dwellings. For each solution details are given of what the solution is, how it can be used, a qualitative assessment of its effectiveness, an indication of the relative costs and comments on its availability and the ease of application.

Solutions are grouped under four chapter headings according to the way in which they can contribute to a reduction in overheating:

- Solutions which limit heat gains
- Solutions which enhance heat rejection (removal)
- Solutions which use cooling
- Solutions based on occupant behaviour

The range of solutions which are explored in this paper are shown in Figure 2 below. As might be expected, some are used much more frequently, such as shading devices. Others are more novel, or might be appropriate for use in certain types of larger schemes or buildings.

Another consideration is that certain solutions, such as using large-scale reforestation as a strategy for limiting urban heat islands and therefore heat gains in buildings, will only be implementable by certain organisations such as national or local government. These “location-related” solutions have been included in the Review with policymakers in mind, rather than building designers.

Figure 2. **Potential solutions to overheating in a domestic building**

SOLUTION	LOCAL AUTHORITY/ REGIONAL	BUILDING DESIGN	RETROFIT	INNOVATIVE
Layout: avoiding tightly packed buildings and canyon configurations	✓			
Increase areas of open water and foliage	✓			
Position buildings away from wide areas of road and pavement		✓		
Ground probes to extract and store heat in summer, then release it in winter		✓	✓	
Install PV in pavements and roads			✓	✓
Increasing the albedo of building surfaces to reflect solar radiation			✓	
Increasing green space	✓			
Minimise surface area to limit fabric solar gains		✓		
Narrow streets to limit solar access to building facades	✓	✓		
Underground or partially underground rooms		✓		
Position bedrooms where heat gains are least for sleeping and health benefits		✓	✓	
Use of glazing types with appropriate levels of infra-red transmission		✓	✓	✓
Location: ensure north glazing can provide natural ventilation		✓	✓	
Daylighting: use of windows and skylights which avoid high solar gains		✓	✓	
Walls & roofs covered with plants to reduce heat gain		✓	✓	
Internal shading		✓	✓	
External shading		✓	✓	
Natural ventilation		✓	✓	
Mechanical Ventilation		✓	✓	
Thermal Mass and building materials		✓	✓	
Storage of heat in summer to use in winter				✓
Direct – evaporation into the airstream				✓
Indirect – evaporation into an airstream then a heat exchanger				✓
Cooled exhaust air to cool the dwelling				✓
Exposing air to regularly cooled thermal mass		✓	✓	
Water pipes embedded in concrete structure		✓		
Refrigeration based, including 'split' and 'multi-split' systems		✓	✓	
Use of curtains and blinds during sunny periods				
Use of external shutters, awnings during sunny periods				

04
SOLUTIONS WHICH LIMIT HEAT GAINS

Regional climate – Reforestation

This section covers the types of steps that can be taken at a regional level by local authorities (or groups of local authorities) to help reduce external temperatures.

The climate at the regional level, up to the size of a county, is largely governed by country and global level climate influences. From region to region there are factors that can be influenced such as solar heat gains which are largely determined by the vegetation cover of the land.

Plants of all sizes use sunlight, through the process of photosynthesis, to produce food for their own growth. This interception of the sunlight, and conversion of a significant percentage of the heat energy into a biological process results in the solar gains occurring to the area shaded by the plant's leaves being very greatly reduced. In addition to this, trees and vegetation absorb water through their roots and emit it through their leaves – this movement of water is called transpiration. The evaporation of water from the leaves and also from the soil around vegetation reduces the temperature of the leaves, soil and air.

However, reforestation and use of large areas of land for relatively dense foliage has an impact on land availability for crops and other uses and while it may be viable, the potential changes at such a large scale require actions by national government to achieve any meaningful change in regional temperatures, similar to international treaties to reduce ozone depletion and CO_2 emissions.

Local climate (city level) – Urban Heat Island (UHI)

Urban areas tend to be warmer on average than rural areas and they cool down more slowly at the end of the day. This is due to the concentration of a large number buildings, physical infrastructure and people using energy, and so the effect is especially pronounced in larger cities.

The recognition of this effect and its impact on the potential for buildings to remain habitable without need for active cooling was first noted in cities such as Tokyo as long ago as the 1960/70's. In such climates the tendency to install a small mechanical cooling unit into dwellings exacerbated the problem as the equipment emitted heat outside the dwellings. The effect is however now noted in UK cities where high levels of anthropogenic heat gains, added to the sheer scale and extent of the man-made structures, results in an elevation of day time air temperatures, but most notably a reduction in the night-time fall in air temperatures (see Figure 3, Figure 4).

The elevation of night-time temperatures reduces the opportunity to reject heat from buildings. While outside air temperatures fall in the mid to late afternoon in rural areas, locations in a deep urban environment may still have outside air temperatures that are equal to or greater than those inside buildings well into the evening, minimising the potential for effective heat rejection.

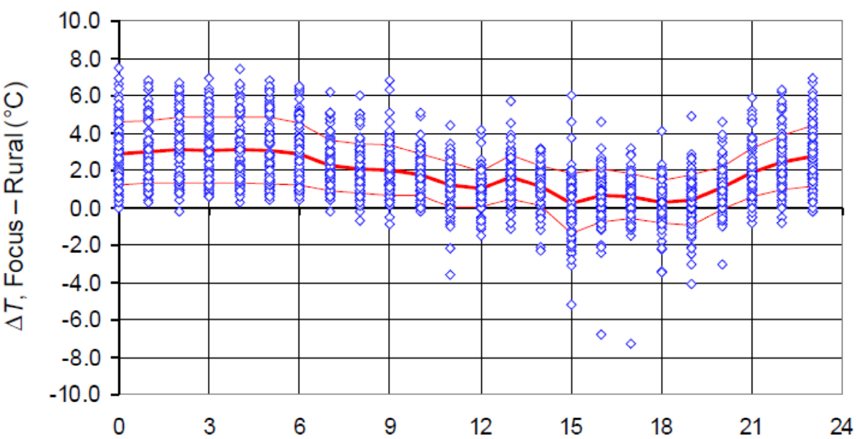

Figure 3. **Effect of UHI in London. Difference in temperature between a range of measurement locations in London compared to a site remote from London, clear of UHI influence. (All data, mean and ± standard deviation)**

Graves, H., et al, Cooling buildings in London: overcoming the heat island, BR431, BRE, 2001.

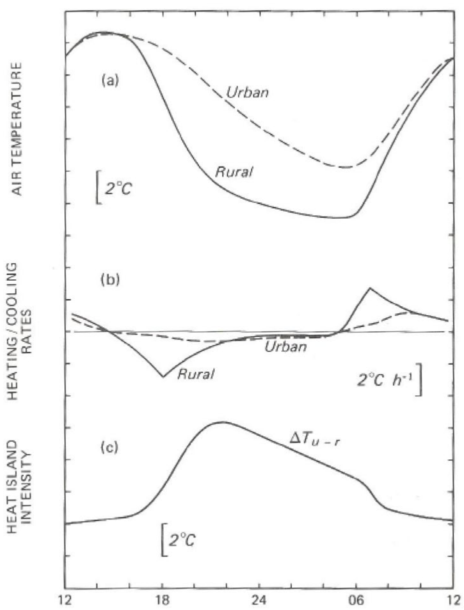

Figure 4. **Typical variations in temperature (a) air temperature in urban and rural, (b) rate of warming/ cooling, (c) heat island intensity.**

Shahmohamadi, P., et al, Reducing urban heat island effects: A systematic review to achieve energy consumption balance, International Journal of Physical Sciences Vol. 5 (6), pp. 626-636, June, 2010

At the local, conurbation scale, the potential to influence the UHI effect relies on master planning pulling together with coordination of urban planners, developers, architects and local or possibly national government.

Decisions that can have an influence on the level of overall UHI effect and that may be influenced by urban master planning are:

- The layout of the urban environment. This will have an influence on the daylight and winter sun availability, the degree of shading in summer and the potential for buildings to use natural ventilation. Tightly packed buildings and canyon type configurations limit the potential to naturally ventilate buildings. However they can also limit solar gains and in certain circumstances create breezes by amplifying air movement.
- The transport system and availability of alternatives to cars and lorries. It may be noted that electrification of vehicles reduces noise and pollution, which are often barriers to opening windows.
- The presence of open water.
- The presence of foliage. Depending on the moisture present, permeable paving is also emerging (in the U.S.) as a means of reducing air temperature. Moisture within the pavement structure evaporates as the surface warms, thus drawing heat out and lowering the surface temperature, similar to the evaporative cooling effect from plants and trees.[1]

Many of the actions that can be taken at a local level will also have an impact at a micro climate level and so will be dealt with in more detail in the following sections.

At an individual building and person level the amount of anthropogenic heat liberated and ejected from buildings has a significant overall impact on the UHI. Many of mans' activities result in heat being liberated, e.g. lighting, heating and cooling buildings, transportation, etc. In addition many non-domestic buildings and an increasing number of domestic buildings in urban environments are mechanically cooled. The rejection of this heat is highly concentrated and adds to the local and in many cases the micro climate air temperature.

Reducing the UHI is a matter of reducing the heat gains that occur due to man's activities and from the solar heating of high concentrations of man-made structures.

Addressing the Urban Heat Island – Trees and green space

As described earlier, plants intercept sunlight and convert some of this energy in biological processes. Moreover evaporation of water from the leaves and soil reduces the temperature of the air.

Reviewing a range of data the US Environment Protection Agency[2] (EPA) reported that evapotranspiration, alone or in combination with shading, can help reduce peak summer air temperatures, with reports suggesting ranges of:

- Peak air temperatures in tree groves that are 5°C cooler than over open terrain.
- Air temperatures over irrigated agricultural fields that are 3°C cooler than air over bare ground.
- Suburban areas with mature trees that are 2 to 3°C cooler than new suburbs without trees.
- Temperatures over grass sports fields that are 1 to 2°C cooler than over bordering areas.

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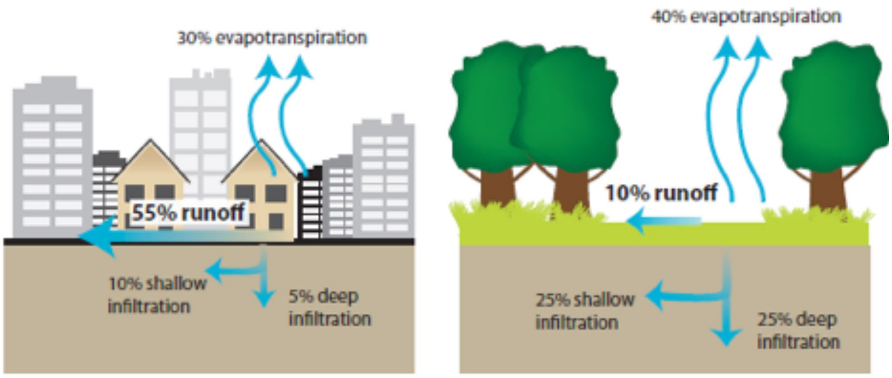
1. *Reducing Urban Heat Islands: Cool Pavements (draft), U.S. Environmental Protection Agency's Office of Atmospheric Programs.*

2. *EPA, Reducing urban heat islands: Compendium of strategies, Trees and vegetation, EPA*

Doick[1] reported a US study based on calculations that concluded the value of shading in Fresno, California, a hot sunny climate, as 2.5 times greater than that of evapotranspiration cooling. However, in temperate climates the role of shading and evapotranspiration are approximately equal. It is clear therefore that while shading is a very obvious result of vegetation, the evaporative cooling is equally important in climates like the UK.

Figure 5 shows a basic breakdown of the typical paths of rain after reaching the ground. The very high run-off in the urban environment reduces the opportunity for uptake by plants, and for evaporation from the exposed ground. Therefore the potential for reduction of the temperature through evaporative cooling is clearly significantly less.

It is this potential to achieve clearly measurable changes in both the local air temperature and the temperature of the shaded surfaces that makes the 'greening' of the urban environment a very promising tool in the efforts to limit the UHI effect.



Highly developed urban areas (right), which are characterized by 75%-100% impervious surfaces, have less surface moisture available for evapotranspiration than natural ground cover, which has less than 10% impervious cover (left). This characteristic contributes to higher surface and air temperatures in urban areas.

Figure 5. **Comparison of water movement and evaporation in urban and rural environments**

EPA, Reducing urban heat islands: Compendium of strategies, Urban heat island basics, EPA

It is interesting to note that some researchers have found that large open areas of grass while providing some reduction in heat compared to that of a concrete slab, do warm significantly as the soil is relatively exposed and thus dries. The best means of absorbing solar radiation is through a canopy of leaves, most effectively trees. This offers cover with grass at ground level and places for people to gather out of the sun. The actual effect on the local climate and the extent of cooling of the air due to the transpiration of the plants may well be limited compared to a dense foliage cover, but the reduction in heat gains is very significant.

At the micro climate level the shading of hard standing areas, walls, windows, etc. offers a very large potential reduction in solar gains to each of these elements. This has a significant impact on the building micro climate and the impact of solar gains on the sourcing of ventilation air.

The planting of trees and bushes at a local level – parks, gardens, road sides, etc. – offers the potential to significantly increase the shading, and interception of the solar energy heating the solid structures of the urban environment. This can be undertaken when planning a new build or as part of a retrofit where space permits.

In a high rise urban location the opportunities are more limited and very large trees

1. Doick, K., et al, Air temperature regulation by urban trees and green infrastructure, FCRN012, Forestry Commission, 2013.

offering shading up to 5+ stories would have implications for safety in storms, etc.

A very detailed review of published evidence has been produced by Bowler[1] on whether urban greening interventions, such as tree planting or the creation of parks, affects temperature and other environmental variables such as ozone, volatile organic compounds (VOCs), nitrogen oxides or UV within the surrounding urban area. The review found evidence of decreased temperatures, but also noted that the impact of greening on non-green areas required more research. This finding was echoed by the Forestry Commission[2] reporting to DEFRA and DCLG in 2010.

Figure 6. **The air temperature difference between a built-up area and a park for each study using data, where available, between 06:00 and 20:00.**

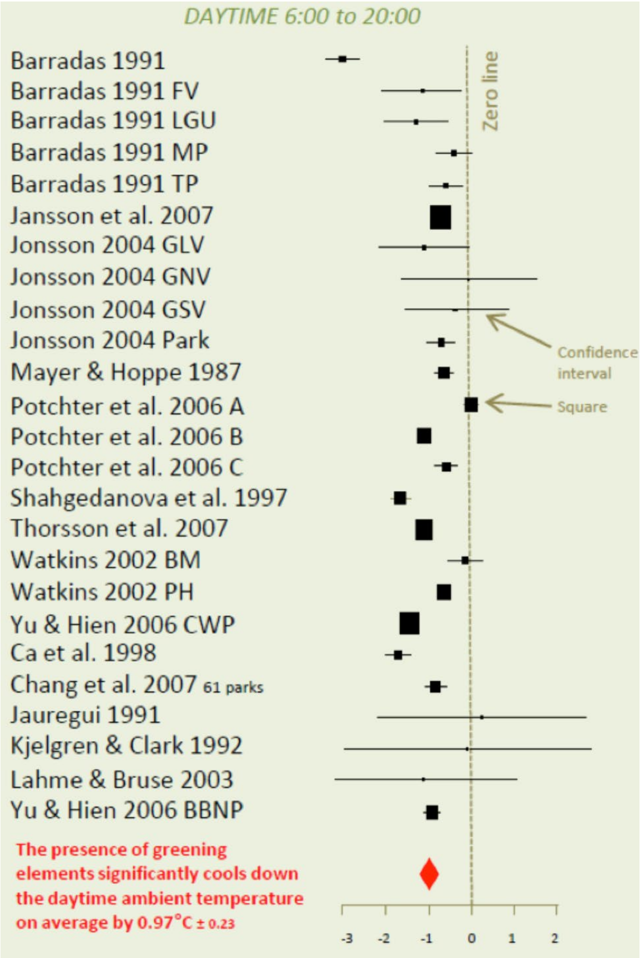


Figure 7. **The air temperature difference between a built-up area and a park for each study using data, where available, between 22:00 and 06:00**

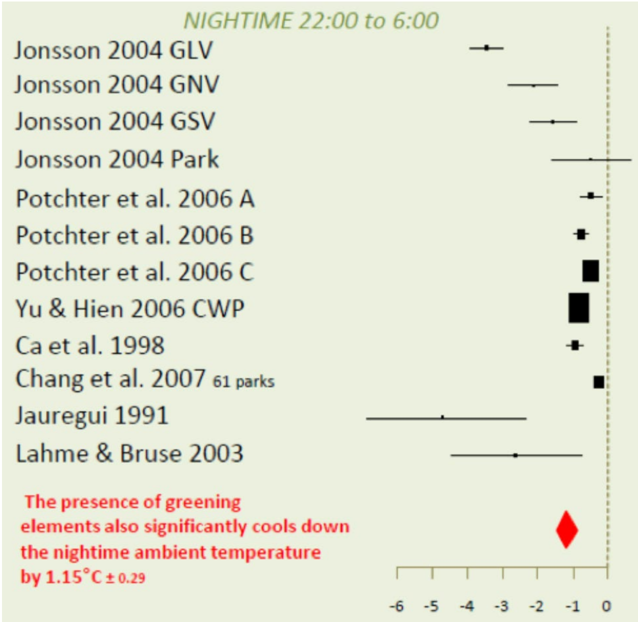


Figure 6 and Figure 7 show the results of the detailed review of impacts of green park land compared to adjacent urban areas.

Doick[3] concluded that for green-spaces to be a minimum of 0.5 ha (1 Hectare = 10,000m^2) in order to achieve cooing at significant distances beyond the site of the vegetation. It is noted that much of the work in this area has been undertaken in warmer climate. The spatial requirements and the effectiveness in a UK climate should be further investigated.

1. Bowler, D., et al. How effective is 'greening' of urban areas in reducing human exposure to ground level ozone concentrations, UV exposure and the 'urban heat island effect'? CEE review 08-004 (SR41). Environmental Evidence: www.environmentalevidence.org/SR41.html.

2. Forestry Commission, Benefits of green infrastructure, Report to DEFRA and DCLG, Forest Research, Farnham, 2010.

3. Doick, K., et al, Air temperature regulation by urban trees and green infrastructure, FCRN012, Forestry Commission, 2013.

The ASCCUE[1] project noted, referring to green infrastructure, that 'whilst such an approach is strongly advocated, the climate related benefits of urban green space are rarely quantified'. The project undertook some assessment based on Manchester and concluded that in this city, increasing green space by 10% could potentially eliminate the effects of climate change on increasing surface temperatures. However reducing green space cover by the same percentage could increase surface temperatures by up to 8.2°C under the 2080 high scenario. The project suggested that Section 106 agreements be used to ensure more green or blue space provision. Such initiatives need local or central government drive to ensure uniformity and consistency.

In London following the 2003 heat wave and the development of the Heat Wave Plan, a lot of work was undertaken on the climate in London, culminating in; The Mayor's Climate Change Adaptation Strategy, published in October 2011. The importance of green infrastructure to address the UHI effect is captured under the heading of City-wide management and contains the following paragraph:

> At all geographic scales, the key factor in determining the intensity of the urban heat Island is the proportion of green space to urban land cover. This is not surprising, given the fact that the UHI is caused by replacing green space with urban materials that store more of the sun's energy. The simplest method of managing the urban heat island, therefore, is to increase the amount of green space cover, by protecting existing green spaces and encouraging new opportunities for 'urban greening', or materials that mimic urban greening.

The strategy included a set of very specific actions. The key ones regarding overheating and green spaces were:

- **Action 5.3.** The Mayor will work with partners to enhance 1,000ha of green space by 2012 to offset the urban heat island effect, manage flood risk and provide biodiversity corridors through the city.
- **Action 5.4.** The Mayor will work with partners to increase green cover in central London by five per cent by 2030 and a further five per cent by 2050, to manage temperatures in the hottest part of London.
- **Action 5.5.** The Mayor will work with partners to increase tree cover across London by 5 per cent (from 20 to 25 per cent) by 2025.
- **Action 5.6.** The Mayor will work with partners to enable the delivery of 100,000m^2 of new green roofs by 2012 (from 2008/09 baseline).
- **Action 5.6** Refers to 'green roofs', these are considered further on page 21.

The forestry Commission has a website that provides details of the most suitable trees for urban areas: **http://www.righttrees4cc.org.uk**. This site has a searchable database and guidance on selecting suitable tree species to plant in urban areas.

1. *http://www.sed.manchester.ac.uk/research/cure/research/asccue/*

Addressing the Urban Heat Island – Albedo

At a local level the albedo or solar reflectivity of the built environment (e.g. buildings, roads and pavements) has an influence on the heat absorbed by these structures and therefore the liberation of heat back into the local environment. This may be a local planning issue but will also fall to individual building owners to implement for existing buildings.

In 1997 LBNL[1] undertook a modelling exercise to estimate potential energy and monetary savings resulting from the implementation of light-coloured roofs on residential and commercial buildings in major US metropolitan areas. The premise was that light coloured roofs reflect more sunlight than dark roofs therefore they should keep buildings cooler and reduce air-conditioning demand. The results were scaled up across the whole USA and a reduction of the annual national cooling electricity use in residential and commercial buildings of 3% could be achieved. Cool roofs are discussed in more detail in Section 04.

More recently the emphasis has extended to assessing the impact of albedo changes on the UHI effect, for example Taha[2] investigated the potential effect of changes to the albedo of roofing and paving materials and reforesting urban areas. The results of the investigation indicated that for a reasonable increase in urban albedo, a decrease in air temperature of 2°C was predicted with localised decreases of up to 4°C if albedo was increased significantly. Similar levels of decrease were predicted resulting from increased vegetation in urban areas.

Researchers[3] have investigated the predicted impact of increasing the paved area reflectance from 10% to 35%. The results suggested that the air temperature could be reduced by 0.6°C and that this would result in significant benefits in terms of lower energy use and reduced ozone levels.

One of the problems of light coloured roads and pavements is that over time, due to weathering and the accumulation of dirt, the solar reflectance tends to reduce. By contrast asphalt consists largely of petroleum derivatives as a binder mixed with sand or stone aggregate and tends to lighten as more aggregate is exposed through wear. Typical reflectance over a period of years are shown in Figure 8 for conventional asphalt and concrete roads. Figure 9 gives a range of light coloured paving materials and an estimation of the service life of each.

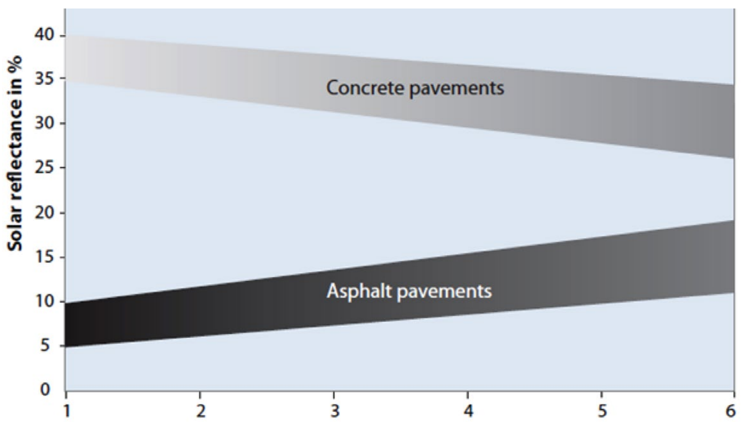


Figure 8. **Typical changes to the solar reflectance of asphalt and concrete roads over a period of years.**

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1. S. Konopacki, Cooling Energy Savings Potential of Light coloured Roofs for Residential and Commercial Buildings in 11 U S. Metropolitan Areas, Environmental Energy Technologies Division, LBNL, May 1997.

2. Taha, H., Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat, Energy and Buildings 25, 99-103, 1997.

3. EPA, Reducing Urban Heat Islands: Compendium of Strategies, Cool Pavements, 2005.

Pavement type	Solar Reflectance (SR)	Uses	Pavement surface life
Clear Resin Binders	Depends on aggregate	New construction & maintenance for streets, sidewalks, parking lots, etc.	20 years
Coatings (e.g., cementitious coating, elastomeric coating)	New: 35–55%	Coatings for preventive maintenance for streets, driveways, parking lots, etc.	1 to 5
Light-Colored Aggregates (e.g., chip seal)	Depends on aggregate	Overlay for preventive maintenance for highways, streets, parking lots	2 to 5 years
Light-Colored Cement (e.g., slag, white cement)	New: 70–80%	New construction & maintenance for highways, streets, sidewalks, parking lots, etc.	40 years
Porous Asphalt Cement (AC), Pervious Portland Cement Concrete (PCC), & Reinforced Grass Pavements	Depends on pavement type	New construction, to aid with stormwater management	varies
Portland Cement Concrete (PCC)	New (gray cement): 35–50% Aged (gray cement): 20–35%	New construction & maintenance for highways, streets, sidewalks, parking lots, etc.	40 years

Figure 9. **Light coloured paving materials**

Global Cool Cities Alliance, A Practical Guide to Cool Roofs and Cool Pavements, R20 Regions of Climate Action, January 2012.

Overall increasing the albedo of paved areas has a positive effect on the extent of the heat gained by the structures and therefore helps to reduce the UHI effect. However some studies[1] have identified that highly reflective roads and paved areas close to a building can increase the heat gains through the windows and thus the cooling load, or risk of overheating. It is therefore recommended that light coloured materials should be considered where they are not adjacent to buildings.

An alternative to using a light or reflective material for the paved areas is to make them porous and introduce some level of vegetation. Where traffic volumes are low or for parking areas the use of concrete or other protective mesh to prevent damage, grass can be planted (see Figure 10).

Figure 10. **Reinforced mesh providing a base for a drivable green space**

http://www.sure-ground.com/applications/car-parks

1. *Yaghoobian, N., Effect of reflective pavements on building energy use, Urban Climate 2 (2012) 25–42*

Local micro-climate – green and blue roofs

There are three main types of eco-roofs: green roofs (vegetated), white roofs (cooling), and blue roofs (water managing). Green, blue, and white roofs have distinct and overlapping benefits compared to typical “black” roofs meant solely to provide shelter.

The term blue is used to describe a structure primarily designed around the use of plants to reduce storm water surges and the impact of very high run-off rates on the drainage systems in urban areas. Systems include green roofs, porous pavements, swales, etc.

The term green is used to describe the covering of a man-made structure with a planted covering. When this is referring to a building the surfaces are the roof and walls.

A typical construction of a green roof is shown in Figure 11. Green roofs are split into two categories depending on the type of plants used and therefore the depth of the substrate/growing medium.

- **Extensive green roofs –** the depth of the substrate is commonly between 5 and 15 cm. This thin layer can dry out in summer and so plant choice is limited to hardy, low height and drought resistant plants. Plants with high stress tolerances have been identified as suitable for growing on roofs are sedum species, grasses and herbaceous perennials. Sedum species outperform the other plants, except in consistently moist substrate deeper than 10 cm. In these conditions, taller grasses and herbaceous canopy layer create shaded conditions that prove unfavourable to the sedum species. Other studies support the suitability of low-growing sedum species for use in green roofs because of their superior survival in substrate layers as thin as 2 to 3 cm.[1] Sedum planted roofs have proven to be sufficiently hardy to not require continual watering systems
- **Intensive green roofs –** these roofs have deeper planting media, irrigation systems and can feature a wide range of plants. Such spaces are grown for aesthetics or recreational spaces, sometimes open for public access.

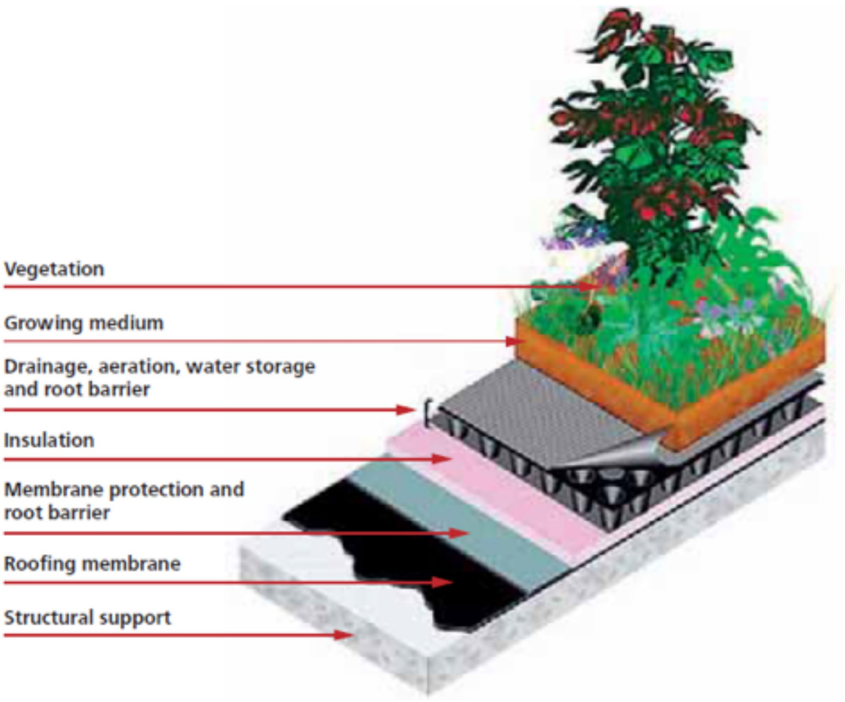


Figure 11. **Typical green roof construction details.**

Foster, J., et al, The value of green infrastructure for urban climate adaption, The Centre for Clean Air Policy, February 2011.

1. *Oberndorfer,E. et al, Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services , BioScience, Vol. 57, No. 10 (November 2007), pp. 823-833*

Green roofs have largely been adopted by single building owners as a feature; however their value has been recognised in some countries as offering potential to curb local heating of the environment, and in some warmer countries to reduce heat gains, thereby reducing overall cooling loads.

In 2003 NASA started to use satellite surveys as the basis to investigate green roofs. The findings from a study in New York suggested that UHI effects could be mitigated by substantial green roof utilisation considering various use scenarios for green roof space, ranging from 20% to 50%. The model predicted that extensive use of green roofs could reduce summer surface temperatures by as much as 1°C. It was also identified that green roofs absorbed 80% of rainfall compared to 2% for standard roofs.

Green roofs have been part of planning policy in Germany for over 30 years aimed at air hygiene and micro climate impacts, i.e. natural rainwater management and new flora and fauna habitats.. A survey of over municipalities with populations over 10,000 found that 36% of the municipalities had green roofs as part of their local development plans.

In the US many cities actively promote the installation of green roofs. For example in June 2008 New York City passed a law which allowed building owners in New York City who install green roofs to receive a significant tax credit. Where the green roof was at least 50% of available rooftop space a one-year property tax credit of up to $100,000 could be applied for. This was equal to $48 per square metre of roof area that is planted with vegetation, or approximately 25% of the typical costs associated with the materials, labour, installation and design of the green roof.

In London the Mayor's Climate Change Adaptation Strategy 2011, included a set of very specific actions with one related to green roofs:

> Action 5.6. The Mayor will work with partners to enable the delivery of 100,000m^2 of new green roofs by 2012 (from 2008/09 baseline).

Livingroofs.org[1] undertook an audit of green roofs in London in 2004. It was acknowledged that the total area of green roofs was potentially underestimated due to the challenges of accessing information from architects, developers and companies. The audit estimated that 76,700m^2 of green roofs had been installed in the Greater London area.

In 2008 a further audit was undertaken in London to assess the amount of green roofs installed between January 2004 and December 2008. This used data provided by a number of green roof companies active in the UK and is estimated that the figures provided represent 80% of the roofs installed during that period. Over 420,000m^2 were installed by the companies suggesting that near to 500,000m^2 were actually installed.

It was noted that the majority of the green roofs were installed in the central core of the city. The largest percentage of installed green roofs was the London Borough of Islington. This borough had actively promoted the use of green roofs through its planning department, thus demonstrating that if urban planning departments embrace and promote these activities the level of uptake increases very significantly. It is noted however that the true level of impact on the UHI does need to be fully evaluated in the UK climate.

1. http://livingroofs.org/

Maintenance costs

In addition to cost of installing green roofs, the cost of maintaining them needs to be considered. The costs of a green roof can be split into two categories, annual and cyclical. The annual costs, the inspection, cleaning of drainage outlets, for an extensive type green roof are little more than for a standard roof. The annual costs for an intensive green roof are governed by the type of plants and therefore the requirements for an irrigation system. Tending the plants, provided safe access can be gained easily, is not significantly different to other managed park-like areas.

Recommended[1] annual maintenance activities for an extensive green roof include:

- Removal of unwanted plant material, i.e. grasses.
- Correction of any localised plant system problems that may have occurred post installation
- Replacement of any naturally failed plants not exceeding 5% of total plants installed
- Application of nutrient source
- Removal of dead flower heads (if required)
- Inspection of rainwater outlet chambers and surrounding vegetation breaks
- Replenishment of any areas of settled substrate

Cyclical costs are the cost of replacement of the waterproof layer, which will be less frequent with a green roof as the UK industry accepts.[2] The life of the roof waterproof covering is doubled when protected by the green roof layer. Overall therefore cyclical costs will be significantly reduced through installation of a green roof.

Green roofs and PV – the lowering of the roof temperature can have a positive impact on the efficiency of PV panels the output of which is temperature sensitive. The output of a solar panel may reduce by between 0.25 and 0.5% per degree C of temperature rise of the panel.[3] Care is needed when using the measures on the same roof.

Local micro climate – albedo

Increasing the albedo, the reflectivity of solar radiation, of a built structure has been shown to have a very strong influence on the resulting temperature of the structure. This approach is common in some Mediterranean countries where houses and many hard standing surfaces are painted white.

A 1997 EPA study[4] highlighted the potential energy and monetary savings from implementing light coloured roofs on both residential and commercial buildings. The report noted that in the southern states where the cooling load dominated building energy use, the use of cool roofs may offset the need for additional insulation to save energy. It is now accepted that both approaches are required to truly achieve energy efficient buildings, and in climates where there is a significant heating load, such an approach would not address the energy use in the heating season.

1. *http://www.sedumgreenroof.co.uk/*

2. *Green Roof Developer's Guide, Groundwork Sheffield, 2011.*

3. *http://www.solar-facts.com/panels/panel-efficiency.php*

4. *S. Konopacki, Cooling Energy Savings Potential of Light-coloured Roofs for Residential and Commercial Buildings in 11 U S. Metropolitan Areas, Environmental Energy Technologies Division, LBNL, May 1997.*

In a UK setting, an investigation[1] of a cool roof installed on a flat-roofed office highlighted the potential reduction in internal operative temperature by adopting a cool roof. A reduction in open office air temperature in the order of 1.7 °C was directly attributed to the painted roof. The data was then used to validate a dynamic thermal model which indicated that for a roof with a U value of 0.23 W/m^{2}K, the energy savings due to avoided use of mechanical cooling amounted to around 1.1 kWh/m^2/yr. This investigation was undertaken as part of a wider European project to demonstrate the potential for this technology across Europe, the study being funded as part of a European level project and supported by the European Cool Roofs Council.

One practical consideration about light coloured roofs are; 'how long does it stay that colour' and 'can I paint it white myself?' In the US there is a well-advertised standard rating for roof coverings that are claimed to be 'cool'. Manufacturers of cool roof materials can participate voluntarily in the ENERGY STAR for Roof Products program. A product qualifies for ENERGY STAR if it meets the solar reflectance criteria expressed in the table below. The maintenance aspect is important as the ENERGY STAR program sets out the performance that must still be achieved after 3 years. The most up-to-date list of ENERGY STAR qualified roof products, can be found on the ENERGY STAR Web site at www. energystar.gov.

	Initial Solar Reflectance		Maintenance of Solar Reflectance*	
Type of Roof Product	Standard	Test Methods	Standard	Test Methods
Low-sloped	65% or higher	ASTM E 903 or ASTM C 1549**	50% or higher	ASTM E 1918 or ASTM C 1549
Steep-sloped	25% or higher	ASTM E 903 or ASTM C 1549**	15% or higher	ASTM C 1549

* Maintenance of solar reflectance is measured on a roof that has been in service for three years or more.
** Manufacturers can also use CRRC Test Method #1 for variegated roof products and can use results from tests conducted as part of CRRC Product Rating Program certification.

To assess if DIY is a viable approach a study was undertaken[2] that included evaluation of both professionally and building owner applied roof treatments. The study concluded that both the reflectivity and emissivity of the professionally installed white membrane coverings (which cost about £20 - £40 per square foot) held up well after even four years in use. These surfaces continued to meet Energy Star standards. The effectiveness of the owner applied white coating (which only costs about 50 cents per square foot) was about cut in half after two years, ultimately falling below the Energy Star standard.

Emissivity is a measure of the efficiency of a surface in emitting thermal energy, compared to a one which emits the maximum possible ('black body' radiation).

Reflectance is the fraction of incident thermal energy which is reflected by a surface.

1. *Zinzi, M., et, al, Report on the five case studies and analysis of the results, Cool roofs case studies in the EU level, WP3: Technical aspects of cool roofs, IEE program SAVE 2007, ECRC.*

2. *Gaffin, S., et al, Bright is the new black—multi-year performance of high-albedo roofs in an urban climate, Environmental Research Letters, 7, 2012.*

In the cooling dominated state of California, the Building Energy Efficiency Standards include a Cool Roof Regulation; Title 24. This was first introduced in 2001 as an energy efficiency option (intended to reduce cooling load rather than avoid overheating) following power shortages during the summer period. In 2008 the provision became mandatory for non-domestic buildings over 190 m^2. In 2014 the provision became mandatory[1] for 'every new building, every building alteration above a given value and every building addition', with few exceptions allowed. The regulations set out the requirements for reflectance and emittance for flat and sloping roofs and sets out the authority of the Cool Roof Rating Council (CRRC) as responsible for administering the state's certification program.

Figure 12. **White roofs in California**

http://thinkprogress.org/climate/2013/12/18/3084181/los-angeles-cool-roofs/

Painting the roofs of buildings only, tends to reflect the heat back towards the sky. However the walls of many buildings are also subject to high solar gains and building owners have looked to increase the reflectivity of these elements in a bid to reduce overall cooling loads. However in street canyons there is the potential that heat reflected from one building will result in heat gains to adjacent buildings. There may also be glare problems for pedestrians, drivers and occupants of adjacent buildings.

Under the chapter heading of 'Reflectivity Dilemma' one study into urban climates in residential areas in Australia[2] discussed this problem. The study noted that if heat was reflected then it could have a detrimental effect on adjacent structures and that white paint did not have the characteristics to prevent reflected heat being a problem. The study reported a scale experiment investigation of this potential problem. The findings are shown in Figure 13. What is clear from this simple experiment is that if heat is simply reflected it raises the temperature of all adjacent structures. However if a retro-reflective finish is applied to the surface subject to the incoming radiation, the reflected heat is largely reflected, reducing the impact on all adjacent structures. A retro-reflective surface reflects light back to its source with a minimum of scattering.

The limitation with this is that retro-reflective coatings are not widely available at the scale required to apply to whole buildings and are likely to be more expensive than normal paint.

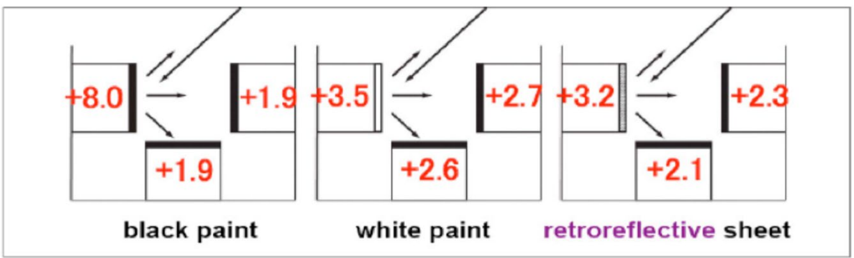


Figure 13. **Simulated urban canyon, changes in surface temperature with different surface treatment of surface receiving direct radiation (Source: Samuels et al.)**

1. *Council of the city of Los Angeles, Ordinance No. 183149, dated June 30th 2014.*

2. *Samuels, R., et al, Micro-urban-climatic thermal emissions: in a medium-density residential precinct, City Futures Research Centre, UNSW, Sydney, 2010.*

Urban layout

The layout of the urban form can have a very significant impact on solar heat gains. The approach of many hotter climates to have very narrow streets in urban areas limiting solar access to the facades of buildings and providing shaded streets for most of the day is very well known. It is however less likely that modern urban spaces in the UK would be developed in such a way, as the practical limitations of such an approach, such as noise, safety and access, would limit its appeal. In addition the low winter sun angle in the UK will modify these effects making the approach less effective.

In addition, deep urban canyons may influence air movement adjacent to building facades, further limiting the potential for natural ventilation, and for use of albedo-increasing measures on the façade of a building, as previously discussed.

Control of urban layout is at the urban planning level and cannot really be influenced by individual dwelling layout. However, design decisions regarding plan layout for large estates of houses and blocks of flats can have a local influence.

Dwelling built form

The ratio of surface area to volume of a building has a direct impact on the fabric heat losses. A compact built form reduces fabric heat losses. Typically a value of ≤ 0.7 m^2/m^3 is considered as a relatively compact built form, however a review of very low energy buildings as part of a modelling project[1] revealed that buildings with ratios of down to 0.41 were typical in heating dominated climates.

A compact built form has advantages in that it may limit fabric solar gains overall, but the primary source of solar gains is windows and therefore their size and orientation is critical to limiting excessive gains. Solar shading, discussed further on pages X may allow larger areas of glass to be used to harvest natural light, taking advantage of solar gains in winter months, but helps to control overheating

It should also be remembered that as the depth of a space is increased, the ability to achieve effective good natural ventilation throughout the space may be reduced. There have been many studies undertaken on the effectiveness of natural ventilation to provide good indoor air quality in office type spaces with guidance produced suggesting limits for different ventilation strategies.[2 3 4]

It follows that when the built form is being considered the focus on reducing overall energy use through optimum fabric design should assess all the impacts on the internal environment and occupant comfort. Adopting a larger surface area to volume ratio to ensure that good natural ventilation can be achieved could have a significant impact on construction costs. However these need to be balanced against the possible long term need for remedial works to provide acceptable internal environmental conditions for the building occupants.

1. *Garde, F., et al, Solutions sets and Net Zero Energy Buildings: A review of 30 Net ZEBs case studies worldwide, IEA Joint SCH Task 40 / ECBCS Annex 52 Towards Net Zero Energy Solar Buildings, IEA, May 2014.*

2. *BRE Digest 399, Natural ventilation in non-domestic buildings, 1994 BRE, Bracknell, UK*

3. *AM10, CIBSE Application Manual. "Natural ventilation in non-domestic buildings." The Chartered Institution of Building Services Engineers London (1997).*

4. *CIBSE, Guide A. "Environmental design." The Chartered Institution of Building Services Engineers, London (2006).*

Orientation

The orientation of a building can only be controlled at the design stage, and even then is subject to site constraints. The main reason for considering the orientation of the building would be to minimise summer and mid-season solar gains while offering the opportunity to utilise winter solar gains.

This tends to lead to an East-West axis of a building where solar gains from the low summer sun late in the afternoon to the West and North-West are minimised with limited glazing on westerly elevations. See sun path diagram Figure 14.

Even where a favourable building orientation is not possible the same principle should be applied. The solar gains to the west should be minimised as these occur late in the day and cannot be easily rejected prior to occupants seeking to sleep. Late low summer sun may also cause glare problems which then result in occupants shutting curtains, potentially reducing ventilation paths.

Orientation of a building to enhance natural ventilation is very limited in the UK as the prevailing winds are not significant enough in any region and across any season. The built form is more important to achieving good naturally driven ventilation through a building throughout the year.

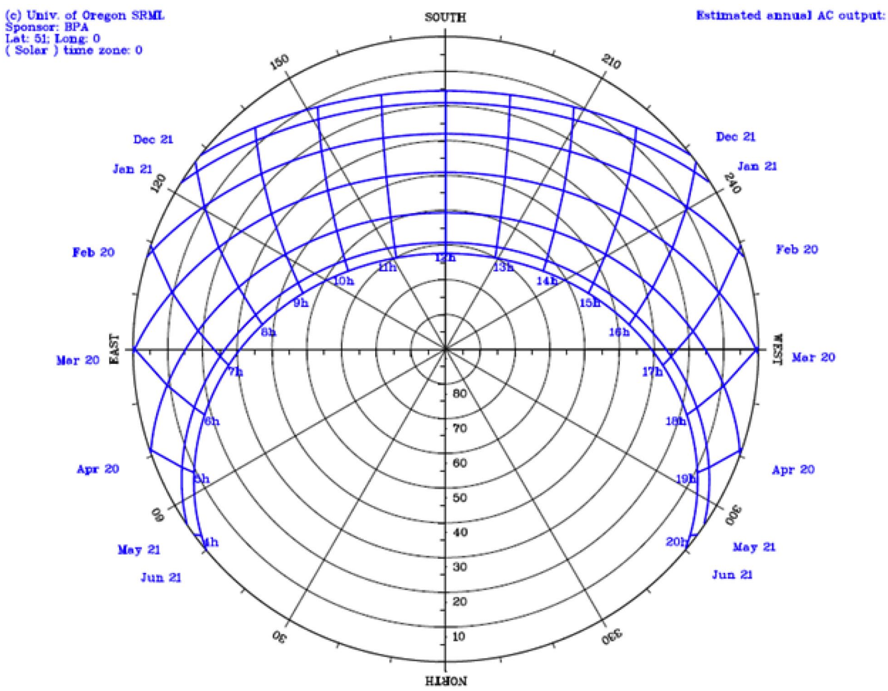


Figure 14. **Sun path diagram for UK (51°N) shows how the sun moves throughout the year and how in winter the West and North-West elevations of buildings are exposed to relatively high sun angles late in the afternoon.**

University of Oregon Solar Radiation Monitoring Laboratory: http://solardat.uoregon.edu/SunChartProgram.html

Underground spaces

The use of underground or partially underground spaces is well developed in many colder countries, where 'basements' are used for a variety of purposes. The thermal stability of the ground, even at relatively low depths makes the use of partially submerged spaces attractive. The drive for having basements in colder countries has been based on the need to have foundations below the ground freezing level. Therefore as walls need to extend into the ground by several meters it is economic to construct a basement at the same time. This is not the case in the UK where the advantage of achieving very good thermal links with the ground would need to be balanced against the very significant additional build costs for a 'standard' above-ground house.

Adding a basement to most existing dwellings for the purpose of providing a cool space is very rarely going to be either practical or an economic option.

High rise spaces

Building above three storeys for a single dwelling would be unusual, but many blocks of flats extend significantly above this level. Wind speeds are greater at higher storeys, and become relatively stable. In contrast, the layer of air close to the ground, known as the "atmospheric boundary layer" has highly variable wind speeds and conditions influenced by the weather and by the terrain...The impact of terrain on wind speeds can be seen in Figure 15 which shows the relationship between wind speed and height depending on location i.e. the presence of buildings and other structures. Figure 15 demonstrates that the opportunity for wind-driven ventilation increase with both height and distance from other large structures.

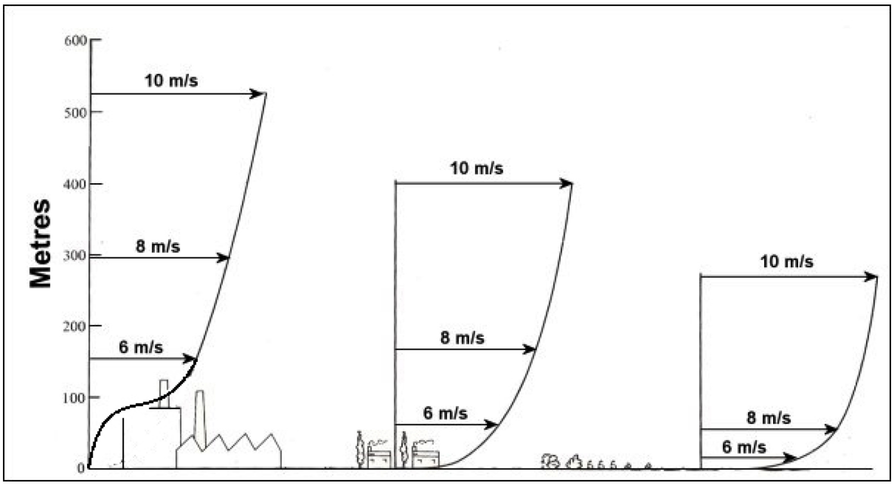


Figure 15. **Atmospheric boundary layer in urban, suburban, rural and flat terrain/maritime**

Adapted from http://easywindenergy.blogspot.co.uk/2013/02/estimating-mean-wind-speed.html

If advantage is to be taken of the increased opportunities for wind driven ventilation, it is important that the design of the windows and vents allows very good control of air flow rate. With increased wind speeds the nuisance of strong winds or gusts may make some windows largely unusable.

Figure 16. **Parallel Opening Window**

http://www.archiexpo.com/prod/wicona/parallel-opening-windows-2884-988597.html

Parallel opening windows (see Figure 16) provide a relatively high overall opening area when opening is limited to 100 mm on safety grounds, are secure against strong gusts and allow stack driven ventilation within each room served. This combination of effects makes this type of window very effective for providing ventilation in tall buildings. In all cases the right balance between providing adequate ventilation and safety needs to be struck.

Internal building layout

Linked to orientation, the internal layout of a house may have a significant impact on the likelihood of heat gains causing discomfort. Designers should consider where rooms should be located around a building to minimise the effect of heat gains on the occupants, for example, locating bedrooms in cooler parts of the property. The north and east sides of a house where over-shading tends to be greatest offer the best locations for achieving minimum solar gains. In addition the ground floor tends to be cooler than upper floors because ground temperatures underneath aremore stable than air temperature, because heat rises, and because upper floors tend to be less shaded by trees etc.

The internal layout of a building or use of rooms may be changed as part of a refurbishment project, and should be of prime importance in space planning for new build projects. However, it is recognised that the opportunity to use the internal lay out as a means of reducing occupant discomfort is likely to be more limited in small houses and flats.

When considering the layout of the internal spaces the movement of air, naturally and mechanically driven should also be considered. A tall house subject to very low levels of wind driven ventilation will tend to be ventilated by stack driven air flows. This will result in the air entering the house at ground or lower floor levels and then exhausting through openings in upper floors. This means that if the heat picked up as the air passes through the house passes through warmer upper floor rooms, the potential for using the stack effect for cooling is more limited. . If these rooms are the bedrooms they will tend to remain warm much longer into the night than the rooms on the lower floors where the cool ventilation air is entering the house. Designers can make the best use of the stack effect in taller buildings by diverting air through other paths, such as through shafts in internal corridors in apartment blocks.

Glazing area and orientation

Glazing in buildings is primarily installed to admit daylight and allow views of the outside. Glazing allows useful solar gains into a building, but in summer the gains may be excessive and result in overheating. There is therefore a need to balance these competing needs in the careful design of glazed elements of a building fabric. The glazing of a building usually has lowerthermal performance than the other fabric elements. For this reason glazing to the north tends to be limited in very low energy house design as this reduces the heat loss and has little impact on the solar gains available in winter. Rooms with windows to the south receive solar gains throughout the year. In winter and the mid seasons the sun is relatively low and solar gains will pass deep into rooms through unshaded windows. In summer the high-angle sun means that the penetration of the sun into rooms is more limited.

Windows to the east and west are subject to significant solar gains in both the mid-season and summer due to the low sun elevation. On east elevations this occurs early in the morning, which may not be a significant problem for overheating as the outside air temperature is at its lowest at this time. However, windows from South-West through to North-West receive low sun late into the day exacerbating gains in a space where the temperature may already have built up over the day. Therefore solar heat gains through glazing on the south-west to north-west elevation are often a cause where overheating occurs.

The likelihood of very high solar gains needs serious consideration in designs that include floor to ceiling glazing in houses. The design of windows to achieve good daylight penetration is vital, but this must be balanced against the very high levels of solar gains that occur through large un-shaded windows. Advances in glazing mean that levels of infra-red transmission can now be much better controlled, but even with high levels of solar control, small gains in modern, airtight dwellings may increase internal air temperatures significantly.

Studies have highlighted the impact of solar gains on the annual energy balance in buildings with advanced glazing.[1] The energy efficient windows now regularly being installed in buildings are very close to the point where, on an annual basis, the heat gains through a window exceed the losses (see Figure 17). For that to occur on an annual performance basis indicates that the heat losses are small due to conduction in winter, in comparison with the solar gains occurring over a much shorter time period across the year. This highlights the problem for limiting overheating in climates such as the UK, where even in the foreseeable future heating will still be required in winter. At the basic energy balance assessment level this appears to be a very good thing, however if the potential for overheating is not assessed adequately, the savings made in heating may be more than offset by summer and mid-season cooling.

1. *http://www.cbe.berkeley.edu/research/facades/FacadeSymposium-Steve-Selkowitz.pdf*

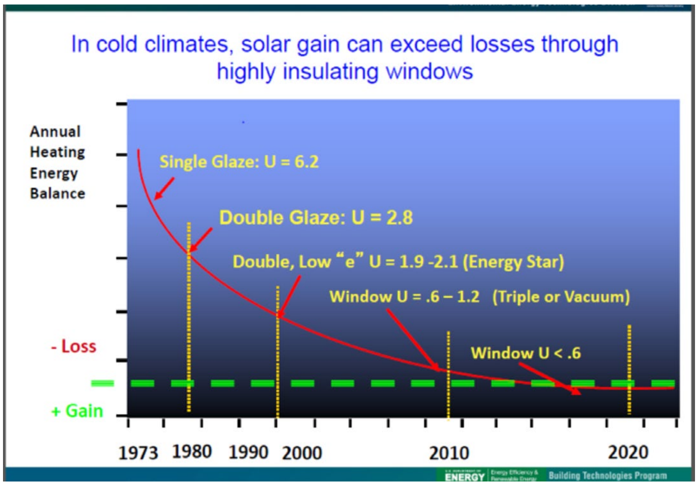


Figure 17. **Net annual energy balance for a window with different U values**

Stephen Selkowitz, High Performance Windows and Glazings: Technologies, Systems and Tools in the U.S.IEA Building Envelope Technologies and Policies Workshop, Paris, 17/11/2011

The health, both physiological and psychological, of building occupants has been demonstrated to be influenced by daylight. A review[1] noted:

> Overall the literature is clear that windows and skylights confer many benefits to home occupants, and these occur simultaneously through physiological and psychological mechanisms. The benefits accrue through both access to a view and to the possibility for increased daylight exposure.

The authors then continued to note that this must be balanced against, 'adverse consequences such as visual and thermal discomfort at the individual level, and energy and environmental consequences at the building level. They also noted that, 'the compartmentalization of disciplines has largely prevented integrated research approaches that would facilitate the development of more comprehensive models and practical applications.' Also noting that the literature reviewed, 'shows relatively little cross-collaboration between the communities that perform daylight modelling and those engaged in thermal and whole-building energy models.'

Commenting on the role of daylight in homes, Hobday[2] noted that our health, well-being, moods and social interaction can benefit from an increase in daylight exposure. Not enough daylight and evidence suggests the risk of depressive illnesses is increased. Hobday continued by commenting that in future. 'I would hope to see that getting daylight into buildings becomes a much higher priority than it is at the moment.'

1. *Veitch Jennifer A. et al, The Physiological and Psychological Effects of Windows, Daylight, and View at Home: Review and Research Agenda, NRC-IRC Research Report RR-325*

2. *http://www.thedaylightproject.co.uk/content/designing-homes-health. Accessed 06/01/2015.*

To assess the public's view of new homes the RIBA commissioned Ipsos MORI[1] to understand whether people are satisfied with their homes and whether standards have a role to play. The findings were:

> Satisfaction with quality of home is generally positive with around three-quarters (77%) of respondents reporting they are satisfied. Dissatisfaction is highest among those living in the newest properties. A primary focus of the survey was to understand the reasons for dissatisfaction, how they occur and their impact.
>
> **Key findings**
>
> High energy bills (49%), lack of space (32%) and lack of natural light (20%) are the most cited causes of dissatisfaction with the home

The findings are presented graphically in Figure 18.

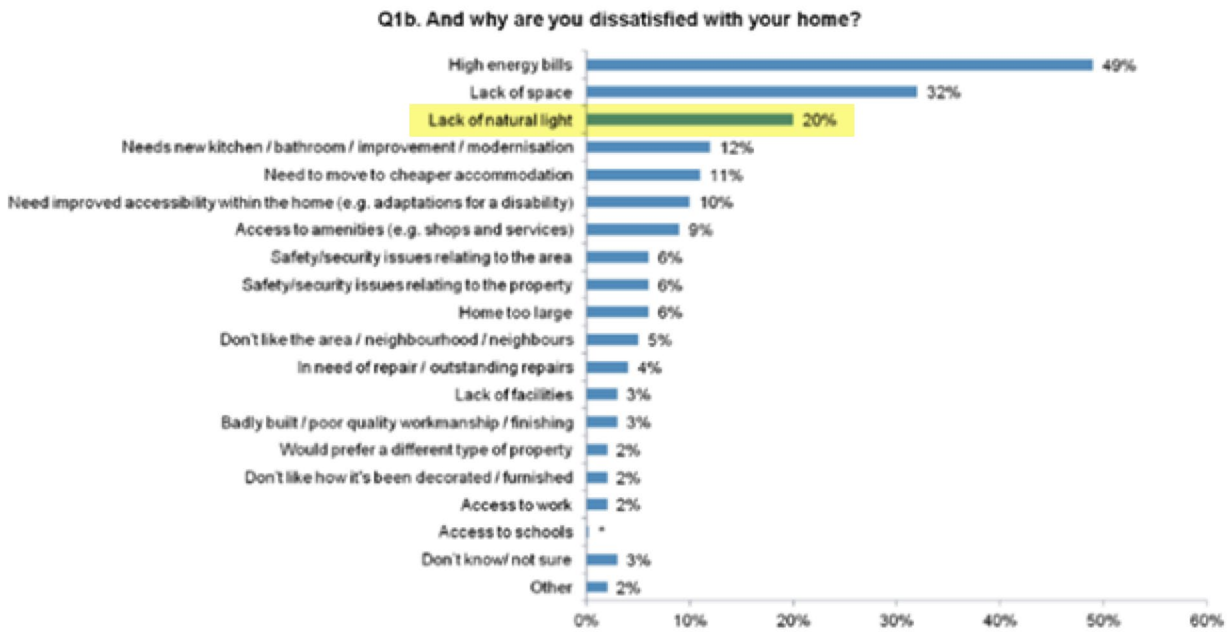


Figure 18. **Findings of RIBA survey of new homes, lack of natural light noted 20% of the time.**

It is interesting to note that the RIBA had no recorded comments regarding overheating. This is in contrast to the Energy Follow-Up Survey,[2] which noted that 20% of households responding had difficulty in keeping at least one room cool during summer the periods in question. The top reason for this was to do with lack of shading, which suggests high levels of solar gain.

1. Housing standards and satisfaction: what the public wants, IPSOS Mori and RIBA survey results, April 2013, RIBA.

2. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/274776/7_Thermal_comfort.pdf

The Code for Sustainable Homes awarded credits for meeting the Daylight Factors based on the British Standard on Lighting for Buildings (BS 8206- 2).[1] Living rooms, dining rooms and studies in new homes must achieve a minimum average Daylight Factor of at least 1.5 per cent. Kitchens must achieve a minimum average Daylight Factor of at least 2 per cent. There were no criteria for bedrooms. The Code for Sustainable Homes did not require sunlight penetration – only skylight. The forthcoming Home Quality Mark scheme (effectively a replacement for CSH) is expected to use similar criteria to give credit for daylighting. By contrast the 2010 draft of the Mayor's London Housing Design Guide[2] states:

> "All homes should provide for direct sunlight to enter at least one habitable room for part of the day. Living areas and kitchen dining spaces should preferably receive direct sunlight."

What is clear from this is that there are still questions about how much daylight, how much sunlight is good for us and what are the health implications of not achieving these levels. Some experts[3] in the area of daylight modelling are proposing different models should be used for assessing design compliance. Whatever modelling is undertaken to ensure that spaces meet the occupant needs for daylight or direct sunlight, the impact of the gains must be fully determined through a fully integrated design approach.

For new build the balance of glazing size and orientation plus the choice of appropriate glazing type and shading can be incorporated into the design at an early stage. For refurbishment the potential to change window area may be limited. However there are a wide range of options for upgrading glazing and including solar control measures.

Fabric – Opaque elements

The move to low U-values and the fabric first approach to energy efficiency means that, going forward, for new build and major refurbishment, the heat gains through the fabric of the building due to high outside air temperatures in the summer are relatively small when compared to other sources of heat gains, such as solar gains through windows.

The impact of solar gains from the sun’s radiation on the fabric of the building will also be reduced by the lower U-values of the opaque elements of the fabric. Changes to the albedo or shading of the outside surface of a building, as discussed above, would further help reduce solar gains on and through the fabric.

Insulating therefore has the potential to limit heat gains and overheating alongside other measures to limit the temperature increasing inside the building.

However only in cases where the building fabric thermal performance is below that required by the Building Regulations will upgrading the fabric have a significant impact on heat gains. In such cases upgrading should be undertaken to reduce both the heating load and the risk of overheating. For existing buildings, built to a good standard, upgrading the fabric further would have a limited effect.

1. *BSI. BS 8206-2:2008. Lighting for Buildings – Part 2: Code of Practice for Daylighting. British Standards Institution. 2008.*

2. *LDA. The Mayor’s London Housing Design Guide: Interim Edition. London: London Development Agency; August 2010.*

3. *J. Mardaljevic. Rethinking daylighting and compliance. Journal of Sustainable Engineering Design, 1(3):2–9, 2013*

Thermal mass

Thermal mass is a term used to describe the ability of a material to absorb and store heat energy. High thermal mass materials like concrete or phase change materials provide “thermal inertia” by slowly changing temperature as they absorb and re-release heat. Insulation on the other hand works to limit heat flowing into or out of the building.

A high thermal mass material is one that has a high thermal heat capacity (kJ/kg/°C) and a high density (kg/m^3). In other words, for a building element to effectively store a significant amount of heat the thermal mass must be high and the mass of the element must be relatively high, i.e. a thin panel of a high thermal mass material will have limited capacity. In addition the rate of heat transfer at the surface of the element must be sufficient to achieve the required heat exchange.

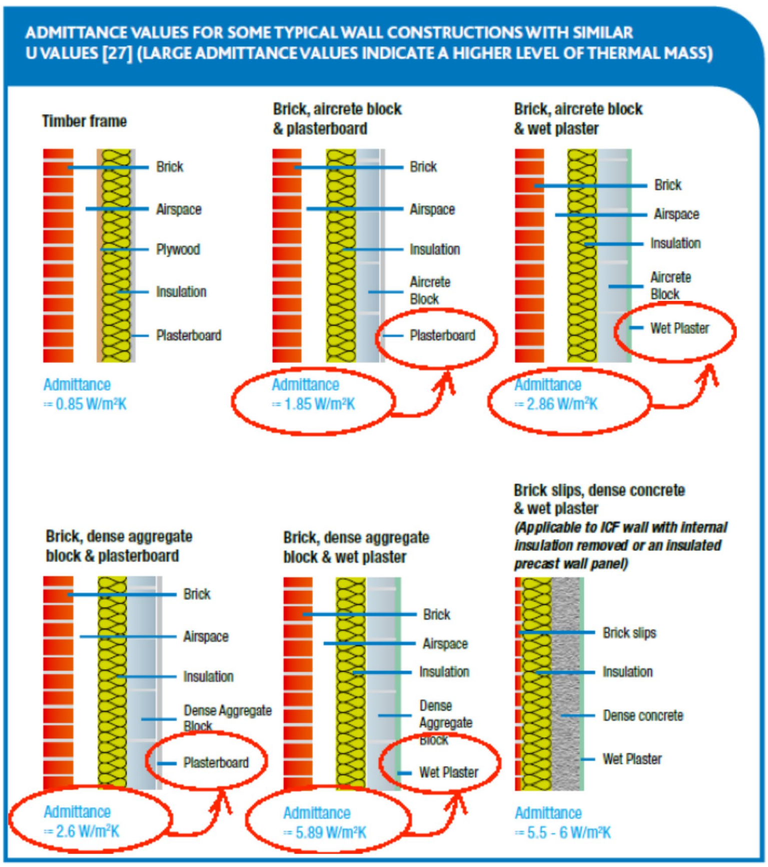
The use of thermal mass to lower the operative temperature in a room has two distinct heat transfer mechanisms. The first is to remove heat from the air by convection during periods when the internal air is at a higher temperature. The other heat exchange mechanism is radiative. If exposed skin is in direct line of sight contact with a cool surface then heat will radiate from the skin to that cooler surface. The total radiation leaving the skin is a function of the temperature of all the surfaces in line of sight. Therefore if an occupant is close to a cool surface then the balance will be heat loss. If however the occupant is significantly removed from the exposed cooler surface, or the exposed cool surface is relatively small, then the influence of that heat loss in the overall balance of radiative interchange between the skin and all the other objects within view (floors, furniture, etc.), will be small. Therefore, for an exposed area of thermal mass to be effective it has to be large enough to convectively transfer heat from the air and provide a large field of view for the occupants to ensure good radiative exchange.

An indication of the thermal mass of a structure is its admittance. The admittance of a structure is a measure of the fabric’s ability to absorb and release heat that occurs when subject to a daily cyclic heat load. The unit of admittance is W/m^{2}K, where K is the change in temperature from the mean when subject to a cyclic load.

The factors that affect the admittance of a structure are its thermal heat capacity, conductivity and density. In addition to these, the surface heat transfer resistance limits the rate of heat transfer. Examples of admittance of a range of wall structures in Figure 19 show clearly how the exposure of the high mass elements of a wall to the occupied room strongly influences the admittance value and thus its ability to store heat.

Figure 19. **20 Range of different wall configurations all having similar U values but significantly varying admittance values**

The Concrete Centre, Thermal Mass for Housing, TCC/04/05, TCC, Camberley, UK, 2008.



A large number of studies have investigated the impact of thermal mass on internal temperatures. Many of these were based on non-domestic buildings,[1 2] which while interesting, have very different occupancy patterns from dwellings. The low occupancy of non-domestic buildings at night provides a long time period for the building to be purged with fresh air. External night-time temperatures do not regularly exceed 20°C in the UK, therefore the introduction of un-conditioned outside air through a building will remove much of the heat that has built up in the fixtures and fittings, and within the exposed thermal mass of the structure of the building. The relatively low thermal conductivity of many high thermal mass materials used in buildings means that to remove the heat from more than the surface layer requires that the cooling is undertaken over an extended period of time.

The thermal mass of a non-domestic building can be used with extended 'flushing' of the spaces overnight to recharge the exposed thermal mass, ready to re-absorb the heat of the next day. Dwellings, on the other hand, are generally occupied both day and night, and in particular in the bedrooms of dwellings, meaning the flushing process is more difficult. CIBSE[3] and other researchers[4] have suggested that night-time ventilation rates of between 6-10 ach may be required to effectively remove the heat build-up from exposed thermal mass. Achieving such high rates through windows and through occupied spaces in dwellings at night may be challenging in deep urban areas where security issues and noise may prevent window opening. It would also be interesting to research further whether such high levels of ventilation at night would be acceptable to occupants in a residential setting.

The level of "exposure" of the thermal mass in a dwelling to natural ventilation air flows affects how effectively it functions. For example, whether it is covered up with carpet or ceiling tiles.

Overall therefore, thermal mass can be used very effectively to stabilise and limit peaks in internal temperature in a building, but this has to be matched with an efficient means of removing the stored heat. In rural and suburban locations where windows may be left wide open at night, this can be a very effective strategy to limit overheating. However in urban and deep urban locations where noise and poor air quality make leaving windows open impractical at night, the means of achieving the very high ventilation rates needed to remove the heat build-up is frequently not present by means of natural ventilation. In such cases the heat will build up in the thermal mass. Deep urban locations are therefore more challenging than other environments and require more thought to be given to achieving secure night-time ventilation whilst also minimising issues arising from noise, security and pollution.

1. *Bramham, D., et al, Thermal mass in office buildings, BRE Digest 454, Part 1 & 2, BRE, 2001.*

2. *The Concrete Centre, Utilisation of thermal mass in non-residential buildings, CCIP-020, Camberley, UK, 2006.*

3. *AM10, CIBSE Application Manual. "Natural ventilation in non-domestic buildings." The Chartered Institution of Building Services Engineers London (1997).*

4. *Orme M, Plamer J, Control of Overheating in Future Housing – Design Guidance for Low Energy Strategies, Faber Maunsell (DTI Partners in Innovation Programme), 2003.*

Building surface micro climate

The impact of solar gains on the external surface of a building and the resulting increase in temperature of the air in the adjacent boundary layer is complex and not considered in building modelling packages. It is therefore not normally included in the assessment of overheating risk for a building.

Figure 20 is a thermal image taken of the road elevation of a block of flats in summer 2013. Late in the afternoon the wall is very hot after exposure to the direct sun, approaching 50°C. The residents have opened their windows to ventilate the flats and reject the solar gains entering the flats through the glazing. However, the flats are in reality being warmed by the boundary layer air being drawn in through the windows.

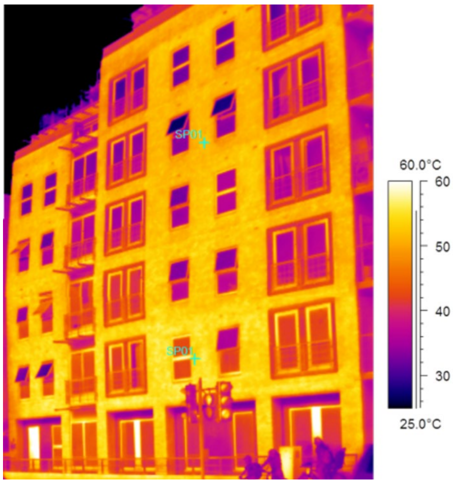


Figure 20. **Thermal image of a block of flats late in the afternoon on a summer day (2013). Residents have windows open to ventilate the flats (Source: BRE).**

Shading is usually only considered for reducing the solar gains to the glazed areas themselves. However, as can be seen in Figure 20, the gains to the façade of the building result in heating of the building boundary layer, and in this case shading of the whole façade could significantly reduce this effect. In this case with the height of the building and the urban setting, the use of trees would not be practical or effective. Installing shading, in the form of louvers for example, may be an option but would require planning approval since it would have an impact on the visual appearance of the building. Retractable versions have been developed, which would have a more limited impact on the building's appearance, but would need to operate as intended and have an ongoing maintenance requirement.

Green structures

The potential for green roofs to help limit the UHI effect and reduce heat gains to buildings has been discussed.

In the UK the use of green structures has tended to be focused on the potential to reduce the UHI effect rather than specifically limit the heat gains to a single building. However, when considering the building micro climate the potential for green walls to offer significant levels of shading to the fabric of a building is very high.

At its most simple a green wall can just be a planting of wall climbers or shrubs (Figure 21). Plants such as pyracantha can provide a very effective planted screen to a wall which can be as effective as the more complex engineered solutions.

Alternatively there is a range of engineered planting systems on the market. These often consist of containers fixed against a wall that contain soil or media for the plants to grow in. Even in the UK such systems usually require irrigation systems and possibly on-going professional maintenance.[1]

1. *https://www.rhs.org.uk/advice/profile?PID=547*

Figure 21. **Simple green wall using a climber and a wire mesh.**

https://www.jakob-usa.com/

Figure 22. **Engineered approach with containers, Rubens Hotel, London**

http://greenroofconsultancy.com/grcs-green-infrastructure-audits/

Figure 23. **Engineered approach showing need for maintenance, Westminster Council office, London.**

(Source: BRE)

Simple wall climber based green walls are relatively cheap to install and as the plants are generally in the ground, the need for irrigation systems is limited and maintenance requirements are low. This is in contrast to fully engineered systems where on-going maintenance is required to ensure the plants remain healthy (Figure 23).

Typically a green wall will cost in the region of £500[1] to £1000[2] per square meter. The running costs are strongly influenced by the type of plants installed with a lower value suggested as £1[3] per square meter for water, pump power, etc., and a value of £20[4] per square meter for a system that is maintained by a contractor.

1. *http://www.marklaurence.com/wp/what-does-it-cost-to-run-a-green-wall/*
2. *http://thelandscapearchitect.net/green-walls/*
3. *http://www.marklaurence.com/wp/what-does-it-cost-to-run-a-green-wall/*
4. *http://www.theguardian.com/lifeandstyle/2013/jun/14/gardens-living-walls*

Albedo – solar reflections from the ground and buildings

The potential benefits of white roofs have been discussed in Section 04. The cost of painting structures in a light colour can be very low, although on large buildings the need for safe access will considerably increase costs. A light coloured structure will also tend to show the dirt, more so in an urban environment. The cost of washing large buildings must be considered as an on-going maintenance cost if the effectiveness of the treatment is to be maintained.

Glazing types – existing technologies

The need to allow daylight into occupied rooms means that totally eliminating solar gains by not installing windows is obviously not an acceptable option. The balance between daylight provision and limiting solar gains is complex but the controlling of high levels of solar gain through whatever glazing and shading level is deemed appropriate to meet daylight requirements is vital.

There is a range of measures that can be incorporated into a glazing system that can have a significant impact on the solar transmittance of glass, as follows.

Tinted glazing

Tinting glass increases the solar energy absorbed and daylight blocked. The tints used to colour the glass are added during manufacture and are chosen to have a given level of absorption across some, or all, of the solar spectrum. For a given tint the level of absorption will increase as the thickness of the glass increases. Generally these tints are bronze or grey in colour.

For all types of tint the absorbed energy becomes heat within the glass and raises its temperature. The heat is then rejected by being re-radiated and by convection on both surfaces of the glass. The proportion of heat rejected depends on the temperature of the surroundings for the radiative heat exchange, and the air speed and temperature for the convective heat exchange. For periods of high outside air temperatures and low wind speeds, the fraction of heat transferred from the inside surface, rather than the outside surface, may be relatively high. It is clear from this that the tinted glass must always form the outer sheet of double glazing. If this is not the case then the heat gain to the internal space will be significantly increased, moreover the radiative heat gains may be significant and result in thermal discomfort for occupants close to the window.

One of the disadvantages of strong tints used to provide high levels of solar control is the reduction in daylight entering a space – the Light Transmittance Value. In addition to the change in colour, designers need to consider whether this may make a space feel dull, causing occupants to revert to artificial lights and adding to internal heat gains. In addition, the reduction of daylight and solar gains in winter must be considered.

To minimise the reduction of daylight transmission certain glass manufacturers have developed a range of 'spectrally selective' glazing tints. These tints allow a higher proportion of visible light through while absorbing high levels of near-infrared (heat). Generally these tints tend to be a light blue or light green.

The characteristics of glazing tints and glass thickness are normally listed by manufacturers, allowing an evaluation of the influence on both solar heat gains and loss of daylight.

Reflective coatings

By reflecting a proportion of the incident solar radiation, reflective coatings can significantly reduce the transmission of heat through the glass. This also reduces the heating of the glass that occurs with tinted glass. A reflective coating can be applied to the surface of the glass and is usually a thin metallic or metal oxide layer, commonly silver, gold, or bronze in colour. It may be applied to the outer surface of the outside pane of glass; however some coatings are not durable and must be applied to the surface of the glass in the sealed void of a double glazing unit. The degree of reflection is governed by the thickness of the coating. They may be used alone on clear glass, or combined with tinting.

As discussed above, reflection of solar radiation may have adverse effects outside the building. The reflections can cause glare to other buildings and to road users and therefore may be subject to planning restrictions in certain locations. The unintended consequences of reflected, and in some cases concentrated solar radiation were highlighted in the press recently:[1]

Application of existing glazing technologies

The specification of these types of glass, either tinted or with a reflective coating, would normally be part of the design process, assessing the balance between solar heat gains and the need for daylight. Both of these glass treatments tend to be used more on non-domestic buildings, however they may be installed on a domestic building.

As part of a major refurbishment, individual or all windows may be replaced.

Laminated glass is used if there are safety requirements, and where required treatments to reduce solar gains can be included, applied to the outer layer, reducing its overall solar transmittance. Laminating glass is undertaken to provide strength and safety in case of breakage. The laminating layer is a tough plastic interlayer made of polyvinyl butyral (PVB) bonded between two panes of glass under heat and pressure and looks like a normal sheet of glass.

Tinted and reflective coatings on glass are available as options from many suppliers, subject to a moderate cost uplift for first time or replacement window units.

Obtaining tinted and reflective coated glass for a dwelling may require some effort to source as they are normally used for non-domestic buildings. In some cases they may not be available in the relatively small quantities required for windows in an individual dwelling. If obtained, however, they may be used as replacements for any existing glazing, enhancing the level of solar protection.

A wide range of glazing materials are available with a range of transmittances and manufacturers provide detailed performance data on products.

1. *http://www.dailymail.co.uk/news/article-2409073/Walkie-Talkie-melted-Jag-Londons-Fenchurch-Street-skyscraper-melts-businessmans-car.html*

Glazing types – Near market innovations

The drive for high levels of daylight transmission and low levels of solar transmittance, driven primarily by the non-domestic market where large expanses of glass are used in buildings, has led to some innovations being currently very close to market, either technically or economically.

Electrochromic glazing

Electrochromic glazing can be switched between a clear and tinted state by applying a DC voltage. In the tinted state, solar radiation is absorbed and this will reduce overheating, in a similar way to the tinted glass discussed earlier. In addition, reflective glazing which is switchable is currently in research and development.

Electrochromic technology has been actively researched throughout the world for over thirty years, and promising laboratory results have led to prototype window development and subsequent product commercialisation, with installations in both commercial and residential applications. Examples of electrochromic window prototypes have been demonstrated in a number of buildings in Japan, Europe, and the United States.[1]

Currently electrochromic glass is available and is generally marketed as a privacy option. The transparency of the glass can be varied allowing a window to become opaque to visible light. The technology is very expensive at present, but in time, as a simple like-for like replacement for glazing (when windows are being replaced), it could be a low disruption option to cope with increasing temperatures.

The electrochromic film is deposited on the glass and consists of three layers sandwiched between two transparent electrical conductors. When a voltage is applied between the electrical conductors, the glazing switches between a clear state and a transparent blue-grey tinted state.

Electrochromic windows typically only require low-voltage power (0–10 volts DC) and some are powered by solar PV in the window. They remain transparent across the switching range, and can be modulated to intermediate states between clear and full colour.

Figure 24. **Switching of zoned glazed panels allowing for solar and daylight control**

http://sageglass.com/wp-content/uploads/2013/04/MKT-048_Product_Guide.pdf

Electrochromic films can be combined with Low E coatings to provide good winter thermal performance characteristics.

1. *http://www.commercialwindows.org*

Technological advances in other types of electrochromic glazing types are:

- Polymer laminate. This has the advantage that, once switched to its new state, no power is needed to maintain this state. This film has a long memory once switched and power is not required for three to five days to maintain a given state.
- All-solid-state laminate. This requires minimal low-voltage power to both change and maintain a given state. The solid state laminate has the advantage of being more durable than polymer laminates. Performance testing suggests that active life could be in excess of 20 to 30 years.

Electrochromic glass gives the occupants of the building the opportunity to control the solar gains through a window. As a result, the need for and cost of additional internal or external shading for solar control and privacy is removed.

Photochromic glazing

Photochromic materials change their transparency in response to light intensity. This technology is now commonplace in spectacles, changing the level of shading as the wearer moves between bright and dark locations. There is therefore the potential to use such a technique on glazing to control the level of light and solar gains through a window. However, they are clearly much larger in size, and cost-effective and durable glazing treatments for windows are not commonly available to date.

Thermochromic glazing

Thermochromic materials change colour and become more light-absorbing as they become warmer. This process is reversible and so offers an opportunity to control solar gains in a glazing system. The approach currently on the market incorporates thermochromic materials into plastic films of polyvinyl butyral (PVB). PVB is widely used as the lamination material in safety glass and is therefore widely available to glass manufacturers.

The level of tint varies with the temperature of the film, so that as the sun moves around a building the tint of the windows on each façade varies. Through careful design of the thermochromic properties, the tint change caused by outside air temperature changes will be minimal, so that the tint is only changing in response to the sunlight.

The change is a direct function of the film temperature and this makes installation much simpler by removing the need for power and controls at each window. However, this also removes the control from the building user which may be a disadvantage.

Thermochromic glazing has been commercially available for a few years and is already being installed in dwellings.

(Windows incorporating a layer of material that changes phase at a given temperature have been referred to as thermochromic. However such materials do not in themselves change light transmission, although the transmission differs in each of the states).

Gasochromic glazing

Gasochromic windows are similar to electrochromic windows with a film changing optical properties, but caused by hydrogen being introduced into the cavity. To reverse the tint oxygen is introduced, diluting the hydrogen content of the gas. It consists of a film of tungsten oxide on the surface of the glass which is modified by varying the levels of hydrogen.

While offering an interesting potential to control solar gains this process is not yet commercially available (as far as we aware) and it would be seen to be a complex solution for individual windows in a dwelling.

Liquid Crystal Device Windows

Liquid crystal displays are widely available and have recently been used to create 'privacy' windows, switching from clear to obscured glazing. This currently requires a voltage of between 24 and 100 Volts to be applied to maintain the clear state. In addition there are only two states, and no gradual change in response to a control variable.

This is not known as being widely available currently as an external window product. Moreover it is suggested that because there are only two states (on/off), this may be less appropriate for domestic application as a solar control measure than other transmittance changing glass treatments.

Other techniques and technologies available

There is a range of glazing treatments and materials that can be used to diffuse radiation and limit solar gains. These include:

- Glass blocks
- Fritted glass
- Diffusers

New technologies and methods of controlling light/solar gains include:

- Special solar control blinds
- Prismatic glazings
- Holographic materials
- Laser cut decorative panels
- Light pipes
- Fibre optics
- Nanotech- dynamic coatings[1]

Although possibly not applicable to mass housing due to cost and complexity, the integration of all the systems within a building, including shading or advanced solar control glazing would, as shown in Figure 25, allow solar control to be another function of the central building management system. These systems exist for commercial buildings and may be scalable to dwellings as advanced glazing and façades become more common.

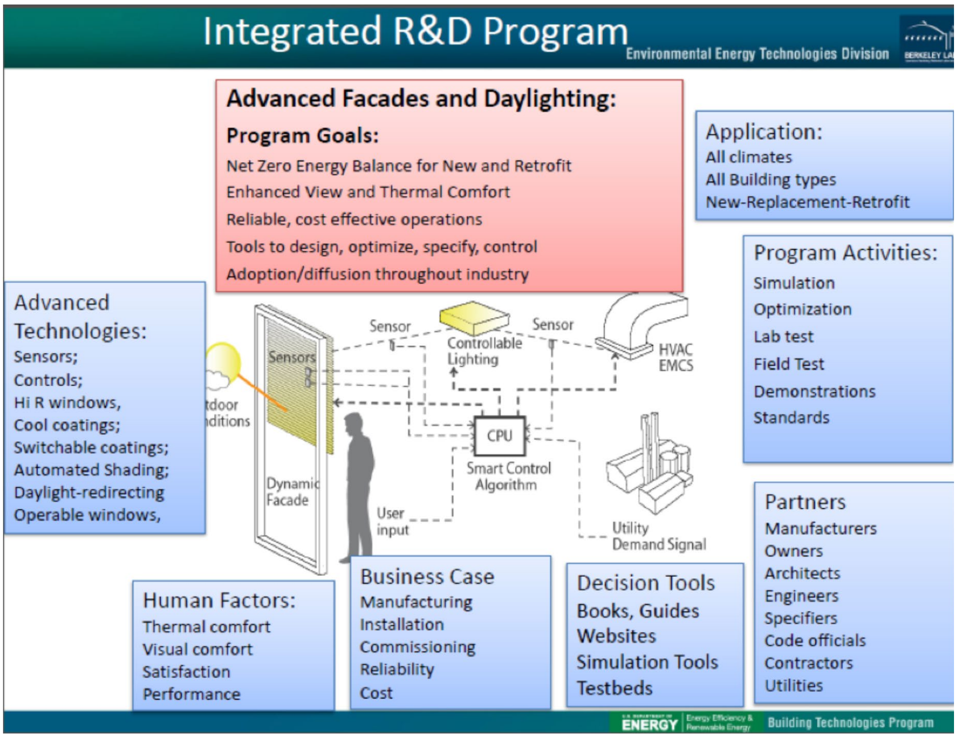


Figure 25. Thermal image of a block of flats late in the afternoon on a summer day (2013). Residents have windows open to ventilate the flats (Source: BRE).

1. *http://www.nature.com/nature/journal/v500/n7462/full/nature12398.html*

Glazing treatment – existing glazing

Solar control films can be applied to existing glass to reduce solar gains and are particularly appropriate as a retrofit measure. Solar control films may be either reflective or have an absorbing tint. Reflective films are now available that allow a greater percentage of visible light through than near infrared.

Window films are most often installed on the internal surface of the inner leaf of glass. However, the film will absorb some of the heat and therefore increase in temperature. The level of heat gain will be a function of the tint of the film, but may result in significant changes in temperature from that anticipated by the glazing manufacturer, possibly causing damage. It is therefore recommended that advice is sought from the glazing manufacturer or an appropriately trained person to ensure that changes in temperature to the glass will not adversely affect the glazing.

Some manufacturers have film that is suitable for installation on the external surface of the glazing. This location is preferable for managing heat gains since a greater percentage of the heat absorbed is removed by re-radiation and convection to the outside air, compared with films installed on the internal surface. However, it is then exposed to the weather and is therefore likely to have a shorter lifetime.

Cost is generally low, although for external application, effective working access to the outside of each window is required, and this may, for example, make installation on high rise residential buildings prohibitively expensive.

Application can be undertaken by a resident or there is a range of commercial companies offering installation services.

Glazing covering – Building Integrated Photovoltaics (BIPV)

Photovoltaics (PV) devices produce electricity when exposed to light. Their integration into the building skin: the walls, roof, and glazing, is now starting. The potential for integration into the vast surface area of the built environment is significant, however they also offer the potential to reduce the solar gains through the elements they are applied to.

As noted previously, the reduction in heat gains through opaque building elements will be small, but applied to glazed areas the effect can be more significant. While this may have significant application to large glazed spaces such as atria, and possibly to conservatory roofs (see Figure 26), the loss of vision may not make it a desirable option for house windows.

Figure 26. **The BRE INTEGER house, featuring glazing integrated PV**

http://ipark.bre.co.uk/page.jsp?id=94

It is claimed[1] that organic polymer photovoltaic materials allow extremely thin coatings to be applied to large areas of glass using low cost high efficiency manufacturing processes resulting in higher levels of transparency. Another manufacturer noted that the solar cell treatment can be dyed almost any colour, making it of great interest to architects.[2]

The overall installation cost of such a product will be higher than traditional windows, both because of the glass itself and also the wiring and power inverters that are part of a photovoltaic installation. This will be offset to some extent by the benefit of the generated electricity. Nevertheless, one PV manufacturer[3] noted that: 'it is unlikely that using photovoltaic glass will be cost effective for most homeowners at present, so for now most installations will likely be confined to large commercial office buildings with hundreds of square meters of windows to allow economies of scale to improve the cost to benefit ratio.'

Solar shading – Windows

An alternative, or in addition to controlling solar transmission through glazing, is the use of shading. Shading can be either internal or external, or both.

Internal shading. Solar radiation that passes through the glass is intercepted by internal shading and thus prevented from directly heating the internal structures and surfaces in a room. It also prevents the discomfort and glare of direct sunlight on occupants. However, by falling on the shading, such as curtains, the solar radiation (which is not reflected) will heat the material and in this way be radiated internally, both into the space and also back to the window as long wave radiation which does not pass through and warms the glass. Heat is also convected from the internal shade, thus warming the room air. As a result a significant proportion of the heat remains in the space.

The use of highly reflective internal blinds can be significantly more effective than curtains or typical Venetian type blinds. Such blinds are available for dwellings, but are much more frequently found in office buildings. If they are used in a domestic setting, then it iis mportant for the occupants to be advised on how to make the best use of them.

External shading. Solar radiation that falls on structures outside a window heats that element and is then lost by radiation to the surroundings and to the air by convection. The re-radiated heat is long wave and thus is not transferred directly through the glass to the internal space, but a proportion will be absorbed by and warm the glass. External shading is generally significantly more effective than internal shading.

1. http://www.polysolar.co.uk/documents/PDFBROCHUREPDFprintready.pdf

2. http://www.theguardian.com/environment/2013/feb/12/printed-solar-glass-panels-oxford-photovoltaics

3. http://uk.solarcontact.com/photovoltaic/installation/design

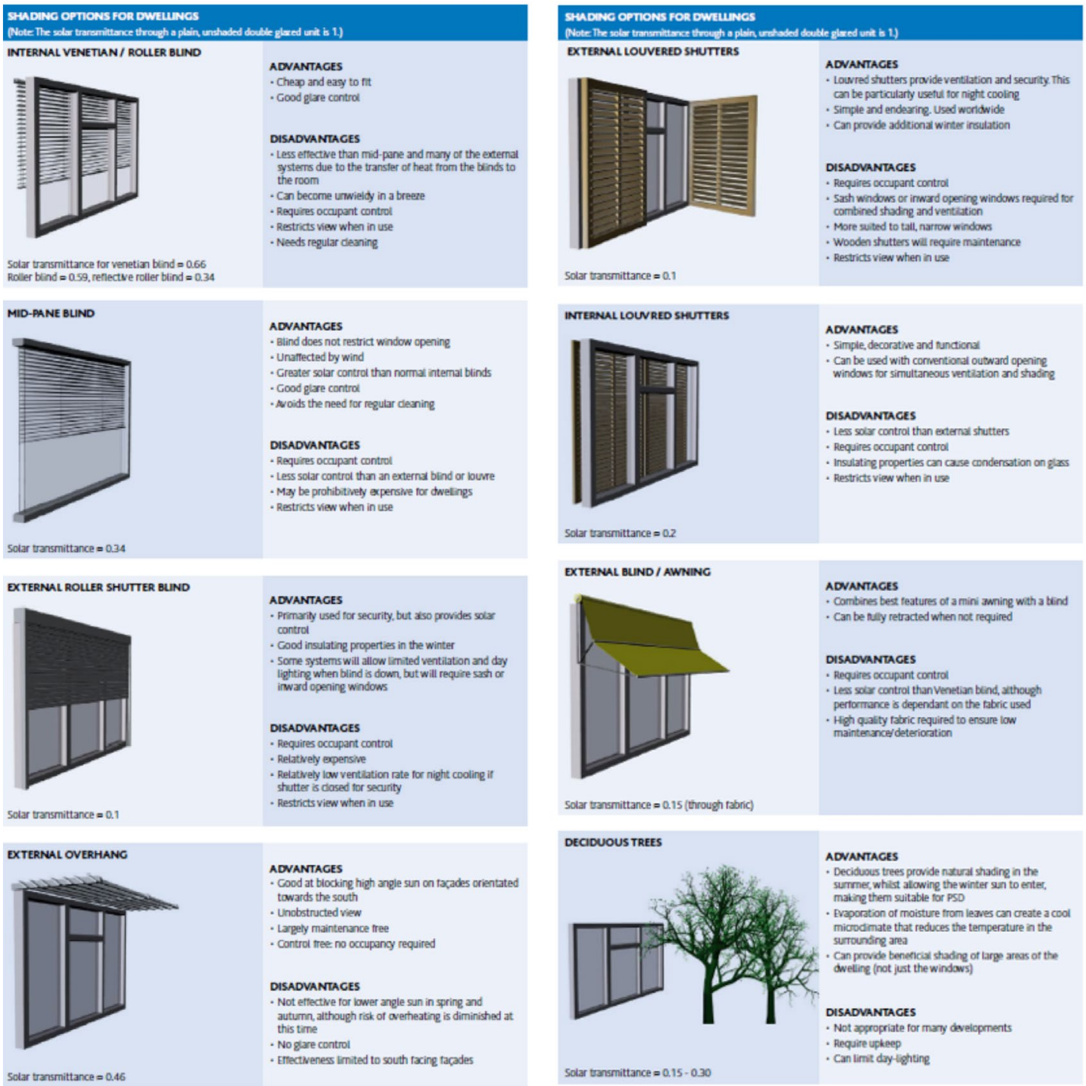


Figure 27. **Resume of shading options**

Thermal mass for housing, The concrete centre, 2008.

The effectiveness of external shading comes from its ability to prevent direct solar radiation falling on the glass. As the sun moves around a building throughout a day and the elevation of the sun varies across the seasons, he effectiveness of a shading device may vary significantly. Fixed overhangs may be appropriate for southerly orientations to limit the solar gains from the high-angle summer sun and allow low winter sun to fall directly on a window. However, using the same approach on a west elevation would be less effective as the sun has a relatively low elevation as it moves to the North-West in the mid/late afternoon in summer. In such situations external vertical louvers, shutters or blinds (which may also be used, of course, on South elevations) would be much more effective.

Guidance on shading is available in a wide range of design guides[1 2 3 4] and aids[5 6] that allow designers assess the suitability of shading devices for any given building elevation.

In heating dominated climates the use of some fixed shading devices reduces the passive solar gains in the winter and therefore has an impact on the annual energy use of the building.[7] While this may be a correct assessment of the annual heating load, great care must be exercised when considering the impact of solar gains during the summer period when the gains are not offsetting a space heating load. Only evaluating the potential of solar gains to offset heating solar gains in the summerwinter period may result in these spaces becoming uncomfortably hot in summer.

Solar shading of windows in refurbishment

For new build, blinds whether external or internal, may be 'designed in' to the new development. When considered as part of a refurbishment the following considerations are particularly relevant:

- **Internal blinds** are particularly easy to incorporate into a refurbishment and can be retrofitted by an occupant
- **External blinds** may require planning permission if they are considered as having a significant impact on visual appearance, and may require confirmation of structural suitability for wind and snow loads.
- **Fixed blinds** must offer a good compromise between daylight and solar shading, and must be appropriate for the elevation.
- **Controllable blinds** require maintenance, user adjustment if manually operated and acceptance/understanding of the control strategy if automated.

Information Availability

The British Blind & Shutter Association (BBSA), in conjunction with partners in the European Solar Shading Organisation (ES-SO), has developed a database of solar shading materials[8] with information which relates to limiting heat gains. This database includes independently validated energy performance data of blind and shutter fabrics and materials to European standards. The database calculates the energy performance of blind and shutter products when used in combination with reference glazing defined in the European Standards EN 13363-1 and EN 14501.

1. *CIBSE, Design for improved solar shading control, CIBSE TM37, 2006, CIBSE.*
2. *Littlefair, P., Solar shading of buildings, BR364, 1999, BRE.*
3. *Littlefair, P., Summertime solar performance of windows with shading devices, FB9, 2005, BRE.*
4. *BBSA's Guide to Low Energy Shading*
5. *http://www.ebd.lth.se/program/parasol*
6. *http://windows.lbl.gov/software/window/window.html*
7. *Curcija, D. C., et al, Energy savings from window attachments, LBL, 2013.*
8. *http://es-so-database.com/essodata*

Sourcing of ventilation air

The l heating up of building structures has been discussed above, causing the layer of air around the building to become very warm. This heat may be so intense in some locations thatdrawing air in from this layer through a window or vent would result in air entering the space at a temperature significantly above that of the free air. The result would be warm air entering the building. The effect has been observed in both urban and non-urban locations. This is a situation where occupants' natural reaction to throw the windows open when they are too hot, could make the situation worse.

Therefore, for naturally ventilated buildings, or where purge ventilation is through manually operated windows, it is important to be aware of this effect in order to prevent warmed air being drawn into rooms. It is suggested that these types of issues should be explained to residents in any 'Building Manual' including how and when different windows should be opened to achieve the most effective ventilation. Planners should also be aware that changing the layout of neighbourhoods, or granting permission for new buildings in dense locations may affect the ability of the people already living there to naturally ventilate their buildings.

To maximise the effectiveness of natural ventilation, it is prudent to design out conditions under which micro climate heating might occur. An effective way is to change the surface albedo of immediately adjacent structures to reduce solar heat gains, and by increasing solar shading, either as part of the building structure or through planting.

With mechanically ventilated systems there is the opportunity to draw air in from locations that do not suffer significant local heating, or even to alternate the source location to the coolest area at any given time of the day. Drawing air in from the north side of a building, or from a significant height above the roof level, will at least minimise the risk of drawing in air that has been heated significantly above the local climate level by such micro climate effects.

At the design stage it is relatively easy to consider the air intake locations and integrate them into a new building. However, altering the route of the ventilation air in existing buildings is highly unlikely to take place as most ducts are located within ceiling voids and boxed-in risers. Thus alterations would require significant disruption of building elements not otherwise affected by the refurbishment.

Internal, electrical appliances

Almost all electrical power used in a dwelling is turned into heat within that dwelling, so turning appliances off, either manually or automatically or switching to low power standby when unused, and using efficient appliances with low power and standby will all contribute to reducing heat gain. Exceptions to this are devices such as extract fans where the heat they generate is expelled from the dwelling to the outside air. Therefore an understanding of where and when the electrical power is being used is key to understanding overall heat gains in dwellings.

When an electrical device is turned off and unplugged the power consumption, and therefore heat gain, is zero. However many domestic appliances are now not turned off, but left in a 'stand-by' mode, to allow them to be operated from a panel or a remote control device at any time. A product's overall power output is therefore not only the power used over the period it is in active use, but also the stand-by power for the hours of the day when it is not being used. Almost all of this power output results in heat gains that increase the temperature in a dwelling.

Over the past 10 years the European Commission has introduced a range of measures to limit the overall power of products when in active use, and placed strict limits on the stand-by power of devices in order to reduce energy use.

The result of these regulations is that a wide range of household appliances are required to display labels detailing their energy use ("A" to "G" ratings), and in addition standby power is now limited to 0.5 W. The appliances covered by labelling requirements are:

- Refrigerators, freezers and their combinations
- Washing machines, dryers and their combinations
- Dishwashers
- Ovens
- Water heaters and hot-water storage appliances
- Lighting sources
- Vacuum cleaners
- Air-conditioning appliances

There is a voluntary scheme covering set-top boxes and imaging equipment (printers).

For new products, power use should therefore be within a defined range and the cumulative power of appliances when not in use should be small. However products that were purchased prior to these regulations coming into force may have significantly higher power levels.

A recent UK study[1] which included a large monitoring exercise showed that across a summer period the cold appliances (fridges and freezers) caused significant power demand. One trend that is increasing the electrical power use in dwellings is larger fridge/freezers with coolers and ice makers. These increase the overall power use of the fridge/freezer, Figure 28. Figure 29 shows the range of stand-by powers for typical appliances. From this data it is clear that continous electricity consumption, and therefore heat gains, in excess of 50 W are very typical in houses during the summer.

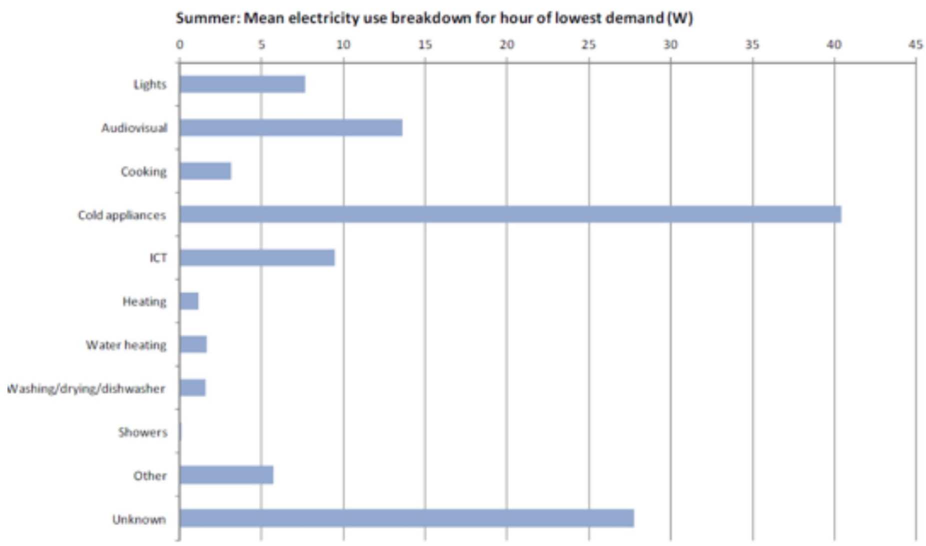


Figure 28. **Typical electrical appliance demand across a summer period**

1. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/275483/early_findings_revised.pdf*

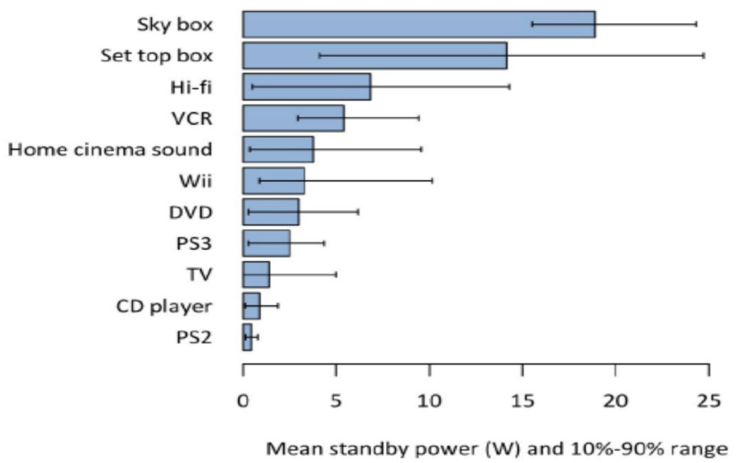


Figure 29. **Mean standby power for a range of electrical appliances**

Internal Domestic Hot Water (DHW) system

This section refers to a DHW system entirely within an individual dwelling (central distribution systems are covered in the next section).

The DHW system in a house is normally a relatively large source of heat throughout the year and insulation of the sources of heat, including pipes and cylinders, may therefore significantly reduce the heat gains. There are two basic system types:

Combi systems

These systems do not have any significant volume of storage and produce DHW on demand.

Sources of heat may be gas boilers orelectric flow..

Storage systems

These systems have a store, commonly a cylinder, within the house that is charged by the heat generator; boiler, solar panels, etc. and this heat is then used as/for DHW.

With both types of system the DHW is delivered to the point of use through pipes which can reach very high temperatures – in the region of 70-80C.. Only in point of use DHW systems with local heating at each outlet is the pipe length likely to be very short. In most domestic applications the water will be supplied to a minimum of a kitchen and one bathroom.

In the case of new dwellings, the Domestic Building Services Compliance Guide, 2013 Edition, notes that the primary DHW circulation pipes (pipework for the heat source to the storage vessel) should be insulated throughout their length, and if the secondary side is pumped (pipework from the storage vessel to the point of use) then all pipes kept hot should be insulated. Building Regulations Part L1A Criterion 3 (Limiting the effects of heat gains in summer) also references this requirement. Further documentation by TIMSA shows the pipes that should be insulated (Figure 30). For combi type systems there is no requirement to insulate the distribution pipes.

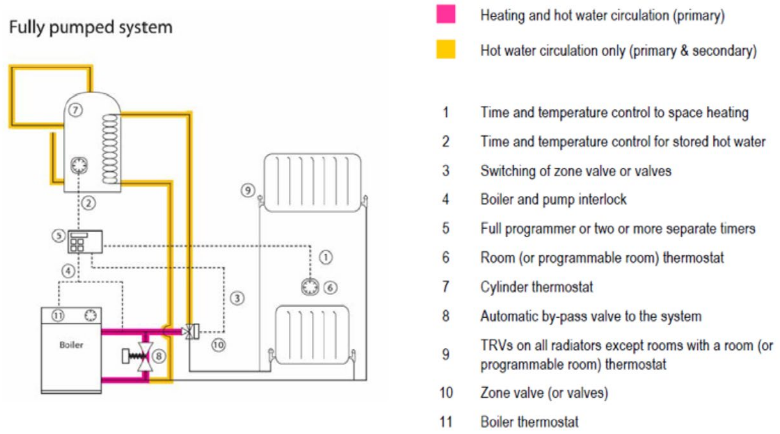


Figure 30. **TIMSA – HVAC Compliance Guide – Feb 2008. Pipes to be insulated are yellow**

The standing heat losses from a DHW cylinder should not exceed:

$$Q=1.15 \times (0.2+0.051\ V^{(2/3)})\ \ \text{kWh/day}$$

Therefore for a typical 210 litre cylinder the heat losses can approach 2.3 kWh/day, i.e. approximately 95 W of continual heat loss.

If this value of 95 W is added to the heat losses from the primary DHW pipes, for a large gas boiler these pipes will be used for possibly only 45 minutes to charge the cylinder, but for a small heat pump it is quite possible the DHW cylinder is charged for up to 3 hours a day. Add a heat loss of approximately 9 W/m (See Figure 31) and, assuming 10m of pipe, and the cooling of the water in the pipe from 60 to 20°C, then these additional losses are approaching 1 kWh. Assuming this is liberated across the day then the heat gains from the DHW primary circuit and cylinder could be as much as 130 W.

While heat gains of 130 W are not high, for a ventilation rate of 25 l/s (typical for dwelling of approximately 85m^2 floor area), such a heat gain would result in over 4°C rise in temperature. In winter this would help offset part of the heating load, but in summer this adds to the potential heat gains that would need to be 'rejected'.

Table 5 Recommended minimum standards for insulation of pipework in gas-fired wet central heating systems

Minimum standard	Supplementary information
a. Pipes should be insulated to comply with the maximum permissible heat loss indicated in the Supplementary information column, and labelled accordingly, as follows: i. Primary circulation pipes for heating circuits should be insulated wherever they pass outside the heated living space or through voids which communicate with and are ventilated from unheated spaces. ii. Primary circulation pipes for domestic hot water circuits should be insulated throughout their length, subject only to practical constraints imposed by the need to penetrate joists and other structural elements. iii. All pipes connected to hot water storage vessels, including the vent pipe, should be insulated for at least 1 metre from their points of connection to the cylinder (or they should be insulated up to the point where they become concealed). iv. If secondary circulation is used, all pipes kept hot by that circulation should be insulated. b. Whenever a boiler or hot water storage vessel is replaced in an existing system, any pipes that are exposed as part of the work or are otherwise accessible should be insulated as recommended above – or to some lesser standard where practical constraints dictate.	Pipe outside diameter (mm) / Maximum heat loss (W/m): 8 – 7.06 10 – 7.23 12 – 7.35 15 – 7.89 22 – 9.12 28 – 10.07 35 – 11.08 42 – 12.19 54 – 14.12 In assessing the thickness of insulation required, standardised conditions should be assumed in all compliance calculations based on a horizontal pipe at 60°C in still air at 15°C. Further guidance on converting heat loss limits to insulation thickness for specific thermal conductivities is available in TIMSA *HVAC guidance for achieving compliance with Part L of the Building Regulations*. **Insulation of pipework in unheated areas** It may be necessary to protect central heating and hot water pipework in unheated areas against freezing. Guidance is available in: • BS 5422:2009 *Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40°C to +700°C* • BRE Report No 262 *Thermal insulation: avoiding risks*, 2002 edition.

Figure 31. **Domestic Building Services Compliance Guide, 2013 Edition – heating system pipework insulation requirements**

Points to note

Solar systems, primarily running in the summer months can have water at in excess of 100°C, see Figure 31. The requirements for heat loss per length of pipe are the same as for a heating system; however, any losses from fittings, pumps etc., will be significantly greater than those for a normal heating system.

The MCS Microgeneration Installation Standard: MIS 3001 states:

> **Solar Heating Systems shall**
>
> 4.4.11 protect against burns and unnecessary heat loss by the insulation of all pipes, with the exception of branch pipes to expansion vessels.

Note: This includes all of the pipes, joints and components in the solar primary circuit from the Solar Thermal Collector to the cylinder via the pump station. It also includes all other pipes connected to the hot water cylinder (boiler primary and hot water draw off), as far as is reasonably practicable, but in any event it must include at least the first one metre of any pipe from the hot water cylinder.

The MCS standard differs from the Domestic Building Services Compliance Guide in that all pipes connected to the cylinder should be insulated as far as reasonably practical, but at least the first one meter. The latter is consistent with the Compliance Guide (note paragraph 'b' in Figure 32).

MCS provides details of the minimum required wall thickness for High Temperature EPDM based rubber insulation products used for solar primary circuits assuming a mean flow temperature of 50°C and a conductivity of 0.038 W/mK.

Table 41 Recommended minimum standards for insulation of pipework in solar hot water systems

Minimum standard	Supplementary information
a. All pipes of a solar primary system should be insulated throughout the length of the circuit.	The insulation should be suitably rated for the maximum foreseeable pipe temperature applicable, and where external also be resistant to vermin attack and climatic degradation.
b. All other pipes connected to hot water storage vessels, including the vent pipe, should be insulated for at least 1 metre from their points of connection to the cylinder, or insulated up to the point where they become concealed.	In a dwelling that already has a solar hot water system, it is recommended that the insulation should be upgraded in line with these minimum provisions where significant work, such as change of solar storage, is carried out.
c. Pipes should be insulated with appropriately labelled materials and in line with the TIMSA guide.	A fully-filled or drainback solar hot water system can have a pipe service temperature of 150°C. The insulation material should be specified to accommodate this temperature. An EPDM based rubber would normally be a minimum requirement for such an application. Any insulation specified should be better than 0.044 W/(m·K) at 40°C mean and the insulation diameter should be 87% of the pipe diameter.
d. Heat loss values should not exceed the values in the Supplementary information column.	

Pipe outside diameter (mm)	Maximum heat loss (W/m)
8	7.06
10	7.23
12	7.35
15	7.89
22	9.12
28	10.07
35	11.08
42	12.19
54	14.12

In assessing the thickness of insulation required, standardised conditions should be assumed in all compliance calculations, based on a horizontal pipe at 40°C in still air at 15 °C.

Further guidance on converting heat loss limits to thicknesses of insulation for specific thermal conductivities is available in the TIMSA *HVAC guidance for achieving compliance with Part L of the Building Regulations*.

Insulation for pipework in unheated areas

It may be necessary to protect water-carrying pipework in unheated areas against freezing. Further guidance is available in:

- BS 5422:2009 *Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range of -40°C to +700°C.*
- BRE Report No 262 *Thermal insulation: avoiding risks*, 2002 edition.

Figure 32. **Domestic Building Services Compliance Guide, 2013 Edition – heating system pipework insulation requirements**

Central distribution systems

A common approach to providing heating and DHW services in blocks of flats is to have a central boiler plant and then distribute the hot water through a primary pipe system to local heat exchangers in each dwelling. Heat gains may be reduced through, for example, insulation and design, as discussed in this section.

To ensure that there is hot water available at any point in the system the whole boiler plant and primary distribution system is kept 'live' 24/7. The heating and DHW systems run from the same primary system therefore there is no scope to reduce the heat losses through having smaller pipes for the DHW system in summer when there is no space heating requirement.

Box 1. **Communal systems**

Some communal systems run the primary systems at approaching 80°C to ensure that all cylinders throughout the system are heated to over 60°C. This satisfies the need to prevent proliferation of legionella, but it increases the heat losses from the system (systems should be designed to a flow temperature of 70°C when possible). The result of this is that heat losses from the primary system occur all year in these systems. The heat losses, which become gains to the building, can be significant. One recent investigation[1] found that UK distribution networks outside the building were in line with predicted levels of losses, but heat losses within buildings were in some cases very high. One case study had heat losses of 43% of heat generated being lost. There is increasing evidence that in the UK the tendency to run primary distribution pipes through long corridor ceiling voids, between well separated service risers, has resulted in these common spaces becoming very warm. This heat is then transmitted through the building structure and through air movement to the flats, resulting in higher internal temperatures throughout the year.

The Building Regulations requirements for limiting heat loss in distribution pipework are set out in the Domestic Building Services Compliance Guide. However, items such as pipe supports and valves add significantly to the heat losses, and although the rate of heat loss is relatively low, this continuous heating results in many ceiling voids, used as service voids, having temperatures between 30 and 40°C all the time. This results in the core of the building becoming warm with the heat ultimately transferring to all internal spaces including the flats and common areas.

The recent CIBSE/ADE guidance on Heat Networks,[2] in section 3.9 of its Design Objectives, addresses the need to minimise heat losses in order to minimise the risk of overheating. Best practice is noted as avoiding the location of distribution pipes in corridors and ensuring all risers are ventilated in summer to remove unwanted heat gains.

1. *DECC, URN 15D/022 – Assessment of costs, performance and characteristics of heat UK networks, DECC, London, 2015.*

2. *CIBSE/ADE, Heat networks: Code of practice for the UK, CP1:2015, CIBSE/ADE, 2015.*

The Domestic Building Services Compliance Guide provides guidance covering the minimum levels of insulation and notes that 'all pipework should be insulated to prevent uncontrolled heat loss when passing through communal spaces'. This guidance is further extended by CIBSE/ADE who note that insulation thicknes may need to be significantly greater than is normally used in most building services applications and that this may impact on the architectural design. The guidance notes that heat losses of a maximum of 15% of the heat delivered should be achieved.

Table 29 Recommended minimum standards for insulation of internal pipework in community heating systems Previou

Minimum standard

a. Pipes should be insulated to comply with the maximum permissible heat loss indicated in the Supplementary information column, and labelled accordingly, as follows:
   i. Primary circulation pipes for heating circuits should be insulated wherever they pass outside the heated living space or through voids which communicate with and are ventilated from unheated spaces.
   ii. Primary circulation pipes for domestic hot water circuits should be insulated throughout their length, subject only to practical constraints imposed by the need to penetrate joists and other structural elements.
   iii. All pipes connected to hot water storage vessels, including the vent pipe, should be insulated for at least 1 metre from their points of connection to the cylinder (or they should be insulated up to the point where they become concealed).
   iv. If secondary circulation is used, all pipes kept hot by that circulation should be insulated.

b. Whenever a boiler or hot water storage vessel is replaced in an existing system, any pipes that are exposed as part of the work or are otherwise accessible should be insulated as recommended above – or to some lesser standard where practical constraints dictate.

Supplementary information

Pipe outside diameter (mm)	Maximum heat loss (W/m)
8	7.06
10	7.23
12	7.35
15	7.89
22	9.12
28	10.07
35	11.08
42	12.19
54	14.12

In assessing the thickness of insulation required, standardised conditions should be assumed in all compliance calculations, based on a horizontal pipe at 60°C in still air at 15°C.

Further guidance on converting heat loss limits to insulation thickness for specific thermal conductivities is available in TIMSA *HVAC guidance for achieving compliance with Part L of the Building Regulations.*

Insulation of pipework in unheated areas

It may be necessary to protect central heating and hot water pipework in unheated areas against freezing. Guidance is available in:

- BS 5422:2009 *Method for specifying thermal insulating materials for pipes, tanks, vessels, ductwork and equipment operating within the temperature range -40°C to +700°C.*
- BRE Report No 262 *Thermal insulation: avoiding risks*, 2002 edition.

Figure 33. **Domestic Building Services Compliance Guide, 2013 Edition – Communal system internal pipework insulation requirements**

Limiting the gains from existing systems installed in large buildings is difficult. Extensive distribution systems, operating at a high water flow and return temperature, liberate a significant amount of heat and if this heat is not removed from these service voids, the adjacent structures will increase in temperature over a long period of time. Increasing the level of thermal insulation will have a positive effect, but the scale of these distribution systems means that reductions in overall heat liberated may tend to be relatively small if this remedial action is undertaken alone.

If long corridors have to be used as the primary distribution route, then some means of removing the excess heat from the service voids can be used to limit the resulting temperature rise of the surrounding structural elements. However, designing systems that do not have long horizontal runs would ensure that voids could be ventilated vertically and more easily. This would minimise the problem of communal areas being too hot for comfort and causing heat gains to occupied areas.

05
SOLUTIONS WHICH ENHANCE HEAT REJECTION

Natural ventilation

The key means of removing heat from a dwelling is through ventilation. Allowing air from outside to replace air in the dwelling results in cooling when the outside temperature is lower. For the majority of the time in the UK the external temperature is below internal comfort temperatures and thus good levels of ventilation are the key means of removing excess heat from a dwelling.

The equation to calculate the heat transferred air movement is:

$$Q = \dot{m} \, C_p \, \Delta T$$

Where

Q = Heat transfer in watts (W); this is the same as Joules of energy per second (J/s)

$\dot{m}$ = Mass flow rate (kg/s)

C_p = Specific heat capacity of air (1.0 kJ/kg °C)

ΔT = Difference in temperature of internal and external air (°C)
(The density of air at room temperature is around 1.2 kg/m^3)

Because the heat capacity of air is very low (compared to water for example), relatively large air-flows are required to remove even a small amount of heat from a building, particularly where the temperature difference between inside and outside is small. The air flow that can be expected from natural ventilation is also highly variable, depending primarily on wind speed and direction. Therefore in the majority of circumstances in order to achieve sufficient ventilation to remove heat gains in the warmer months of the year, large ventilation openings need to be provided that are suitable for leaving open for long periods during the cooler periods of the day.

Another issue related to enhancing heat rejection through natural ventilation is the current trend to install very large windows and patio doors and use these as the means to achieve purge ventilation. Background ventilation in homes is provided by a mechanical system or through the provision of trickle vents, usually a ventilation rate of 0.5 air changes per hour. Background ventilation at these low rates of air change, as noted above are not intended to and cannot control internal temperatures when there is anything above small heat gains. Therefore nearly all rejection of heat is through the action of purging large volumes of air for lengthy periods of time (when compared to the levels needed to remove pollutants etc).. The large windows and doors meet this requirement as set out in Part F of the Building Regulations for control of pollutants and excess moisture, cooking, showers, etc., but heat rejection requires continual ventilation. To provide continuous ventilation windows/doors would need to be left open for long periods of time.

There are situations where leaving large windows open for extended periods of time is a practical and low energy solution to controlling thermal comfort, but the reality of some dwellings, especially in urban areas, is that the external environment is noisy and/or polluted, and there may be security issues with windows being left open, or safety issues when windows are open above ground floor level and children are present. The location of the window in relation to the layout of the room may also be restrictive (many tilt and turn windows open inwards and sometimes, for example, swing in over the bed), etc. Some of these issues can be addressed through a better understanding of the needs of occupants of dwellings by the building designers and provision of more controllable openable windows or vents.

Automated secure night vents are now available, however if there are noise and pollution issues outside then reverting to a mechanical means of achieving control of the thermal environment may be necessary. It is important for the UK to look to hot countries such as Greece to learn from their experiences of delivering large amounts of secure natural ventilation in built up areas.

Mechanical ventilation

As noted in the discussion regarding natural ventilation, the relatively low air flow rates required for background ventilation are not intended to and normal have little effect on internal air temperatures in the summer in particular. Mechanical ventilation may be either intermittent or continuous in operation. If the fans operate intermittently then background ventilation is usually achieved through trickle vents. If the fans operate continuously then the ventilation rate in each room of a dwelling can be effectively controlled; this is therefore more appropriate for highly insulated and air tight dwellings.

Mechanical systems installed in UK houses are normally sized to achieve the requirements of the Building Regulations. For continuously running mechanical systems that is to achieve the minimum low and minimum high air flow rates or a supply air flow rate of 0.3 $l/s/m^2$ floor area. Purge ventilation is generally taken as equivalent to approximately 4 air changes per hour (ach). For simplicity if the background ventilation rate is taken as approximately 0.5 ach, then purge ventilation rate is eight times higher. Considering the pressure losses in one component such as a straight duct, see Figure 34, it is evident that increasing the air flow rate eight-fold would increase the overall pressure drop in the system significantly. The result of this would be that noise and fan power would likely make the system impractical to operate.

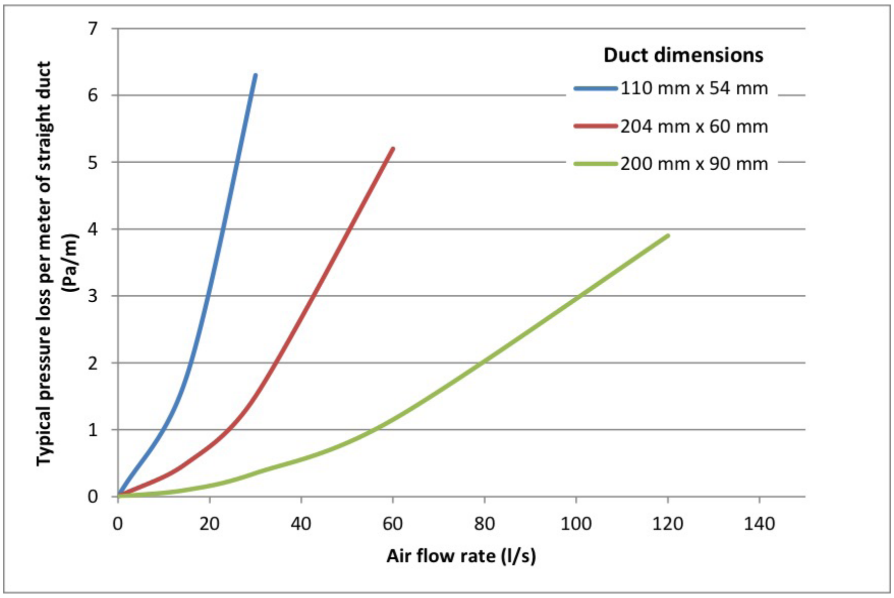


Figure 34. **Duct pressure losses (Source: BRE)**

It is therefore suggested that attempting to combine the roles of whole house background ventilation and whole house purge ventilation may be impractical or uneconomic at present.

.This issue is being acknowledged by some designers, leading to two separate systems being installed in dwellings where reliance on opening windows is impractical. Separate ventilation systems for the different air flow rates are required for background and purge ventilation, resulting in two sets of fans, ducts, outside air terminals and room supply/extract valves.

Thermal mass

As discussed above, thermal mass has the ability to store heat so it may be used to absorb heat and reduce peak temperatures. However, this heat needs to be removed from the building later, which requires either ventilation air flowing over it and removing heat from the exposed surface, or some form of active cooling of the mass itself. This latter means of rejecting heat using water flowing through pipes embedded in the mass is discussed on page 68.

06
SOLUTIONS WHICH USE COOLING

Evaporative cooling (passive)

When non-saturated air passes over a wet surface, water is evaporated. Evaporation requires heat and that is taken from the air and water. The result of this is that air is cooled as it passes over water and the moisture content of the air is increased, i.e. the relative humidity (RH) of the air increases.

Care must be taken when exposing large areas of wetted surface to a still air mass as this will tend to increase the RH to levels that eventually become uncomfortable. Evaporation of sweat from the skin is a primary thermoregulatory function of the body and if this is lost due to very high levels of room air RH then the potential for heat stress is increased. Therefore for evaporative cooling to be effective an air flow across the wetted surface must be maintained.

Passive evaporative cooling systems have been used in dwellings in areas where the air flow through the building takes a predefined path. This has been traditionally used in areas where there is a very well established wind pattern that can be relied upon across a seasonal period, i.e. the Middle East and Southern Europe. It is suggested that at a dwelling level this is not likely to be widely applicable to the UK where wind direction and strength are both highly variable across all seasons, but is increasingly being used in offices and commercial buildings.

Figure 35. **An open water feature used to provide visual interest and some evaporative cooling in a dwelling**

http://www.pocketfullofdesign.com/2012/05/introducing-the-coolest-interior-spaces-in-singapore-part-4-of-7/

Evaporative cooling (active)

(Mechanical free cooling)

Low energy evaporative cooling uses the same psychometric process as passive evaporative cooling, but combines it with a mechanical ventilation system to pass the air over or through wetted material. It therefore can be used in any location or building.

There are two ways of using evaporative cooling to provide cooled air to a building:

Direct The ventilation air is cooled directly by evaporation of water into this air stream. This is the most effective form of evaporative cooling, but it increases the RH of the air entering the spaces. In hot dry climates this may not be a particular problem, but in the UK the RH can be relatively high.. The only power consumed is by the water pump and air handling fans. CoPs of over 60 have been claimed; this compares with typical Coefficient of Performance (CoPs) for refrigeration based systems of between 3 and 4.[1]

Indirect Using evaporation to cool an air stream and then using this to cool the supply air stream through an air to air heat exchanger is well established, however this will normally be less effective than direct evaporative cooling. The advantage is that the RH of the air supplied to the building is not increased.

An example of this type of system incorporated into a small air handling unit (AHU) is shown in Figure 36. In this configuration the exhaust air passes through a water spray as it passes through a heat exchanger. The evaporation of water cools the exhaust air and heat is also removed from the supply air through the heat exchanger plates.

Figure 37 compares the wet and dry bulb data for Leeds. From this data it is clear that the wet bulb remains below 20°C indicating that as the dry bulb increases to the mid 20's°C the potential for evaporative cooling to work effectively increases. Only when the dry bulb air temperature drops to around 15°C does the potential to achieve any significant cooling decrease; at these temperatures cooling is normally not required.

The treatment and elimination of all carryover of water droplets from any water based system must be very carefully evaluated prior to adoption of this technology to avoid high humidity, and the risk of legionella proliferation addressed.

The capital cost may also make it inappropriate for a single dwelling, and the need for on-going maintenance may make it more appropriate for commercial and other non-residential buildings.

1. *http://www.ecocooling.co.uk/generalcooling/savings.php*

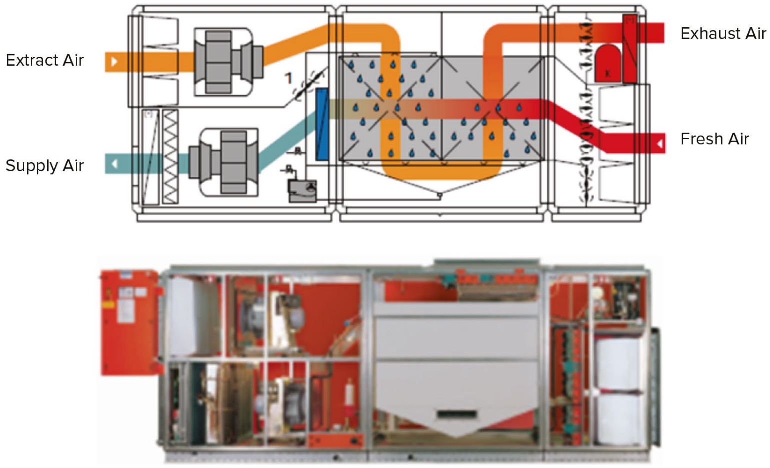


Figure 36. **Air handling unit with evaporative cooling of extract air being used to cool incoming fresh air**

http://www.menerga.com/en/products/product-bcd/ad-solair-type-56-58/

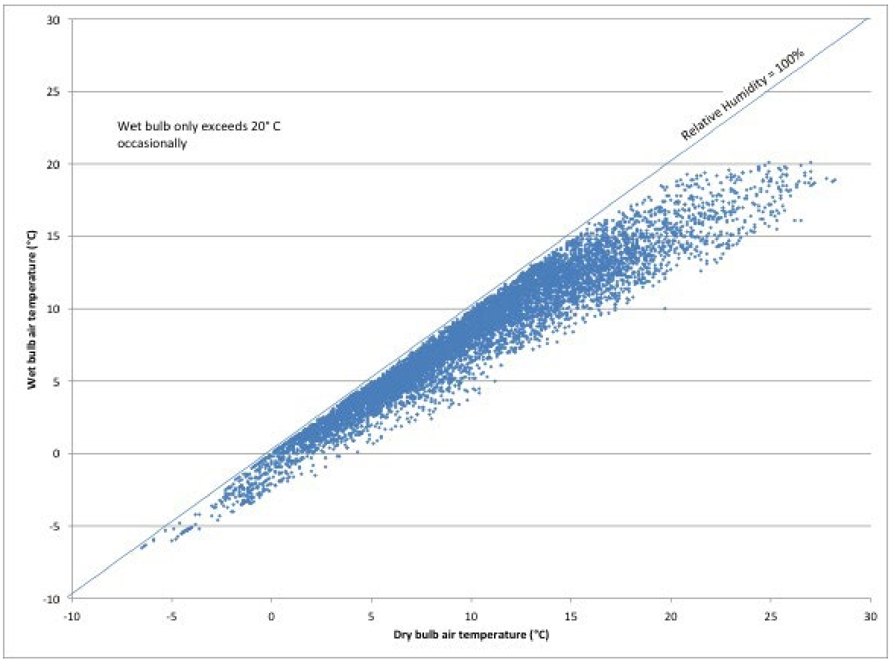


Figure 37. **Wet bulb and dry bulb air temperatures plotted for Leeds Test Reference Year**

Ground loop for ventilation (earth tubes) (Mechanical free cooling)

Drawing air through earth tubes, i.e. ventilation ducts buried in the ground, has been used extensively in Passivhauses as a means of pre-heating cold winter air before it is drawn into a building. The preheating of the air reduces or eliminates the need for a pre-heater to raise the incoming fresh air to around 0°C to prevent freezing of the heat exchanger of a MVHR system. In the UK the need for such a system to provide frost protection is limited due to our relatively warm winters.

In summer when the temperature in the earth tubes is cooler than the outside air, there is a significant potential to reduce the incoming air temperature from its daily maximum, i.e. to 'peak load lop' and deliver the air to a building at a temperature below that outside. With a peak seasonal ground temperature at below 15°C, there is a large temperature difference between peak day time temperatures and that of the ground.

Earth tube systems require a relatively large area of land to install, although if they are being installed during a new build then placing the tubes adjacent to the footings reduces the need to excavate large areas of land.

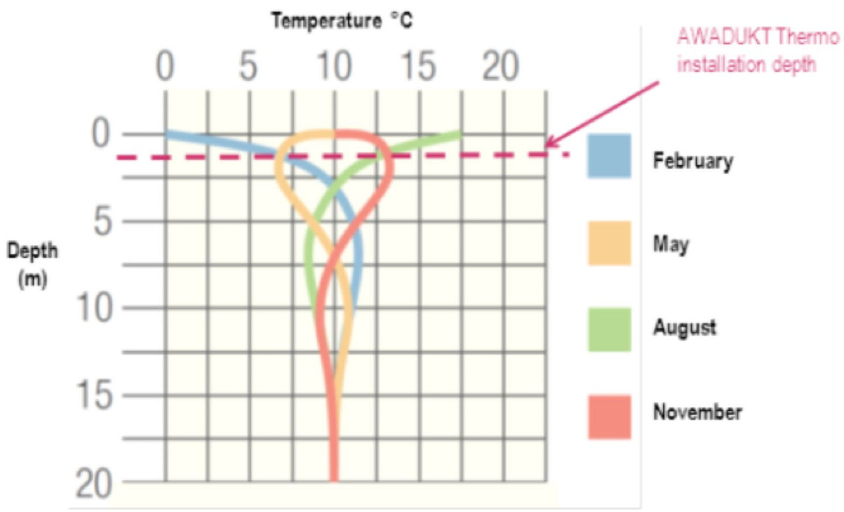


Figure 38. **Typical sub ground temperatures across a year**

Extract from http://www.rehau.com/download/1304276/renewable-source-of-ventilation-presentation-charlie-ward-rehau.pdf

Questions have also been raised about potential mould growth due to condensation within the ducts. Although the reasons for problems of mould growth have not been fully determined, the cooling of warm moist air in summer may result in significant quantities of condensation occurring within the earth tubes. For this reason the installation of the tubes must be carefully controlled and falls laid back to a sump draining into a sewer, or pumped out as required.

To ensure that any contamination of the earth tubes is minimised the ventilation system air filters must be placed at the inlet to the tube system. For Passivhaus developments this is an F7 filter (relatively high grade which is unusual in the UK).Manufacturers of earth tube systems, recommend inspecting the tubes annually and undertaking cleaning as set out in the Heating and Ventilating Contractors Association's Guide to Good Practice, TR/19, Internal cleanliness of ventilation systems. This guide provides details of a range of cleaning methods and is the document used by commercial duct cleaning contractors.

The sizing of earth tubes to achieve a given level of performance is a function of both the thermal characteristics of the ground and the physical characteristics of the earth tube system. The thermal characteristics of the ground can be highly variable and very much driven by the moisture content. A higher level of moisture increases the thermal conductivity of the earth and makes the transfer of heat into and out of the pipe more efficient.

Several papers have been written looking at the economics of ground heat exchangers.[1,2] At the design stage the information available from manufactures of these systems can be used as a good guide to performance.

1. *Thermoeconomic design of an earth to air heat exchanger used to preheat ventilation air in low energy buildings, Vlad, G. et al, Recent Researches in Energy, Environment, Entrepreneurship, Innovation, ISBN: 978-1-61804-001-5*

2. *T'Joen, C., et al, Comparison of Earth-Air and Earth-Water Ground Tube Heat Exchangers for Residential Application (2012). International Refrigeration and Air Conditioning Conference. Paper 1209.*

Figure 39 shows the design predicted performance data for an earth tube system proposed for a small commercial/agricultural application. The design intent was to run the system 365 days a year. The results clearly show the potential of such a system to attenuate diurnal swings. The design predicted some level of cooling in winter which would be counterproductive in a residential application and should be avoided through control of the source of the ventilation, i.e. use of the earth tubes only when appropriate cooling or warming of the air is achieved.

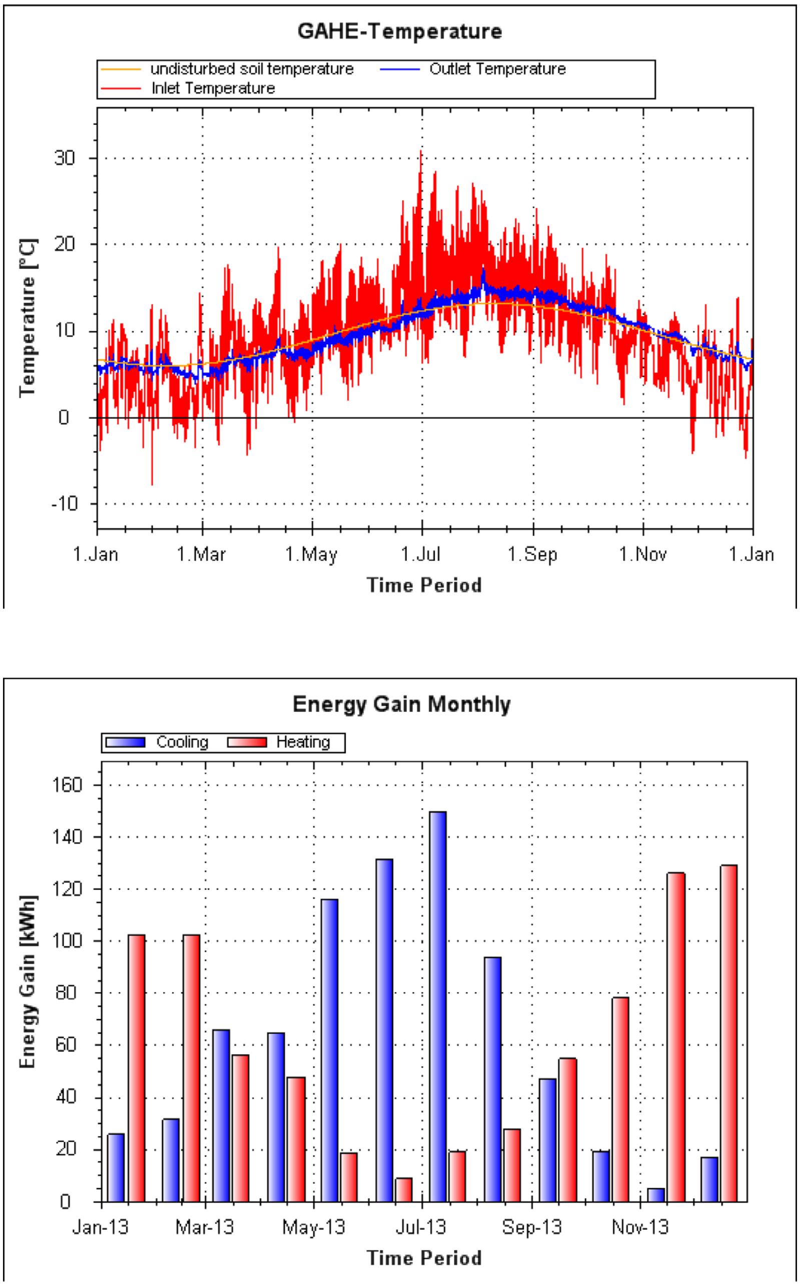


Figure 39. **Ground loop predicted performance Design data for a small commercial/agricultural buildingdwelling assuming the system is running 365 days a year (Source: BRE data)**

An alternative to using pipes is the use of a labyrinth. The use of a purpose built labyrinth would be unlikely to be economic for a small dwelling, but they have been used for larger buildings. Figure 40 shows a schematic of a labyrinth system and the pre-cast concrete panels used to construct the sub ground system. A system this size can be cleaned by accessing the air path on foot.

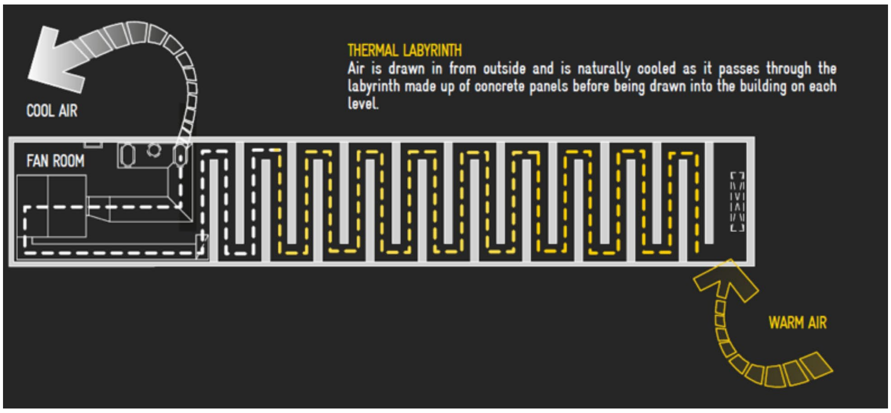


Figure 40. **Typical sub ground temperatures across a year**

http://www.y2architecture.com.au/projects/education/keysborough---springvale-regeneration-project

Brine based ground loops for ventilation (Mechanical free cooling)

Brine ground loops are now being used for both pre-heating and pre-cooling in ventilation systems. As with earth tubes, the concept has been extensively used in colder climates as a preheating system to remove the need for a frost protection heater prior to air being taken into an MVHR unit.

The ground loop required is similar to that of a ground source heat pump, however the required heat output is significantly smaller and therefore the area required for the loop maybe reduced. As with earth tubes, laying the loop in a trench adjacent to the footings reduces the need for installing it in open land. There are also several examples of the loop being installed under the insulated slab of a dwelling. This removes the need for all additional ground works and also reduces the risk of the pipe being damaged in future.

As the heat exchanger coil is in the air stream directly from outside, the air temperature will fall below 0°C in winter, meaning it is important that the ground loop is filled with a suitable antifreeze solution. Systems are available from a range of manufacturers as kits, only requiring installation of the ground loop. The resulting system is self-contained and the need for maintenance is minimal other than an annual check on the pressure within the system. The internal components of such a system can be seen in Figure 41.

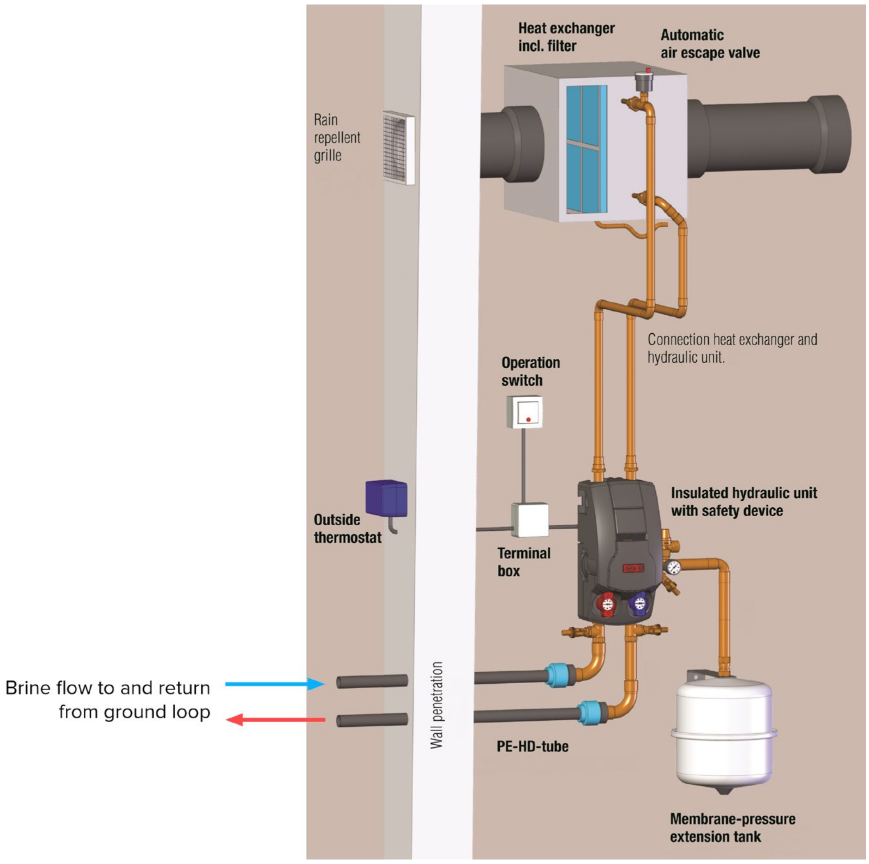


Figure 41. **Components of a ground loop system (source: Helios)**

Considering the ground temperature data in Figure 39, a typical summer ground temperature at 2m depth should be below 12°C. If the outside air temperature is warm and the wish is to reduce the supply air temperature within areas on the dwelling, then the temperature difference is in excess of 10°C. It must always be remembered that supplying air at a very low temperature may result in cold draughts. This may be due to dumping from supply valves if they are not commissioned to give an effective throw to the supply air before it enters the occupied zone of the room. For PassivHauses the minimum supply air temperature is considered to be 16°C and it is recommended that this should be taken as a minimum for all installations. Therefore, with an appropriately sized ground loop and brine to air coil, achieving supply air temperatures close to this should be possible throughout UK summers.

The heat exchanger in the air flow must not be undersized. It is also very important that the operation of the cooling system is linked to the internal temperature control so that it does not result in overcooling of the building. This would be counter-productive as it may result in thermal discomfort and the need for heating to be used to bring spaces back up to an acceptable temperature for occupation.

District cooling (Mechanical cooling)

District cooling provides cooling to a number of dwellings through a network of pipes from shared equipment, normally including storage of 'coolth' and/or heat. By the very nature of attempting to store heat or 'coolth' on a seasonal basis, the scale of the store is much larger than would perhaps be considered as economic for a single dwelling. If undertaken on a small scale the losses or dilution of the store could overwhelm the effectiveness of the scheme, i.e. the surface area to volume ratio would be too large. At the larger, small community to large scale single building, or community scale, there are a wide range of inter-seasonal stores that have been developed and are currently in use. The most common form of these stores is the storage of heat in summer from solar collectors or heat pumps using the high summer air temperatures to generate higher grade heat very efficiently. This store of heat is then used in the winter as the heat source for heat pumps and delivered through a piped distribution network. The heat stores are usually subsoil or large open bodies of water.

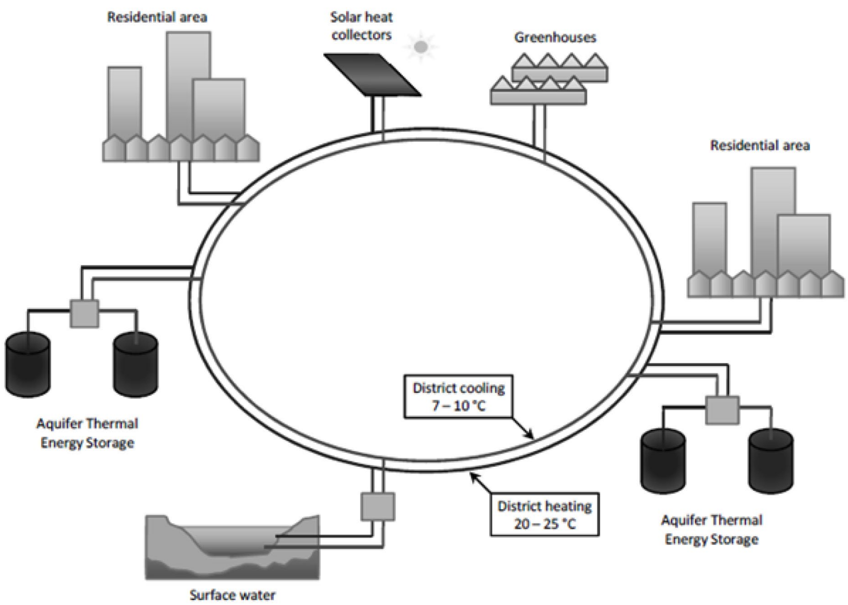


Figure 42. **Concept drawing of a heating and cooling district system using a range of heat sources and sinks**

http://www.iftec.es/files/ATES_in_NL_in_2020-r6cngn.pdf

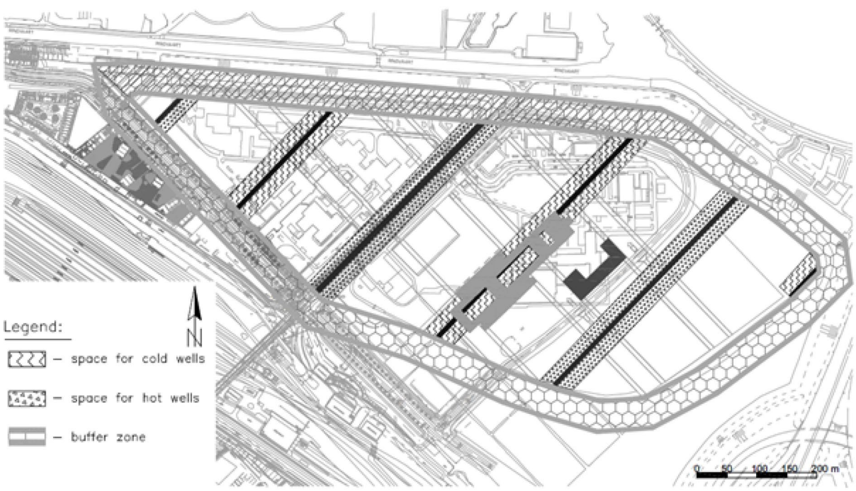


Figure 43. **Organisation of heat and coolth storage for a communal system**

Godschalk, M., et al, 20,000 ATES systems in the Netherlands in 2020 – Major step towards a sustainable energy supply, IF Technology.

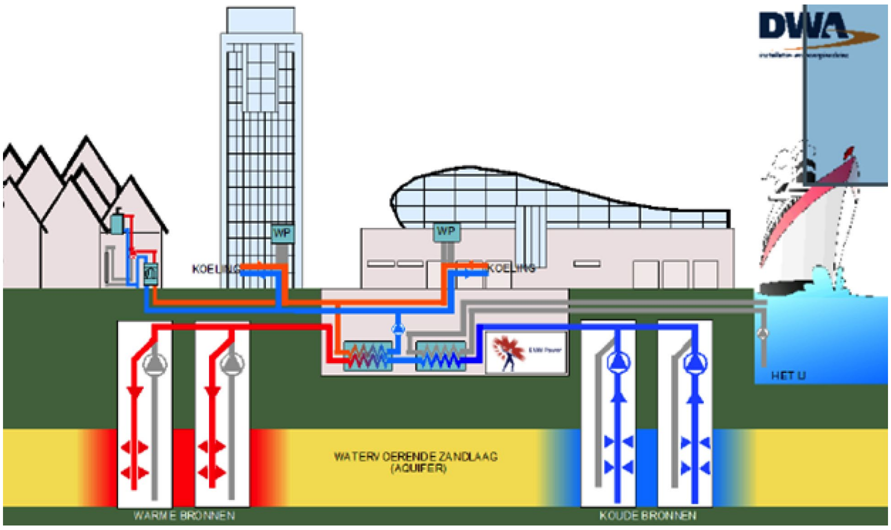


Figure 44. **Schematic of a heat and coolth store in Holland. System serves ferry terminal and residential buildings. Installed in 2000, by 2012 this was one of 700 such systems installed in Holland**

http://www.icax.co.uk/pdf/IFTech_Presentation_Rehau_31May2012.pdf

The first publicised heat and coolth storage system in the UK was Westway Beacon in west London[1] completed in 2006. The scheme was a 128 flat development of affordable and shared ownership dwellings. The system was based on a Dutch design using a heat pump to extract heat from the warm store in winter and then using the cool water in summer to provide cooling without use of the heat pump, i.e. pumped ground water from the cold borehole. The system was monitored and returned a reported CoP of 4.0 in winter and 8.6 in summer.[2]

To provide cooling, systems have been developed that reject heat over the winter, cooling a large sub ground store and then use that as a source of coolth to provide either a very efficient sink for a heat pump or use the store passively.

An alternative system installed in the UK uses significant areas of piping in paved areas, mainly car parks and play grounds as the means of rejecting the heat built up in a thermal store during the summer, over the cooler winter period.[3] The advantage of using rejection of heat during the winter period and storing the coolth seasonally, is that it can be undertaken passively with little need to useheat pumps. The cool store can then be used to supply cool water through much of the summer without the use of a heat pump. The seasonal efficiency is therefore relatively high compared to air source heat pump cooling systems.

1. *http://www.building.co.uk/beyond-ground-source-heat-pumps/3097129.article*

2. *http://www.gshp.org.uk/documents/8.NicholasBoid.pdf*

3. *http://www.icax.co.uk/index.html*

One of the advantages of storing and distributing coolth through a distribution pipe network is that because the temperature differences between the water and the ground, even in summer, are small, the rate of heat gain (loss of coolth) will be relatively small, thus making the system efficient as a distribution means. This is less so for heating as the temperature losses are often significant reducing the overall efficiency of the system as a whole. This fact is going to increase in relevance as dwelling heat loads for space heating fall as a result of better fabric insulation and airtightness, but the standing / distribution system losses remain largely fixed.

These systems, including the Westway Beacon project where the infrastructure was serving a single building, are relatively expensive compared to the more traditional system of a gas boiler or heat pump. However the long term running costs are very significantly lowered by using this heat storage approach. The cooling potential is also relatively high so the building has a level of future resilience that would be missing if the design only had space heating specified.

District cooling has a very high potential efficiency, but the capital outlay to install the infrastructure is high so the 'drivers' for making such a system economic would need to be political as well as profit driven.

Exhaust air heat pump (Mechanical cooling)

The concept of using a heat pump to extract the heat from the exhaust air of a dwelling is very well established in cold climates. This is particularly the case in Sweden where the adoption of MVHR based heat recovery has not been common until recently. However, the amount of heat available from the exhaust air stream is relatively small, so a well-insulated and airtight dwelling is required. The heat is normally stored in a hot water cylinder for use when required, with an immersion heater to allow the hot water temperature to be topped up as necessary.

In summer when the only requirement for heat is for DHW, there is the potential to use the cooled exhaust air, rather than discharging it directly to outside. The air could be used as a means of cooling the supply air stream through a heat exchanger for example.

A small exhaust air heat pump has a total heating output of approximately 1 kW. The cooling capacity is therefore around 670 W based on a CoP of approximately 3.0. The heat output would be required for approaching 6 hours of continuous run to charge the cylinder of a 'typical' family (EN16147 draw-off for medium size family is ~ 6 kWh/day). Therefore there is potentially a source of cooling available as an exhaust stream from the heat pump for a period of time. If this were carefully controlled / scheduled it could be used as evening/night cooling for bedrooms etc. At the time of writing, there is currently no such system on the market.

Linked thermal mass and ventilation systems (Mechanical free cooling)

The exposure of thermal mass to an occupied space offers both convective and radiative heat exchange between the mass and both occupants and other materials within a space. This has the potential to offer significant opportunities to peak load lop (i.e. to dampen large diurnal variations in internal temperature). However for this strategy to be effective over an extended period of time the heat must be effectively removed, i.e. the coolth 'recharged'. As discussed, for buildings where the occupancy is 24 hours a day, or primarily overnight, the opportunity for using natural ventilation to achieve this may be limited. Therefore the linking of the thermal mass to the ventilation system in such situations does allow some of the limitations of using natural ventilation to be addressed.

There are two approaches that have been taken to linking thermal mass to HVAC systems:

- Passing air through a void exposed on one side to the thermal mass of the building. Most commercial buildings have either a raised floor or a false ceiling, and in many cases both. Passing air through these voids and then into the occupied zone allows the air speed to be kept high and the flow rate controlled, both important to controlling the recharging of the thermal mass of a building. It is rare that such voids exist in most dwellings or large multi residential buildings and therefore such an approach may only be realistic in new build.
- Passing air through the thermal mass. This approach uses hollow cores within the thermal mass elements of the building as air circulation ducts. The advantage of this is that the air flow rate is significantly increased and the system does not rely on the air tightness of a ceiling or floor to prevent leakage. One such system has been very effectively used in commercial building, e.g. the Elizabeth Fry building at UEA.[1]

The system has not been widely used in dwellings but the concept does offer significant potential for combining a domestic ventilation system with ducts located within the thermal mass in new dwellings.

The key to the success of any system that combines the mass of a building and a mechanical system is good control. The two key risks are:

- warm wet air will be passed over a cool section of thermal mass and condensation will occur on the surface of the mass
- ventilation with cool air for too long will overcool the thermal mass resulting in the air delivered to the occupied spaces being too cool. This would have the unfortunate result of heating being required to offset the thermal discomfort

1. *http://www.termodeck.com/*

Thermally active building systems (TABS) (Mechanical free cooling)

Thermally active building systems are water based heating and/or cooling systems which consist of pipes embedded in the concrete structures of the building. For cooling applications this approach uses the building's own thermal capacity to store heat alongside natural heat sinks such as ground water or via reverse cycle heat pumps to reject the heat.

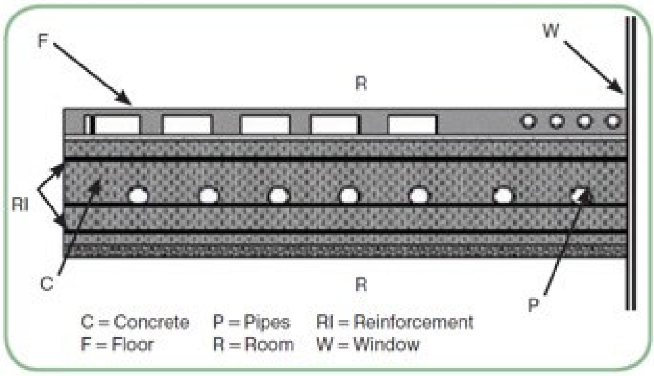


Figure 45. **Example of a TABS configuration with pipes within the concrete structure of the building slab**

Olesen, B., Using building mass to heat and cool, ASHRAE Journal, vol. 54, no. 2, February 201.

TABS have several advantages when compared to typical comfort cooling systems which are sized to handle peak loads. TABS uses the thermal inertia of the building structure to smooth the variations in cooling loads thus reducing the peak load and as a result the required plant size; this increases the potential for mechanical free cooling heat sinks to be used.

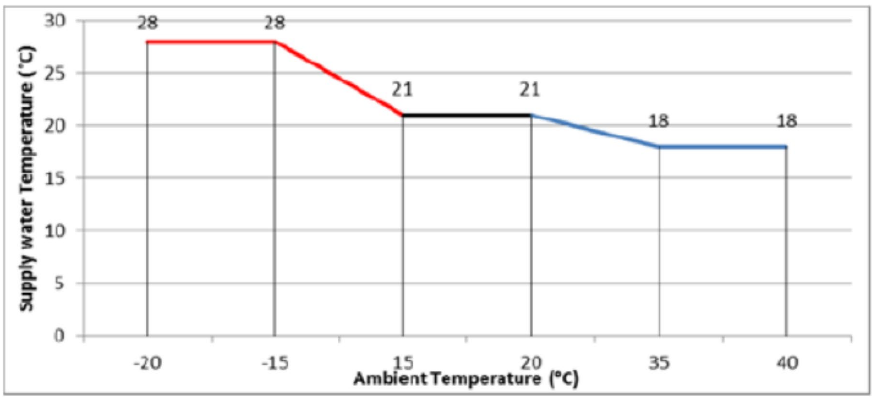


Figure 46. **Example of a TABS configuration with pipes within the concrete structure of the building slab**

Yang, Y., The role of optimization and simplified methods in the design of Thermally Activated Building Systems (TABS), Eindhoven University of Technology, 2013.

As with the use of non-active thermal mass to attenuate variation in internal air temperature, the transfer of heat between the exposed structure of the building and the occupants and other internal structures is by a mix of radiation and convection, with up to 50% of the heat transfer by radiation. The difference between using non-active thermal mass and TABS is that the means of heat removal is significantly more predictable and effective with TABS. The use of night time ventilation to remove heat from a structure, especially in a domestic setting, relies on large quantities of air passing through a space and good contact between the air and the exposed thermal mass. Incorporating a water-based system within the thermal mass elements means that the heat can be removed continually over 24 hours. This significantly reduces the need to purge the heat out of the structure over a relatively short period of time when the outside air temperature is below the internal air temperature.

Although this is clearly a technological approach that is really mainly applicable to new build, REHVA[1] note that it is being adopted increasingly in private housing. REHVA also note that savings of 80 to 90% can be made when free cooling is used instead of traditional chillers.

The thermal outputs of TAB systems can be up to 40 W/m^2, however the upper limit of the cooling capacity is governed by the need to prevent condensation on the surface of the structure. This limits the lowest temperature of the water in the pipes and therefore the temperature difference between the exposed structure and the room air. For example the dew point of air at 26°C and 50% relative humidity is approximately 15°C.

The technology has been used in buildings for over 20 years and longer in the in the form of under floor heating (the materials used being very similar) which is relatively widespread. There are a range of EN standards covering the design and thermal output of such thermally active building systems:

- EN1246-1 to 5, Water based surface embedded heating and cooling systems.
- EN15377-1 to 3, Heating systems in buildings – Design of embedded water based surface heating and cooling systems.

Marketing information[2] details how the concept of embedding pipes into every element of a dwelling could be achieved. The information and range of controls now available to the domestic market, moving down from larger commercial based systems, indicates that this is a new application of a relatively mature concept.

Night radiation (roof ponds)

Roof ponds require a large volume of exposed water on the roof, with the major living and sleeping spaces directly beneath. Heat is radiated to the sky overnight. However, this measure is only effective in a hot dry climates and so is not applicable in the UK.

1. *Nielsen, L., Building integrated system design for sustainable heating and cooling, REHVA Journal, pp 24-27, February 2012.*

2. *http://issuu.com/uponor.com/docs/free-cooling-guide_56044b25cc243d/40?e=9821309/7023496 accessed 09/10/2014.*

Mechanical cooling

Full air conditioning takes air from outside the building, and draws it through a refrigeration unit before ducting it into the rooms. This is not commonly used in UK dwellings as the need for plant space and the size of the ducts makes it only suitable for very large dwellings/ schemes. Mechanical cooling when applied to UK dwellings normally refers to the use of a refrigeration based system to provide cooling directly to the air of one or more rooms, referred to as comfort cooling. In this type of system the room air is drawn through a unit in the room, cooled and ejected back into the room. Heat is rejected via a separate refrigerant circuit and heat pump to outside air – hence the name “split unit”.

The rise of the ‘split’ unit and the move recently to the ‘multi split’ from many of the major manufacturers has meant that reliable comfort cooling is now widely available. These consist of units in one or more rooms (‘split’ or ‘multi split’ respectively) where heat is absorbed from the room air to a refrigerant fluid which is circulated to a fan unit outside the dwelling where the heat is ejected from the fluid. These are available at a relatively low cost and ranging from a few hundred watts of cooling suitable for a single room, to tens of kilo-watts suitable for large dwellings or multi-occupancy dwellings. Because of this ease of installation, relative low cost of purchase and very significant cooling capacity, it is easy to see why mechanical cooling is seen as an effective solution to overheating.

However, mechanical cooling systems may have on-going maintenance costs, although many are now near maintenance free over their operational life, and they have a running cost that is influenced by the size of the system, how it is used and the prevailing outside air temperature. Because a comfort cooling system is cooling the air within the building, it is running at the peak load times of the day which results in the efficiency of the system, the CoP, being at its lowest. If such a system were installed and only used to provide a safe internal temperature for vulnerable groups by peak temperature “lopping” back to a safe and more comfortable level, then provided all measures had been undertaken to minimise the gains and reject heat by passive and low energy means when possible, it offers a level of guaranteed safety.

However, such a system might, in reality, be operated for much longer periods of time, or when windows are open or external blinds or shading devices have not been operated to minimise the cooling load. This will result in significant increases in the running costs and heat rejected to the local urban climate, potentially contributing to the UHI effect.

07
SOLUTIONS BASED ON OCCUPANT BEHAVIOUR

Active occupant participation

The occupants need to be advised of building design features that minimise heat gains and how rejection of heat can be achieved. If this is not undertaken then the actions they take may be counterproductive, reducing opportunities to minimise gains and failing to reject heat. The result of this will be an increased tendency to overheat.

Experience has shown that many occupiers are unaware of the heat gains that result from sun shining through windows. Even when large areas of glazing are facing north – diffuse solar radiation from the sky is not insignificant, and if very large areas of glazing exist and are not shaded, then heat gains will accumulate. Reductions in solar gains and a reduced risk of overheating can be achieved through using internal shading such as curtains or blinds during sunny periods, particularly if the sun is shining directly on the window. It appears that many people are unaware of this effective action; and the BBSA, for example, provide simple best practice guidance to help educate people in this area. Alternatively using external shading, such as shutters, is even more effective as it prevents solar radiation warming the internal shading and the air between it and the window, which then transfers to the room.

'French' style external window shutters are often noted as a sensible option to minimise solar gains, but many older and vulnerable people may not be able, or remember, to operate them in such a way as to minimise gains. There is evidence[1] that many occupants in the US use their blinds very occasionally, preferring to leave them on one position for extended periods. The report noted:

> 'People rarely move their window coverings. Approximately half of coverings are closed at all times. Between 75% and 84% of coverings remain in the same position throughout the day, depending on the season (summer or winter) and time of week (weekday or weekend). Moreover, between 56% and 71% of households do not adjust any of the covering in their house on a daily basis, depending on the season and time of week.'

1. *Residential windows and window coverings: A detailed view September 2013 Prepared for: Building Technologies Office, Office of Energy Efficiency and Renewable Energy U.S. Department of Energy*

This finding reinforces the suggestion that most people are not aware of or forget to operate their window blinds in a way that would maximise useful daylight when available and minimise unwanted solar gains.

The same study also considered the use of the air conditioning system and found that in hot weather in all US climatic regions over 50% of the households either left their A/C units running all of the time or most of the time, Figure 47. This again reinforces the suggestion in Section 06 that if the system is not designed to only undertake peak load lopping, it will tend to be used more often than is absolutely necessary.

Use of Air Conditioning in Hot Weather	Climate Zone		
	Northern (%)	Mid Tier (%)	Southern (%)
Number of Households	584	589	685
Once I turn it/them on, they stay on all the time until the weather cools down	24.1	41.8	54.6
Leave the air conditioning on most of the time	36.0	36.2	34.6
Only use air conditioning at night	4.6	3.6	3.8
Only use air conditioning during the day	6.5	3.9	2.3
Only use it once in a while when it gets really hot	28.8	14.6	4.7
Total	100.0	100.0	100.0

Air Conditioning In Home	Climate Zones			
	Northern (%)	Mid Tier (%)	Southern (%)	All (%)
Count	690	702	709	2101
Yes	84.6	83.9	96.6	88.4

Figure 47. **Percentage of houses with air conditioning in US across three climate zones and householders response to questions regarding operation of A/C in warm weather (Source: See footnote 105).**

08
COST OF MEASURES

The cost of applying a measure to mitigate overheating depends significantly on the building type it is applied to, the location and surroundings of the building, and the point at which the measure is applied:

- **New build –** when a dwelling is designed and built there are very significant opportunities to minimise the propensity for overheating, such as by choice of building orientation and built form; however site or location restrictions may also limit the scope for such measures.
- **Major refurbishment –** at this stage the structure of the building is usually set, but there are significant opportunities to change the windows, internal layout, means of ventilation, etc.
- **Major Retrofit Project –** during a simple retrofit there are limited options to significantly change heat gains or the means of heat rejection unless the source of the heat is easily identified. For example blinds and/or shutters may be a good option if excess solar gain is the main issue.

Given the above, measures are presented here with an indicative cost associated with the three main opportunities for consideration (see Table 1), primarily as a means of comparison between options. The indicative cost, based on the experience of the BRE authors, are presented as:

- High (£££)
- Medium (££)
- Low (£)
- Not applicable (x)

Table 1. **Indicative relative cost of measures for prevention of overheating**

MEASURE	NEW BUILD	MAJOR REFURB	RETROFIT
SOLUTIONS WHICH LIMIT HEAT GAINS			
Local Climate / Urban Heat Island			
Layout; avoiding tightly packed buildings and canyon configurations	£	x	x
Increase areas of open water and foliage	£	£££	£££
Increasing albedo of the building and ground surfaces	£	££	££
Local micro climate – hardscape			
Position buildings away from wide areas of road and pavement	£	x	x
Ground probes to extract and store heat in summer, then release it in winter	££	£££	£££
Install PV panels in pavements and roads	£££	£££	£££
Local micro climate – albedo			
Increasing the albedo of building surfaces to reflect solar radiation	£	£	£
Local micro climate – green and blue space			
Increasing green space, particularly trees and bushes	£	££	££
Dwelling built form			
Minimise surface area to limit fabric solar gains	£	x	x
Avoiding deep plan, compact form, to allow good natural cross ventilation.			
Avoiding single sided natural ventilation, again to allow utilisation of natural cross ventilation.	£	x	x
Urban layout			
Narrow streets to limit solar access to building facades	£	x	x
Streets shaded for most of the day	£	x	x
Orientation			
Minimise summer and mid-season solar gains (and maximise winter gains)	£	x	x
Height and underground spaces			
High rise spaces	££	x	x
Underground or partially underground rooms	£££	x	x
Internal building layout			
Position bedrooms where heat gains are least for sleeping and health benefits	£	£	£
Glazing area			
Design to minimise summer gains while providing sufficient daylight	£	x	x
Use of glazing types with appropriate levels of infra-red transmission	££	££	££
Location: ensure north glazing can provide natural ventilation	£	£	£
Daylighting: use of windows and skylights which avoid high solar gains	£	££	££

MEASURE	NEW BUILD	MAJOR REFURB	RETROFIT
Thermal mass			
Thermal mass to dampen diurnal temperature swings. Addition of new thermal mass	£	£££	£££
Thermal mass to dampen diurnal temperature swings. Exposure of existing thermal mass	£	££	££
Building level micro climate – green structures			
Walls & roofs covered with plants to reduce heat gain	££	££	££
Fabric			
Fabric thermal performance near building regulations standard not presenting an opportunity for upgrade	x	x	x
Solar shading			
Internal shading – blinds & drapes	£	£	£
External shading – blinds, overhang, louvered shutters, awning, trees	£	££	££
Glazing types			
Solar control glazing – Tinted or reflective coatings	££	££	££
Glazing Types – Near market innovations			
Electrochromic glazing – low voltage switches between clear and tinted	£££	£££	£££
Photochromic glazing – changes transparency in response to light intensity	£££	£££	£££
Thermochromic glazing – changes colour/absorbency with temperature	£££	£££	£££
Gasochromic glazing – changes optical properties when exposed to certain gas	£££	£££	£££
LCD glazing – low voltage switches between clear and obscured	£££	£££	£££
Glazing treatments			
Solar control films	£	£	£
Glazing/fabric covering			
Building integrated photovoltaics	£££	£££	£££
Sourcing of ventilation air			
Design ventilation to source cool air when outside air is cooler than inside	£	£	£££
Internal electrical appliances			
Reduce power and stand-by power, turn off when unused	£	£	£
Domestic Hot Water system			
Insulate cylinder and all DHW pipework	£	£	£
Central distribution systems (e.g. in flats)			
Insulate all distribution system pipes	£	£	£
Provide means to remove heat from all voids containing distribution pipes	£	££	£££

MEASURE	NEW BUILD	MAJOR REFURB	RETROFIT
SOLUTIONS WHICH ENHANCE HEAT REJECTION			
Natural ventilation			
Provide adequate and usable natural ventilation (reasonable if built in when new, but not for refurbishment where none initially).	£	£££	x
Mechanical ventilation			
Standard mechanical background ventilation; is not generally designed to provide both purge and background ventilation	x	x	x
Parallel mechanical ventilation systems; designed to provide both purge and background ventilation	£	£££	x
Thermal mass			
Thermal mass on its own does not reject heat, must be linked with ventilation or active cooling	x	x	x
SOLUTIONS WHICH USE COOLING			
Evaporative cooling (passive)			
Requires an established airflow path	x	x	x
Ground loop (earth tubes) for ventilation			
Potential to deliver cooler air at peak temperatures	££	£££	£££
Brine ground loops for ventilation (active)			
Alternative to earth tubes	££	£££	£££
Seasonal storage heat pumps (active) + District cooling (active)			
Storage of heat in summer	£££	£££	£££
Evaporative cooling (active)			
Direct – evaporation into the airstream	£££	£££	£££
Indirect – evaporation into an airstream then heat transfer via a heat exchanger	£££	£££	£££
Exhaust air heat pump			
Potential to use cooled exhaust air resulting from summer water heating	£££	£££	£££
Linked thermal mass and HVAC systems			
Integration of ventilation system and building thermal mass to remove heat gains from the mass	££	££	x
Thermally active building systems (TABS)			
Water pipes embedded in concrete structure	£££	x	x
Night radiation (roof ponds)			
Not practical in the UK climate	x	x	x
Mechanical cooling			
Refrigeration based, including 'split' and 'multi-split' systems	££	££	££

MEASURE	NEW BUILD	MAJOR REFURB	RETROFIT
SOLUTIONS BASED ON OCCUPANT BEHAVIOUR			
Active occupant behaviour			
Use of curtains and blinds during sunny periods	£	£	£
Use of external shutters, awnings during sunny periods	£	£	£

SOLUTIONS TO OVERHEATING IN HOMES

EVIDENCE REVIEW

ZERO CARBON HUB