Thermal comfort in a 21st century climate

Addressing the impact of climate change on the built environment

Summary
This briefing summarises the key findings of research commissioned by DTI and led by Arup into the likely effect of climate change on thermal comfort and HVAC system performance. Overheating risk, energy consumption and carbon emissions of several types of existing dwellings, schools and offices have been modelled.

In response to rising summer temperatures simple passive design measures should be considered for all buildings to reduce overheating. Overall it is concluded that with appropriate design it is possible to produce low-energy solutions that will provide acceptable space conditions into the 2080s.

Climate change scenarios
The most recent report of the Intergovernmental Panel on Climate Change (IPCC) concludes that the trend in global warming since the beginning of the industrial revolution is largely due to the emission of greenhouse gases into the atmosphere. As a result our climate is already changing and will continue to change throughout the next century. The rate and extent of change is uncertain. It depends on future greenhouse gas emissions, but average annual temperatures in the UK are likely to increase by somewhere in the range of 2 °C to 3.5 °C over this century. Parts of the south-east may be 5 °C warmer in summer. Rainfall patterns will also change, with wetter winters and drier summers predicted. While recent record-breaking summers in Europe do not on their own establish that climate change is happening, they do serve to demonstrate the problems of prolonged high temperatures, especially for more vulnerable members of society.

Changes in climate will affect energy use in buildings. Naturally ventilated buildings may overheat more frequently, and air conditioning systems may fail. Full air conditioning may be demanded in more buildings to control summer temperatures as well as humidity, with the associated increased energy usage. Conversely, energy consumption for winter heating may reduce. Given what is already known about climate change, designers now need to consider likely future scenarios when developing designs, to ensure that buildings can provide comfortable and healthy internal environments over their service lives whilst minimising energy use and greenhouse gas emissions.

Modelling the future
This briefing summarises the key findings of a research project commissioned by DTI and led by Arup into the likely effect of climate change on thermal

* Full report to be published by CIBSE as TM36: Climate change and the internal environment

(1) The IPCC is the United Nations body which assesses the science of climate change. Its assessments, peer reviewed by over 2000 leading climate scientists worldwide, are the most authoritative available.
comfort and HVAC system performance. Overheating risk, energy consumption and carbon emissions of several types of dwellings, schools and offices have been modelled.

The study modelled the performance of heated, naturally ventilated buildings, two low-energy cooling systems and one example of full air conditioning. To address the viability of using air conditioning in dwellings, the effect of installing a simple system in one case study house was assessed. In the non-domestic sector the study considered the effect of limiting future cooling capacity on internal conditions in a fully serviced office building.

An important aspect of the study was to estimate how design features could limit temperatures in buildings without recourse to mechanical cooling. These features include control of solar radiation, ventilation strategies and, where appropriate, use of building mass as thermal storage. It has been suggested that all that is needed is to adopt what is done in other warmer countries. However, whilst these give some useful indications, they often employ particular architectural engineering solutions that may not be appropriate or acceptable in the UK, and are unlikely to be applicable to existing buildings.

**Predicting future climate**

The best current predictions of future UK climate are published by the UK Climate Impacts Programme (UKCIP). The latest predictions, released in 2002, are known as the UKCIP02 scenarios. They give mean monthly values of climate variables on a 50 km × 50 km grid for three time slices for the 21st century: 2011–40 (‘2020s’), 2041–70 (‘2050s’) and 2071–2100 (‘2080s’). Four greenhouse gas emissions scenarios are used, ranging from a low-energy use sustainable future, to an intensive fossil fuel use future, and produce a complete set of climate data for each scenario. Details of the scenarios are available from the UKCIP website (http://www.ukcip.org.uk).

The Medium-High Emissions scenario, which assumes preservation of local identities, continuously increasing population and economic growth on regional scales, is closest to the present world economy and patterns of energy use. At present there is no probability assigned to any particular scenario; they are all equally plausible. It is vital to remember this range of possibilities in climate predictions.

The Medium-High Emissions scenario, which predicts an increase in global temperature of 3.3 °C by the 2080s, was used to modify the CIBSE Design Summer Year (DSY) for Heathrow, producing hourly climatic data files. These contain all parameters necessary for a dynamic simulation (dry-bulb, wet-bulb solar radiation etc.). This modification of the DSY was carried out for the three time periods used in UKCIP02. Table 1 shows the predicted rise in global temperature in these three time periods for the Medium-High Emissions scenario.

![Figure 1: Increasing summer temperatures](image)

**Table 1. Increasing global temperatures (relative to 1961–1990 average) over the coming century**

<table>
<thead>
<tr>
<th>Period</th>
<th>Corresponding increase in global temperature / °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>0</td>
</tr>
<tr>
<td>2020s</td>
<td>0.9</td>
</tr>
<tr>
<td>2050s</td>
<td>1.9</td>
</tr>
<tr>
<td>2080s</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Figure 1 shows how summer external dry bulb temperatures might look for ‘Design Summer Years’ (DSYs) for London (presently 1989) in the three timeslices. Occurrence of temperatures over 28 °C rises from around 20–50 hours (approximately 1 per cent of time) now to about 500 hours (approximately 6 per cent) by the 2080s. It is worth noting that this is total cumulative time over the threshold, not the number of days on which the threshold is exceeded for part of the day.

The hourly data were then used to model the performance of the case study buildings, to establish how they would be affected by the climate changes predicted by the Medium-High Emissions scenario. This information was then used as the basis for considering what measures might be proposed to minimise the impact of the changes on comfort in buildings.

**Tomorrow’s climate — today’s buildings**

The key question is how buildings with particular features might respond to climate change, and what might be done to adapt these buildings to obtain a more acceptable performance in the anticipated future climate. To assess this a range of building types and design features were selected as case studies to provide indicators as to the design features that are likely to be most successful in coping with the effects of climate change on buildings.

The case studies included four types of dwelling, two school buildings and four office buildings. This briefing gives one example, a new-build dwelling. Novel techniques such as embodying phase change materials with the building fabric were not included, as the purpose was to examine what can be done with existing technology. For the purposes of the study it was assumed that there will not be significant changes in the level of internal gains over the time periods considered.

Figures 2, 3 and 4 show how the medium mass house can be expected to perform under the Medium-High Emissions scenario. Figure 3 indicates the increasing...
Case study: New-build house

General description: Modern four-bedroom detached house built to Part L 2002 Building Regulations standards, of approx. 140 m² treated floor area, representative of a typical new-build 'executive home'.

Orientation: The living room/main bedroom side of the building faces south.

Construction: Three types of construction considered for case studies:


Fenestration and shading: Double glazing: \( U = 1.3 \text{ W/m}^2\text{°K} \) and \( \text{sc} = 0.67 \). Glazed area of south façade of living room: 14%. No shading assumed.

Insulation: External walls: \( U = 0.3 \text{ W/m}^2\text{°K} \).

Airtightness: Background infiltration of 0.5 ACH from trickle ventilators assumed.

Thermal mass: Three cases considered — see ‘Construction’ above.

Lighting: Controlled by a special algorithm. Lights come on when daylight falls below fixed threshold but only if room is occupied and the occupants are awake.

Base-case performance

The high mass house offers better comfort conditions than the other two constructions up until the 2080s when there is little difference between them based on the exceedance data. However examination of average temperature above 28 °C, suggests better performance from the high mass construction.

Under the current ventilation strategy and internal gains the energy consumption for space heating of the high mass house is about 12% greater than for lower mass constructions.

Suggested adaptation

Winter:

- Reduce solar gains - shading devices (e.g. integral blinds, external shades)
- Improve ventilation control strategy to reduce fresh air thermal gains in summer.
- Phase change materials to enhance thermal mass (positioned in ceiling tiles, radiators, etc.)

Summer (active):

- Water-based cooling
- Domestic air conditioning
- Mechanical ventilation to obtain night cooling

Adapting to the future

The best performing passively cooled buildings have high thermal mass combined with an intelligent 24-hour ventilation strategy. In response to rising summer temperatures simple passive design measures should be considered for all buildings to reduce overheating. These simple measures or adaptation strategies should be based upon the following principles:

- Switch off: add external shade and reduce internal gains.
Case study: New-build house

Figure 2 Living room temperatures in the summer months predicted for the high and low mass cases of the new build house with 50% shade and 6 ACH controlled ventilation under the 2050s Medium-High Emissions scenario.

Figure 3 Overheating in living and sleeping areas for the medium mass cases of the new-build house under the 2050s Medium-High Emissions scenario.

Figure 4 Energy consumption and carbon emissions for the medium mass cases of the new-build house under the 2050s Medium-High Emissions scenario. Note that energy consumption only includes equipment that might be found in living areas, not cookers, washing machines, refrigerators etc. Hot water is also excluded. Carbon emissions are derived directly from the energy consumption figures.

◆ Absorb: increase mass.
◆ Blow away: introduce a ventilation strategy.
◆ Cool: introduce mechanical cooling to reduce peak temperatures.

The results from the wider report, based on the Medium-High Emissions scenario, suggest that, in relation to the temperature effects and adaptation to high temperatures in buildings, the following:

◆ The increase in external dry bulb temperature will be greater between the 2050s and 2080s than in preceding decades.
To minimise energy use for mechanical cooling heat gains need to be reduced as far as possible by the following:

— Use solar control to keep the sun out during hot days.
— Ventilation air brings heat into buildings when it is hot outside and should be reduced to a minimum during hot periods. Ventilation is a source of cooling when it is cooler outside. Strategies require secure ventilation pathways (either natural or mechanical) and may be aided by automated intelligent controls.
— Many internal gains are unnecessary: switch off lights and equipment when not required.
— Night-time ventilation coupled with closed shutters and ventilators in the daytime can produce lower internal temperatures than outside.
— Reduced heating demand due to warmer winters will to some extent offset increased carbon emissions due to energy used for cooling. For example, carbon emissions from domestic heating may fall by about 20–30% by the 2080s relative to 1989 demand. However, this is insufficient to achieve the 60 per cent reduction in carbon emissions by 2050.
— Increased use of renewable, building integrated, generation capacity such as solar, thermal, wind and photovoltaic power would reduce emissions

Overall it is concluded that with good engineering and architectural design it is possible to produce low-energy solutions that will provide acceptable space conditions into the 2080s. Design teams and clients need to work together in a holistic manner to ensure that all aspects of the buildings, including envelope, fabric, services, building management systems and operational use of the BMS and maintenance regimes function together to ensure good thermal performance with low-energy.

The results of the research also emphasise the importance of reducing carbon emissions towards the levels represented by the Low Emissions scenario.

For further information

◆ UK Climate Impacts Programme (UKCIP): helps organisations assess how they might be affected by climate change, so they can prepare for its impact. UKCIP is funded by DEFRA and based at the University of Oxford.
http://www.ukcip.org.uk
◆ University of East Anglia, Climate Research Unit: widely recognised as one of the world’s leading institutions concerned with the study of natural and anthropogenic climate change.
http://www.cru.uea.ac.uk/

CRU also has several project-related websites, including:

— European Union funded STARDEX project on ‘STAtistical and Regional dynamical Downscaling of EXtremes for European regions’.
http://www.cru.uea.ac.uk/cru/projects/stardex/
— ‘BETWIXT’: Built Environment: Weather scenarios for investigation of Impacts and eXtremes, funded by the EPSRC as part of the EPSRC/UKCIP initiative on Building Knowledge for a Changing Climate (BKCC): The impacts of climate change on the built environment.
http://www.cru.uea.ac.uk/cru/projects/betwixt/
◆ Hadley Centre for Climate Prediction and Research: part of the Met Office, providing a focus in the UK for the scientific issues associated with climate change.
◆ Tyndall Centre: a national UK centre for trans-disciplinary research on climate change, dedicated to advancing the science of integration, to seeking, evaluating and facilitating sustainable solutions to climate change and to motivate society through promoting informed and effective dialogue. It is the result of a unique collaboration between nine UK research institutions, three of the UK Research Councils (NERC, EPSRC and ESRC) and the DTI.
http://www.tyndall.ac.uk/
◆ Department of Environment, Food and Rural Affairs (DEFRA) This site provides information on climate change, what causes it, how the world and the UK could be affected, what is being done to tackle the effects of climate change, and how industry, businesses, and individuals can do their bit to reduce greenhouse gas emissions.
http://www.defra.gov.uk/environment/climatechange
◆ Intergovernmental Panel on Climate Change (IPCC) is responsible for the international scientific collaboration on the issue of climate change and its likely impacts.
www.ipcc.org

Further reading

◆ CIBSE Guide A: Environmental design
◆ Building Regulations Parts F and L and associated Approved Documents
◆ SAP 2001 and 2005 editions