UK Climate Impacts Programme

ARUP

dti

BEATING THE HEAT:

keeping UK buildings cool in a warming climate

This document was authored by Jake Hacker (Arup), Stephen Belcher (University of Reading and Arup) and Richenda Connell (UK Climate Impacts Programme). It should be referenced as:

Hacker, JN, Belcher, SE & Connell, RK (2005). Beating the Heat: keeping UK buildings cool in a warming climate. UKCIP Briefing Report. UKCIP, Oxford.

The Arup team also included Michael Holmes (Modelling Leader) and Gavin Davies (Project Director). The preparation of the report was assisted by Mark Wolfeden at Arup and Courtney Blodgett at UKCIP.

The results contained in this report are drawn from a longer technical report published by the Chartered Institution of Building Services Engineers (CIBSE): Climate Change and the Indoor Environment: Impacts and Adaptation (CIBSE TM36). The illustrations of the case study buildings in this report were provided by CIBSE. Photographs on pages 27 and 28 courtesy of MS Hacker. The work for the study was carried out by the consultants Arup working with the UK Climate Impacts Programme (UKCIP) and other stakeholders. The study was co-funded by Arup and the Department of Trade and Industry through the Partners in Innovation scheme.

Foreword

Climate change is threatening the future existence of mankind. Research and delivery of ways to avoid this catastrophe must be our primary aim. Buildings are responsible for 50% of the world's generation of CO_2. How can design mitigate this alarming statistic?

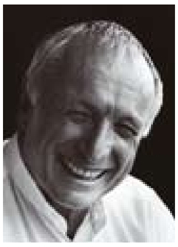
The priority is to find alternative, preferably 'natural' means of achieving benign environmental conditions. Working with the climate, rather than trying to defeat it, means accepting, for example, that architecture should respond to its location – a building in Marrakech should not be a duplicate of one in Montreal. The urgent task is to forge environmentally responsible modern architecture, to use technology to achieve beneficial ends - the ultimate aim being to achieve carbon dioxide neutral environments.

The 1970s saw a growing recognition of the enormous opportunity for a dramatic, design-liberating discipline for buildings. Today, the issue is not about 'saving energy' (or money) but about saving the planet. Finally, after decades of indifference, all those involved in the process of construction are beginning to respond to that cause. In a typical city, 47% of all energy is consumed by buildings (which generate half the total emissions of carbon dioxide), 27% by industry and 26% by transport (with the private car taking the lion's share). Since the Second World War, the crisis of the 1970s notwithstanding, commercial and public buildings in the developed world have generally become sealed, artificially-lit containers, heated in winter, air-conditioned in summer, which while meeting the requirements of low capital cost (and thus making a quick buck) are disastrous when measured against long-term sustainability. The increasingly evident threat to the global environment posed by buildings of this sort cannot be ignored.

The findings of this report indicate that there will be increasing challenges to designing a sustainable built environment over the next 100 years. Designers will require greater creative skills and better understanding of building performance to ensure that such low energy and passive buildings can continue to meet end-user needs and expectations. The good news is that this study demonstrates how passive, low energy buildings can be designed despite a likely increase in global warming over the coming century. The downside is that more passive features are likely to be needed to achieve the necessary performance.

We must endeavour to employ technologies that sustain rather than pollute, that are durable rather than replaceable, and that add value over time rather than falling prey to short term economies. Many projects have been developed that explore to a high degree the use of alternative sustainable energy solutions. Central to all discussions on sustainability issues must be the conviction that the structural and conceptual framework of modern architecture has the potential for environmental benefit and that architectural progress is not about re-styling.

The main issue is how technology is used, who controls it, and to what end.



Richard Rogers
Architect

Rich R

Photograph courtesy of Jeremy Young

Contents

Main messages

The majority of buildings in the UK are cooled in summer by opening windows.

Traditionally, this approach has prevented thermal discomfort. But summers are getting warmer because of climate change. When it is hotter outside then we want it to be inside a building, opening windows provides no real cooling benefit. Climate change means, therefore, that buildings in the UK are likely to become increasingly uncomfortable in summer unless other methods of cooling are used.

In this briefing report, the likely implications of climate change for increased thermal discomfort in existing buildings are examined through computer modelling of a number of case study buildings.

The latest climate change projections for the UK [1] were investigated for three different locations: London, Manchester and Edinburgh. These scenarios indicate that peak summer temperatures could be up to 7°C warmer than today by the 2080s. One solution to reducing uncomfortably hot indoor temperatures is wider use of air conditioning. However, this is undesirable since it will increase the energy consumption of buildings and hence the carbon dioxide ($C0_2$) emissions that are causing climate change. Here, ways in which buildings can be adapted to minimise thermal discomfort are examined with a focus on passive and low-energy methods. Further details can be found in the companion technical report CIBSE TM36 [2]. Buildings currently account for around 50% of national $C0_2$ emissions and so it is critical that low-energy solutions are found if the UK is to meet its emissions reductions targets [3].

The most successful passive cooling adaptation options identified (in approximate order of effectiveness) were:

- Shading from the sun
- Making provision for controllable ventilation during the day and high levels of ventilation at night (without compromising building security)
- Using heavier weight building materials combined with night ventilation, to enable heat to be absorbed and released into the building fabric
- Improving insulation and air tightness (e.g. cutting down on draughts) which enables undesirable heat flows to be controlled.

Passive measures can greatly reduce mechanical cooling needs. For homes in London, they have been shown to work well into the 2080s. For London's offices and schools, it is likely they will need to be supplemented by mechanical cooling from the 2050s onwards.

This is because offices and schools have high indoor "waste heating" from people, lighting, computers and other electrical appliances. One solution is to adopt a 'mixed mode' approach in which passive cooling measures are used as far as possible but mechanical cooling systems are still provided for times of need. With careful design and system management, such buildings can provide high levels of indoor comfort while still operating in a relatively energy efficient manner.

In London, it was found that increased thermal discomfort is likely to be a major problem for many existing buildings unless they are adapted for the changing climate.

In Manchester, the climate is currently significantly cooler than in London and this will continue to be the case under the climate change scenarios; thermal discomfort is therefore currently less of an issue. However, it has been found that by the 2050s, levels of thermal discomfort in buildings in Manchester are likely to be similar to those in London in the 1980s. The climate of Edinburgh is cooler still and for this location, no significant occurrences of thermal discomfort were found in the case study buildings until the 2080s. These findings indicate that significant variations will exist across the UK with regard to potential for summertime thermal discomfort. Consequently, a 'one size fits all' form of architecture will become less and less appropriate for the UK.

Thinking about climate change today when planning new developments will help to ensure a lasting legacy in the building stock by providing sustainable development for the future.

Climate change is no longer a distant threat but something we are having to live and deal with now. Delivering buildings that provide the optimal balance between high quality indoor environment and reduced carbon dioxide emissions is a challenge that is becoming increasingly important.

The decisions we make today will determine how well buildings can deliver on those objectives over their design lifetimes.

1.Introduction

Climate change is one of the most serious issues facing us at the start of the 21st century. It may come to threaten the very future of humanity as well as many natural ecosystems. The key objectives of the global effort to deal with climate change are to reduce vulnerability to climate changes through adaptation and to reduce the production of the greenhouse gas emissions that are causing climate change, particularly carbon dioxide emitted from the burning of fossil fuels. The way in which buildings are designed and used is crucially important for our ability to meet both of these objectives.

Buildings in the UK have evolved historically to provide thermal comfort in a temperate northern European climate. The preoccupation has been with winter heating and the provision of high levels of sunlight. Thermal discomfort in summer has not traditionally been much of a problem. This is because if buildings did become warm, they could be cooled effectively through ventilation with external air. However, this approach is becoming less effective because of climate change. In the last few decades, summertime temperatures have increased, with temperatures over 30°C now commonplace in South East England during summer. In 2003, temperatures in London and parts of the South East exceeded 38°C (100°F) for the first time in recorded history [Box 1]. Projections for climate change in the UK indicate that peak summer temperatures could be up to 7°C warmer than today by the latter decades of this century [1,2].

It is likely that the overheating of buildings in summer and the associated thermal discomfort will be an increasing problem because of climate change. As well as affecting the amenity of buildings, overheating is a serious health issue. During heat waves, heat stress is a major cause of mortality, particularly among the elderly [4]. While some effort can be made in the design of new buildings to take account of future climate changes, by far the majority of UK buildings, particularly dwellings, are already in existence and are likely to continue to be in use for several decades to come. A real concern is that these buildings, which are not well adapted to the new climate conditions, will come to rely on inefficient air conditioning systems to avoid thermal discomfort in summer. This will increase the carbon dioxide emissions from energy use in buildings, which are already around 50% of the UK total.

How significant will these impacts be and what options are available to keep buildings comfortably cool in the future? These questions have been investigated in recent research by the consultants Arup. This briefing report provides some of the key findings. Full details of the study can be found in the technical report: CIBSE TM36 Climate Change and the Indoor Environment: Impacts and Adaptation [2]. The study looked at eleven case

Box 1: The European heat wave of 2003

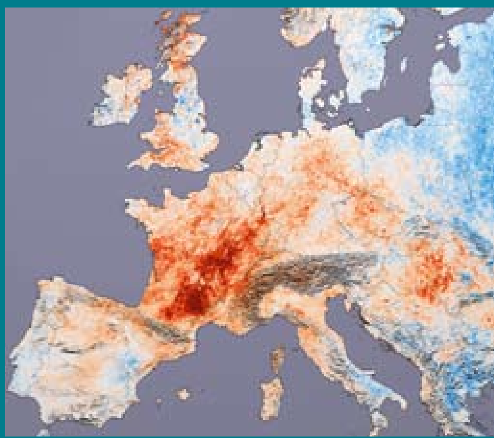


Image by Reto Stockli and Robert Simmon, NASA's Earth Observatory Team.

Figure 1: Europe seen by thermal imaging satellite at the height of the summer 2003 heatwave. The temperature anomaly against historical records exceeded 10°C in southern France. [Source: NASA. Image acquired 31 July 2003].

The European summer of 2003 was the hottest in at least 500 years. It is estimated to have been the worst natural disaster in Europe for 50 years. More than 20,000 people lost their lives as a result of heat stress, with the elderly particularly hard hit[4]. Temperatures soared all over the continent and, in the UK, topped 38°C (100°F) for the first time since records began. Climate models suggest these conditions may be the norm by the middle of this century.

study buildings including homes, offices and schools; six of the studies are included here. The buildings were modelled on a computer to see how well they would be able to limit thermal discomfort under the changing climate in the UKCIP02 Climate Change Scenarios for the United Kingdom [1]. Different ways in which the buildings could be adapted to perform better under the climate changes were also examined. Determining how best to adapt to climate change can be difficult and this study has been one of the first to use the UK Climate Impacts Programme's (UKCIP) climate change risk management framework [5] [Box 2, Figure 2] to determine how best to adapt to climate change.

Structure of the report

The main focus of this report is how to avoid summertime thermal discomfort in buildings while still minimising energy use. In Section 2, we define what comfortable means and how acceptable levels of carbon dioxide emissions are currently defined. In Section 3, we begin to look at the climate change scenarios and how they have been used. In Section 4, the features of buildings enabling them to stay cool in summer are discussed. Section 5 makes a qualitative assessment by taking a first look at the likely impacts of the projected climate changes. Section 6 presents the quantitative results of the computer modelling for the case study buildings in London. In Section 7, the results of the modelling for Manchester and Edinburgh are discussed. Section 8 discusses what we can learn from buildings in warmer climates and draws some final conclusions.

Box 2: Climate change adaptation decision making

Adaptive capacity is a term used to describe the extent to which natural and human systems will be able to cope with climate change. Increasing adaptive capacity is a central part of coping with climate change. Deciding how to best build adaptive capacity can be a difficult process because of uncertainty about how both climate and non-climate related facts will change in the future. To help decision-makers implement climate change adaptation, UKCIP, working with the Environment Agency, has published an 8-stage framework for taking account of climate risks and uncertainties[5]. The present study is one of the first to make use of the framework (Figure 2). Stages 1 and 2 emphasise the importance of clarifying objectives for a decision and agreeing decision-making criteria (e.g. criteria for thermal discomfort) before undertaking a risk assessment. The risk assessment involves understanding which climate variables have an influence and evaluating the impacts of the climate changes – for instance, in terms of how often the thermal discomfort criteria will be exceeded in the future in the various case study buildings. Adaptation measures to manage overheating risks are evaluated against the performance targets at stage 5.

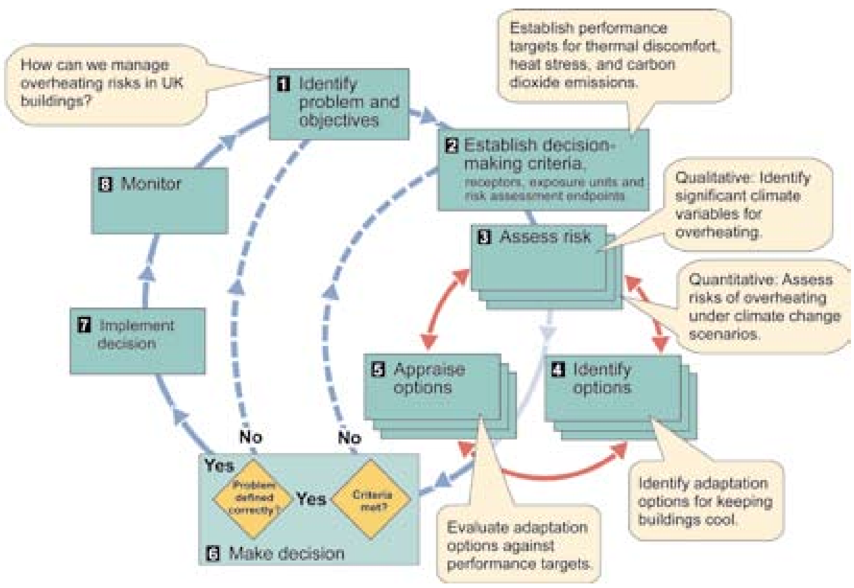


Figure 2: The UKCIP decision-making framework [5] and its implementation in the present project (summarised in the call-out boxes).

2.Performance targets

In order to make a quantitative assessment of how well the case study buildings will cope with climate change, it is helpful to first define ‘performance targets’. The important factors regarding the targets are: summertime thermal discomfort, heat stress, and energy consumption/carbon dioxide emissions.

Thermal discomfort

Different individuals have different perceptions of whether or not a room is too hot, but most people begin to feel uncomfortable between 25°C (77°F) and 28°C (82°F). In this study, two threshold temperatures for thermal discomfort were used: a ‘warm’ threshold and a ‘hot’ threshold. These thresholds are given in Table 1. Lower thresholds were used for bedrooms since people generally expect night-time temperatures to be lower and are less tolerant of higher temperatures when trying to sleep.

In this study, a building has ‘overheated’ if temperatures are above the ‘hot’ threshold for more than 1% of the time that it is occupied in any year. This criteria is close to that currently used for the design of most naturally ventilated offices and is similar (but slightly more stringent) to the current overheating standard for schools [6]. No overheating limit is currently in widespread use for homes.

Heat stress

At high temperatures, heat stress can prove fatal. Heat stress is caused by an inability of the human body to maintain its core temperature of 37°C. As well as being determined by temperature, heat stress risk is affected by high relative humidity which limits the ability of the body to lose heat through perspiration. No upper limit on acceptable building temperatures is presently specified in health and safety guidance or building regulations in the UK. Guidance from the American Society of Heating, Refrigeration and Air-conditioning Engineers recommends that 35°C is the heat stress ‘danger line’ for healthy adults when relative humidity is 50% [7]. This danger line temperature decreases by several degrees for higher humidity levels and for more vulnerable groups such as the elderly.

Carbon dioxide emissions

New and more stringent limitations on allowable carbon dioxide emissions from new and refurbished buildings will be in force from 2006 as part of building regulations [8]. For the present study, changes in carbon dioxide emissions relative to carbon dioxide emissions levels of the 1980s, rather than absolute values, have been assessed.

Thermal discomfort	‘Warm’ temperature threshold	‘Hot’ temperature threshold
Offices, schools and living areas in homes	25°C	28°C
Bedrooms in homes	21°C	25°C
	Building has ‘overheated’ if it is over ‘hot’ temperature for more than 1% of occupied hours	
Heat stress risk	Indoor temperature above 35°C (for healthy adults at 50% relative humidity)	

Table 1: Thermal discomfort temperatures and heat stress criteria used in this study.

3.Using the climate change scenarios

When a new building is designed, the local climate of the site is taken into account when establishing the heating and cooling needs of the building. The design team may also use this information to examine different options to reduce the energy use of the building as much as possible.

At the most sophisticated level, this assessment involves constructing a computer model to predict the thermal behaviour of the building and the energy consumption of its heating and cooling systems. The model is typically used to predict performance over a complete year of weather data – a so-called 'weather year'. This is the approach that has been used here to examine the case study buildings.

The type of weather year used to assess overheating risk is called a Design Summer Year or DSY. Standardised DSYs for building design are currently provided by the Chartered Institution of Building Service Engineers (CIBSE) for three locations - London, Manchester and Edinburgh [9]. For each location, the DSY is the third hottest year over the period 1976-1995 and so is representative of warm summers in the climate of the '1980s'. However, the climate has become warmer since the 1980s. What's more, the DSYs currently used by building designers do not take into account potential future climate warming.

The latest projections for climate change in the UK are the UKCIP02 climate change scenarios [1]. These scenarios give four different projections for climate change over the 21st century based on four different scenarios for greenhouse gas emissions: Low, Medium-Low, Medium-High and High emissions, over three timeslices: 2020s (2011–2040), 2050s (2041–2070) and 2080s (2071–2100). Projections for changes in monthly average weather variables are provided for each scenario on a 50km grid covering the British Isles. Figure 3 shows the historical temperatures for the UK and the UKCIP02 projections for changes to summertime average temperatures.

For the present study, future DSYs at hourly resolution were required; however, data at such short time intervals are not currently available from climate models. To deal with this problem, the UKCIP02 climate change scenarios were combined with the existing CIBSE DSYs to produced DSYs for the future. This is called 'climate morphing' [10]. The method has limitations as it assumes that the

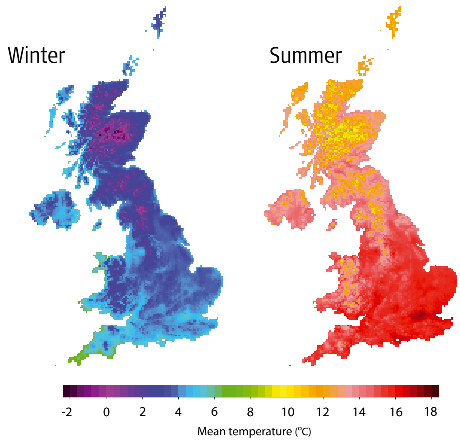


Figure 3: (a) Historical (1961-90) temperatures for the United Kingdom

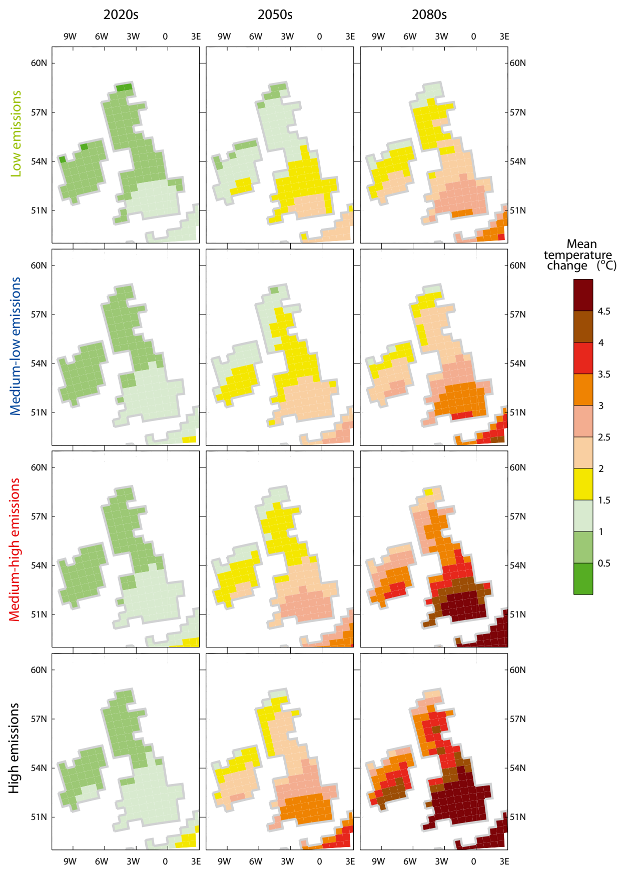


Figure 3: (b) Projected changes in average summer temperatures over the 21st century under the four UKCIP02 climate change scenarios [1].

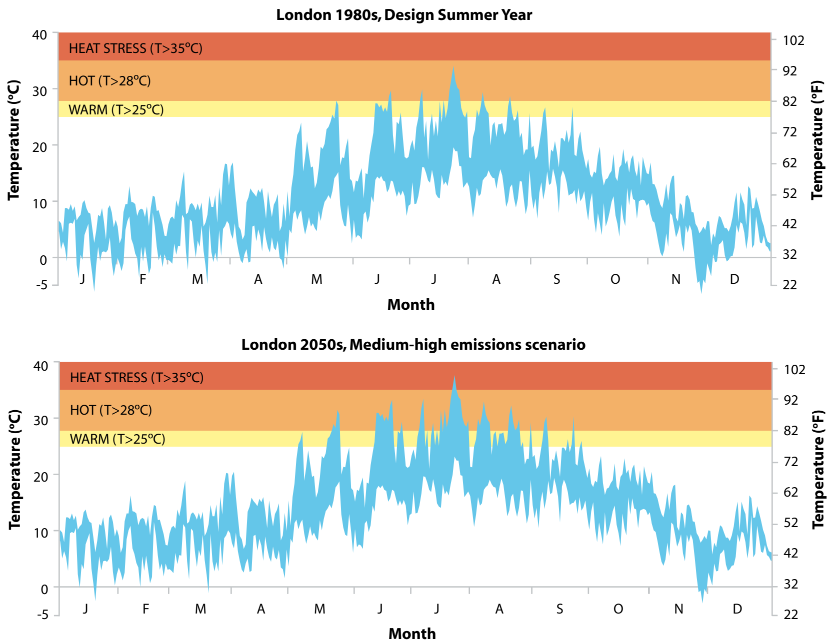


Figure 4: Daily temperature ranges in the CIBSE London Design Summer Year for the 1980s (upper panel) and 'morphed' ranges for the 2050s under the UKCIP02 Medium-High emissions scenario (lower panel).

patterns of future weather (for example the intensity and duration of heat waves) will be the same as they are today, which may not be the case. However the approach enables the impact of the changes in monthly average climate to be assessed.

Figure 4 shows daily temperature ranges in the 1980s CIBSE DSY for London and its 'morphed' future counterpart under the Medium-High emissions scenario for the 2050s. The 'warm' and 'hot' thermal discomfort threshold temperatures of 25°C and 28°C are indicated on the graphs as well as the heat stress danger line of 35°C (see Table 1).

In the 1980s, DSY maximum temperatures rarely enter the 'hot' zone, with the exception of one warm period in the middle of July, where temperatures peak at just below 34°C. At no point during the year do they enter the heat stress zone. In contrast, in the 2050s DSY, most of the summer warm spells have peak temperatures in the 'hot' zone, and the warm spell in July has peak temperatures in the heat stress zone, at just below 38°C. Also, minimum night-time temperatures are approaching the 'hot' discomfort temperature threshold defined for bedrooms (25°C), reaching 23°C in the hottest spell. Although a projection for the future, it is worth noting that the temperature ranges in the 2050s DSY July hot spell are similar to those experienced in South East England during the summer 2003 heatwave. Some of the qualitative implications of these changes for building design are discussed in Section 5.

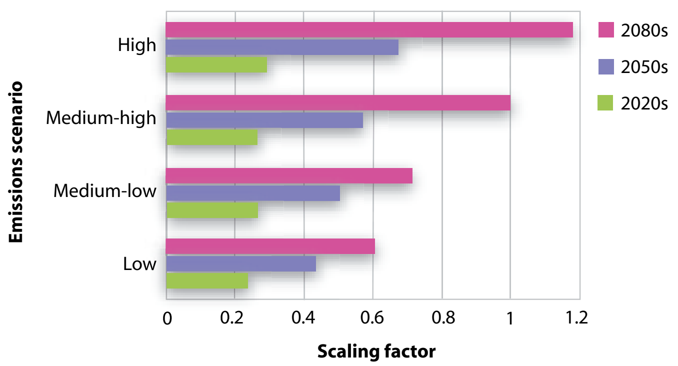


Figure 5: The 'climate scaling' factors in the UKCIP02 scenarios.

The quantitative assessments of the case study buildings that are presented in Sections 6 and 7 were all made using the Medium-High emissions scenario. However, the way in which the UKCIP02 scenarios are constructed makes it possible to make rough comparisons between the four emissions scenarios. For each scenario, the regional climate changes are obtained by multiplying those for the 2080s Medium-High scenario by a scaling factor obtained from a global climate model (Figure 5).

Although the response of the indoor environment cannot be scaled directly using the climate scaling factors (technically, because the response of the buildings is 'non-linear'), they provide an indication of the differences between scenarios. For example, the changes for the 2020s are of a similar magnitude in all four emissions scenarios and the Low emissions 2080s is very similar to the Medium-High emissions 2050s (Figure 5).

4.Building design issues

The temperature of a room is established by a combination of natural flows of heat, related to the external climate, and indoor heat inputs which are not directly related to external climate (Figure 6). 'Passive design' involves optimising these heat flows to make the best use of the external climate [Box 3]. The important aspects of the design of a building are described below. For the climate-related design issues, the relevant climate factors are shown in brackets.

Climate related design issues

Glazing (sunshine): Sunshine entering a room warms up surfaces, producing radiant heat. This heat then becomes trapped in the room by the windows because glass is an effective absorber of infrared radiation. Unshaded windows are therefore a major source of heat build-up in buildings.

Ventilation (temperature, humidity and wind speed): Ventilation is one of the most fundamental needs of a building – it maintains the indoor air quality necessary for health and well being. It also constitutes one of the largest heat flows. In winter, ventilation is usually kept to a minimum to reduce the need to heat cold air coming in from outside. In summer, ventilation is usually thought of as a source of cooling. However, this is only the case when the outside air is cooler than the air inside the building; otherwise, ventilation becomes a heating source. Ventilation also has a major role in determining the indoor humidity, which, as was discussed in Section 2, has an effect on thermal discomfort and heat stress at higher temperatures. Wind speed also provides a natural driving force for ventilation.

Thermal mass (temperature): Heavier weight building materials, such as concrete and stone, have a tendency to exchange significant amounts of heat with the inside air. This is called the 'thermal mass' effect. It causes the indoor daily temperature variation to be less than that of the outside climate. This effect is one of the reasons why the inside of a high thermal mass building, such as a church, feels cool even on a very hot day. Thermal mass has the beneficial effect of reducing peak indoor temperatures but can also have the negative effect of keeping a building warmer at night. For this reason, to be effective at moderating temperature, thermal mass needs to be combined with night ventilation to remove heat absorbed during the day.

Insulation (temperature and sunshine): Insulation in buildings plays an important role in reducing heat loss in winter by trapping heat inside. In summer, it can have two effects: a beneficial one of preventing heat entering the building during the day and a negative one of preventing heat escaping at night. In summer, insulation can also have the beneficial effect of preventing the heat that builds up in the building's external façade as the sun shines on it reaching indoors.

Air tightness (temperature and wind speed): All buildings have a natural tendency to exchange air with their outside surroundings through draughts and small cracks in the building fabric. This is called 'infiltration' and has a similar affect on heat flows as a lack of insulation. Infiltration is controlled by increasing the building's 'air tightness'.

Non-climate related design issues

Waste heat: Modern buildings often have significant inputs of 'waste heat' from people, computers, lighting and other electrical equipment.

Heating systems: Nearly all buildings in the UK have a heating system, typically gas-fired central heating. In buildings with modern standards of insulation and air tightness, trapped waste heat can substantially reduce the demand on the heating system.

Cooling systems: The natural sources of cooling in a building are typically only ventilation and thermal mass. These factors cannot be guaranteed to keep buildings cool all year round, particularly in warmer climate conditions. For this reason, many buildings make use of mechanical cooling systems. The most common type of cooling system is refrigeration based air cooling ('air conditioning'), but there are also other more energy efficient options available, such as water cooled ceilings or beams [12].

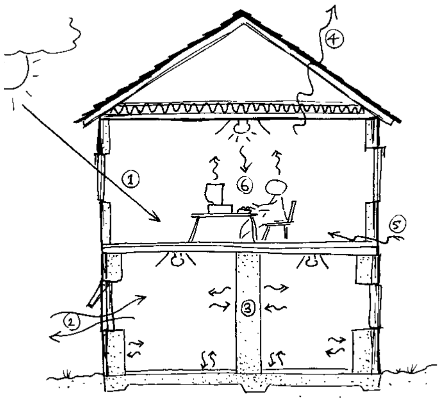


Figure 6: Schematic of heat flows in buildings.

5.Qualitative risk assessment

From the discussions of the elements of building design affecting the indoor environment in the previous section and of the projected climate changes in Section 3, it is possible to carry out a qualitative assessment of the likely impacts of climate change without carrying out detailed computer modelling.

As indicated in Section 4, the most important climate variables affecting the indoor environment are temperature, sunshine, humidity and wind speed. Of these variables, the greatest change in the UKCIP02 projections is in temperature. It is therefore possible to largely 'screen out' the other climate variables as being relatively unimportant for the qualitative risk assessment. This is not to say that they are not important factors, but that their role will be largely unchanged from that today. What then will be the main effects of the increases in temperature?

As discussed, the main 'passive' method for cooling buildings is ventilation, for example, opening windows. If very high ventilation rates are possible, the best that this approach can achieve is to make the indoor temperature equal to the external temperature. From the discussion of the temperature changes in Section 3 (Figure 4), it is evident that over the next century, there is likely to be a substantial increase in the proportion of the year that a building relying only on cooling for ventilation will experience 'hot' and heat stress risk temperatures.

The other 'passive' method of cooling that has been discussed is thermal mass heat storage coupled with night ventilation. In the absence of sunshine and any waste heat inputs, the best that this approach can achieve is to make the internal temperature close to the average daily temperature (usually mid-way between the maximum and minimum daily temperatures). From Figure 4, it is evident that achieving the average daily temperature will on the whole keep the building out of the 'hot' thermal discomfort zone. There is considerable potential, therefore, for this approach to work well under the future climates. In general, there will be other heat inputs to the inside of the building – from the sun and indoor waste heat sources – so the success of this approach is dependent on the extent to which these heat sources can be minimised.

When the passive approaches have failed to keep the building out of the thermal discomfort zone, the only alternative is to make use of some form of mechanically-assisted cooling system. Warmer summer temperatures will mean that the cooling system installed needs to work harder, thereby increasing energy consumption and the carbon dioxide emissions from the building. Conversely, in winter, increased temperatures will lead to a decrease in winter heating needs, which may to some extent offset the increase in cooling energy consumption.

Box 3: Passive design

In some climates it is possible to make buildings that are essentially self heating and self cooling by controlling the natural heat flows. This is called 'passive design'. Traditional buildings around the world make use of passive design principles, from the sheltering and insulating properties of an igloo to the very high thermal mass traditional buildings of desert regions, to improve indoor comfort conditions. Using passive design principles helps create low-energy consumption buildings because the need for mechanical heating and cooling systems is reduced.

6. The case studies

The quantitative assessments of the case study buildings made using computer modelling are described in this section. The case study buildings are:

- 19th century house
- New build house
- 1960s office
- Advanced naturally ventilated office
- 1960s school
- Advanced naturally ventilated school.

While the case studies are not intended to represent actual existing buildings, they are realistic and are representative of much of the current UK building stock.

The output provided by the computer modelling is hourly values of indoor temperature in each room and a prediction for the energy consumption of the heating, ventilation and cooling systems. From the energy consumption predictions, carbon dioxide emissions can be calculated using an assumed mix of fuel types. The assumption made here is that heating systems use natural gas and all other services use mains electricity. The carbon dioxide emissions per unit of delivered energy for mains electricity are currently around three times those of natural gas used for on-site heating, due to the inefficiencies of the electricity generation and supply processes [11]. In each case, the models were run for the 'baseline' 1980s as well as the 2020s, 2050s and 2080s, as described in Section 3.

For each case study, the building was modelled in two different ways. The first case, 'as built,' represents the building as it was originally designed and is likely to be used currently. The second case, 'adapted', represents the building as it might exist when adapted to improve its performance under the climate change scenarios.

The results of the computer models for each case study are presented as 2 page 'data sheets'. The full results are shown in the graphs with key facts highlighted in the text. The first page of each data sheet presents the results for the 'as built' case and the second (facing) page presents the results for the 'adapted' case. For both cases, the results are for the Medium-High emissions scenario for London. They are presented in the following way:

Thermal discomfort temperatures: the fraction of hours in the design year for which indoor temperatures go over the discomfort temperature thresholds (Table 1).

Extreme temperatures: the number of hours that extreme indoor temperatures occur, for comparison with the heat stress risk threshold of 35°C (Table 1).

Carbon emissions: the percentage change in carbon dioxide emissions relative to the 1980s 'as built' case. For each case study, carbon dioxide emissions from lighting and computers are also shown. [Note that throughout the data sheets we have used 'carbon emissions' as shorthand for carbon dioxide emissions].

19th century house

As built

Building description

This is a family house constructed in the late 19th century, typical of many towns and cities in the UK. The house has four bedrooms and is semi-detached. It has a brick and render façade and a slate roof. The building is poorly insulated, with solid wall construction and single-glazed windows. It also has poor air tightness leading to relatively high air infiltration (draughts). The building is 'medium weight' in terms of its thermal mass.

Heating is provided by gas-fired central heating. Ventilation is provided by opening windows. There is no mechanical cooling system. When it becomes warm inside the building in summer, the occupants open windows to encourage ventilation. In the computer model, occupants begin to open windows when temperatures reach 22°C. All the windows are fully open by the time the indoor temperature has reached 28°C. To address security concerns, the windows in individual rooms are closed when they are not occupied.

Indoor temperatures

During the summer, the 'warm' and 'hot' discomfort temperatures are often exceeded. In the living room, the percentage of occupied hours over the 'hot' threshold temperature of 28°C is 2% in the 1980s and 13% in the 2050s (Figure 7a). For the bedroom, the percentage of occupied hours over the 'hot' threshold temperature of 25°C is 7% in the 1980s and 18% in the 2050s. This compares poorly to the 1% overheating limit. Peak temperature in the living room is 32°C in the 1980s and 36°C in the 2050s, putting that room into the heat stress zone. Peak temperatures in the bedroom are similar to those in the living room (Figure 7c).

The failure of the building to regulate indoor temperatures is a consequence of a number of factors but particularly the lack of shading from the sun and poor control of ventilation. These factors are addressed in the 'adapted' case.

Figure 7a: Discomfort temperature

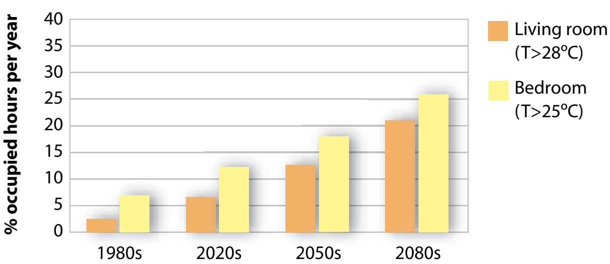


Figure 7b: Extreme temperatures: Living room

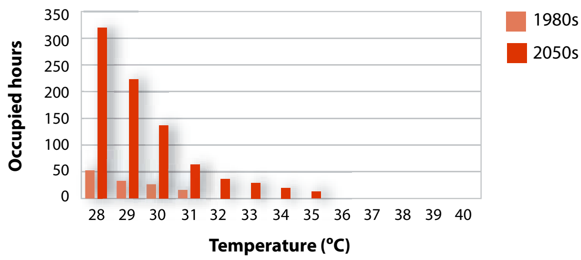
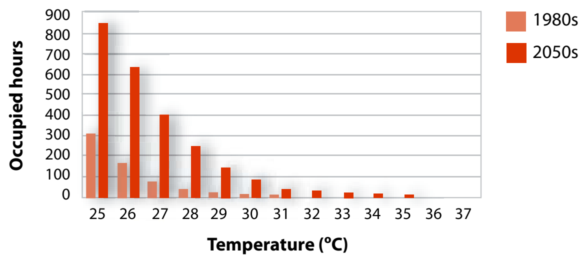


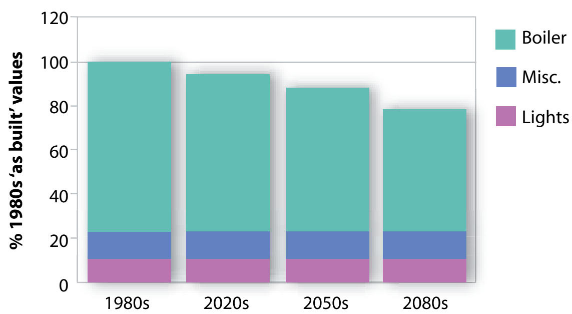
Figure 7c: Extreme temperatures: Bedroom



Carbon emissions

Heating energy consumption is relatively high due to the poor insulation and air tightness. Carbon emissions from heating dominate the other contributions, constituting 70% of the total emissions in the 1980s. Heating energy reduces, as external temperatures rise, by around 15% from the 1980s to the 2050s (Figure 7d).

Figure 7d: Carbon emissions



19th century house

Adapted

Specification

1) Solar shading: external blinds or shutters capable of screening out 95% of sunlight during the day.
2) Ventilation: a secure means of ventilation, capable of providing ventilation rates similar to those provided by opening the windows. Here, it is assumed the ventilation system is mechanical, but it could potentially use natural ventilation. The system is automatically controlled to maximise the cooling potential from outside air. The ventilation system provides maximum ventilation whenever indoor temperatures are above 24°C and above the outside temperature (e.g. when the outside air provides cooling benefit). The maximum ventilation rate is assumed to be 6 room air changes per hour. At other times, a minimum ventilation rate is provided. The minimum ventilation rate that is necessary to ensure good air quality is assumed here to be 0.5 room air changes per hour.

Indoor temperatures

The adaptation measures considerably reduce the proportion of hours in which the discomfort temperatures are exceeded. For example, in the 2050s, the proportion of hours exceeding the 'hot' thresholds is reduced in the bedroom from 18% to 6% and in the living room from 13% to 3%. However, the 1% overheating limit is exceeded from the 2020s onwards in the bedroom (3% exceedance) and from the 2050s onwards in the living room (Figure 7e). The adaptation measures have a limited effect on reducing peak temperatures, which are decreased by about 1°C from those in the unadapted case, to 34°C in the living room (Figure 7f) and 33°C in the bedroom.

Figure 7e: Discomfort temperature

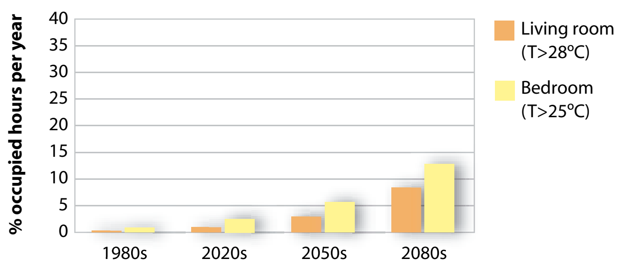
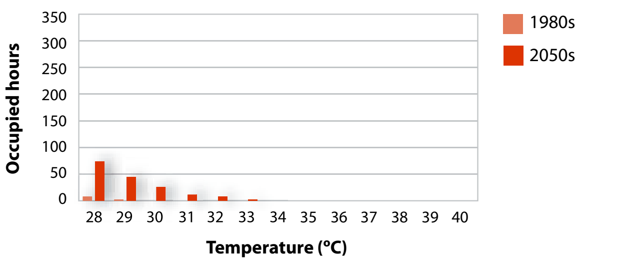


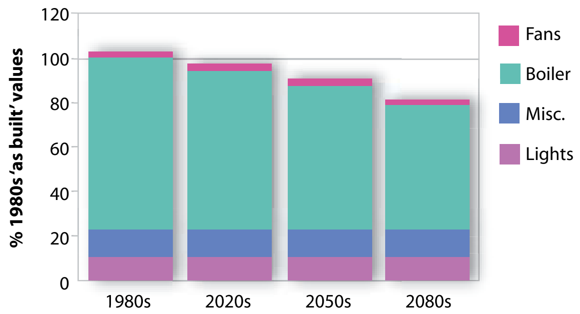
Figure 7f: Extreme temperatures: Living room



Carbon emissions

The adaptation measures are only applied during the summer and so have no affect on heating energy. In summer, additional energy is required to power the fans for the ventilation system. The predicted energy consumption of the fans is relatively small, but the calculation is sensitive to the details of the system; for example, the energy consumption could be substantially higher if smaller ventilation ducts and larger fans were used. If the ventilation system was implemented using natural ventilation only, there would be no additional energy consumption (Figure 7g).

Figure 7g: Carbon emissions

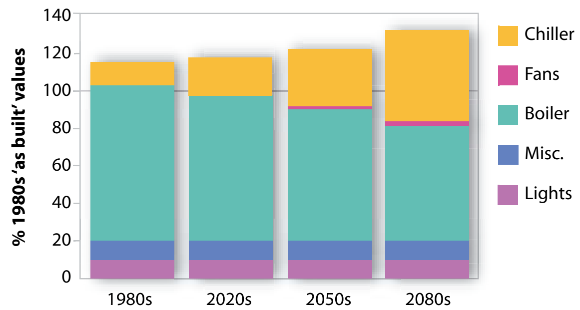


The price of air conditioning

The house could alternatively be kept cool using air conditioning. This scenario has been modelled by assuming a whole-house air conditioning system which comes into operation when space temperatures exceed 25°C. Once in operation, the system acts to limit temperatures to 23°C. The system modelled is a 'split system' which acts to cool room air but does not provide ventilation (this is assumed to still be provided by natural means).

The price of using the chiller is the high carbon emissions. This increase in emissions more than offsets the reduction in emissions resulting from less winter heating. For the 1980s climate, the air conditioning system results in a 14% increase in total emissions from the building, rising to 20% by the 2050s and 30% by the 2080s (Figure 7h).

Figure 7h: Carbon emissions with chiller



New build house

As built

Building description

This is a newly constructed family house. The house has four bedrooms and is detached. It has a brick façade and a slate roof. The building has good insulation and air tightness, meeting the 2002 Building Regulations standards. The windows are double glazed and the walls have cavity insulation. The inner walls are made from concrete blocks. The thermal mass of the building is 'medium weight'.

Heating is provided by gas-fired central heating and ventilation by opening windows. There is no mechanical cooling system. When it becomes warm inside the building in summer, the occupants open windows to encourage ventilation. The assumptions made regarding window operation are as for the 19th century house.

Indoor temperatures

During the summer, temperatures often exceed the 'hot' discomfort temperature threshold. In the living room, the percentage of occupied hours over 28°C is 1% in the 1980s and 7% in the 2050s (Figure 8a). In the bedroom, the percentage of occupied hours over 25°C is 11% in the 1980s and 23% in the 2050s.

The level of exceedance of the discomfort temperature in the living room is significantly lower than in the 19th century house, but in the bedroom is significantly higher. The good insulation and air tightness in the 'new build' case mean that heat is kept out more effectively during the warmer parts of the day but is retained at night. Otherwise, the reasons for the failure of the building to regulate indoor temperatures are as in the 19th century house: the lack of shading from the sun and poor control of ventilation.

Peak temperatures in the living room are up to 33°C in the 1980s and 36°C in the 2050s, which is about 1°C warmer than in the 19th century house; this again puts that room in the heat stress zone. Peak temperatures in the bedroom are around 2°C lower than the living room in both timeslices (Figures 8b and 8c).

Figure 8a: Discomfort temperature

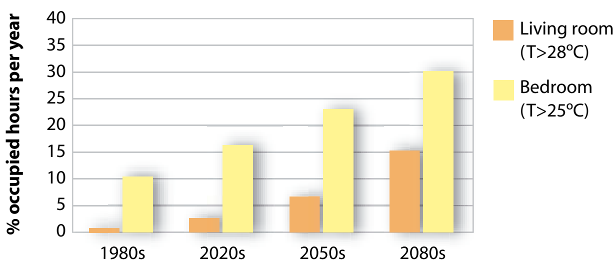


Figure 8b: Extreme temperatures: Living room

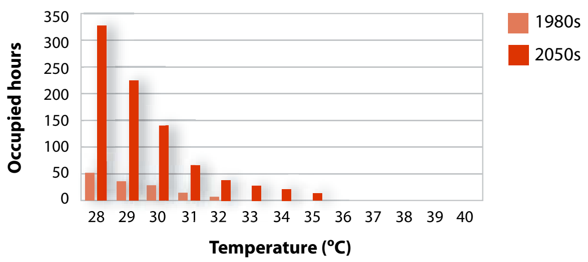
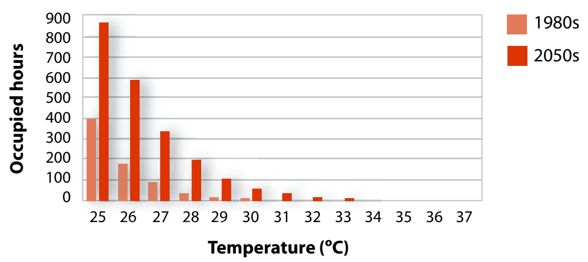


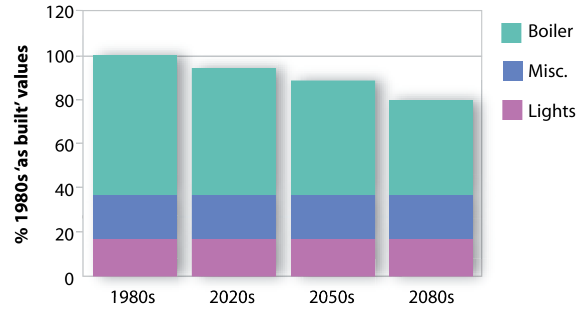
Figure 8c: Extreme temperatures: Bedroom



Carbon emissions

Heating energy consumption is less than in the 19th century house and constitutes a smaller, although still the major, portion of overall emissions. Heating energy reduces by around 18% from the 1980s to the 2050s.

Figure 8d: Carbon emissions



New build house

Adapted

Specification

This building is adapted using shading and automated ventilation control as in the 19th century house 'adapted' case.

For new dwellings, an additional adaption option is to increase the thermal mass of the fabric. This is not examined here, but in CIBSE TM36 [2] it is shown how this option can provide further passive cooling.

Indoor temperatures

These adaptation measures are more successful in limiting indoor temperatures than in the case of the 19th century house due the better insulation and air tightness which reduce the size of the uncontrolled heat flows. The performance target (not more than 1% of the year over the discomfort temperatures) is now met in the 1980s and 2020s in both the bedroom and living room and is failed only marginally in the 2050s for the bedroom (2% exceedance increasing to 5% by the 2080s) and in the 2080s for the living room (also 2% exceedance) (Figure 8e). Peak temperatures in the 1980s are 26°C in the bedroom and 27°C in the living room (Figure 8f) and in the 2050s, 27°C and 30°C, respectively, in the two spaces.

Figure 8e: Discomfort temperature

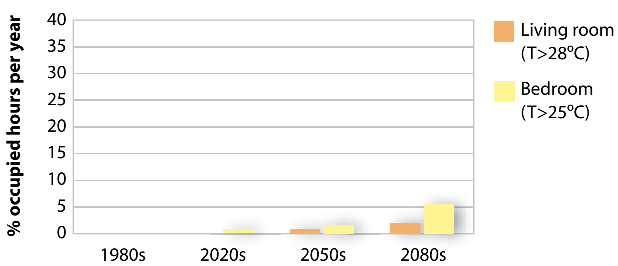
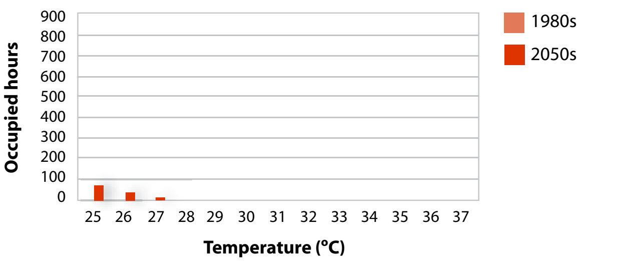


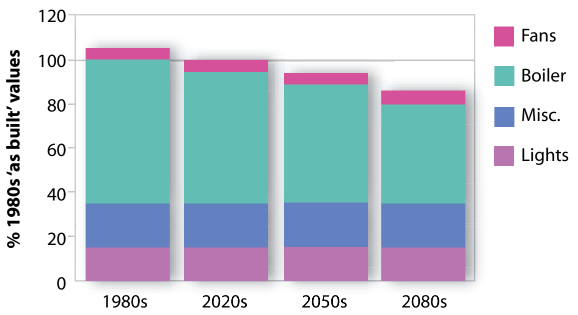
Figure 8f: Extreme temperatures: Living room



Carbon emissions

The adaptation measures are only applied during the summer and so have no effect on heating energy (Figure 8g). In summer, additional energy is required to power the fans for the ventilation system. The predicted energy consumption of the fans is relatively small, as in the 19th century house, but again the calculation is sensitive to the assumptions made regarding the system. If the ventilation system was implemented using natural ventilation only, there would be no additional energy consumption.

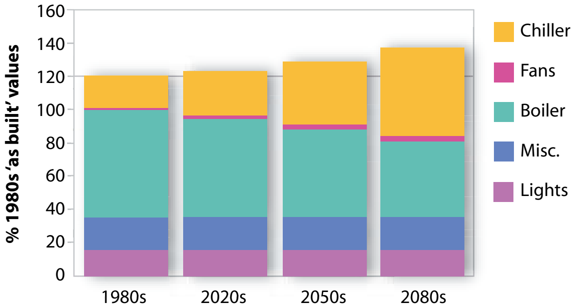
Figure 8g: Carbon emissions



The price of air conditioning

A 'whole-house' air conditioning system was modelled using the same assumptions as for the 19th century house. Again, the carbon emissions from the chiller more than offset the reduction in emissions resulting from less winter heating. Although the absolute amount of cooling energy required is less than for the 19th century house, the proportional increase is larger. For the 1980s climate, the air conditioning system results in a 20% increase in total emissions from the building, rising to 29% by the 2050s and 37% by the 2080s (Figure 8h).

Figure 8h: Carbon emissions using chiller



1960s office

As built

Building description

This building is a medium sized 3-storey office building, typical of many offices built in the 1960s and 1970s. It has poor insulation and air tightness. It has single glazed windows and is constructed of relatively lightweight building materials.

Heating is provided by gas-fired central heating and ventilation is provided by opening windows. There is no mechanical cooling system. When it becomes warm inside the building, it is assumed that occupants will open windows. In the computer model, the occupants begin to open windows when the indoor temperature reaches 22°C. By the time the indoor temperature has reached 28°C, all the windows are fully open. For security reasons, the windows are shut at night.

Indoor temperatures

During the summer, temperatures often exceed the 'warm' and 'hot' discomfort temperatures of 25°C and 28°C. The percentage of occupied hours over 28°C for the building as a whole is 6% in the 1980s, 10% in the 2020s and 16% in the 2050s (Figure 9a). The 1% overheating limit is greatly exceeded therefore in all timeslices. The top floor is predicted to be the warmest part of the building and there, peak temperatures are 34°C in the 1980s, 35°C in the 2020s (not shown) and 37°C in the 2050s, putting that floor into the heat stress zone from the 2020s onwards (Figure 9c).

The inability of the building to limit indoor temperatures is principally a consequence of the high waste heat inputs (from occupants, lights and computers) and the lack of shading from the sun. The 'as built' building relies solely on ventilation to dissipate these heat gains.

Figure 9a: Discomfort temp: Building average

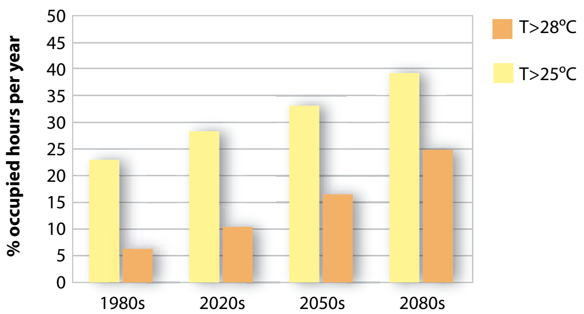


Figure 9b: Extreme temp: Ground floor

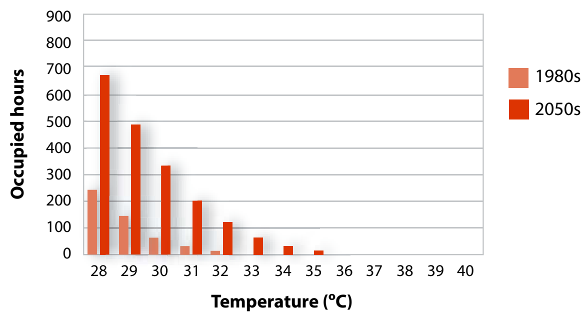
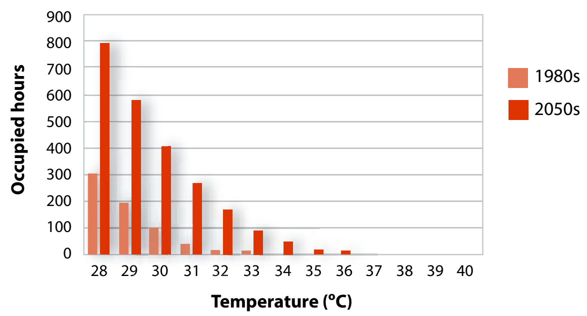


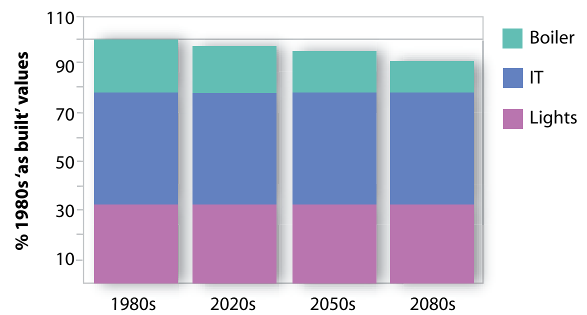
Figure 9c: Extreme temp: Top floor



Carbon emissions

The overall carbon emissions are dominated by the emissions from lighting and IT equipment. Heating energy decreases over the timeslices, as temperatures rise, with a reduction of 22% between the 1980s and 2050s. The net decrease in carbon emissions between the 1980s and 2050s is 6%. The heating energy consumption of the building is relatively high, due to the poor insulation and high infiltration (Figure 9d).

Figure 9d: Carbon emissions



1960s office

Adapted

The performance of the 'as built' building is poor and worsens through time. The building requires major adaptation. The existing structure of the building means that adaptation to an advanced passive mode of operation (see Advanced naturally ventilated office case study) would be difficult without major structural alterations. As a practical alternative, a mixed-mode strategy is proposed. This is an approach currently used for many new offices in Europe.

Specification

1. Improve the building's envelope by upgrading windows to double glazing.
2. Increase fabric insulation and air tightness to the 2002 Building Regulations standards.
3. Introduce solar shading to enable a 50% reduction in transmitted sunlight.
4. Expose the thermal mass in the concrete floor slabs by removing suspended ceilings.
5. Introduce automatically controllable mechanical ventilation via an underfloor air supply system.
6. In summer, use the ventilation system for night-cooling.
7. In winter, reclaim heat from the exhaust air in the ventilation system to help heat the incoming ventilation air.
8. Introduce water-chilled beams to provide additional cooling, operating when temperatures exceed 25°C.

Indoor temperatures

The indoor temperature of the building in summer is substantially improved by the adaptation measures. The performance target is easily met in all timeslices up to the 2080s with no incidences of temperatures above 28°C (Figure 9e). Some incidences of temperatures between 25°C and 28°C occur for an hour or two while the cooling system takes effect.

Figure 9e: Discomfort temp: Building average

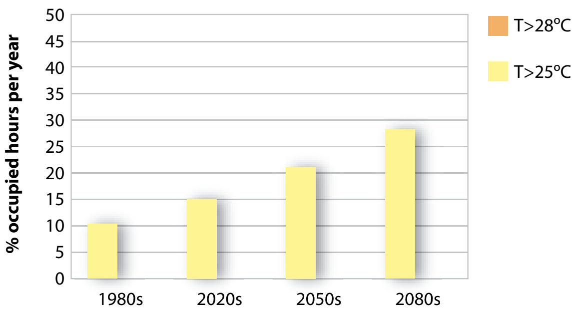
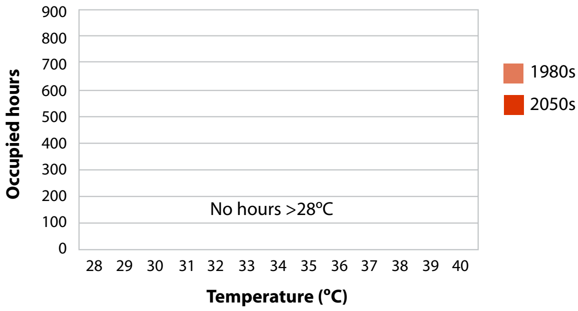
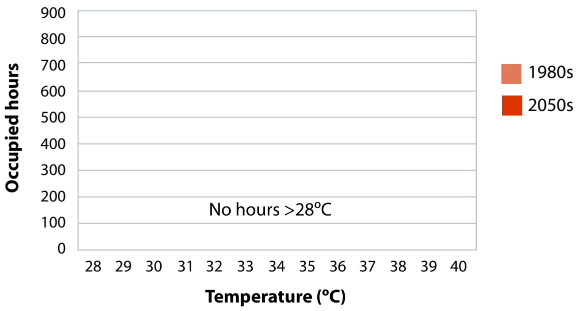


Figure 9f: Extreme temp: Ground floor



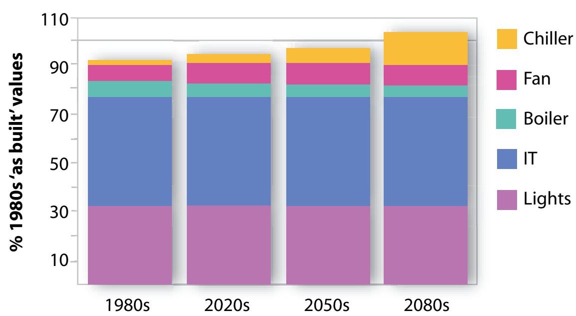
Carbon emissions

Figure 9g: Extreme temp: Top floor



Upgrading the building envelope and introducing heat reclaim reduce the heating energy substantially. Overall carbon emissions in the 1980s are around 10% less than the unadapted 'as built' case, despite the use of the mechanical ventilation and cooling system. The mechanical systems do, however, carry a significant carbon emissions premium which increases through time as the external temperature rises. The total fan and chiller energy consumption in the 2050s is nearly twice that in the 1980s. By the 2050s, overall emissions have almost reached the 1980s 'as built' level (Figure 9h).

Figure 9h: Carbon emissions



Advanced naturally ventilated office

As built

Building description

This is a medium sized 3-storey office building with passive features: fixed external shading, advanced natural ventilation via ventilation stacks and thermal mass in heavyweight ventilated floor slabs. On the top floor, the roof, being of timber construction, is thermally lightweight. The building has good insulation and air tightness, meeting the 2002 Building Regulations standards.

Heating is providing by gas-fired central heating. Ventilation is provided by the advanced natural ventilation system. Cooling is providing through a combination of daytime ventilation control, thermal mass heat absorption and night cooling by ventilation. The natural ventilation system has an automated control to maximise the benefit of cooling which is similar to that described for the two adapted houses but with a separate set of rules to control night cooling.

Indoor temperatures

For the building as a whole, the design target (of not more than 1% of occupied hours over 28°C) is met in the 1980s. The building fails only marginally in the 2020s (1.5% exceedance) and by a larger amount in the 2050s (3.6% exceedance) (Figure 10a). However, there is a large variation between the relatively heavyweight ground and intermediate floors and the top floor. The ground floor only marginally fails the design criteria in the 2050s (1.2% exceedance), whereas the upper floor fails quite badly in the 2050s (8.4% exceedance). Peak temperature in the 2050s is 31°C on the ground floor and 34°C on the top floor (Figure 10c).

Figure 10a: Discomfort temp: Building average

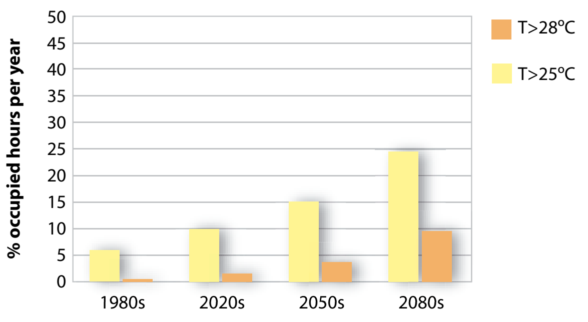


Figure 10b: Extreme temp: Ground floor

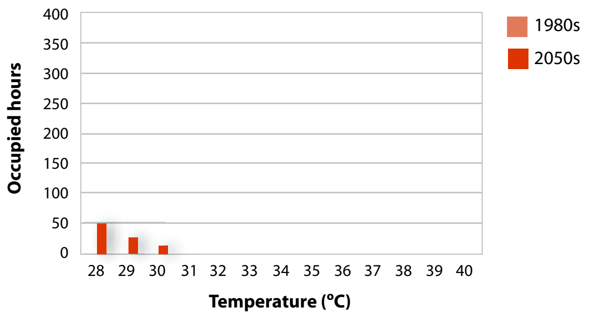
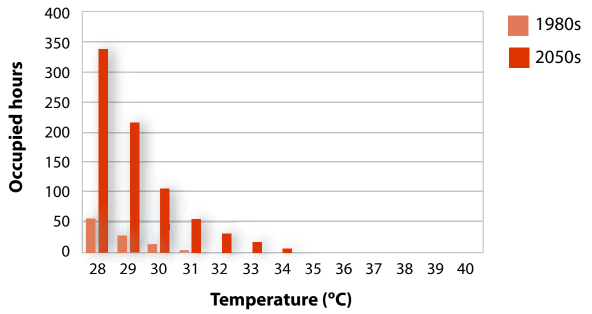


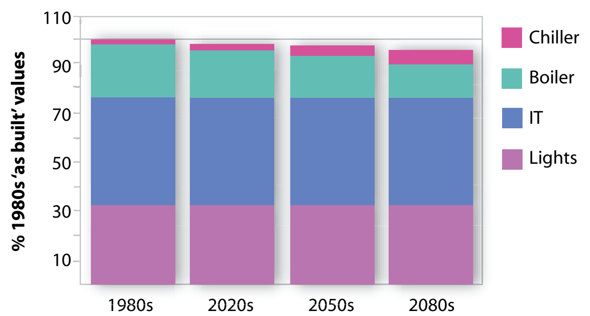
Figure 10c: Extreme temp: Top floor



Carbon emissions

The heating energy of the building is relatively high, being similar to that of the 1960s office. In part, this is due to the heating energy needed to heat the high mass fabric up to room temperature and, in part, because in the model it was assumed that there is uncontrolled infiltration through the natural ventilation system in winter. Both of these factors are known to be potential problems in high mass advanced naturally ventilated buildings. However, these issues can be addressed (see 'adapted' case) and the winter heating energy premium is offset by the good passive summertime thermal performance.

Figure 10d: Carbon emissions



Advanced naturally ventilated office

Adapted

The top floor of the unadapted building performs relatively badly as it has little in the way of active thermal mass, due to the lightweight roof. This problem could be addressed by replacing the existing roof with a thermally heavyweight structure. This is likely to be expensive and could affect the structural integrity of the building. However, for a new building, including a high mass ceiling on the top floor would be a beneficial design modification.

The adaptation option investigated here is to add mechanical cooling through the use of chilled beams.

Specification

There are water-cooled 'chilled beams', in all spaces, which come into operation when indoor temperatures exceed 25°C.

Indoor temperatures

This strategy is effective at keeping space temperatures below 28°C until the 2080s though some hours over 25°C do occur when the cooling system is taking effect (Figure 10e).

Figure 10e: Discomfort temp: Building average

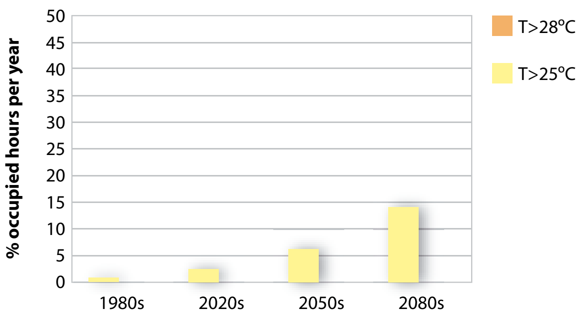


Figure 10f: Extreme temp: Ground floor

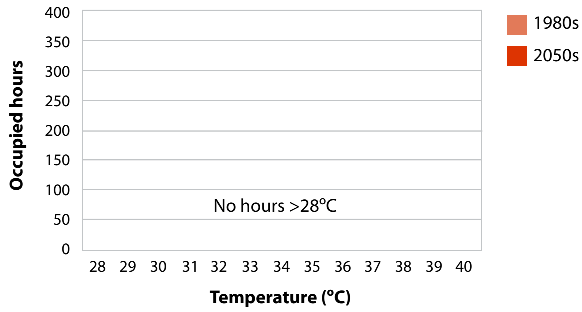
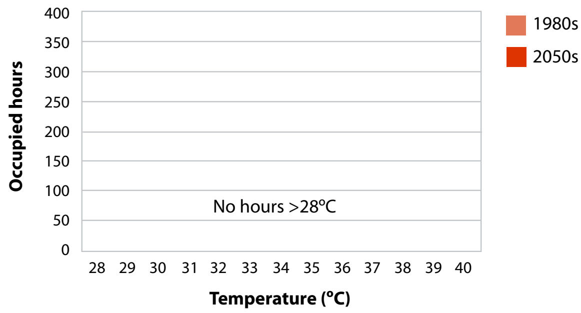


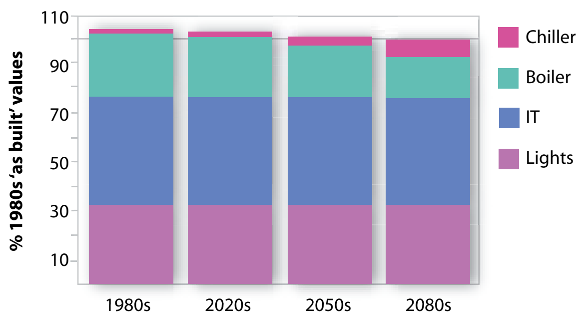
Figure 10g: Extreme temp: Top floor



Carbon emissions

The predicted carbon emissions associated with the energy use of the cooling system are relatively low compared to the emissions from other sources (Figure 10h). It should be stressed this is because the very good passive features of the building limit the overall cooling needs.

Figure 10h: Carbon emissions



1960s school

As built

Building description

This is a single storey primary/junior school with a flat roof, typical of 1960s and 1970s construction. There are eight classrooms situated on either side of a central corridor which face east and west. The windows are single glazed and the insulation and air tightness is poor. The building is relatively lightweight in terms of its thermal mass.

The building is heated by gas-fired central heating. Ventilation is provided by opening windows, using similar assumptions to the 'as built' cases in the 1960s office and houses. There is no cooling system.

Indoor temperatures

During the summer, indoor temperatures exceed the 'hot' discomfort temperature of 28°C by a large amount in all timeslices. In fact, indoor temperatures are often higher than the outside temperatures in summer. The percentage of occupied hours over 28°C in the building is 14% in the 1980s and 23% in the 2050s (Figure 11a). Peak temperatures in west facing classrooms are 37°C in the 1980s and 43°C in 2050s (Figure 11c). This puts the building in the heat stress zone even in the 1980s climate.

The inability of the building to limit indoor temperatures is principally a consequence of the high heat gains to the building (from the lack of shading from the sun and the heat generated by occupants, lights and computers) and the lack of means to remove or dissipate this heat (due to the 'lightweight' building form, lack of ventilation control during the day and lack of ventilation at night to cool the building fabric). The flat roof combined with the poor insulation also contribute to the temperature problem.

Figure 11a: Discomfort temp: Building average

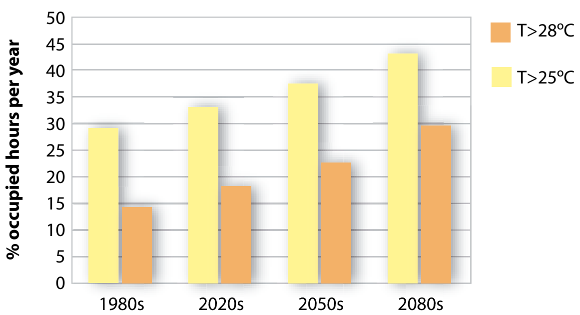


Figure 11b: Extreme temp: East facing

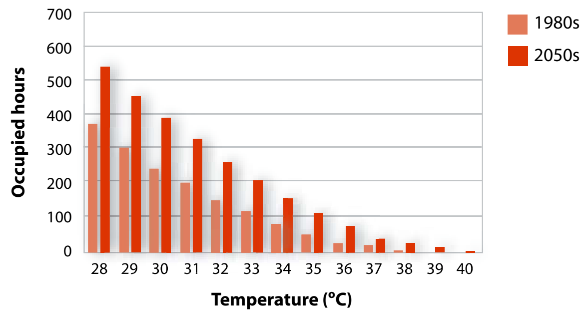
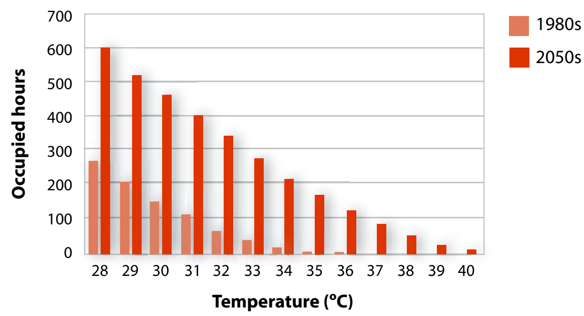


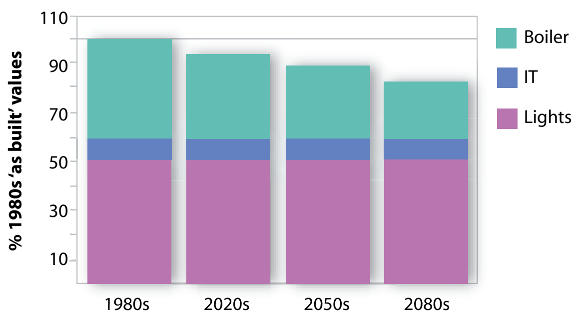
Figure 11c: Extreme temp: West facing



Carbon emissions

The carbon emissions from heating energy are relatively high, due to the poor insulation and high infiltration. Heating energy reduces over the timeslices, with a reduction of 25% between the 1980s and 2050s. The largest contribution to carbon emissions is lighting, which accounts for over half of the overall carbon emissions in the 1980s. The net decrease in carbon emissions between the 1980s and 2050s is 11%, due to the reduced need for heating.

Figure 11d: Carbon emissions



1960s school

Adapted

To upgrade the building to modern standards of insulation and air-tightness would require a major retrofit with it being likely that complete demolition and rebuilding would be necessary. As an interim measure, however, solar shading could be added to reduce the heat gains to the classrooms.

Specification

There is solar shading capable of reducing transmitted sunlight by 90% (note that the lights are left on).

Indoor temperatures

The percentage of the time that the discomfort temperatures are exceeded is much reduced compared to the 'as built' case. For the building as whole, the percentage of hours over the 'hot' discomfort temperature is reduced from 14% to 5% in the 1980s and from 23% to 13% in the 2050s. Peak temperatures are also reduced significantly, for the west facing classrooms from 37°C to 34°C in the 1980s and 43°C to 38°C in the 2050s (Figure 11g). These levels of overheating and peak temperatures are still likely to be unacceptable, however.

Figure 11e: Discomfort temp: Building average

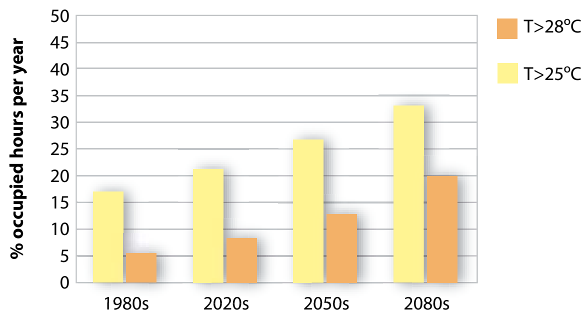


Figure 11f: Extreme temp: East facing

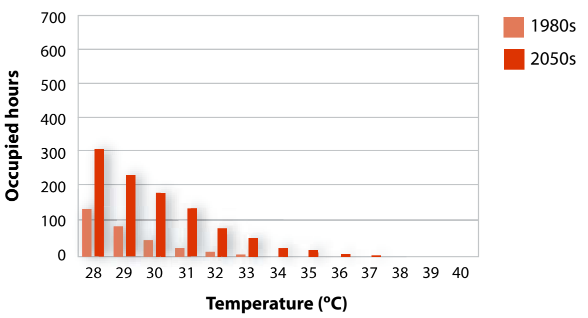
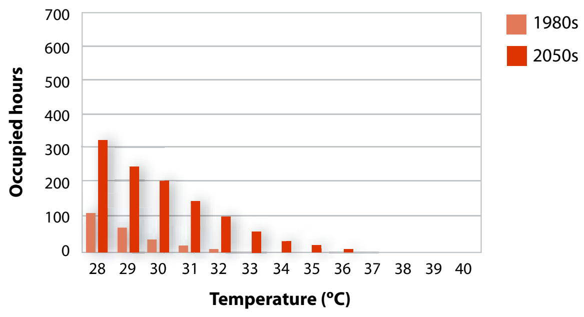


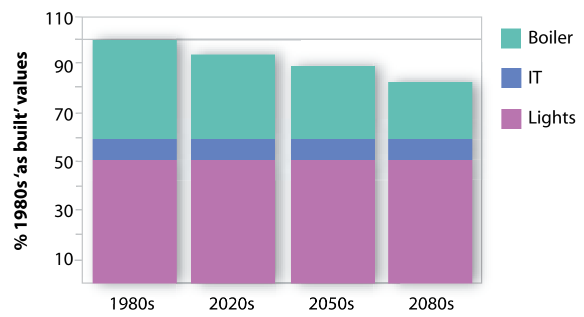
Figure 11g: Extreme temp: West facing



Carbon emissions

Carbon emissions are not affected by the adaptation measures.

Figure 11h: Carbon emissions



Advanced naturally ventilated school

As built

Building description

This is a 2-storey classroom block with a central north-south running corridor. The lower floor has a moderately high thermal mass concrete ceiling whereas the second floor has a relatively lightweight timber roof. The classrooms are naturally ventilated via low level openings underneath the windows and high level extraction to a central ventilation tower. The movement of air through the ventilation tower is encouraged by the natural buoyancy of the warm air and the effect of wind blowing over the roof ridge. The standards of insulation and air tightness are high.

Indoor temperatures

For the building as a whole, the discomfort temperatures are exceeded for a significant portion of the year. The 'hot' discomfort temperature is exceeded 2% of occupied hours in the 1980s, increasing to 8% by the 2050s (Figure 12a). The ground floor, however, experiences fewer hours over the discomfort temperatures than the top floor. Peak temperatures on the top floor in the 1980s are 33°C rising to 36°C by the 2050s, which is into the heat stress risk zone (Figure 12c). Peak temperatures on the lower floor are about 3°C lower.

The better thermal performance of the ground floor is due to the additional thermal mass in the ceiling construction.

Figure 12a: Discomfort temp: Building average

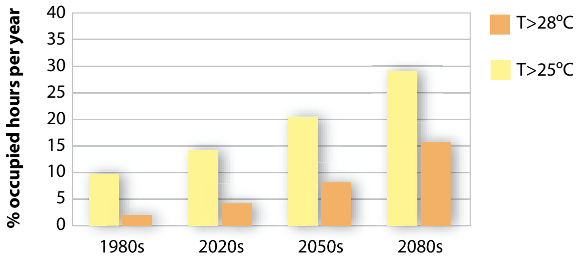


Figure 12b: Extreme temp: Ground floor

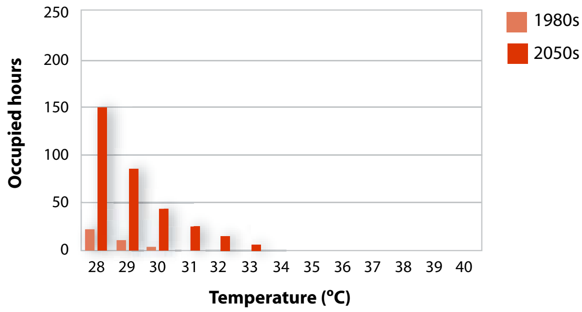
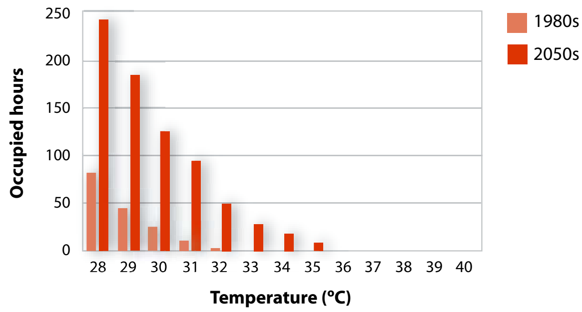


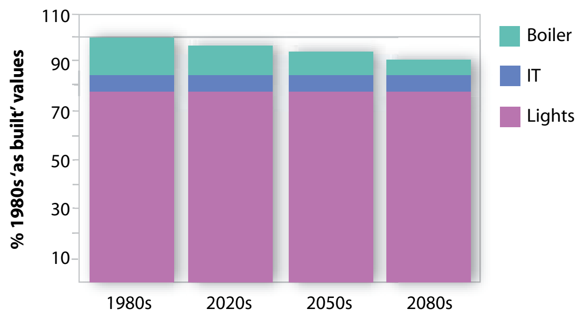
Figure 12c: Extreme temp: Top floor



Carbon emissions

The overall energy consumption of the building is dominated by lighting as the good insulation and air tightness of the building limit the winter heating needs. Consequently, the reduction in winter heating as the climate warms has only a small impact on overall carbon emissions, which are reduced by 5% by the 2050s and 8% by the 2080s (Figure 12d).

Figure 12d: Carbon emissions



Advanced naturally ventilated school

Adapted

Specification

The thermal performance of the building could be improved by including a high mass ceiling on the first floor and by increasing the amount of thermal mass elsewhere. However, it would be difficult to implement this form of adaptation measure as a retrofit.

The adaptation measure examined here is to add mechanical cooling, for example by using chillers at the point where the ventilation air enters beneath the windows. It is assumed that the ventilation system continues to be naturally driven so that no fans are required. The chillers come into operation when the internal space temperatures exceed 25°C and thereafter act to limit temperatures to that level.

Indoor temperatures

There are a number of hours where the temperature exceeds 25°C as the cooling system takes effect, particularly on the top floor, but few hours over 28°C occur in any of the timeslices, indicating that the cooling system is effective (Figure 12e).

Figure 12e: Discomfort temp: Building average

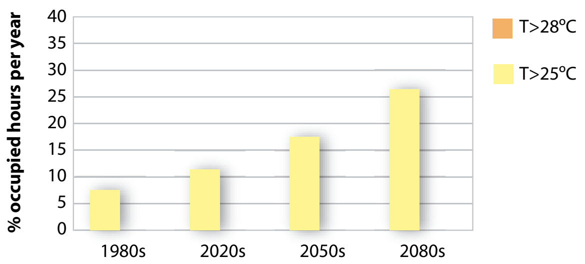


Figure 12f: Extreme temp: Ground floor

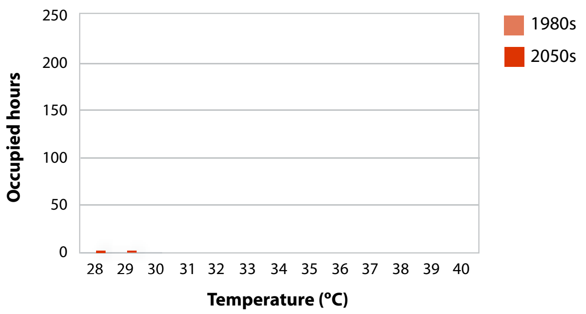
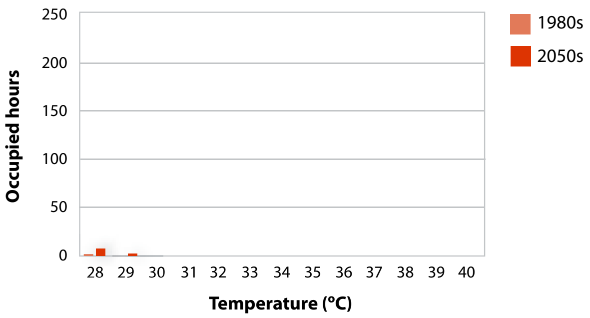


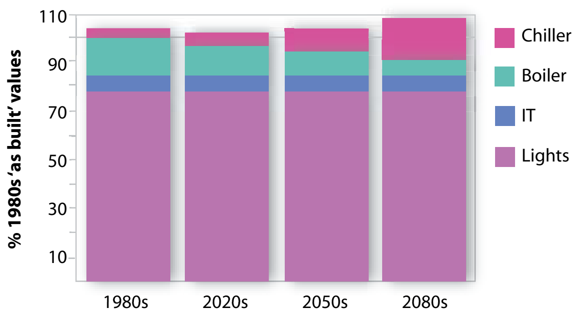
Figure 12g: Extreme temp: Top floor



Carbon emissions

The consequence of the cooling system for the overall carbon emissions from the building is an increase of around 4% in both the 1980s and 2050s and around 9% in the 2080s (Figure 12h).

Figure 12h: Carbon emissions



7. Assessments for other UK cities: Manchester and Edinburgh

The case study buildings were also analysed in the climates of Manchester and Edinburgh. Figure 13 compares the percentage of hours that the 'hot' discomfort temperature is exceeded in four of the case study buildings. Broadly speaking, levels of thermal discomfort in the different cities can be summarised as:

- Manchester in the 2050s is comparable to London in the 1980s
- Manchester in the 2080s is comparable to London in the 2020s
- Edinburgh experiences occurrences of thermal discomfort only in the 2080s, then being comparable to Manchester in the 1980s.

Manchester could, then, experience significant and increasing summertime thermal discomfort problems from the 2050s onwards. Similar adaptation measures to those analysed in Section 6 for London are likely to be as appropriate for Manchester. In particular, buildings with advanced natural ventilation and passive features should perform well without the need for mechanical cooling.

For Edinburgh, summertime thermal discomfort is unlikely to be a serious problem until the 2080s. This indicates that buildings cooled by simple natural ventilation are likely to continue to cope well with summer conditions throughout the century under the climate scenarios.

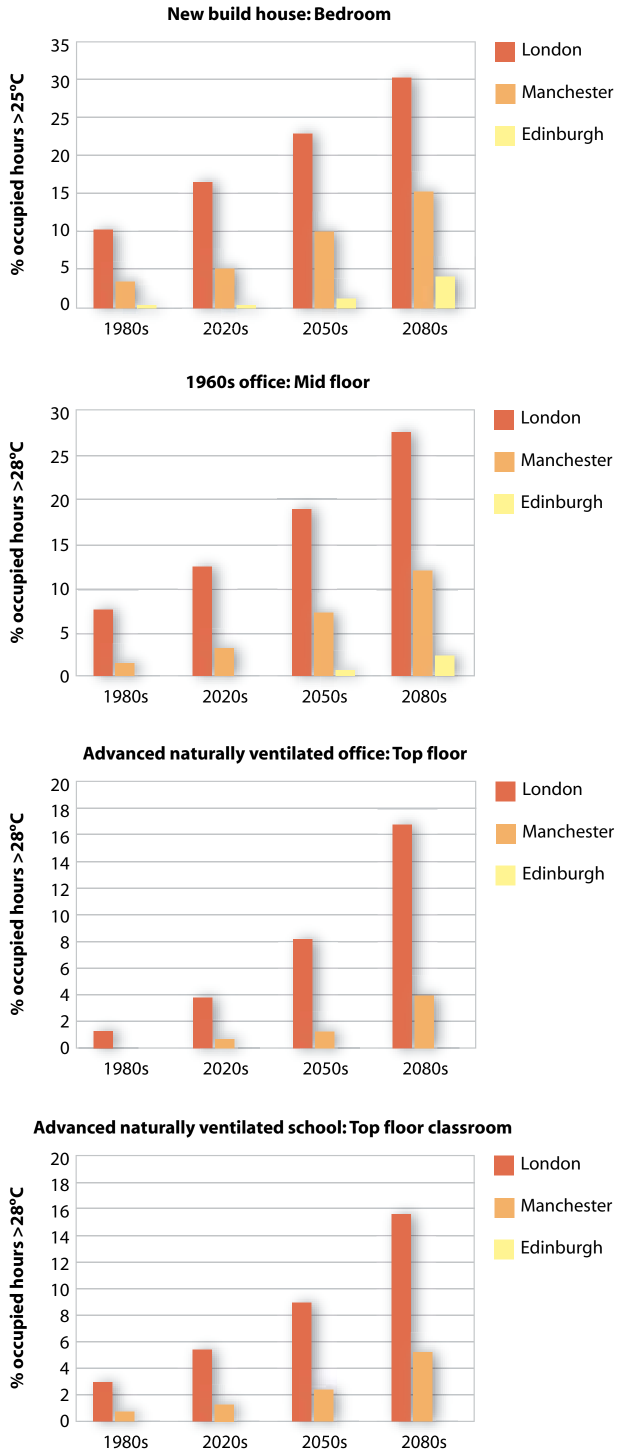


Figure 13: The percentage of hours that the 'hot' discomfort temperature is exceeded in four of the case study buildings.

8. Learning from warmer climates

As the case studies have shown, because of climate change, many existing buildings in the UK will be vulnerable to high levels of thermal discomfort and possibly heat stress risks. The buildings at highest risk tend to be those lacking shading, controllable ventilation and thermal mass, and which have poor insulation and air tightness. The most vulnerable buildings were found to be the 1960s office and schools, which have these negative features combined with high levels of indoor waste heat.

However, buildings exist and are used successfully in many different types of climate. Can the architecture of countries with warmer climates provide ideas to the ways in which buildings in the UK could be adapted for climate change?

It is sometimes said that climate change will make the climate of the south of England similar to that of the south of France. Figure 14 is a comparison of the ranges of temperature for Marseille (1961-90) and those projected for London in the 2080s under the High emissions scenario [13]. It is evident that the temperature ranges are very similar, indicating that Marseille provides a good temperature analogue for London under this scenario.

How useful is this analogy? Temperature is only one aspect of climate affecting thermal discomfort in buildings, as discussed in Section 4. Of the other factors, sunshine is the most important. The level of sunshine in the absence of cloud cover is determined by latitude and so will always be greater in Marseille than London. The climate analogy is not a perfect one and so, must be treated with caution. Regardless, it still allows for important observations to be made.

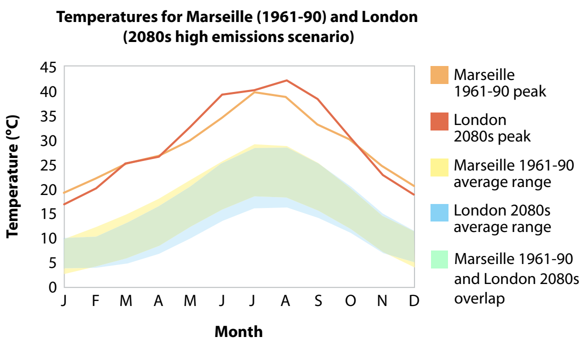


Figure 14: A comparison of predicted average and maximum temperatures in London in the 2080s under the High emissions scenario with those in Marseille for 1961-90.

Figure 15: Shutters are used widely in warmer climates to provide shade. These shutters are slatted and can tilt at the base so that ventilation can still be provided via opened windows during the day.

One of the most striking features of Mediterranean traditional architecture is a preoccupation with shade and shelter from the sun, at both the building and city scale (Figures 15 and 16). This preoccupation is often thought to originate from the need to deal with the stronger sun. However, it also originates from the fact that the outside air is much warmer, thereby reducing its cooling potential and making it more important to gain shelter from the heat of the sun.

Mediterranean traditional architecture has evolved to provide the best possible thermal comfort with the available passive techniques and building materials. But even these traditional passive measures are still not sufficient to completely avoid some level of thermal discomfort in the Mediterranean summer. Societal adaptations to the climate, such as siestas, early morning working/school times and longer summer vacations, have also been an important part of dealing with the heat. It is not clear whether or not such societal adaptations could be adopted in the UK in the future.

We have shown in this report that it is possible to achieve acceptable levels of summertime thermal comfort under the projected warmer future climates using passive cooling measures with modern building materials and modern design methods. Increased solar shading, controllable natural ventilation and high thermal mass significantly decrease overheating, with little increase in energy usage and carbon emissions. However, such buildings remain atypical of most construction in the UK, and in some cases may be difficult to realise due to site restrictions, cost, external air quality, noise pollution or other constraints, particularly in the refurbishment of existing buildings and in urban areas.

Another approach, as shown in the adapted office case studies, is to combine passive and mechanical systems in such a way as to minimise energy use and carbon dioxide emissions as far as is possible within project constraints. This is the so-called "mixed mode" approach. Proactive building management is required to ensure that the systems are used in the most effective way.

Delivering buildings that provide the optimal balance between high quality indoor environment and reduced carbon dioxide emissions – whether through an entirely passive or mixed mode approach – is a challenge that will be increasingly important in the future.

Figure 16: Narrow streets provide shade from the sun and enhance cooling from the thermal mass of the buildings.

References

Where reports are freely available via the world-wide web, links have been given.

[1] Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report. Hulme, M., Jenkins, G.J., Lu,X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. and Hill, S. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich. (2002). www.ukcip.org.uk.

[2] Climate Change and the Indoor Environment: Impacts and Adaptation (CIBSE TM36). Hacker, J.N., Holmes, M.J., Belcher, S.E. and Davies, G. (2005). Chartered Institution of Building Services Engineers. London.

[3] Climate Change: the UK Programme. HMSO. (2000). http://www.defra.gov.uk/environment/climatechange.

[4] Impacts of Europe's changing climate: an indicator based assessment. European Environment Agency, Copenhagen. (2004). http://themes.eea.eu.int/Environmental_issues/climate/reports.

[5] Climate Adaptation: Risk, Uncertainty and Decision-Making. Willows, R. and Connell, R. (eds.), UKCIP Technical Report. UKCIP, Oxford. (2003). www.ukcip.org.uk.

[6] Guidelines for Environmental Design in Schools Building Bulletin BB87 (2nd edn., version 1). Department of Education and Skills, School Building and Design Unit. London. (2003). www.dfes.gov.uk.

[7] Fundamentals. 2001 ASHRAE Handbook. American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE). (2001).

[8] Approved Document L (Part L of the Building Regulations): Conservation of fuel and power. Proposals for implementing the European Energy Performance of Buildings Directive. See: http://www.odpm.gov.uk/stellent/groups/odpm_buildreg/documents/divisionhomepage/br0052.hcsp.

[9] Weather, Solar and Illuminance data. CIBSE Guide J. Chartered Institution of Building Services Engineers. London. (2002).

[10] Constructing design weather data for future climates. Belcher, S.E., Hacker, J.N., Powell, D.S. Building Services Engineering Research and Technology Vol 26(1) pp. 49–61. (2005).

[11] Energy Consumption Guide 19: Energy Use in Offices. Energy Efficiency Best Practice Programme. (2003).

[12] See GPG290 – Ventilation & Cooling Option Appraisal – A Clients Guide. Energy Efficiency Best Practice Programme Good Practice Guide 290. www.thecarbontrust.com; also: Thermal Mass: A concrete solution for the changing climate. Saulles, T. de. The Concrete Centre. Camberley, UK. (2005). www.concretecentre.com.

[13] Data source: World Meteorological Organisation 1961-90 average data for London (Gatwick Airport) and Marseille.

UK Climate Impacts Programme

The UK Climate Impacts Programme helps organisations assess how they might be affected by climate change, so they can prepare for its impacts. Based at the University of Oxford, UKCIP was set up by the Government in 1997 and is funded by the Department for Environment, Food and Rural Affairs (Defra). For more information, see www.ukcip.org.uk or email enquiries@ukcip.org.uk.

Arup

Arup is a multidisciplinary design consultancy specialising in holistic design of buildings and the built environment. The firm has expanded beyond its structural engineering beginnings – with a heritage of work that includes the Sydney Opera House and the Pompidou Centre – to become a firm of professional consultants with more than 7000 staff working from 73 offices in 32 countries. For more information see www.arup.com.

We are grateful to the project steering group: Prof Brian Moss (CIBSE) (Chairman), Prof Stephen Belcher (University of Reading and Arup), Martin Best (Hadley Centre, Met Office), Dr Richenda Connell (UKCIP), Dr Hywel Davies (CIBSE), Dr Clare Goodess (Climatic Research Unit, University of East Anglia), Dr Chris Gordon (Hadley Centre, Met Office), Hilary Graves (Building Research Establishment), Prof Vic Hanby (De Montfort University), George Henderson (WS Atkins on behalf of DTI), Dr Gary Hunt (Imperial College), Prof Susan Roaf (Oxford Brookes University), and Edward Williams (Hopkins Architects).

Printed using waterless printing with vegetable-based inks on paper made from 75% post-consumer waste and 25% mill broke. Printed August 2005. Designed by One Design and Communication.

ISBN 0-9544830-7-3