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Bill Dunster Architects

**UK Housing and
Climate Change**

Heavyweight vs.
lightweight construction



Feilden Clegg Bradley Architects LLP

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APPENDICES**APPENDIX A**

Occupancy, heating and equipment schedules

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1. EXECUTIVE SUMMARY

This study proposes a building design response to climate warming for dwellings. It draws on research work examining the impact of climate change on thermal comfort in buildings done by Arup on behalf of the UK Department of Trade and Industry.

With a significant proportion of the UK's expected new homes to be in the Southeast where climate change will be most pronounced, it will be important to ensure these homes are future proofed for climate change. The alternative is homes that may become prematurely obsolete; requiring the addition of mechanical cooling, increasing energy costs and future increasing greenhouse gas emissions.

This research illustrates the relatively poor performance of thermally lightweight construction, as part of a response that includes solar, ventilation and internal heat gain control. It also shows the importance of how we operate our homes and the need to adapt this to climate change.

The issue of dealing with heatwaves is both a physical and societal one. The tradition of buildings designed simply to maximise daylighting and passive solar heating for a cool Northern European climate will no longer be appropriate. In contrast, traditional buildings in Southern Europe have developed elements to minimise unnecessary heat gain and maximise passive cooling, through; use of shade, restriction of window areas, courtyards, shutters and high thermal mass combined with hard surfaces to maximise heat exchange between internal air and building fabric. Northern European cultures need to socially adapted to deal with very warm weather, for example; by working and school hours timed to coincide with the cooler parts of the day; the taking of afternoon siestas, and indeed the way they operate their homes.



Mediterranean response to warmer temperatures



Room exposed thermal mass with sunspace

The characteristics that will help climate future proofed home include:

- Large areas of room exposed heavyweight thermal mass to absorb excess heat gains
- Generous volumes of cooler air ventilation particularly during night time with the increasing diurnal temperature swing.
- Good opaque shading to block direct solar gain, ideally outside the occupied rooms
- Limiting ventilation during the hot periods of the day.
- Positioning bedrooms north facing away from direct solar gain
- Domestic appliances with reduced heat output, particularly on 'stand-by'

In design terms this suggests the need for:

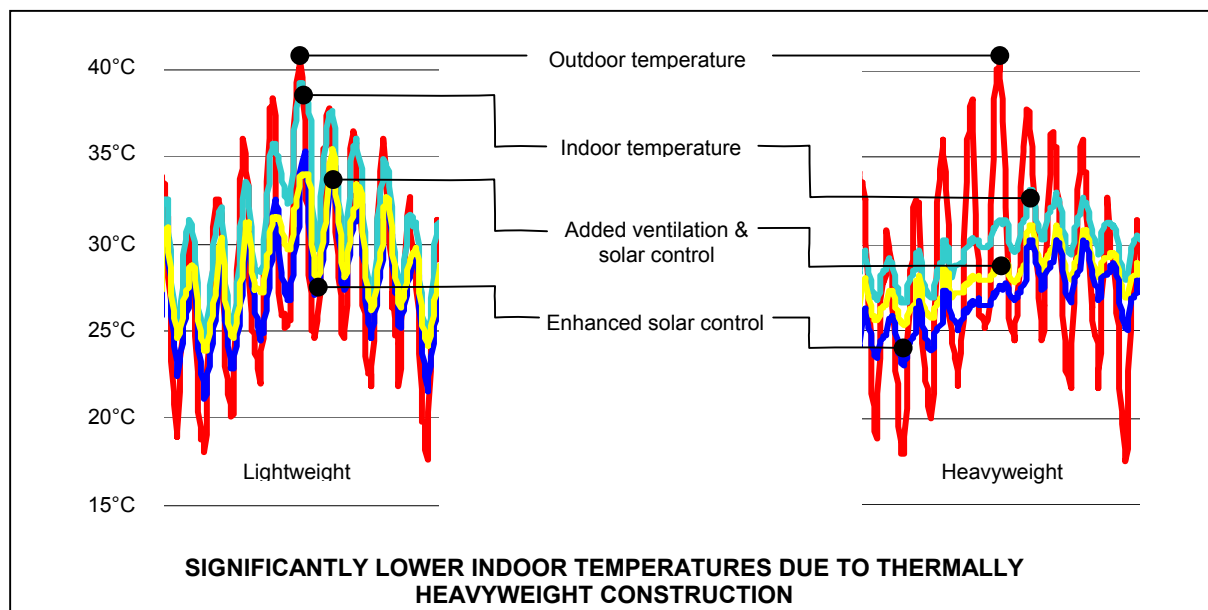
- Ventilation openings designed so they can be left securely open during night and unoccupied periods
- Limiting window areas into the occupied rooms
- Shutters / shading that can be used during warm and hot weather periods, but can be easily removed for winter and mid-season daylighting and limited solar gain.
- Manually adjustable shading positioned in wind protected sunspaces with generous ventilation provision, separated from the main living spaces with lockable inner doors.
- Use of light coloured surfaces and reflected daylight, instead of direct solar for natural lighting
- Airtight building envelope so ventilation can be restricted during peak temperature hours
- Issuing simple operating recommendations to the occupiers

In occupant user terms:

- Anticipating hot weather
- Using shutters / shading as the weather starts to get warmer and throughout summer
- Open all windows for early morning and evening purge, with windows and shading closed for hottest hours of warm and hot days.
- Close internal doors between the solar exposed rooms and cooler solar protected bedrooms during hottest hours of the day.

For winter performance the high thermal capacity works best with enhanced envelope thermal insulation and airtightness standards, so reducing the overnight temperature drops and the resulting recovery periods for intermittent heating. This also enhances ability to absorb daytime heat gains and re-emit them during night time periods of higher heat loss. As climate change reduces winter heating needs it also prompts a review of the need for a full conventional central heating system and increases the opportunities for 'zero heating' homes.

In summary, mitigation of climate change effects can be achieved by designing homes with thermally massive passive features. This enables us to adapt the way we operate our homes to offset the expected temperature increases. On the other hand thermally lightweight homes would result in substantially higher room temperatures and levels of discomfort.



This study was commissioned by Bill Dunster Architects with additional support from Feilden Clegg Bradley Architects, The RIBA and Arup.

2. INTRODUCTION

For several decades, it has been realised that anthropogenic greenhouse gas emissions, principally carbon dioxide from the burning of fossil fuels, could significantly alter the Earth's climate by strengthening the greenhouse effect. Over the last decade or so, evidence that this process is occurring has strengthened and has become compelling, culminating in the publication of the third Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR)[1] in 2001, which carried the statement that "most of the [climate] warming observed over the last 50 years is attributable to human activities".

Predictions from climate models suggest an increase in global average temperature of up to 6°C and an increase in sea level of up to 1.0m over the coming century. These changes would have a substantial impact on the world, its populations, economies and natural systems. Furthermore, climate models indicate that such changes would persist for many millennia following the cessation of increases in atmospheric greenhouse gas.

In the UK, an immediate implication of climate change is an increase in summertime temperatures. In the central England temperature record, which goes back to the 17th century, 4 of the 5 hottest summers have occurred since 1990. Last summer (2003) saw temperature records broken across the country, with in the South-East temperatures exceeding 38°C (100°F) for the first time since records began. These changes are leading to increased propensity for thermal discomfort in buildings and increased demand for air conditioning. These trends are projected to continue and accelerate under climate change scenarios. Further, poor thermal performance of buildings should not only be seen as an issue for comfort, but also a potentially serious issue for health. Research by the Earth Policy Institute has estimated that 35,000 additional deaths resulted from heat stress in the 2003 heatwave in Europe, particular amongst the elderly.

In part, the issue of dealing with heatwaves is a societal one: northern European cultures are not adapted to deal with very warm weather, not having measures in place, such as those in Southern Europe, developed over time, to deal with the heat, for example working and school hours timed to coincide with the cooler parts of the day; the taking of afternoon siestas. Another reason, however, is the difference in the physical make up of the building stock which has developed to deal with a cool Northern European climate designed to maximise day lighting and passive solar heating with a defensive envelope to retain heat during winter. Cooling in summer, if needed, is provided by ventilation through openable windows, utilising the fact that the external air is generally lower than that required for comfort within the building. In contrast, traditional buildings in warmer parts lacking this availability of ventilative free cooling, have developed elements to minimise unnecessary heat gain and maximise passive cooling, such as: use of shade, restriction of window areas, courtyards, shutters and high thermal mass combined with hard surfaces to maximise heat exchange between internal air and building fabric.

Taken together, these two factors mean that UK buildings are not necessarily well suited to the climatic conditions now being experienced in summer and projected for the future, particular in the South-East. Moreover, new buildings are still being designed to historic climate records, despite evidence that past climate is no longer considered to be indicative of future climate.

In 2001, Arup were commissioned by the Department of Trade and Industry, through the Partners in Innovation research programme, to examine these issues, by quantifying the possible impact of climate change on thermal comfort in buildings and to consider the suitability of the various design and adaptation options. The outputs of this project are due to be published shortly as a CIBSE Technical Memorandum[3]. The present report, for Bill Dunster Architects, draws on material from this project to investigate the benefits of high-mass (heavyweight) vs. low-mass (lightweight) construction in housing.

3. DESIGN SUMMER YEARS FOR FUTURE CLIMATE

3.1 The UKCIP02 scenarios

In 2002 the UK Government (through the UK Climate Impacts Programme (UKCIP)) released a comprehensive set of climate change scenarios for the United Kingdom - the 'UKCIP02' scenarios[4]. The scenarios contain a comprehensive set of climatic variables for three 'timeslices' (2020s, 2050s and 2080s) on a 50km grid, for four greenhouse gas emissions storylines (Low, Medium-Low, Medium-High and High). [See www.ukcip.org for further details.]

The details of each of the emissions storylines are given in Table 2.1 and the projected emissions rates associated with each scenario are shown in Figure 2.1. The Low emissions scenarios represents a future where there is a commitment to sustainability on a global scale resulting in the phasing out of fossil fuels; even under this scenario, however, greenhouse gas emissions are projected to continue to increase until the middle of the century. The closest scenario to that of present-day economic and technological development is the Medium-High scenario ("National Enterprise"). Since the future course of societal development is unknowable, no probability can be assigned to any one of the scenarios; they are all intended to represent plausible futures. Hence, consideration should be given to the range of scenarios to gauge the range of likely impacts under climate change.

Predictions for global average temperature changes under the four emissions scenarios from the UKCIP02 global climate model are shown in Figure 2.2. The various temperature changes do not start to diverge appreciably until the middle of the century, indicating that a significant level of climatic change needs to be considered even under the lower emissions scenarios. Beyond the middle of the century, the implications of the Medium-High and High emissions scenarios are considerably greater than those projected for the lower emissions scenarios. Figure 2.3 shows the relative change in global average temperature as a proportion of that in the Medium-High emissions scenario 2080s timeslice, termed here the 'climate scaling factor' (CSF).

A feature of the UKCIP02 scenarios is that all the regional (50km grid) projections are derived from a single run of a regional scale model (embedded within the global-scale model) for Medium-High emissions in the 2080s timeslice through a linear scaling of all variables using the climate scaling factors shown in Figure 2.3.

The UKCIP02 scenarios all relate to greenhouse-gas-driven global warming, and do not contain other climate change scenarios, such as the sudden cooling "ice age" scenario that has recently received attention in the popular media. While this type of climatic change scenario in response to elevated greenhouse gas concentrations cannot be ruled out, it is considered to be of low probability and is not produced in any existing climate model under IPCC emissions scenarios.

Figure 2.4 shows the UKCIP02 climate changes for a number of key variables for the Medium-High 2080s scenarios (CSF=1.0). Note that the changes for the other scenarios may be obtained by simply multiplying these changes by the CSF values in Figure 2.3. The greatest changes are in temperature, particularly in summer and in London. The predicted increases in maximum temperatures are greater than the predictions for minimum temperatures, resulting in a slight increase in diurnal range. There are also appreciable increases in solar irradiance in summer (principally due to reduced cloud cover). Air moisture content increases in winter and decreases in late summer and autumn, but relative humidity is reduced in all seasons due to the increase in temperature, decreasing quite sharply in summer. Average wind speeds show smaller magnitude changes, typically less than 5%, increasing in winter and decreasing in summer.

UKCIP02 Climate Change Scenarios	IPCC SRES Emissions Storyline	UKCIP Socio-economic scenario	Description
Low Emissions (L)	B1	Global Sustainability	Clean and efficient technologies; reduction in material use; global solutions to economic, social and environmental sustainability; improved equity; population peaks mid century
Medium-Low Emissions (ML)	B2	Local Stewardship	Local solutions to sustainability; continuously increasing population
Medium-High Emissions (MH)	A2	National Enterprise	Self-reliance; preservation of local identities; continuously increasing population; economic growth on regional scales
High Emissions (H)	A1F1	World Markets	Very rapid economic growth; population peaks mid century; social, cultural and economic convergence among regions; market mechanisms dominate.

Table 2.1. Characteristics of the UKCIP emissions scenarios.[Use same colour codes for table above & following figs]

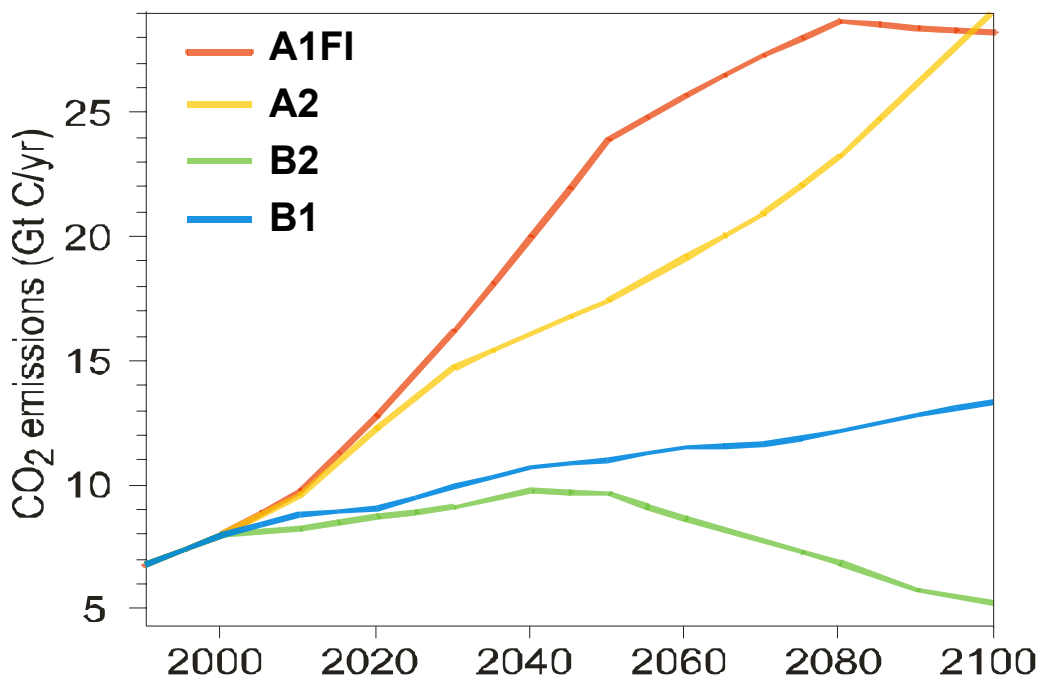


Figure 2.1. Projected carbon dioxide emissions under each of the four scenarios considered in UKCIP02.

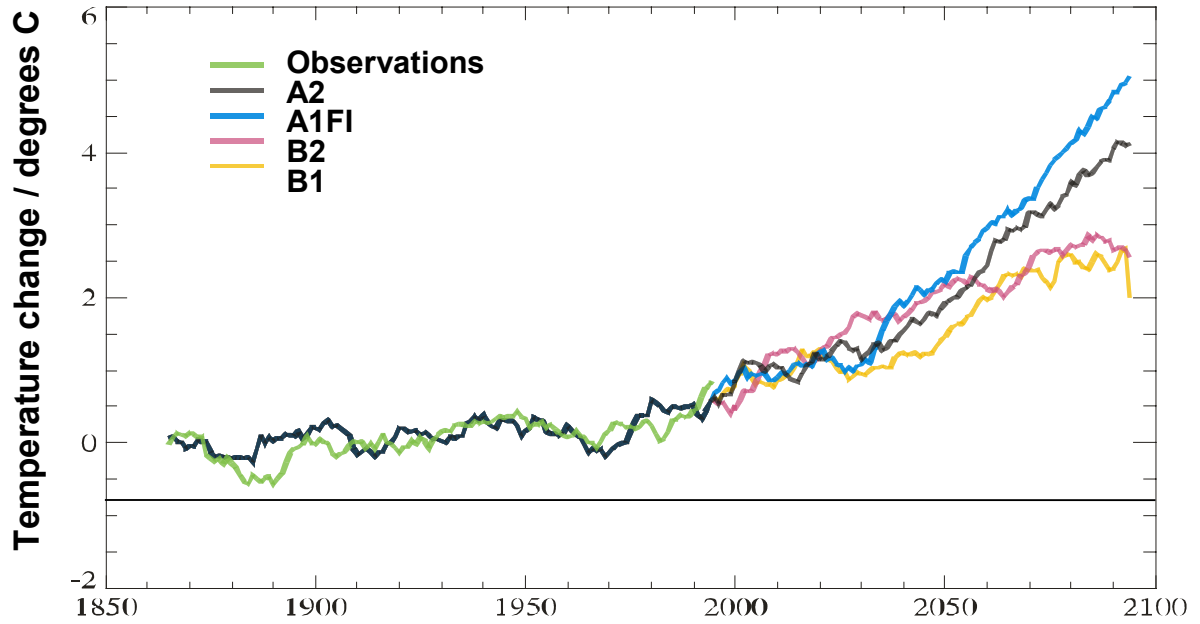


Figure 2.2. Predictions of global annual-average temperature in the UKCIP02 climate model runs.

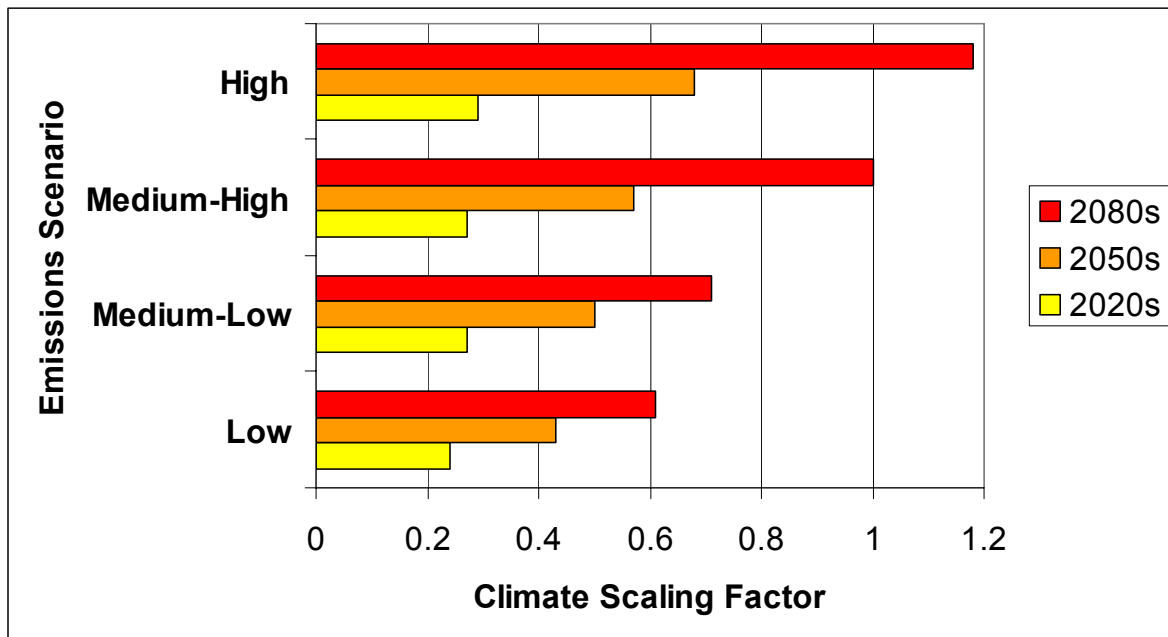


Figure 2.3. Predictions for global annual-average temperature in the UKCIP02 scenarios expressed as a “climate scaling factor” – the fractional change relative to the Medium-High emissions 2080s value.

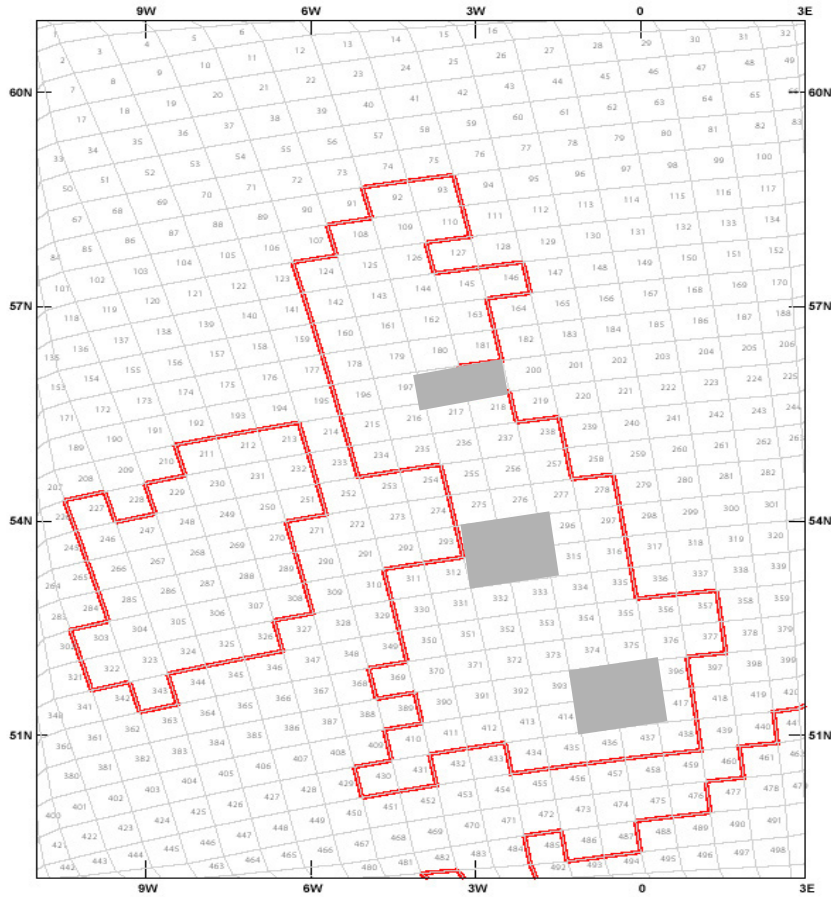


Figure 2.4 The UKCIP02 regional model grid with the locations of the grid boxes used for London, Manchester and Edinburgh shaded.

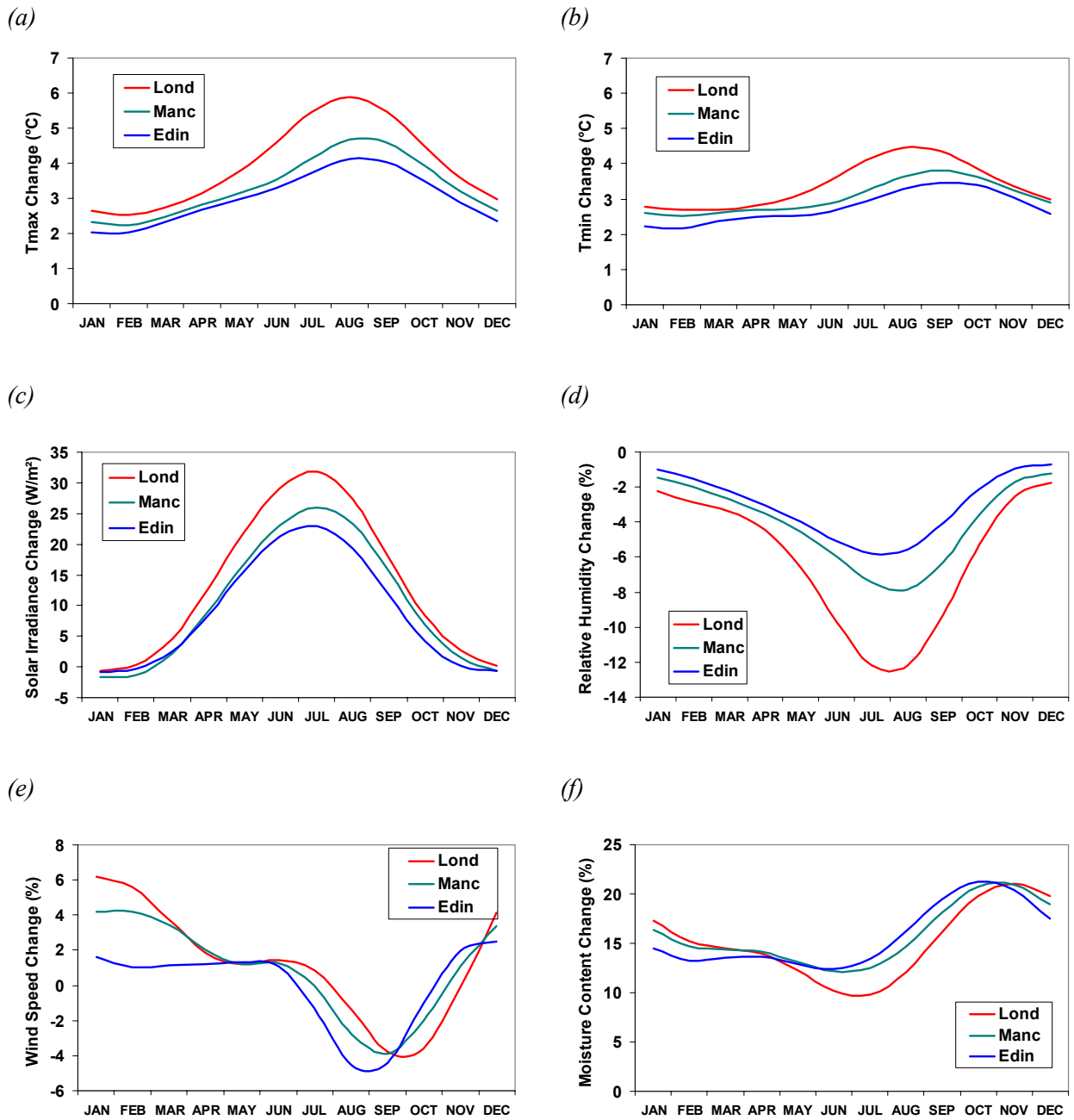


Figure 2.5. Predicted changes in monthly-average climate variables under UKCIP02 Medium-High scenario. Changes for the other emissions scenarios and timeslices can be obtained by multiplying by the climate scaling factors given in figure 2.3.

3.2 Use of the UKCIP02 scenarios for building environmental design

To predict the performance of high-mass buildings and to calculate energy use, dynamic thermal computer simulation provides a useful tool. Such a program requires detailed climate data – typically a complete ‘weather year’ – with data recorded at hourly intervals. The UKCIP02 scenarios only given information regarding monthly average variables, and so cannot be used directly for this purpose. The approach adopted here was to combine the present-day CIBSE Guide J [5] design weather years for London, Manchester and Edinburgh with the UKCIP02 predicted monthly climate changes to produce synthetic future weather years for these locations. These new weather years contain the diurnal variations and weather variability of the present-day climate but the average climatic properties (e.g. daily average temperature, solar irradiance, wind speed etc.) of the UKCIP02 scenarios. We have called this method ‘climate morphing’ [6].

To assess summertime thermal performance, CIBSE Guide J recommends that a ‘design summer year’ (DSY) be used. Presently, this is defined to be the 3rd hottest summer over the period 1976-1995 (henceforth, the “1980s timeslice”). The DSY years, therefore, represent a 1 in 8 summer for that climatic period. Summers in the UK have grown warmer on average since the 1980s, and so the DSY years do not relate to this return period for the present climate.

Temperature ranges in the DSY years for London (1989), Manchester (1982) and Edinburgh (1981) are shown in figures 2.6 – 2.8 together with those in their morphed counterparts for 2080s Medium-High Emissions.

A lightweight building with moderate internal gains and moderate ventilation rates will tend to have daily peak temperatures somewhere close to the peak external air temperature. Hence, for the London 1980s DSY this would mean space temperatures being over 25°C for much of the summer, with a peak of around 33°C. For the morphed 2080s Medium-High scenario space temperatures would be over 30°C for much of the summer with peak temperatures of around 40°C.

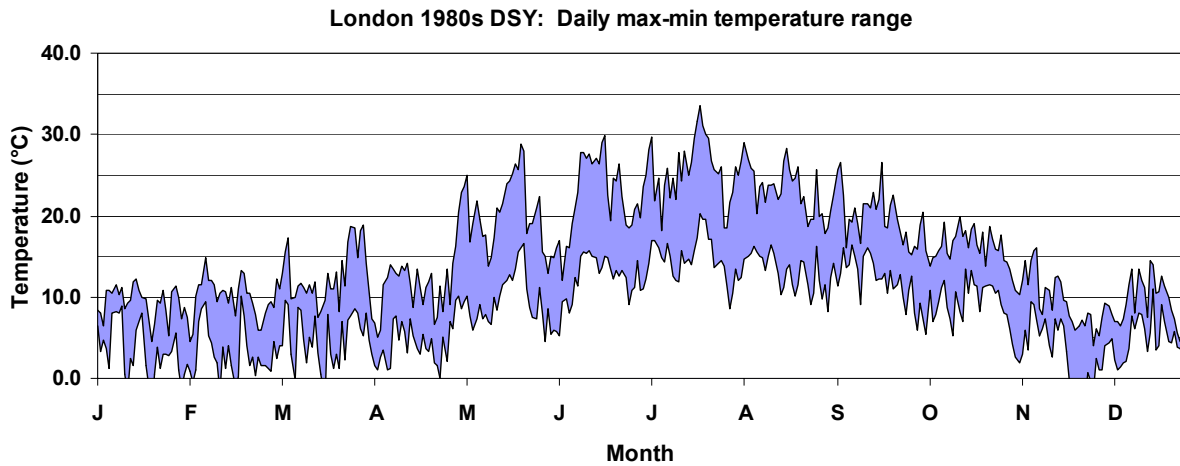
A good passive building with high thermal mass and only moderate internal gains should be capable of achieving temperatures close to the daily average external temperature. For the London 1980s DSY daily average temperatures rarely exceed 25°C, but in the 2080s DSY do so on a number of days, with a peak value of 32.5°C. The ability of passive buildings to attain the daily average temperature is also to some extent dependent on the availability of cool air for night-cooling. When minimum temperatures are below 20°C, it may be considered that there is good source of ‘free cooling’ from night ventilation. For the London 1980s, minimum nighttime temperatures are generally below 20°C. However, under 2080s Medium-High this, minimum nighttime temperatures exceed 20°C on a number of occasions, being as high as 25°C.

These projected changes to the 2080s London DSY years indicate substantially warmer conditions than at present. Indeed, the projected temperature range for the 2080s under the High Emission scenario are similar to those associated with towns in the South of France such as Marseille. The climates of Manchester and Edinburgh are significantly cooler than that of London in the present-day and the UKCIP02 predicted changes are also smaller (figure 2.4). The Manchester DSYs do not exceed the London 1980s DSY until the 2080s, and then only marginally. The Edinburgh 2080s DSY has peak temperatures comparable to the Manchester 1980s DSY, but is still significantly cooler than the London 1980s DSY.

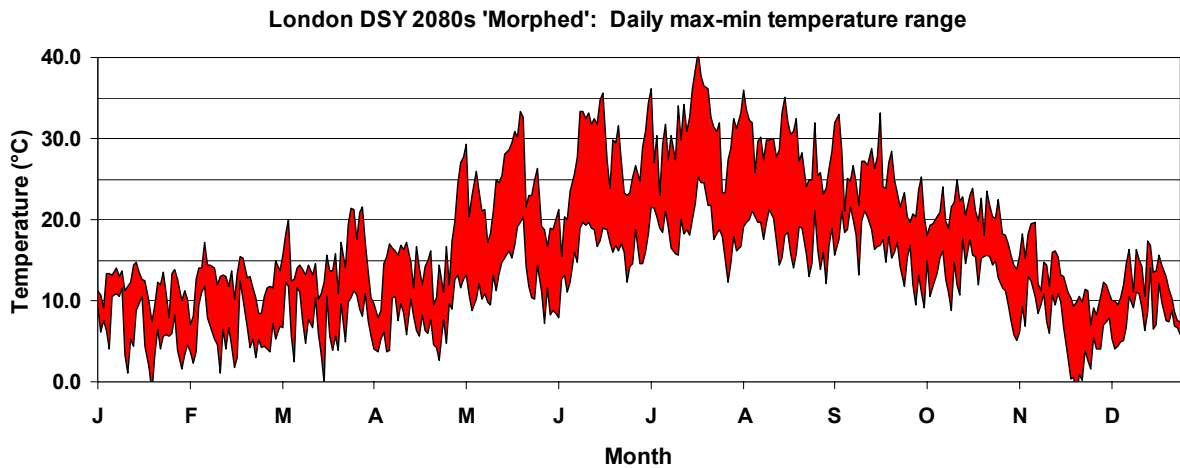
¹ CIBSE Guide J: Weather, Solar and Illuminance data. Chartered Institution of Building Services Engineers. 2001.

² Belcher, Hacker & Powell (2004) “Constructing Design Weather Years for Future Climate”, Building Services Engineering Research and Technology (to appear).

(a)



(b)



(c)

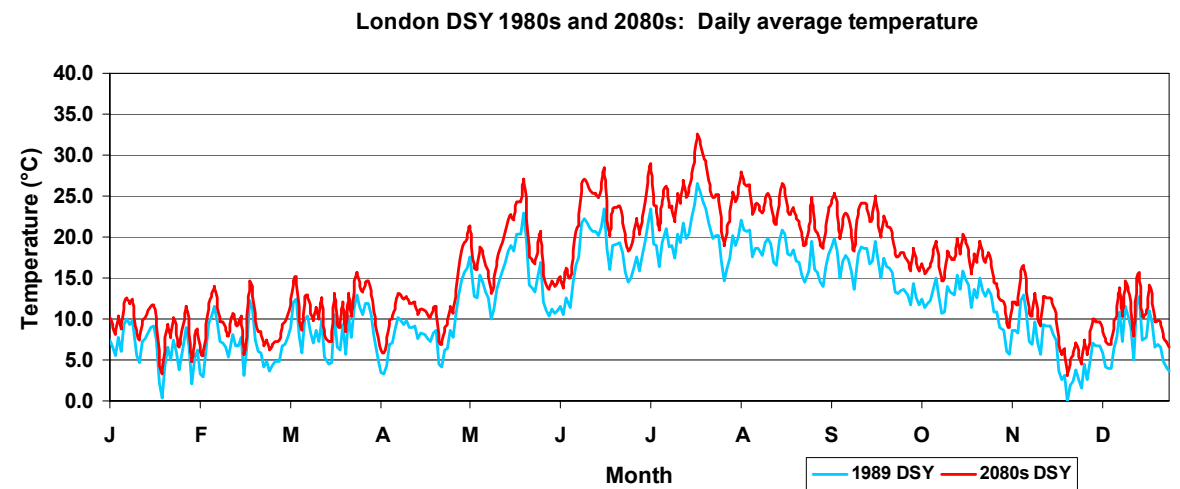
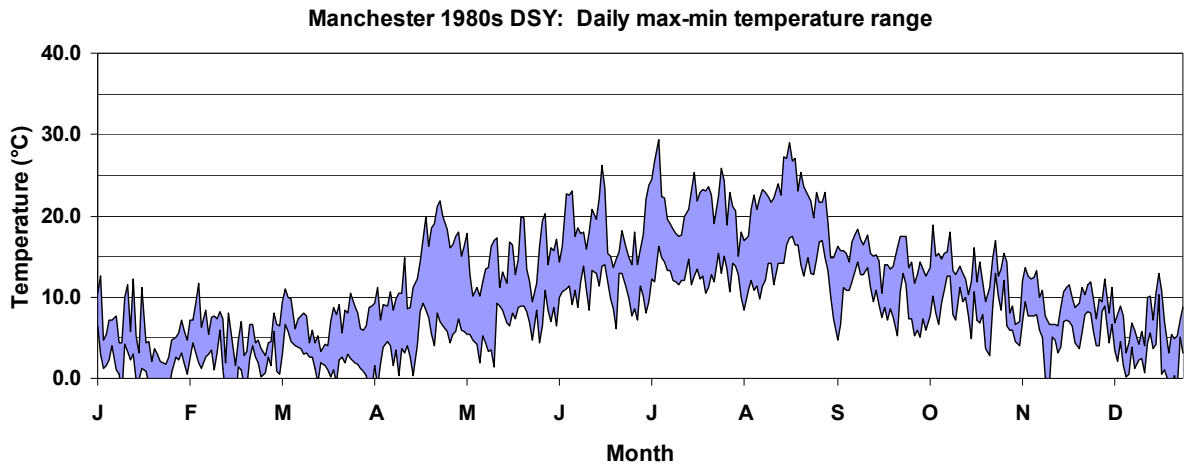
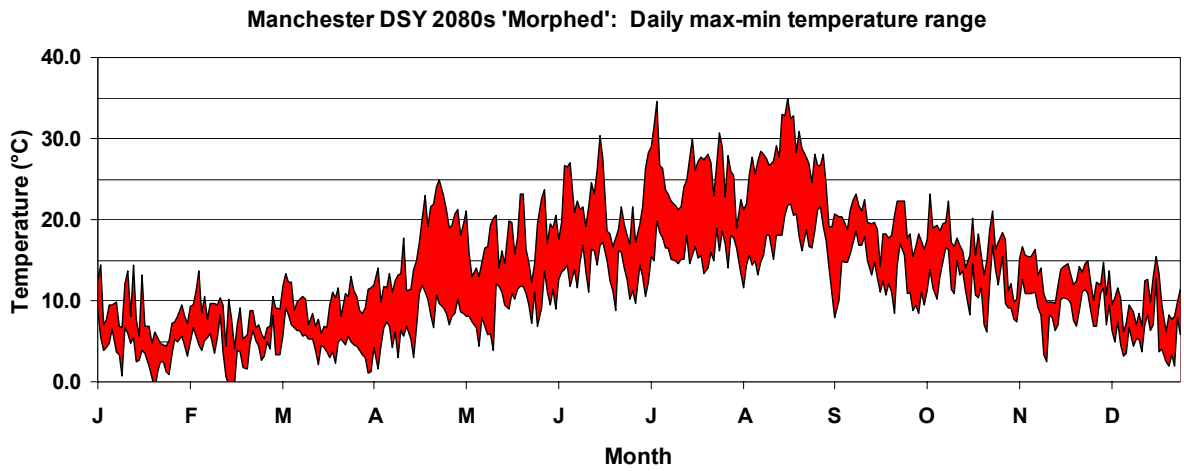


Figure 2.6. Daily temperatures for London CIBSE 1980s DSY and future 'morphed' 2080s DSY under UKCIP02 Medium-High emissions scenario: Max-Min temperature range for (a) 1980s and (b) 2080s; (c) daily average temperature for 1980s and 2080s.

(a)



(b)



(c)

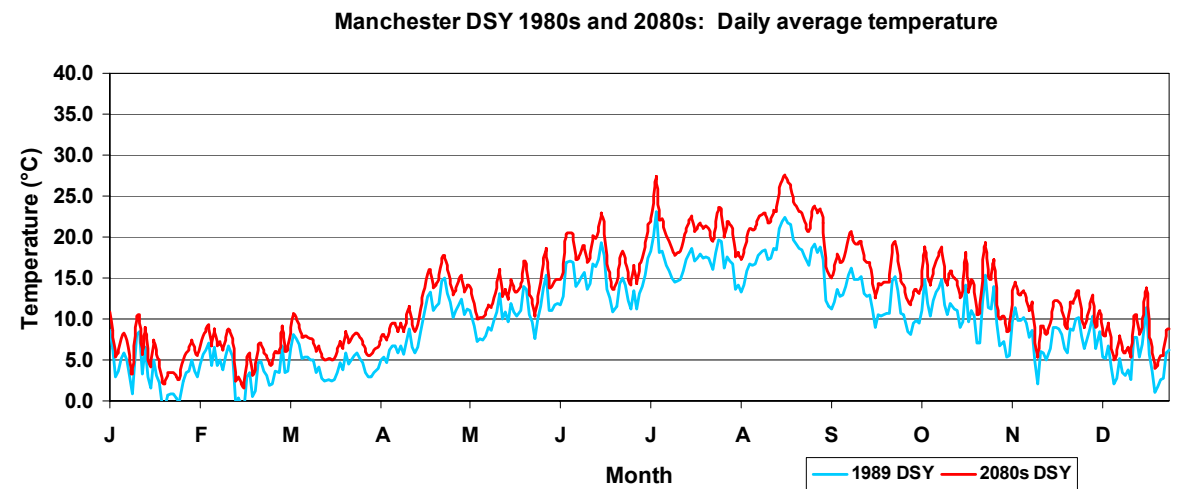
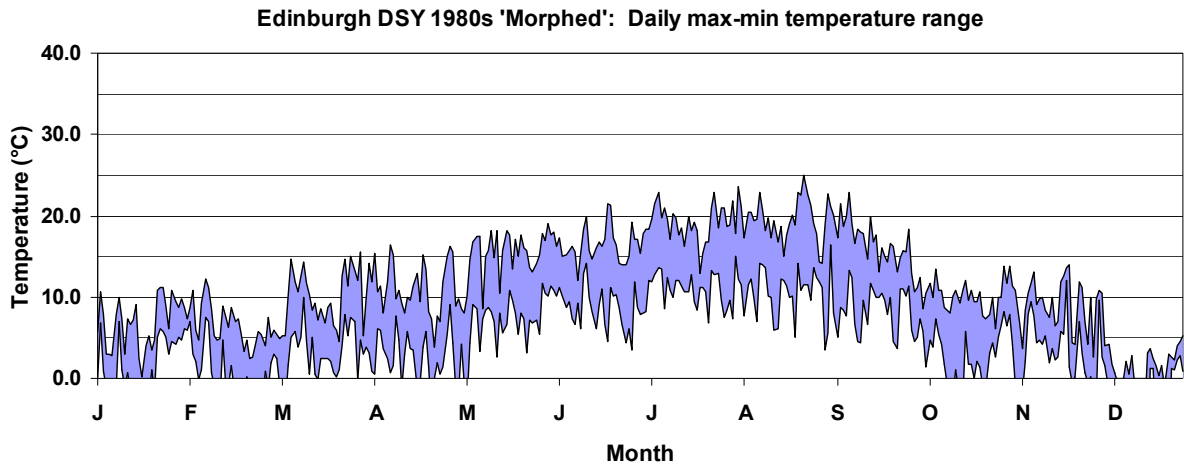
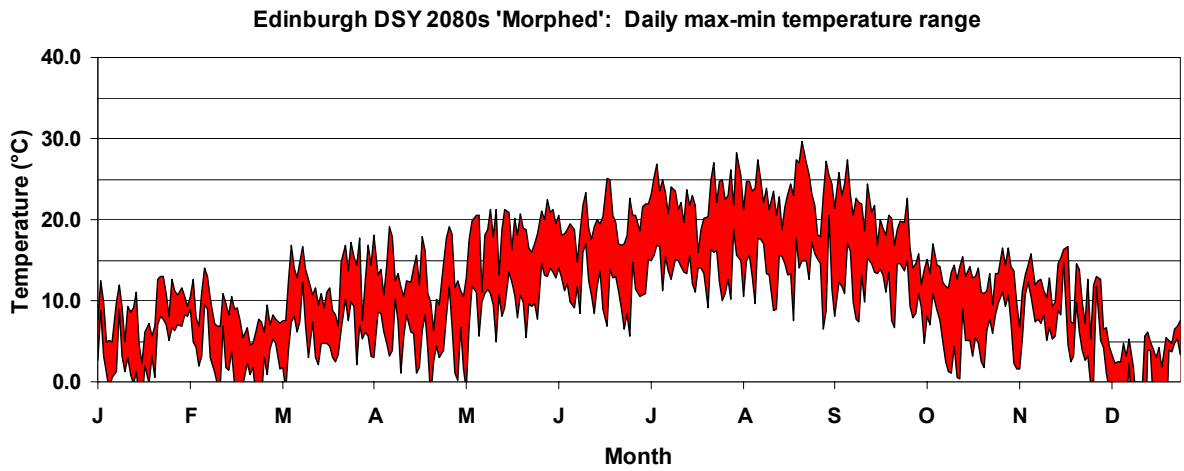


Figure 2.6. Daily temperatures for Manchester CIBSE 1980s DSY and future 'morphed' 2080s DSY under UKCIP02 Medium-High emissions scenario: Max–Min temperature range for (a) 1980s and (b) 2080s; (c) daily average temperature for 1980s and 2080s.

(a)



(b)



(c)

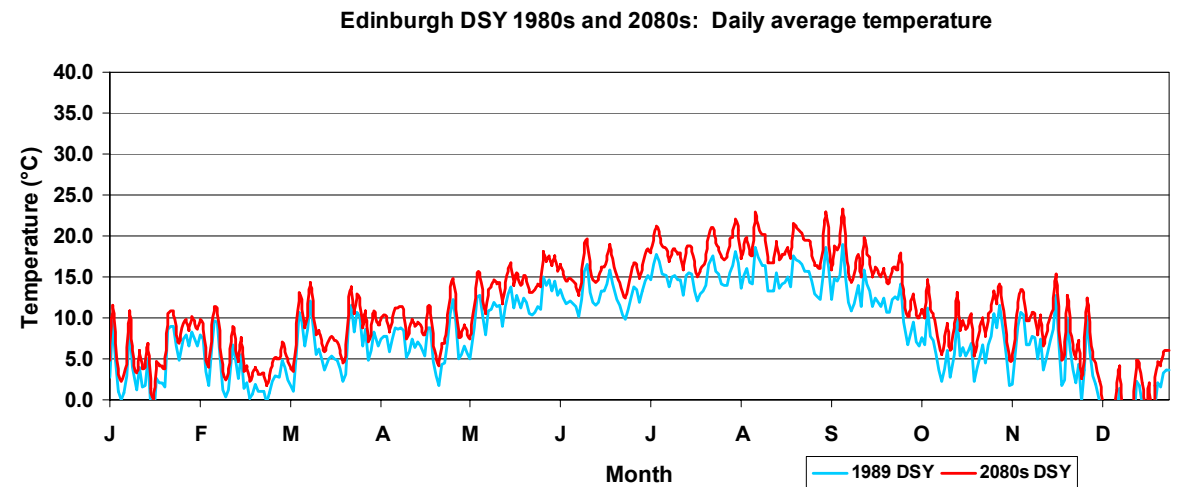
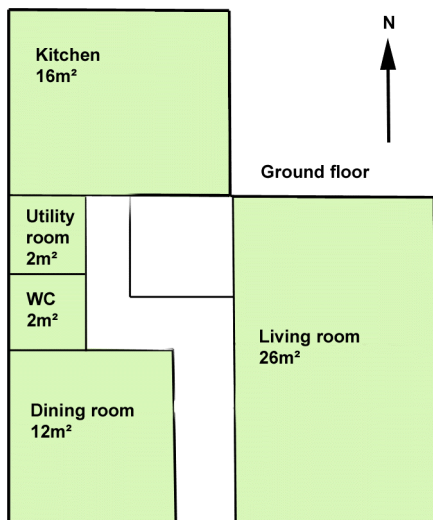
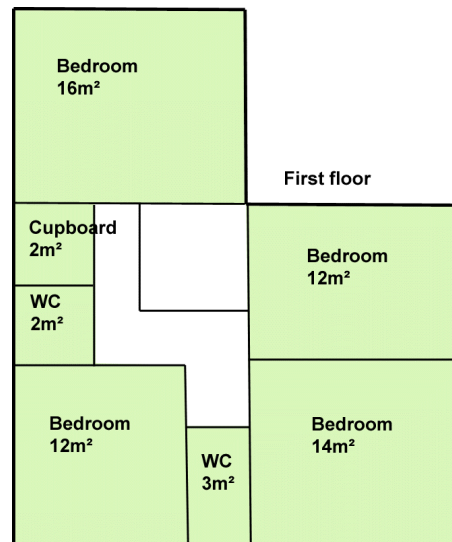


Figure 2.7. Daily temperatures for Edinburgh CIBSE 1980s DSY and future 'morphed' 2080s DSY under UKCIP02 Medium-High emissions scenario: Max-Min temperature range for (a) 1980s and (b) 2080s; (c) daily average temperature for 1980s and 2080s.

4. THE HOUSE MODEL



Ground floor plan and room dimensions



First floor plan and room dimensions (Note WC = bathroom/WC)

- **General description:** Four-bedroom detached house built to Part L 2002 Building Regulations standards of fabric insulation and air tightness. Total floor area of approx. 140 m², typical of a new-build 'executive home'.
- **Orientation:** The living room/ main bedroom side of the building faces South as indicated on the floor plans.
- **Construction:** Three types of construction were considered:
 1. **Medium Mass ("traditional" construction)** External walls: 150mm medium-weight concrete block with plasterboard finish (interior side) – insulated cavity – brick skin (exterior). Internal walls stud plaster board. Timber floors on upper storey, solid on ground floor, all carpeted. Synthetic slate tiled roof.
 2. **Low Mass** External walls: timber frame with plasterboard finish (interior side) – insulated cavity – timber cladding (exterior side). Internal walls stud plaster board. Timber floors on upper storey, solid on ground floor, all carpeted. Synthetic slate tiled roof.
 3. **High Mass** External walls: 150 mm heavy-weight concrete block wall (interior side) – insulated cavity – brick skin (exterior). Internal walls: 100 mm medium-weight concrete block. Precast concrete floor slabs. Concrete ceilings and walls exposed. Floors tiled (not carpeted). Synthetic slate tiled roof.
- **Fenestration:** Double glazed P-UVC units. South façade glazed area is approximately 14%.
- **Insulation:** External walls: $U=0.3 \text{ W/m}^2\text{K}$. Windows $U = 1.9 \text{ W/m}^2\text{K}$.
- **Air-tightness:** Background infiltration of 0.5 ac/h provided from trickle ventilators assumed.
- **Heating system:** Gas central heating with thermostatic radiator valves fitted to all radiators. The heating set points were 22°C for living areas and 18°C for bedrooms.

- **Occupancy:** The house is occupied by two adults and two children. It is assumed that all occupants are out during the day from Monday to Friday and present to varying degrees at the weekend.
- **Lighting:** Lighting level assumed to be controlled by occupants according to available day-lighting. Lights come on when daylight falls below a fixed threshold in occupied rooms, except in bedrooms when occupants are asleep.
- **Internal gains:** Heat gains due to lighting and TV/Stereo in the living room were included. Heat gains from kitchen appliances and hot water services were not modelled.
- **Ventilation and Shading:** the details of shading and ventilation provision and controls are dependent on the manner in which the house is being used. Two different cases are considered in §5 and §6.

5. ANALYSIS

5.1 Dynamic Thermal Model: Energy 2

Dynamic thermal modelling of the three houses was carried out using Energy2, a program developed in-house at Arup over a number of years. The program has a finite difference representation of wall heat transfer, uses hourly weather data (with 4 time steps per hour), and has a 2-layer stratification model to represent buoyancy driven flows. The program has been found to give predictions close to the median of a range of dynamic thermal simulation models considered in international software validation tests (IEA 21c [7] and Bestest [8]). The program was used as it enabled computer code, output and input information to be customised according to the particular needs of the study.

5.2 Comfort benchmark temperatures

There is no universally agreed standard for overheating in buildings in the UK. Moreover little research has been carried out on thermal comfort in dwellings, particular for the important issue of effects on sleep. However, in order to enable an objective quantitative assessment to be made, illustrative benchmarks have been defined.

For living areas, comfort threshold temperatures of 25°C and 28°C have been considered. These thresholds are close to those predicted by the Fanger [9] deterministic comfort model for 20% persons dissatisfied for low air speed and fixed relative humidity for clothing levels of: trousers, shirt and tie (25°C) and light summer dress (28°C). They are also the comfort temperature benchmarks used for the performance specification of the BRE Energy Efficient Office of the Future [10], for which exceedances of over 5% time over 25°C or 1% over 28°C were defined to indicate overheating. The 28°C threshold is also close to the 20% persons dissatisfied threshold predicted by the ASHRAE 55 Standard Adaptive Comfort model [11], which lies between 27.5°C to around 29.5°C for the London DSY climates under the Medium-High Emissions scenario.

For bedrooms, lower comfort benchmark temperatures of 21°C and 25°C have been considered on the grounds that people are more susceptible to thermal discomfort when asleep. As noted above, little research has been done on thermal comfort during sleep and so these benchmarks are more subjective than those for living areas.

In each case, the lower threshold temperature will be taken to indicate when occupants will start to feel 'warm' and the upper threshold temperature to indicate when they will start to feel 'hot'. It is considered that occurrences of both hot conditions or prolonged periods of warm conditions will motivate occupants to seek comfort cooling.

5.3 Comfort diagnostics

In order to quantify the level of thermal discomfort, the percentage of the year that space temperatures exceeded the comfort temperature thresholds *when occupied* were calculated for each room in the house. In all cases operative temperatures (average of air and space

surface temperatures) were considered, as this temperature more closely relates to thermal comfort than ambient temperature.

5.4 Model runs

Each of the three house models was run for London, Manchester and Edinburgh for the 1980s baseline timeslice and Medium-High emissions scenario 2020s, 2050s and 2080s timeslices. Here focus will be given to the results for London. Levels of overheating for Edinburgh and Manchester are generally lower than for London 1980s in all timeslices (with the exception of Manchester 2080s) and will be commented upon in Section 7.

6. THE UNADAPTED HOUSES

The first case to be considered is the ‘unadapted’ case, which is intended to represent the manner in which the house would normally be used in the present day. The factors that will be varied between this case and the ‘adapted’ case to be considered in §6 are solar shading and ventilation provision and controls. These factors are defined for the unadapted cases as:

- **Shading:** It is supposed that no solar shading is used.
- **Ventilation provision:** Ventilation is provided from openable windows in each room. The natural ventilation through the windows is capable of providing 6ac/h (above background infiltration) when the windows are fully open.
- **Ventilation control:** It was assumed that occupants would be to open windows when space temperatures reached a certain level and thereafter would continue to open windows further for temperatures above this level, regardless of whether it was hotter outside than inside. The space temperature threshold for window opening was taken to be 22°C and it was assumed that by 28°C windows would be fully open. A linear increase in window area between these two points was supposed. For simplicity, the ventilation rate was assumed to be linearly proportional to the open window area, varying from zero to the maximum of 6 ac/h. It was further assumed that because of security issues windows would only be opened when rooms were occupied. This assumption may not be entirely realistic. In some areas of the country, security concerns might preclude occupants from opening windows even when they are in the house, especially at night, whereas in other areas occupants would be happy to leave windows open most of the time .

Figures 5.1 – 5.2 show results for the ‘unadapted’ houses for 1980s and future timeslices under Medium-High emissions. Note that results for the other UKCIP02 emissions scenarios are not shown but some indication of comparative performance can be made by reference to figure 2.3.

6.1 Thermal performance

Figure 5.1 shows the predicted time variation of space operative temperatures in the living room and main bedroom of each house together with the external air temperature through the month of July for the 1980s DSY. Note that this is the month containing the warmest day of the year (33.6°C), which falls on a Sunday. The medium weight house generally tracks along the upper range of the external air temperature (or above it on some of the cooler days). The lightweight house has maximum temperatures close to the external temperature, but also shows a larger diurnal swing than the medium-weight house indicating that the building exhibits a fast thermal response to ventilation in the evening and at night. The minimum daily temperatures are lower than those in the medium-weight house. The heavyweight house shows the smallest diurnal range, as would be expected due to the high thermal inertia of the building, but also has temperatures some way below the external peak temperatures on the warmer days, tracking somewhat just above the monthly average mean temperature. In the medium and heavy weight cases, the bedroom temperatures are slightly warmer than the living areas throughout the day.

6.2 Overheating

Figure 5.2 show the thermal comfort diagnostics extracted from the model outputs. In the living rooms, the performance improved broadly in line with the level of thermal mass, although all three buildings experience reasonably high percentage hours of exceedance in

at least one timeslice. Significant levels of exceedance of 28°C (greater than 1% occupied hours) are predicted from the 1980s, 2020s and 2050s onwards, respectively, in the light-, medium- and heavy-weight cases, respectively.

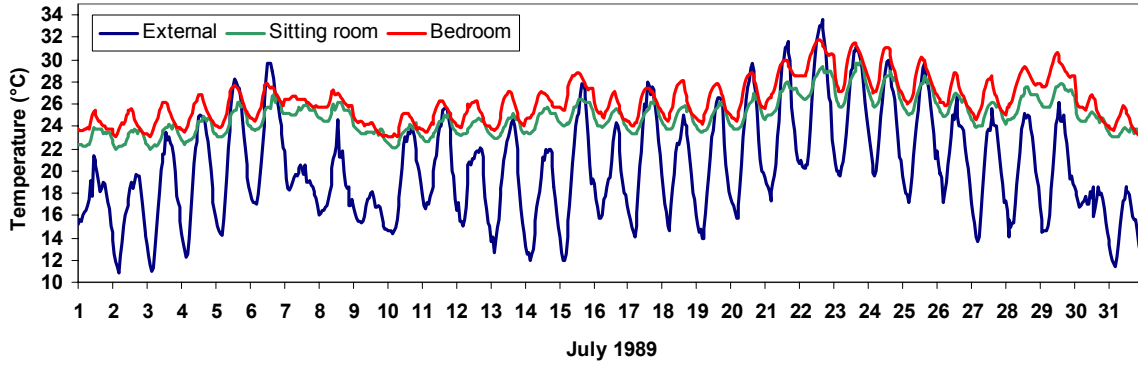
In the bedrooms there is much less difference between the thermal performance of the three buildings. In fact, the lightweight house is marginally better than the other two cases, and the medium-weight house the worse. This is because heat built up during the day is being retained during the day and reradiated at night in the heavier weight houses, while the lightweight building responds quite quickly at night to the cooling effect of ventilation air. However, all three buildings show significant levels of exceedance of both temperature thresholds in all timeslices including the 1980s.

6.3 Winter heating energy use

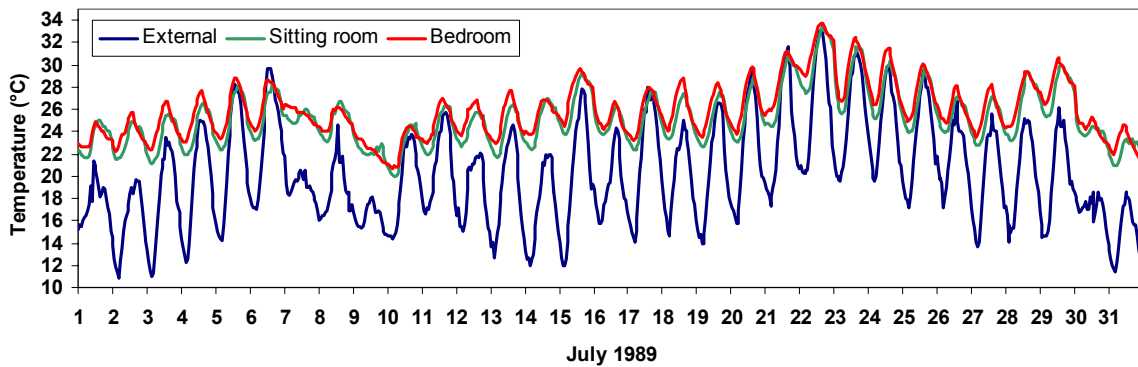
Changes in winter heating energy use are not shown, but were broadly similar in the three cases, being a reduction of around 30% from the 1980s to the 2080s timeslice. The predicted energy usage for the 1980s DSY in the low- and medium- weight houses, being 69.4 and 69.5 kWh/m², respectively, and slightly higher for the high-mass house at 77.5 kWh/m². The larger figure for the high-mass house is again due to the slower thermal response time, which carries an energy premium due to the intermittent way in which the heating has been scheduled. The high-mass house would benefit from a lower output continuous heating source, such as an underfloor system. It should also be noted that the high-mass house has not been optimised here to benefit from passive solar heating.

**LONDON BASE CASES (UNADAPTED)
1980s DSY**

Mediumweight



Lightweight



Heavyweight

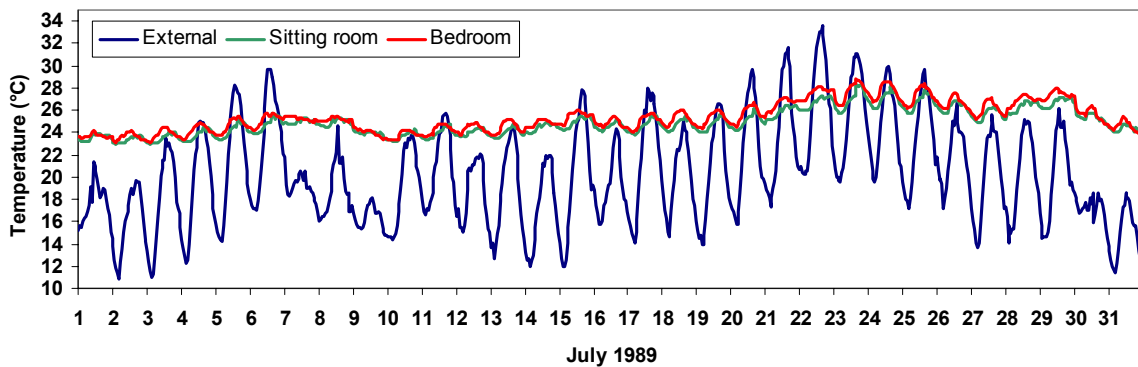


Figure 5.1. Predicted time variation of space operative temperatures in the living room and south-facing main bedroom of each house together with the external air temperature through the month of July for the 1980s DSY.

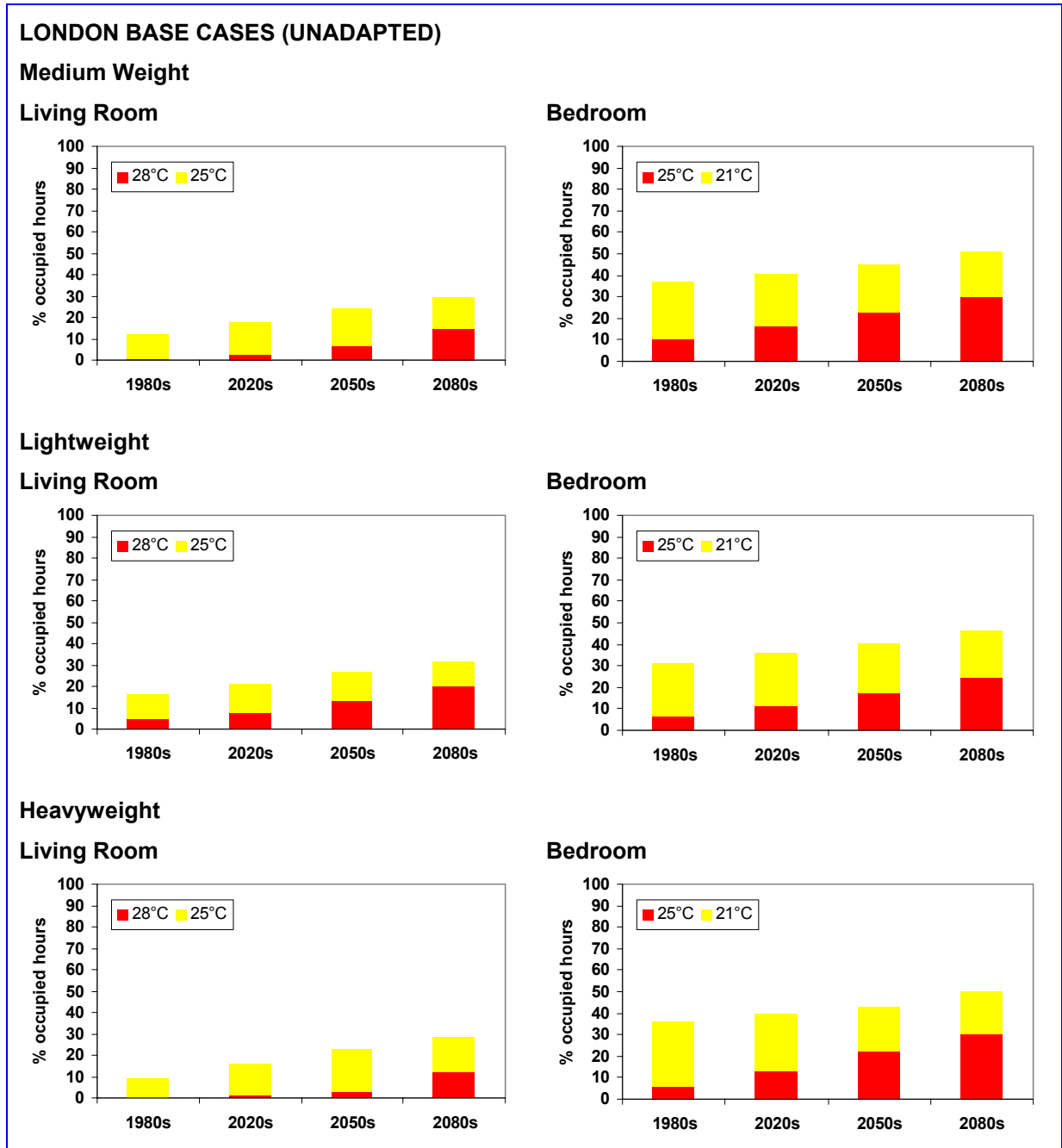


Figure 5.2. Percentage of occupied hours comfort benchmark temperatures exceeded in the three house models for 1980s and synthetic future DSYs under Medium-High emissions.

7. THE ADAPTED HOUSES

7.1 Adaptation Options

In order to improve the performance of the three houses, two 'passive' measures were considered: control of solar gains and control of ventilation.

7.1.1 Solar control

Since it was assumed that the houses are largely unoccupied during the day, quite high levels of solar shading were considered possible. Cases in which 50% and 90% of solar gain was excluded were considered, e.g. as might be achieved using external blinds or shutters. These shading levels were applied throughout the year for the purpose of the experiments, although in practice the shading would be regulated according to time of year, weather conditions, and daylighting needs.

7.1.2 Ventilation control

Ventilation can provide passive cooling relief, but when external temperatures are higher outside than inside, also constitutes a heat source. The objective, then, was to regulate ventilation rates so that they were at a minimum during warm periods and at a maximum during times of benefit, particularly at night. Note that night ventilation can provide substantial benefit in low-mass buildings as well as high-mass buildings if ventilation rates, due to the thermal storage of the air within the spaces. To model a controlled ventilation system, a mechanical ventilation system with a fixed achievable ventilation rate was supposed. Note however that this assumption does not preclude the possibility that the same effect could be achieved using a natural ventilation system where external conditions or building form are conducive to such an approach. The following simple control algorithm for the ventilation system was used:

1. **IF** the space is occupied **AND** the space operative temperature is above the heating set point and at least 3°C above the external temperature **THEN** switch the ventilation system on.
2. **IF** the space is unoccupied **AND** the space operative temperature is above 24°C and at least 3°C above the external temperature **THEN** switch the ventilation system on.
3. **OTHERWISE** switch off the system and allow fabric infiltration and/or trickle ventilators to provide the necessary minimum fresh air change rate for occupant health.

Note that windows are assumed to be closed at all times and each room has individual control.

Mechanical cooling

Mechanical cooling is another possible option, which is creeping into the domestic sector, particular among 'higher-end' apartment developments. Domestic air conditioning is widespread in many countries with warm climates, particularly the US. This option has not been considered here, the primary aim being to investigate how far thermal performance can be improved using passive cooling sources. [Note that an air conditioned house model has been done for the Partners in Innovation project, and results are available on request].

7.2 Performance

Figure 6.1 shows the effect of shade and ventilation control on the number of hours operative temperatures exceed 28°C in the living room of the lightweight and heavyweight houses. In each case the percentage of occupied hours over 28°C during the summer months (June, July and August) is plotted against the air-change rate provided by the mechanical ventilation system. Note that zero ac/h corresponds to the naturally ventilated unadapted case considered in §5. Different coloured curves on each graph relate to different levels of shading.

It can be seen from figure 6.1 that for given levels of shading, increasing ventilation rates to around 5ac/h provides a marked reduction in the number of hours of exceedance in both the heavyweight and the lightweight case. Increasing ventilation rates above this level provides limited additional benefit. It can also be seen that solar control provides strong benefits. These benefits are greatest in the base case, where the effect of introducing 90% shade is comparable to that of introducing controlled ventilation at over 5ac/h with no shading.

In all case the heavyweight house continues to perform better than the lightweight house, and the introduction of solar and ventilation control has larger relative benefits.

Figure 6.2 shows the percentage hours of exceedance of 28°C and 25°C in the living rooms, and 25°C and 21°C in the south-facing main bedroom of the lightweight and heavyweight house for the adapted case of 90% shade and a 6ac/h controlled ventilation system. These graphs should be compared with those in figure 5.2 for the unadapted cases. It can be seen that the introduction of the adaptation measures produces a dramatic reduction in the hours of exceedance of 28°C in both house types and in all rooms. Hours of exceedance are relatively small in all timeslice with the exception of the 2080s. The heavyweight house though continues to perform better than the lightweight house. In particular, while overheating in the bedroom of the heavyweight house was comparable to that in the lightweight house in the unadapted case, in the adapted case, the thermal performance of the bedroom of the heavyweight house is substantially better.

Further graphs showing the time variation of space temperatures in the heavyweight and the lightweight houses for the various cases are shown in the figures contained in Appendix B.

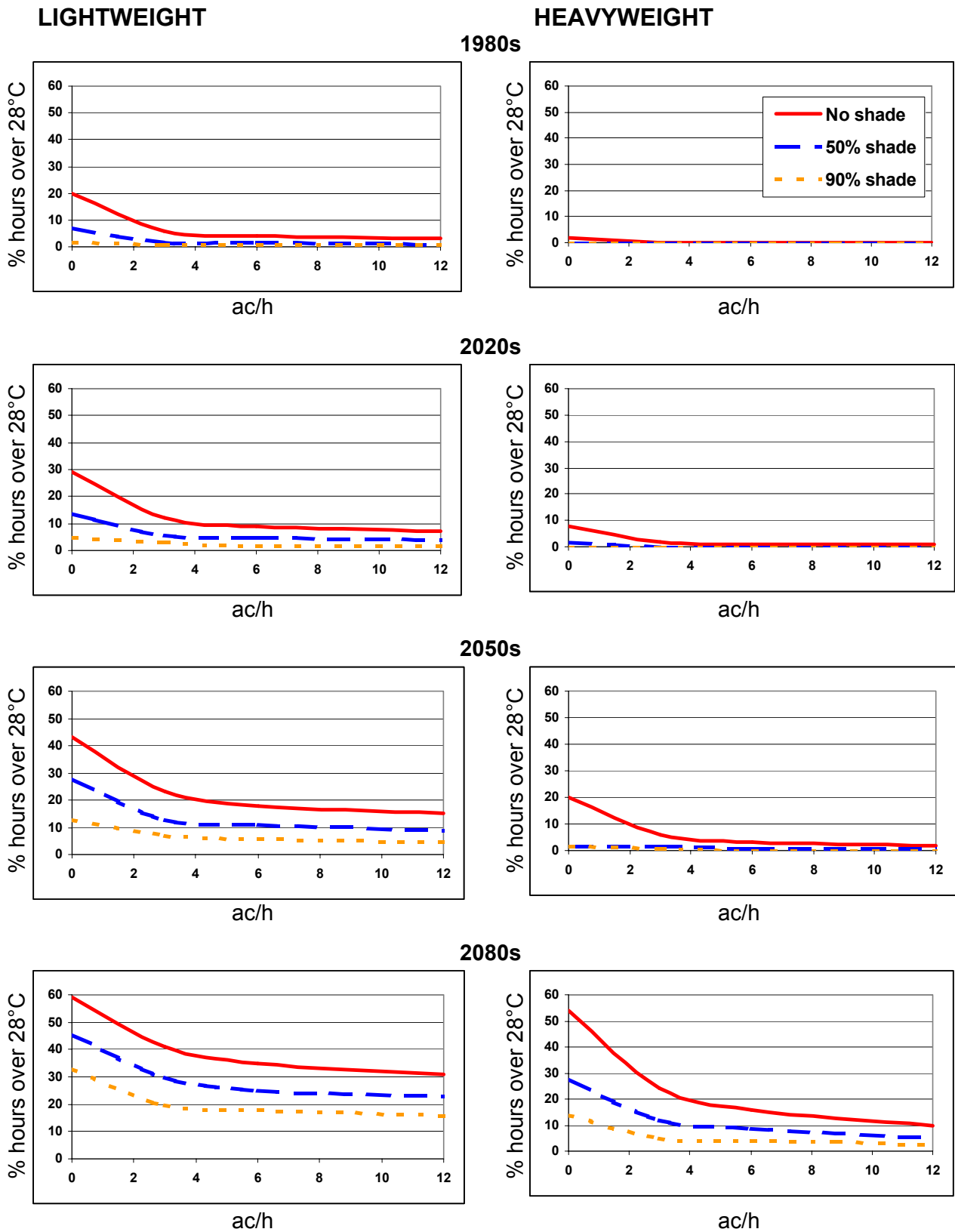


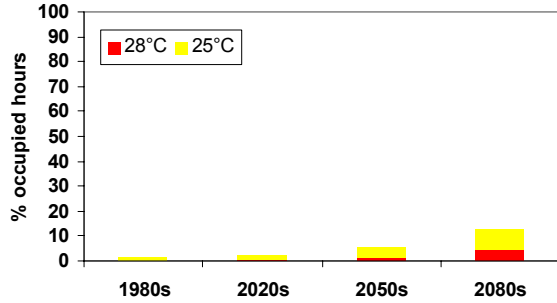
Figure 6.1 Effect of shade and achievable ventilation rate on hours of exceedance of 28°C as a percentage of occupied hours during the Summer months June-July-August. The ventilation system is controlled using the rule-based algorithm given in the text. An air-change rate of zero corresponds to the base case (unadapted) window based ventilation control algorithm, described in §5.

ADAPTED CASES:

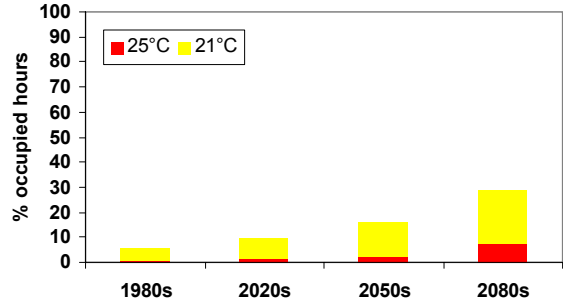
Shading at 95% + vent control up to 6 ac/h

Lightweight

Living Room

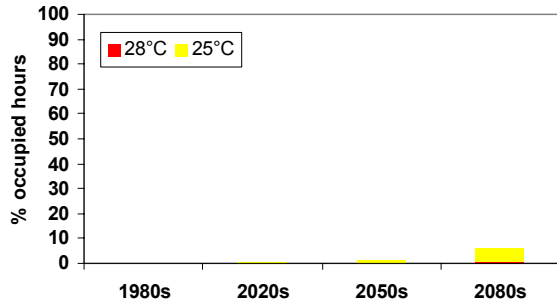


Bedroom

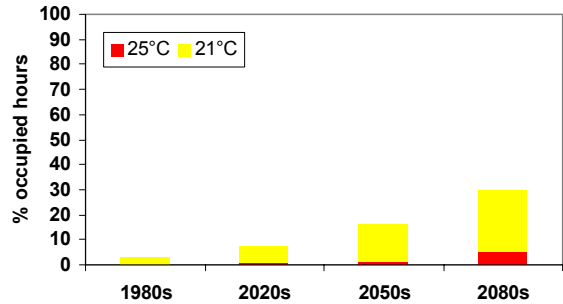


Heavyweight

Living Room



Bedroom



8. MANCHESTER AND EDINBURGH

Figure 7.1 shows a comparison of the results for the living room of the lightweight house for London, Manchester and Edinburgh under the Medium-High emissions scenario. For Manchester, the hours of exceedance of 25°C do not become larger than those for London 1980s until the 2080s, and then lie someway between the values of London 1980s and 2020s. For Edinburgh, the hours of exceedance of 25°C do not become larger than those for Manchester 1980s until the 2080s, and then are comparable to those for Manchester 2020s.

These results indicate that levels of overheating in Manchester and Edinburgh by the 2080s under the Medium-High emissions scenario would be comparable or slightly larger to those experienced in the present day in London and Manchester, respectively.

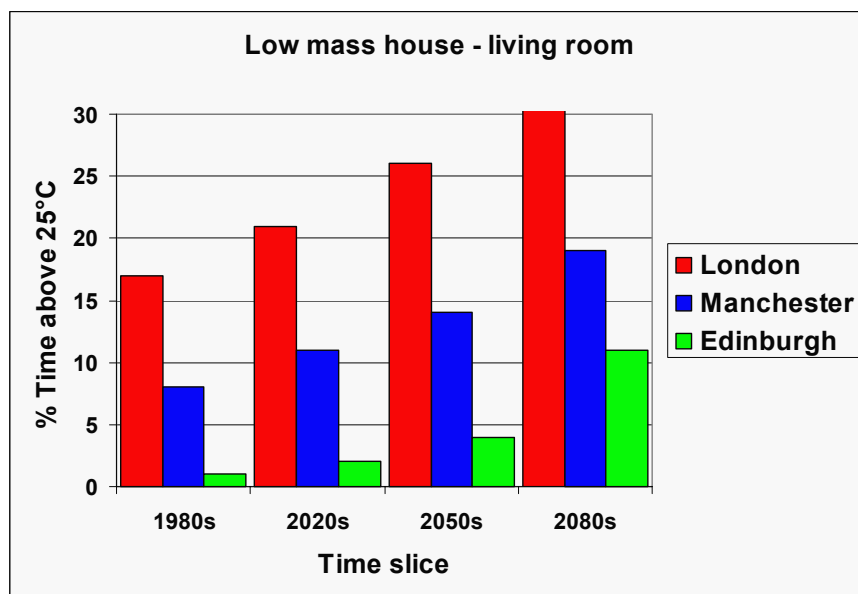


Figure 7.1 Comparison of the percentage of hours in the year that operative temperatures in the living room of the lightweight house exceed 25°C for London, Manchester and Edinburgh DSYs under the Medium-High emissions scenario.

9. REFERENCES

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11. ASHRAE Standard 55 –*Thermal Environmental Conditions for Human Occupancy*. Atlanta, ASHRAE Inc (2004).

APPENDIX A

**Occupancy, heating
and equipment
schedules**

1	Living Room	
2	Kitchen	
3	Dining room	
4	WC	
5	Utility	
6	Hall	
7	Stairs	
8	Bedroom 4 (north facing)	
9	Bedroom 1 (south facing)	
10	Bedroom 4 (north facing)	
11	Bedroom 2 (south facing)	
12	Bathroom	
13	Bathroom	
14	Cupboard	
15	Landing	

Table A1. Room number references.

LIVWD	living space	weekday
LIVWE	living space	weekend
KITWD	Kitchen	weekday
KITWE	Kitchen	weeken
BEDWD	Bedroom	weekday
BEDWE	Bedroom	weekend
BATWD	Bathroom	weekday
BATWE	Bathroom	weekend
HTWD	Heating	weekday
HTWE	Heating	weekend
ZERO		
CONST		

Table A2. Shedule types used for the different rooms. The schedules are defined in table A3.

Hour	% of maximum for each profile											
	LIVWD	LIVWE	KITWD	KITWE	BEDWD	BEDWE	BATWD	BATWE	HTWD	HTWE	ZERO	CONST
0-1	0	0	0	0	100	100	0	0	0	0	0	100
1-2	0	0	0	0	100	100	0	0	0	0	0	100
2-3	0	0	0	0	100	100	0	0	0	0	0	100
3-4	0	0	0	0	100	100	0	0	0	0	0	100
4-5	0	0	0	0	100	100	0	0	0	0	0	100
5-6	0	0	0	0	100	100	0	0	100	100	0	100
6-7	0	0	0	0	75	100	25	0	100	100	0	100
7-8	0	0	25	0	25	100	50	0	100	100	0	100
8-8	0	0	75	25	0	50	25	25	100	100	0	100
9-10	0	25	0	50	0	0	0	25	0	100	0	100
10-11	0	50	0	50	0	0	0	0	0	100	0	100
11-12	0	50	0	0	0	0	0	0	0	100	0	100
12-13	0	0	0	50	0	0	0	0	0	100	0	100
13-14	0	25	0	25	0	0	0	0	0	100	0	100
14-15	0	50	0	0	0	0	0	0	0	100	0	100
15-16	0	50	0	0	0	0	0	0	100	100	0	100
16-17	50	50	0	0	0	0	0	0	100	100	0	100
17-18	25	25	25	25	0	0	0	0	100	100	0	100
18-19	0	0	100	50	0	0	0	0	100	100	0	100
19-20	50	25	25	75	0	0	25	0	100	100	0	100
20-21	50	25	25	25	0	0	0	0	100	100	0	100
21-22	50	50	0	0	0	0	0	0	100	100	0	100
22-23	0	50	0	0	50	100	0	0	0	0	0	100
23-24	0	0	0	0	100	100	0	0	0	0	0	100

Table A3. Schedule profiles.

Ref.	Occupants				Lighting (W/m2)			Machines (W/m2)			
	No.	Act.	Clo	Profile	Load (W/m2)	Type	Profile	Sens. Heat input (W/m2)	Rad%	Late.	Profile
1	4	1	1	LIVWD	8	TUNGS	HTWE	5	30	0	LIVWE
2	4	1	1	KITWD	8	TUNGS	HTWE	15	.	0	KITWE
3	0	1	1	ZERO	8	TUNGS	HTWE	0	.	0	LIVWE
4	0	1	1	ZERO	0	TUNGS	HTWE	10	.	0	HTWD
5	0	1	1	ZERO	8	TUNGS	HTWE	5	.	0	HTWE
6	0	1	1	ZERO	8	TUNGS	HTWE	0	.	0	HTWE
7	0	1	1	ZERO	8	TUNGS	HTWE	0	.	0	HTWE
8	1	1	1	BEDWD	8	TUNGS	HTWE	0	.	0	BEDWE
9	1	1	1	BEDWD	8	TUNGS	HTWE	0	.	0	BEDWE
10	1	1	1	BEDWD	8	TUNGS	HTWE	0	.	0	BEDWE
11	1	1	1	BEDWD	8	TUNGS	HTWE	0	.	0	BEDWE
12	1	1	1	BATWD	8	TUNGS	HTWE	0	.	0	BATWE
13	1	1	1	BATWD	8	TUNGS	HTWE	0	.	0	BATWE
14	1	1	1	BATWD	8	TUNGS	HTWE	0	.	0	BATWE
15	0	1	1	HTWD	8	TUNGS	HTWE	0	.	0	HTWE
16	0	1	1	ZERO	0	TUNGS	HTWE	0	.	0	HTWE
17	0	1	1	ZERO	0	TUNGS	HTWE	0	.	0	HTWD

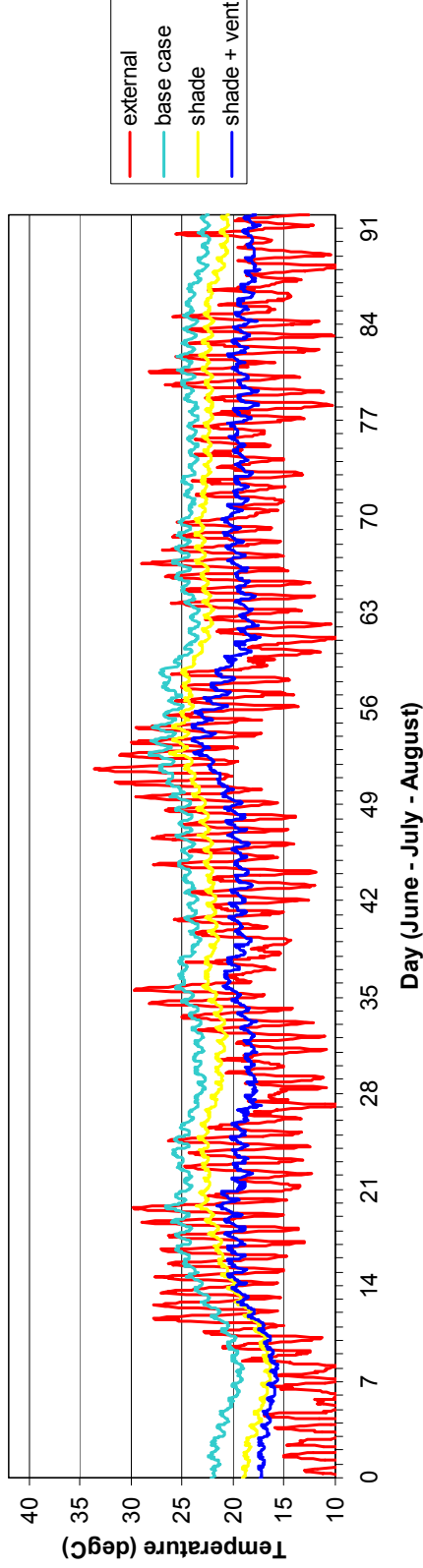
Table A4. Maximum number of occupants, lighting load and machine load (to be used with the profiles in table A3). Note that lights only come on when solar gain in a space falls to below 100 W/m2.

APPENDIX B

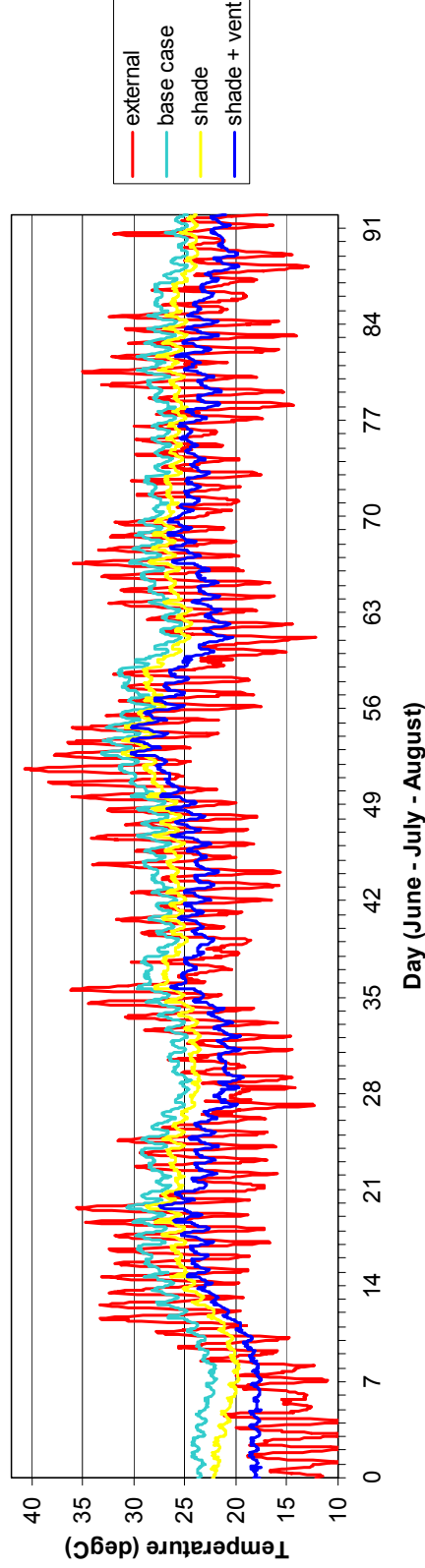
**Temperature
Timeseries**

B1. HEAVYWEIGHT HOUSE

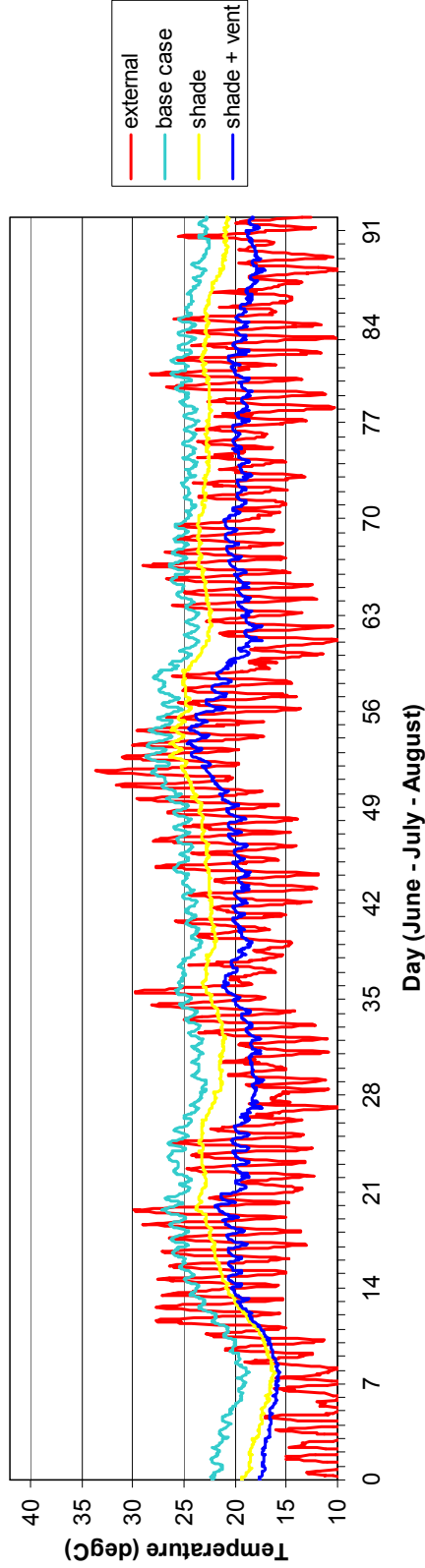
Heavyweight Living Room 1980s (Medium High Emissions)



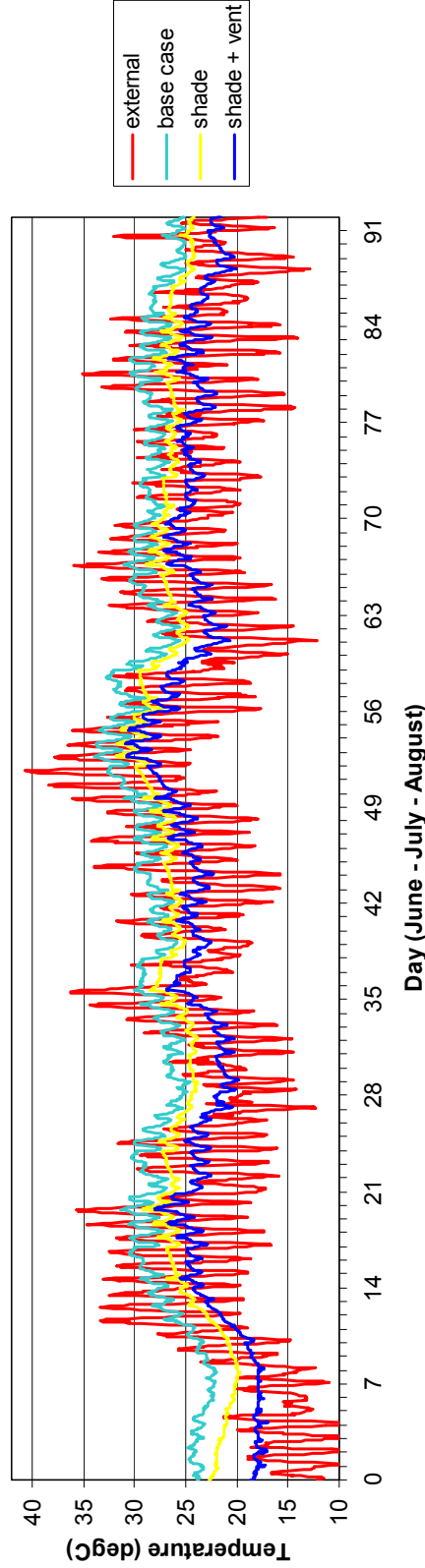
Heavyweight Living Room 2080s (Medium High Emissions)



Heavyweight Bedroom 1980s (Medium High Emissions)

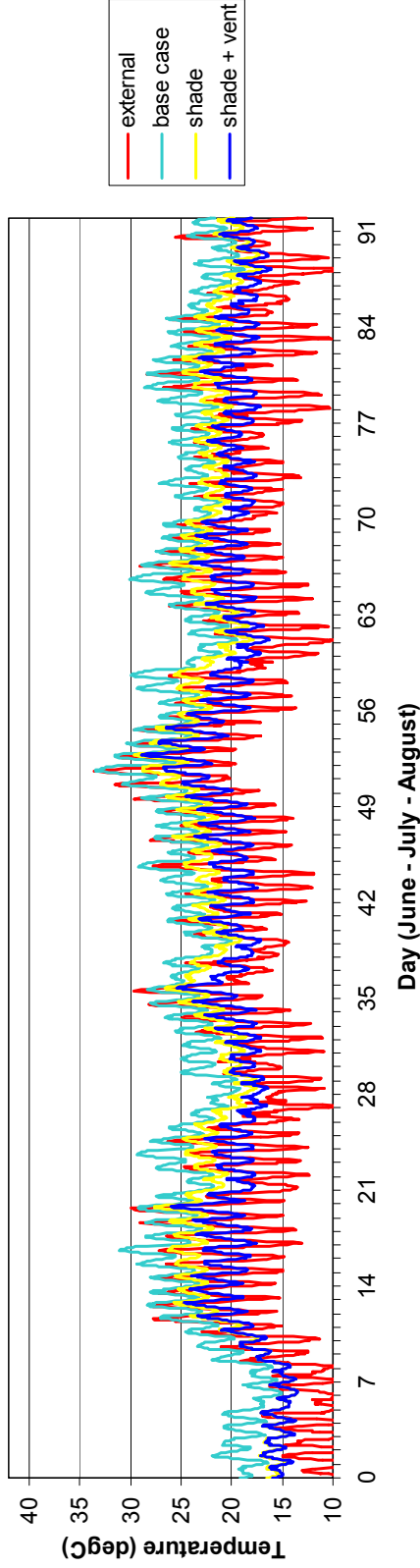


Heavyweight Bedroom 2080s (Medium High Emissions)

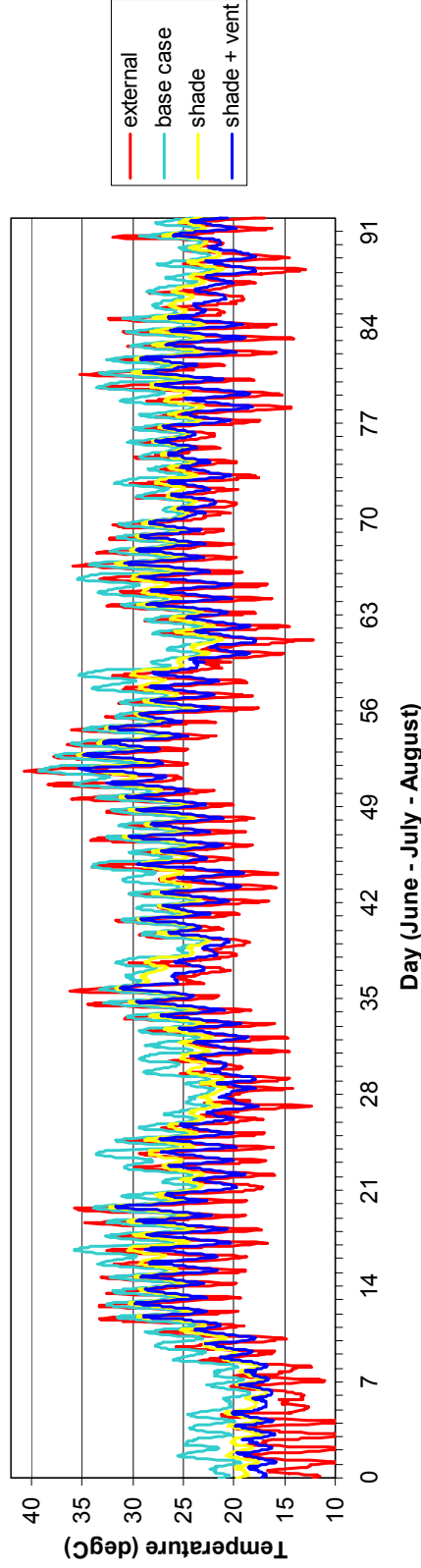


B2. LIGHTWEIGHT HOUSE

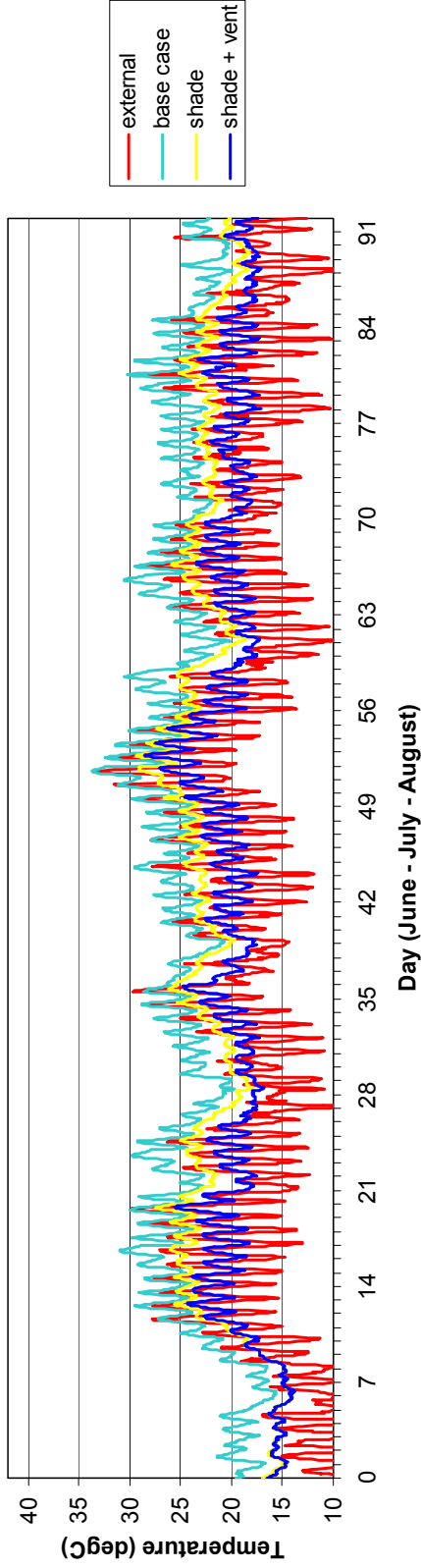
Lightweight Living Room 1980s (Medium-High Emissions)



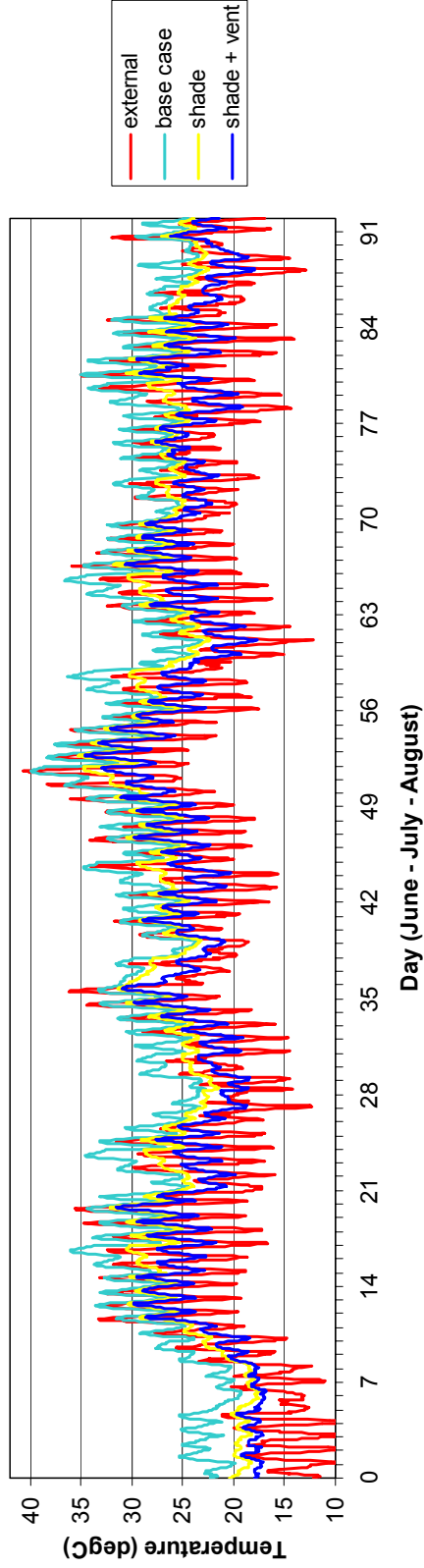
Lightweight Living Room 2080s (Medium-High Emissions)



Lightweight Bedroom 1980s (Medium-High Emissions)

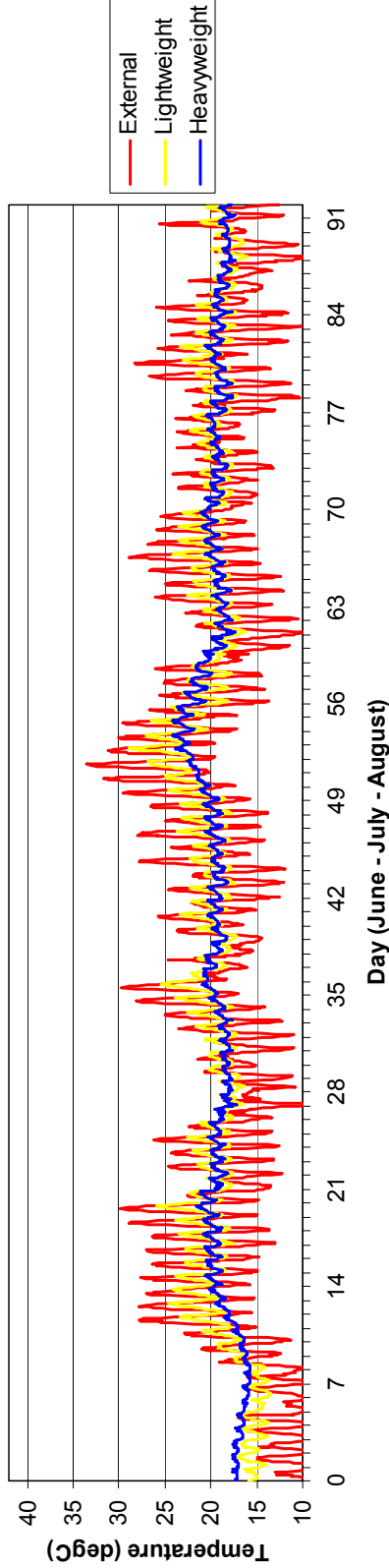


Lightweight Bedroom 2080s (Medium-High Emissions)

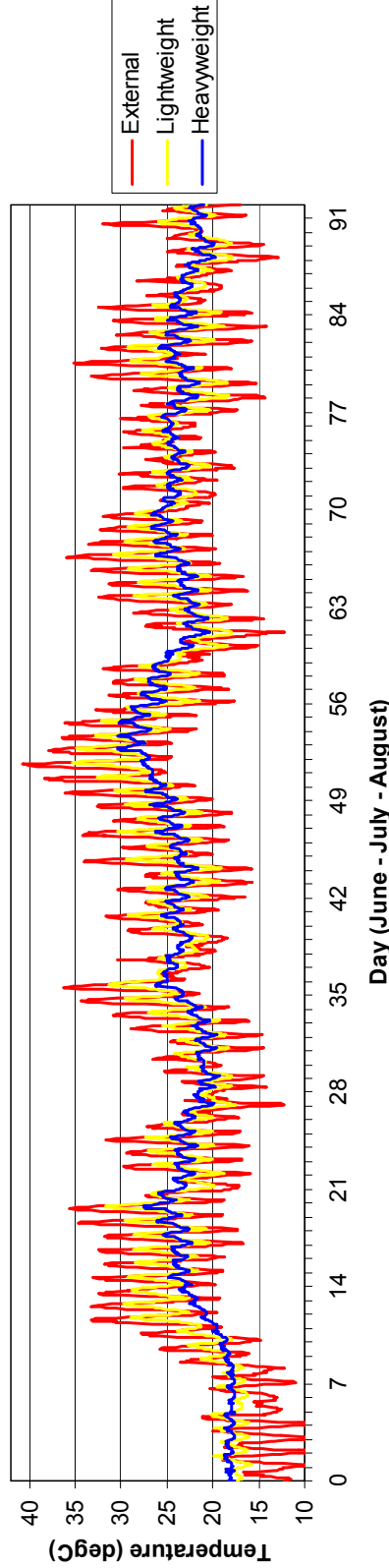


B3. COMPARISONS

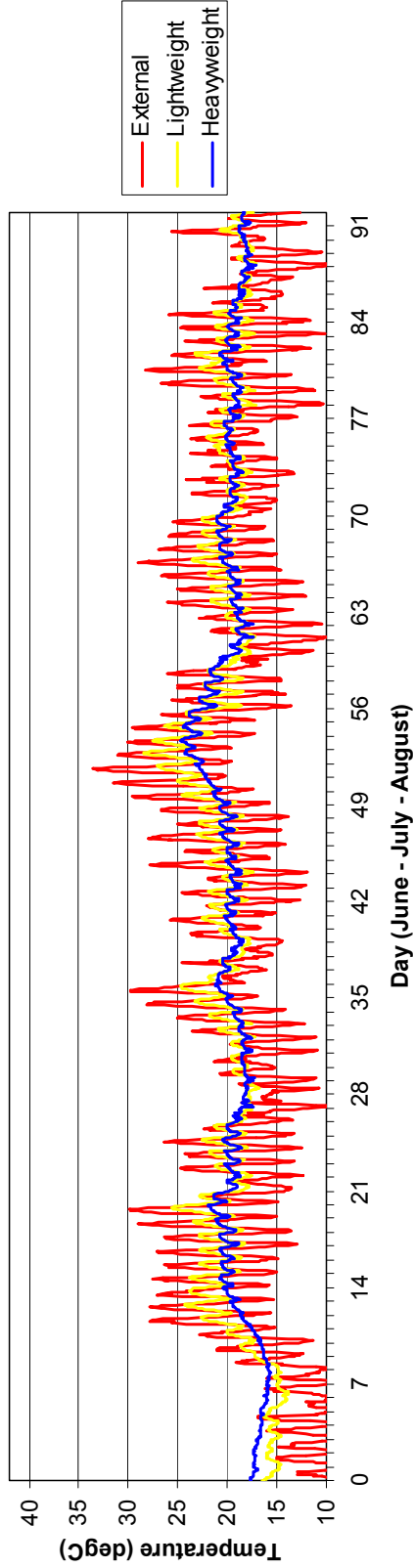
Living Rooms 1980s Medium-High Emissions: Shade + Ventilation Control



Living Rooms 2080s Medium-High Emissions: Shade + Ventilation Control



Bedrooms 1980s Medium-High Emissions: Shade + Ventilation Control



Bedrooms 2080s Medium-High Emissions: Shade + Ventilation Control

