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COPSE: Coincident probabilistic
climate change weather data
for a sustainable built environment

Deriving and using future weather data for building design from UK climate change projections – an overview of the COPSE Project

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Contents

Datasets and other outputs

Matlab scripts forming the weather data generators developed at Northumbria University are available for Matlab users. Contact Professor Chris Underwood: chris.underwood@northumbria.ac.uk.

Test Reference Years and other building design weather data for future climates derived from UKCP09 data may be provided by the University of Manchester. Contact: Professor Geoff Levermore: geoff.levermore@manchester.ac.uk.

Foreword

Climate change has increasing implications for the economic and social life of the UK, as the reports of the UKCIP[1] and the UK Climate Change Risk Assessment 2012[2] make clear. In particular, it will impact on the performance of our built environment – our buildings and the civil infrastructure that supports our urban communities and our communications networks. Recognising this, the Engineering and Physical Sciences Research Council has funded successive programmes of research aimed at improving understanding of the impact of climate change on the built environment and into means of improving its adaptability and resilience. A recent phase of this research brought together a number of research projects, including COPSE, under the umbrella of the Adaptation and Resilience to Climate Change (ARCC) Co-ordination Network (CN)[3].

The ARCC CN has sought to develop close links between those directly involved in the research, who are principally in universities, and prospective users of the outputs, such as policy-makers, architects and engineering consultants. To that end, it has held conferences and technical events, published summaries of the research programmes and issued regular newsletters, with the aim of promoting the outputs of the research and facilitating their application. This publication further contributes to that overall aim.

Academic research is, rightly, first published in peer-reviewed journals where it can be subject to the scrutiny of other researchers, and the findings compared with those of similar studies. Journal publications are often, though, not easily accessible for practitioners who will be principally concerned with the findings and their implications rather than the methods through which they were obtained. By contrast, short non-technical summaries do not provide a suitable basis for application of the findings. This publication seeks to fill that gap, in that it offers an overview of the COPSE project which, while summarising the research undertaken, gives most attention to the outputs and their relevance for practitioners. By also providing full details of the publications from COPSE research, it facilitates further investigation by those who wish to take advantage of latest research findings.

I hope that this booklet will be both useful and relevant to all those engaged in ensuring that our buildings meet their occupants' comfort requirements without excessive energy use, both now and in the future.

Roger Street

UKCIP **Technical Director for Adaptation Science, UKCIP**

arcc cn

ARCC CN – Enhancing resilience across the urban environment

The Adaptation and Resilience to a Changing Climate Coordination Network brings together a range of research projects funded by the Engineering and Physical Sciences Research Council. These look at the impacts of climate change and possible adaptation options in the built environment and its infrastructure including water resources, transport systems, telecommunications, energy and waste.

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[1] *www.ukcip.org.uk*

[2] *www.defra.gov.uk/publications/2012/01/26/pb13698-climatechange-riskassessment/*

[3] *www.arcc-cn.org.uk*

Executive summary

The COPSE (COincident Probabilistic climate change weather data for a Sustainable built Environment) research project was undertaken between 2008 and 2011. Led by Manchester University, with eventually six academic research partners and the Meteorological Office contributing to the overall programme, the core aim of the project, addressed by the Manchester research team, was to develop robust methodologies for producing weather data files for assessing building designs in future climates, considering the period up to 2080, with particular reference to comfort and energy use. But the scope of the project was much wider; topics studied (and the universities involved) included:

- a critical analysis of future projections of solar radiation and its characteristics (Napier)
- the impact of future climates on the internal temperatures experienced in typical buildings, particularly examining the proportion of time for which these would exceed conventional comfort temperatures and the additional energy required for mechanical cooling systems (Northumbria);
- the interaction between internal temperatures and the external noise environment, now and in the future, since the noise environment influences the ability of building occupants to achieve comfort conditions by opening windows and increasing ventilation rates (Sheffield/Liverpool);
- the implications for future energy use of the adoption of 'adaptive comfort' criteria in the design of buildings, since this approach would reduce demand for mechanical cooling (Bath/Kent);
- the Urban Heat Island in the Greater Manchester conurbation, with new modelling tools being developed (Manchester);
- the potential change in national demand for energy for space heating and cooling in the building stock (Bath).

Chapter 1 provides an introduction to the project, outlining its background and some principal findings.

Chapter 2 describes the research related to the production of future weather files for use in modelling building performance. Conventionally, two sets of weather data are used in building design. The first is a Test Reference Year (TRY); this consists of hourly values of key weather variables (dry-bulb temperature, solar irradiance and relative humidity) which, as judged by a defined statistical process, best represent average conditions for the year. This set is used for assessing annual energy use. The second is a Design Summer Year, produced by a different process, which presents hourly data for the same variables that are representative of more extreme summer conditions. These data are used when modelling the performance of the building during periods of hot weather to assess the likelihood of over-heating.

The Weather Generator associated with the UKCP09 Climate Projections produces 3000 years of synthetic hourly data for any UK location and future time period up to 2080, under three different climate change scenarios: Low, Medium and High emissions. However, some variables that are important for building design (e.g. wind speed) are not included. These were deduced from the other data and from the augmented data set 21 TRYs were produced for each of three locations: London, Manchester and Edinburgh. These TRYs related to seven future dates (2020 to 2080) and three emissions scenarios. One finding was that while average winter temperatures are projected to increase, average summer temperatures will increase faster.

The standard process for deriving the Design Summer Year is known to produce anomalous results for some locations. Hence an improved method for deriving data sets representative of more extreme conditions was developed, the resulting data files being termed the Design Reference Year (DRY). The internal environmental conditions in a building are determined not by a single weather variable but by the combination of the three key weather variables (hence the reference to 'coincident' in the title of COPSE). For an individual building, the relative importance of each varies with the building characteristics, its orientation and across seasons. Thus, for example, a building with extensive west-facing glazing may be less likely to overheat during summer months than during spring and autumn, because of the higher solar angle during the summer. A key feature of the new method for providing data representative of more extreme conditions is that DRYs may be derived using different weightings of the weather variables, thus enabling designers to test the building performance with a DRY that is suited to the characteristics of the individual building.

As with TRYs, a DRY may be produced from the synthetic weather data for any location, future time period and emissions scenario. In addition, designers have the option of specifying the probability associated with the DRY; thus modelling performance using a DRY that is representative of conditions that on average occur only once in 100 years is a more demanding assessment than if the DRY represents conditions that occur on average every 20 years.

The derivation of future TRYs and DRYs fulfilled the aim of providing robust methodologies for deriving future weather data files for building design which reflected both the probabilistic nature of weather data and the need to test designs with data representative of more extreme combinations of the key weather variables.

As part of the process of preparing the synthetic weather data from which the TRYs and DRYs were derived, the solar variables produced by the UKCP09 Weather Generator were subject to close analysis. This showed that both the hours of sunshine and the proportion of direct to diffuse radiation were projected to increase in the future, although the physical basis for these changes was not evident. Subsequent interactions with the team responsible for the Weather Generator resulted in a revised generator being published in 2011.

Chapter 3 covers the work undertaken, using the future weather data files, to explore how buildings would perform in future climates. Four contrasting buildings – an office building, a primary school, a hospital and a residential care home – were modelled in different locations, using not only the future weather files from COPSE research but also those available from other sources (although the conclusions from each were broadly similar). These studies showed a steady rise in the proportion of time for which the internal temperatures exceeded the conventional upper limit for comfort of 28°C; for the office building in Manchester, for example, this rose by 2050 to more than 15% of occupied hours. The rate of increase varied – thus for example the hospital showed a relatively slow increase because of the high proportion of deep-plan spaces which are not as influenced by future increases in solar radiation. Clearly, though, the need to minimise over-heating will become an increasing factor in design, and the ability of an existing building to maintain acceptable internal temperatures will be a factor in decisions on whether to demolish or refurbish.

The modelling studies also produced estimates of the cooling capacity and associated energy consumption required in these buildings. Again, a steady increase was observed, with a doubling of cooling energy consumption by 2050 under some emission scenarios. Because of its warmer climate, demand in London is significantly higher than in the other cities. However, the increase in cooling energy use has to be set against a projected decline in energy use for heating in winter. This was also estimated through the modelling studies, with the conclusion that the reduction in winter energy demand would exceed the increase in the summer. Because future winters would continue to have periods of low temperatures, though, there would be little impact on the capacity required in heating plant.

A separate study examined the relationship between the external noise environment and the ability of occupants to increase ventilation rates through opening windows. As ambient temperatures rise, occupants have greater need to open windows, but this may mean that they are exposed to external noise for an unacceptable length of time. By combining 'noise mapping', through which the external noise level on different parts of a building could be calculated, and thermal modelling, the impact of rising temperatures on comfort and cooling energy requirements could be studied. This research showed that, unless noise levels could be reduced, cooling energy requirements would rise significantly. Hence avoiding the need to install mechanical cooling in buildings that currently rely on natural ventilation may require a combination of measures, not only to improve the thermal performance of the building but also to reduce external noise levels.

The studies outlined above were based on the conventional design approach of taking 28°C to be the upper limit of the comfort band for most building occupants. However, previous research has shown that people adapt to warmer periods, for example by changing their clothing, and can be comfortable at higher temperatures. This observation underpins the theory of Adaptive Comfort, which predicts the upper comfort temperature from of the external temperatures experienced in the immediately preceding few days. **Chapter 4** summarises research carried out to determine the extent to which adoption of that approach to comfort could reduce the need for mechanical cooling of buildings and the associated energy use. The research demonstrated that the maximum cooling energy saving in a building over the summer could be related to a novel metric, the number of Adaptive Comfort Degree Days, and this in turn could be derived simply from the weather data for the location of the building.

Further, there are two methodologies for predicting the maximum comfort temperature using Adaptive Comfort principles, one set out in a European standard and the other in a US standard. The research modelled the performance of a building in future climates and showed that if the comfort temperature were calculated using the US standard, the building would require mechanical cooling much earlier than if the European standard were used. Hence the latter maximised the potential energy savings.

Temperatures in urban areas are generally higher than those in surrounding rural areas, the effect being known as the Urban Heat Island (UHI). The UHI, which can be up to 8°C in Manchester, needs to be taken into account when assessing a building's propensity to over-heat. Studies of the UHI in Manchester, outlined in **Chapter 5**, particularly focussed on the way that 'street canyons' influence the temperature, by reducing the rate at which heat may be lost through radiated to the atmosphere. This research resulted in a new model for estimating the UHI at an urban location which takes into account the 'Sky View Factor', i.e. the proportion of the sky that can be seen from street level.

Complementing the studies of future energy consumption in individuals buildings, described in Chapter 3, a top-down assessment of the impact of climate change on energy use in the national building stock was undertaken and is summarised in **Chapter 6**. The study was based on data on gas consumption published by the National Grid. The relationship between gas consumption and the average daily temperature was determined for 13 regions. The effect of warmer winters could then be explored, using the future weather data files. The research showed that, depending on the emissions scenario chosen, energy use for space heating (currently, about one sixth of national energy use) would fall by 16–18% by the 2030s and by around twice that proportion by the 2080s. Thus climate change will itself bring about a significant reduction in national energy demand (and there will be additional reductions because of changes in the stock, with newer buildings being thermally more efficient than those in the present stock).

The findings from this broad range of research illuminate different aspects of future building performance, while the weather data files will be available to support future research and design studies. The report includes full details of the publications resulting from COPSE, and contacts through whom the future weather data files may be accessed. The current revision of a key document for the design of building services, Guide A of the Chartered Institution of Building Services Engineers, is drawing on COPSE outputs. Further studies will build upon the work reported here.

1 Introduction

This report summarises the research undertaken and the findings of the COPSE (Coincident Probabilistic climate change weather data for a Sustainable built Environment) project, funded by the Engineering and Physical Sciences Research Council between 2008 and 2011. The project was led by Manchester University, the other academic research partners being Bath University (and after a staff move, the University of Kent), Napier University, Northumbria University and Sheffield University (with, following another staff move, Liverpool University). The Meteorological Office was also research partner. The research was informed by a Stakeholder Group on which were representatives of key potential users of COPSE findings – building owners, architects, engineering consultants, suppliers of design software etc. This Group met on five occasions during the course of the project.

COPSE developed and applied tools for examining the performance of buildings in climates which the UK may experience in the course of this century. Buildings have long operational lives; most are expected to be in use for 50–100 years and some for even longer. In previous eras, designers could assume an unchanging climate, and buildings which provided acceptable internal conditions when first occupied could reasonably be expected to do so until the end of their useful lives. This assumption is no longer valid; the global climate is changing, as evidenced by the reports of the International Panel on Climate Change[4]. Hence designers need to be able to model the performance of buildings under future climatic conditions in order to give prospective investors and occupiers assurance that they will continue to provide acceptable conditions, perhaps with some modifications during their service life. Reflecting the general trend towards a warmer climate, a particular need is to be able to assess a building's propensity to over-heat during a prolonged period of hot weather.

The core aim of the COPSE project was to develop robust methodologies for producing weather data files for assessing building designs in future climates, with particular reference to comfort and energy use. These data files were based on the probabilistic outputs of the Weather Generator associated with the UKCP09 Climate Projections[5], published in 2009. At the same time, however, the opportunity was taken to improve upon standard procedures for producing weather data for assessing over-heating, in particularly by enabling designers to select data by reference to a combination of key variables: external temperature, solar irradiance and relative humidity. This new methodology therefore incorporated the characteristics of *coincidence* and *probability* that featured in the project's title.

However, the research undertaken within the COPSE project covered a much larger range of topics. In addition to taking lead responsibility for the development of the new weather data files, Manchester University recorded hourly temperatures at 59 locations throughout Greater Manchester in order to characterise the Urban Heat Island in the conurbation. From these data, new models were developed to assist designers to estimate more accurately the actual external temperature to which buildings in urban areas will be exposed, thus improving the prediction of internal temperatures in those buildings.

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[4] *Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report of the IPCC. (2007) Cambridge: Cambridge University Press. Available at www.ipcc.ch*

[5] *Available at http://ukclimateprojections.defra.gov.uk*

Napier University undertook a critical analysis of future projections of solar weather data, notably projections of hours of sunshine and the relationship between direct and diffuse radiation, as part of the process of developing new weather data files. This analysis showed up anomalies in the output from the original UKCP09 Weather Generator and led to the publication of an amended generator.

The impact of future weather patterns on both the thermal performance and the energy consumption of typical buildings was studied by Northumbria University. Using future weather files developed by COPSE and other projects, this research showed the extent to which internal temperatures would exceed the conventional comfort criterion of 28°C, under different climate scenarios. It also enabled the cooling energy required to maintain comfort conditions to be estimated. Winter performance was also studied, with the conclusion that the reduction in space-heating energy demand consequent on warmer winters would more than compensate for the increase in summer cooling energy requirement. However, there would be little impact on the plant capacity required.

Complementing this work on individual buildings, the University of Bath examined the impact of possible future climates on energy consumption for space heating in the national building stock, drawing on gas consumption data published by National Grid. This showed that energy use was likely to decline by around 17% by the 2030s, with further reductions in later decades.

The team at Bath also explored the way in which adopting 'adaptive comfort' principles in building design could affect assessments of over-heating. This term relates to the ability of people to adapt to warmer external conditions, which means that they can feel comfortable when the internal temperature in a building is higher than the conventional upper limit for comfort. As a consequence, there is reduced need for mechanical cooling and with its associated energy demand. Bath developed a novel metric, the Adaptive Comfort Degree Day (ACDD), for exploring this effect.

Finally, Sheffield University examined the relationship between internal temperatures in naturally ventilated buildings (i.e. those which rely on opening windows to produce comfortable internal temperatures in warm conditions) and the external noise environment, under present and future climates. Clearly, the ability of occupants to open windows is influenced by the external noise level and as external temperatures increase, it becomes more likely that the building will need to be equipped with some form of mechanical cooling. The level of external noise could be a factor in determining whether an existing building can continue to be used.

Hence the COPSE research programme illuminated a number of aspects of the impact of climate change on buildings in the UK and provided tools relevant to the assessment of both existing and future buildings. The following chapters present in more detail the research undertaken and the findings, and draw out the implications for building design and performance assessment. A full list of COPSE published outputs is also provided.

2 Projecting future weather

2a Test Reference Years and Design Reference Years

Building designers model the thermal performance of proposed designs: first to estimate annual energy consumption and secondly to provide information on internal environmental conditions (temperature, air change rates etc) during periods of hot weather. The latter process leads either to an assessment of the adequacy of natural ventilation for maintaining acceptable internal conditions or to an estimate of the cooling capacity that will need to be provided by mechanical plant to maintain environmental conditions appropriate for the activities within the building.

For these assessments, designers turn increasingly to computer-based modelling techniques, although manual methods may also be used. Whichever approach is used, there is a need for sets of weather data for the proposed location which suitably represent the conditions to be assessed. In the case of annual energy estimates, the data will be representative of an average or typical year. For assessments of performance in hot weather, data representative of more extreme conditions will be used.

These data are derived from weather observations stretching back over a period of 20–30 years. There are different methods for converting observational data to weather files for building design but those most widely used in the UK are set out in ISO and European Standards[6] and the resulting data appear in CIBSE Guide A[7]. The final data for annual assessment of performance are assembled into a Test Reference Year (TRY) while the data for summer-time assessment are presented as a Design Summer Year (DSY). Each takes the form of files of hourly data relating to weather parameters such as external temperature, solar irradiance and relative humidity. In principle, different DSYs may be derived, each based on a particular interpretation of *extreme* conditions; the data in the standard DSY represent conditions that have a 12.5% probability of being exceeded.

A core element within the COPSE project concerned the development of such weather data files based not on historic data but on future weather patterns as generated by the Weather Generator associated with the UKCP09 climate projections. These files provide designers with the ability to model the performance of designs under defined future conditions, thus providing greater assurance that buildings designed now will continue to provide acceptable environmental conditions in future decades.

But COPSE went further, by developing a different way of assembling data for summer-time assessments, the Design Reference Year (DRY). The DRY addresses some well-known shortcomings of the Design Summer Year and gives designers an alternative approach to modelling designs in future climates. The advantages of the DRY over the DSY are discussed more fully later.

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[6] *BS EN ISO 15927-4: 2005 Hydrothermal performance of buildings – calculation and presentation of climatic data, Part 4: Hourly data for assessing the annual use for heating and cooling.*

[7] *Chartered Institution of Building Services Engineers. Guide A: Environmental Design (2006).*

UKCP09 Weather Generator Output

The Weather Generator[8] associated with the UKCP09 Climate Projections produces files of simulated hourly weather data based on the climate projections that result from the application of Low, Medium and High Emission scenarios to the UK Climate Model. The projections relate to 10 year intervals starting at 2020 and finishing at 2080. For each future date, e.g. 2050, the Generator provides 3000 years of simulated weather data, each year being based on a random starting point. Hence 3000 years of simulated weather data are available for 21 combinations of emission scenario and future date. Furthermore, the data can be obtained relating to any defined location, since the underlying UK climate model is based on a grid of the UK and takes into account factors such as elevation, exposure to the sea, degree of urbanisation etc.

However, the output from the Weather Generator does not include all the weather variables required for assessments of building performance. In particular, wind speed and direction and cloud cover are not included. Hence before any derivation of weather files could commence, methods for filling these gaps had to be devised (see Box 1).

Box 1 Additions and corrections to UKCP09 data

Wind speed

Building simulation models require wind speed data for modelling natural ventilation performance. These data are produced in the course of generating the UKCP09 datasets and are used, in conjunction with temperature and humidity data, to calculate the rate of Potential Evapotranspiration (PET) which is important for some (e.g. agricultural) applications of the dataset. However, they are not reported separately owing to the values having low statistical confidence levels. Fortunately, it is a relatively simple task to compute the wind speed from the PET values provided in UKCP09, the other weather parameters also provided and the particular algorithm used to calculate the PET. The calculated wind speeds were compared with output from a similar weather generator and found to agree very well. Current climate models cannot model wind speed with sufficient accuracy to be able to give meaningful predictions of future wind speeds. Hence the distribution of wind speeds derived from the UKCP09 data essentially matches the current distribution of wind speeds.

Wind direction

The procedure adopted provided typical data taken from historical weather files. For a given location, a frequency analysis of hourly wind direction data (0–360° in 10° steps) was carried out for each calendar month over the 10 years 1996–2005, as well as for each month taking all years together. 12 months were then chosen whose hourly data were closest to the average pattern for that month in the 10-year frequency distribution. These 12 selected months provided the wind direction data required. While these data represented typical wind direction time series data for a site, there was no linkage with the other weather parameters derived from the CP09 datasets, e.g. wind speed, temperature or solar radiation. Moreover, these data inherently assumed that historical patterns of wind direction would continue into the future, there being no basis for assuming otherwise.

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[8] *Jones, P.D., Kilsby, C.G., Harpham, C., Glenis, V. and Burton, A. (2009). UK Climate Projections science report: Projections of future daily climate for the UK from the Weather Generator. University of Newcastle, UK. University of Newcastle, UK http://ukclimateprojections.defra.gov.uk/22588*

Cloud cover

The radiation balance for a building depends partly on whether the sky is clear or cloudy. Cloud cover was derived from the UKCP09 data by taking the data on the proportion of each hour for which there was sunshine (S), and calculating oktas from the formula 8(1-S). (An okta is a unit of cloud cover, 8 oktas being total cover.) No cloud cover data could be directly derived at night time and so this was estimated by linear interpolation between the values at dawn and dusk.

Box 1 Additions and corrections to UKCP09 data (continued)

Solar radiation

UKCP09 data provide values for diffuse and direct solar irradiation on the horizontal plane. It was found that at low sun angles these gave rise to unrealistically high values of direct normal beam irradiation. These low angle errors in the UKCP09 data were corrected by setting the direct radiation to zero for the first and last two hours each day, the diffuse radiation being left unchanged. (For a further account of the solar correction, see page 19).

Barometric pressure

UKCP09 data do not include an air pressure variable and therefore a standard, fixed value of 101 350 Pa was assumed. This was a less significant approximation than the others because barometric air pressure, in contrast to wind pressure, has a very small impact on building performance.

Test Reference Year

A Test Reference Year (TRY) takes the form of an hourly data file for a single year whose weather patterns are close to the average weather pattern over a 20-30 year period. The TRY used in the CIBSE Guide consists of 12 months of observed hourly data. Each month is selected separately and is the month with cumulative distribution profile for daily data (average daily dry-bulb temperature, humidity and solar radiation) closest to the cumulative profile for that month for the whole 20–30 year period. 'Closeness' is defined by the Finkelstein–Schaffer (FS) statistic for the distribution[9]; this provides a measure of the difference between two cumulative distributions of data – for example, the distribution of daily average temperatures for a particular month (e.g. August) with the distribution of daily temperatures over the complete set of Augusts. The lower the FS-statistic, the closer is a particular August's distribution of temperature to the overall distribution for August.

This process was applied to the augmented and corrected UKCP09 data, using the 3000 years of generated weather data available for any defined location, climate scenario and future period. The FS statistic was calculated for each month by comparing the distribution of average daily values for that month with the distribution over the whole set of 3000 months. This was repeated for each of the three weather variables of dry-bulb air temperature, humidity and solar radiation, producing 9000 FS statistics. For each month, a combined FS statistic was then calculated by taking the means of the FS-statistics for the three parameters (dry-bulb air temperature, humidity and solar radiation).

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[9] *Finkelstein JM and Schafer RE (1971) Improved Goodness-of-Fit Tests. Biometrika 58(3), 641-645.*

The January with the lowest combined FS statistic was then selected as the January for inclusion in the TRY, and so on for the 12 months. Hourly data for these months were then extracted and concatenated to form a complete TRY of 8760 hourly sets of data. The inconsistencies in the data at the beginning and end of each month were left unsmoothed as there are already large discontinuities in the generated hourly data at the daily joins (at each midnight).

The final form of the TRY was an Excel file of weather data whose monthly distributions of daily averages for air temperature, relative humidity and solar irradiation are closest to the average distribution of these variables over the whole set of data for the 3000 synthetic years. Data in this form are suitable for testing the future energy performance of a building using building simulation software. The file could be read by, for example, IES building simulation programs, or through a conversion macro, by Designbuilder. (The latter requires the weather file first to be converted to CIBSE TRY format – which is automatic within the COPSE software – and then processed by the program CCweathergen to produce an Energy Plus Weather file for Designbuilder to read.)

In principle, it is possible to produce a range of TRYs, each based on a different combination of the three weather variables; however, it was thought that designers would prefer to operate with a single TRY which is a common, practical future weather year for assessing the average performance of proposed designs. In COPSE, this TRY was derived, for any location, for each of the 21 combinations of emissions (high, medium and low) and time period (one of seven up to 2080–2099) for which covered by the UKCP09 projections.

Figure 2.1 illustrates the projected impact of climate change. It shows, for Heathrow, the average daily temperature for each month of the current TRY and also for TRYs derived for future years under the UKCP09 High emissions scenario. Under this scenario, the mean January temperature in the 2080s is projected to be some 4°C higher than in the 1970s while the projected increase in the mean July temperature is around 6.5°C. Thus summers are expected to become warmer at a faster rate than in winters. This increase in summertime temperatures will increase the risk of overheating in buildings.

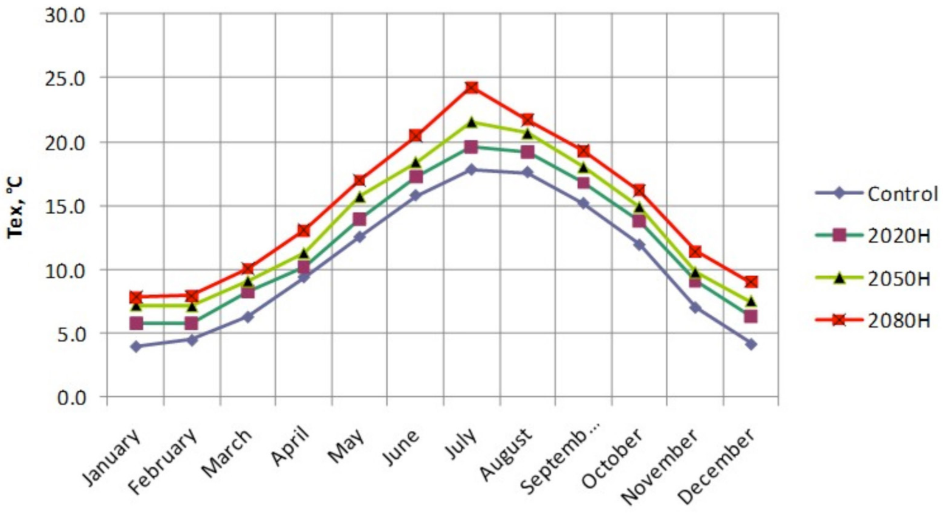

Figure 2.1: Monthly mean temperatures for the TRYs for Heathrow under the high emission scenario.

Design Reference Year

As noted above, the performance of a proposed building design during a period of hot weather is currently assessed using a file of weather data known as a *Design Summer Year*. This is an actual year of hourly weather data, although in practice only the data in the period April-September are used in the assessment. The selected year is the third warmest over that six-month period out of a total period of 20 years (i.e. the 87.5 percentile), as determined from daily average dry-bulb temperatures. Thus since the selection is based on the six-month average, there is no guarantee that the resulting DSY will contain a period when temperatures tend towards the extreme.

Moreover, the internal environmental conditions within a building during a period of hot weather depend not only on the external temperature, but also on solar radiation, humidity and wind speed. The selection process for the DSY does not take these other factors into account and it can, therefore, result in a year of actual data which does not incorporate the most testing conditions for the building. In some locations, the DSY as constructed by this procedure has a summer period which is cloudier than the *typical* conditions of the TRY.

Indeed, for some buildings, the most testing conditions occur when external temperatures are unlikely to be at a maximum. The perimeter zones of buildings with a high proportion of glazing will be particularly responsive to solar radiation at lower angles, and so the most testing conditions may occur during a warm period in April or May, rather than during a period of higher temperatures in June or July. Recognising this, the CIBSE method for manual assessment of building thermal performance (In Guide A, referenced previously) provides separate tables of weather data, one incorporating near-extreme solar radiation and the other near-extreme dry-bulb temperatures These rarely coincide, as shown in Figure 2.2. To create this figure, the average daily temperature for the same day in the year – 1st June, 2nd June etc. – was calculated for each year of a 30-year period centred on 2050, using weather data generated from the UKCP09 projections, and the 10 highest averages selected. The same process was carried out using data on solar irradiance. The result is an ‘L’ with only a small overlap in the two plots where periods of high average temperature coincide with periods of high irradiance. One explanation is that periods of high irradiance have low cloud cover, and with the clear skies the night-time temperature drops significantly, thus reducing the daily average.

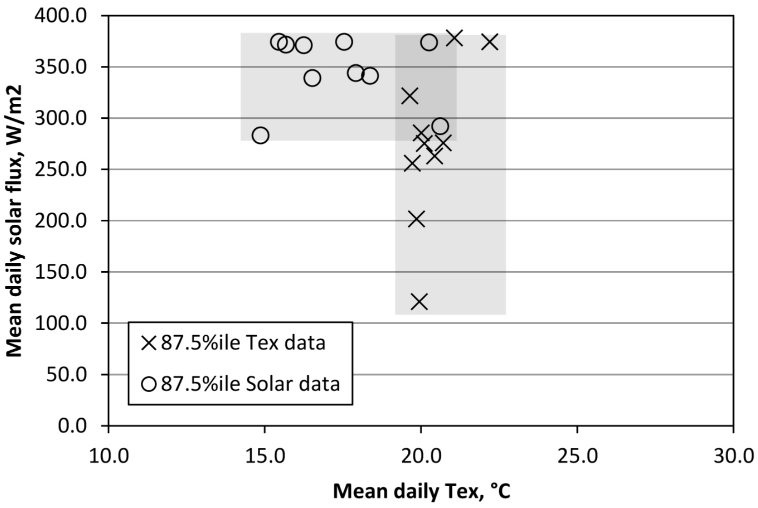

Figure 2.2: Coincidence of warm and sunny days in June. DRY data for Turnhouse, Edinburgh (2050, High emissions scenario).

To overcome the shortcomings of the DSY, COPSE developed an alternative method of selecting data for summer-time testing, and brought these together in a Design Reference Year (DRY). As with the DSY, the data are selected using a percentile, but for the DRY each month is selected separately, and on the basis of more than one weather parameter – not just temperature. The process also differs from that of the DSY by having two stages, the first of which selects a band of candidate months on the basis of one parameter, and the second then selects from those months using all three parameters.

The procedure for constructing the DRY based on external temperatures, using weather data generated from the UKCP09 projections, is described in Box 2. It is designed to produce weather data representative of the more extreme end of the weather spectrum, and with a realistic coincidence between high values of the different weather variables. However, it should not result in weather conditions that would rarely be experienced in practice.

One important difference between the DRY and the DSY is that the first stage of section for a DRY can alternatively be based on humidity or irradiance data, so giving emphasis to aspects of the weather that may be more significant for a particular building. Hence, for any particular choice of initial risk factor – 87.5% in the example in Box 2 – and for each combination of emissions scenario and future date, three DRYs may be constructed: based respectively on daily mean temperature (DRY-1), on relative humidity (DRY-2) and on total solar irradiance (DRY-3).

Box 2 Construction of the Design Reference Year

Each DRY relates to a specified emissions scenario and a specified future date and for a selected combination of emissions and future date, 3000 years of simulated hourly weather data are available. The mean monthly air temperature was computed for each calendar month and, for each January, February etc, the 3000 mean monthly temperatures were sorted into ascending order. The point on the monthly distribution corresponding to a chosen percentile, e.g. 87.5%, was then selected. The years corresponding to the band of 20 points centred on that point were identified and the data from that month from those 20 years were extracted from the 3000 years in the original weather file. Thus 20 Januaries, Februaries etc were selected. From the set of Januaries, a specific January was selected for the DRY using the same statistical process as was used for the TRY with the added refinement that the three years with the lowest combined rank sum (taking into account dry-bulb temperature, humidity and irradiance) were selected and the year within this group which had the closest mean monthly wind speed to the mean of all 20 years was chosen. The 12 months of the DRY were thus selected.

Once all twelve months had been chosen, the relevant data were extracted from the UKCP09 weather file, the months were concatenated and the month boundaries smoothed (linearly interpolated between the last eight hours of one month and the first eight hours of the next month). The end of December was also smoothed to join smoothly to the January month. These final data form a DRY based on the original selection of the 87.5% level of monthly external air temperature. As with the TRY, the data are held in an Excel file which is readable by proprietary software used for modelling building thermal performance.

Figure 2.3 compares an example of DRY-3 with the corresponding DSY, for the three principal weather parameters used in the selection process. Each plot shows mean monthly values calculated from UKCP09 data for a 5km square at Manchester's Ringway Airport using the High Emissions scenario for the year 2080. For the comparison, only the months of April to September are relevant since the DSY is not intended to be used outside this period (by contrast, all 12 months of the DRY are potentially useable – see below). The figure shows that when the near-extreme data are selected primarily on solar irradiance, the DRY has a higher level of irradiance than the DSY, by up to 60 W/$^{m^2}$, or about 25%, in June, July and August. By contrast, air temperatures for DRY-3 are lower in the main summer months (by 5–7°C) than for the DSY. Relative humidity over the summer is similar on average but with up to a 15% difference in individual monthly means. This DRY may, therefore, be more relevant for testing buildings or parts of buildings sensitive to the level of solar irradiance.

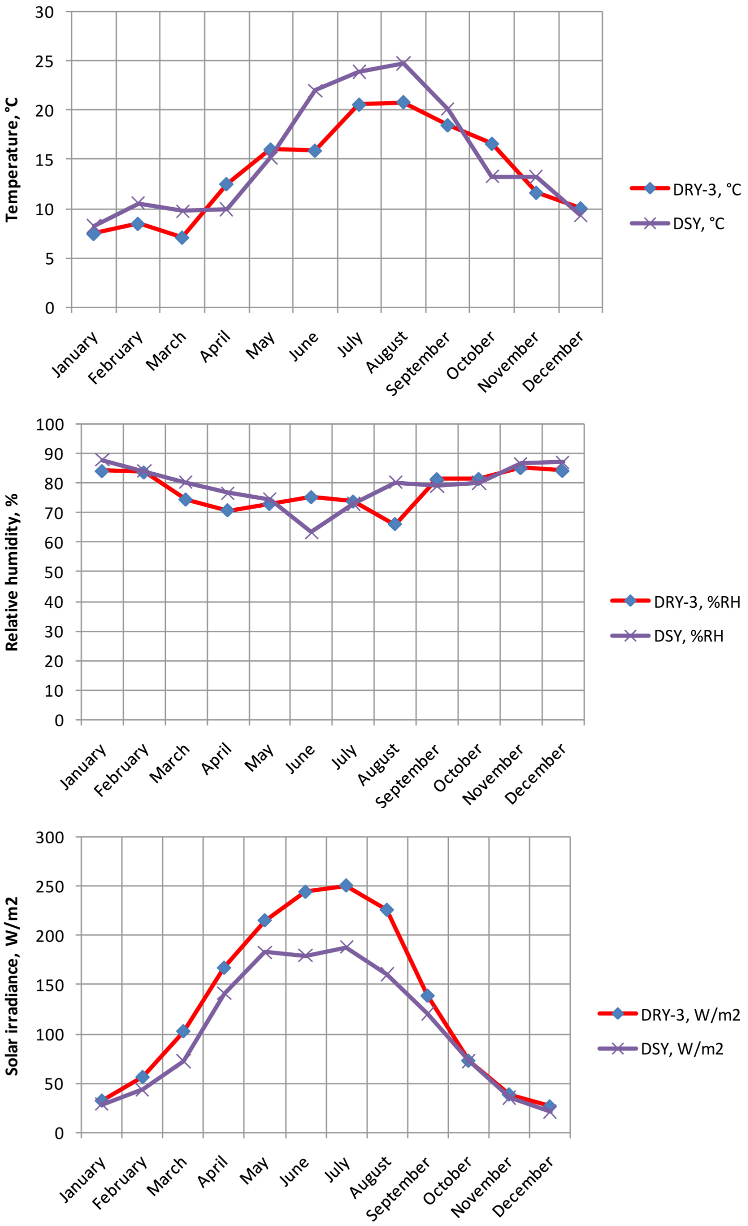

Figure 2.3: DRY-3, selected primarily on solar irradiance. Comparison of key parameters with the DSY (2080 High emissions) monthly averages for Manchester Ringway.

Use of the DRY

The ability to derive a DRY based on different weather parameters gives designers more scope for identifying the critical conditions for over-heating in a proposed building. The building is first modelled using the complete DRY as the weather file; from this, the month with the highest risk of overheating is identified. The effect of varying the design is then explored using that month's data. Only one month is selected since the concatenation of extreme months that forms the DRY produces a weather year that is extremely unlikely to ever occur in its entirety. However, in a multi-zone building, it may be advisable to investigate the performance in each zone separately, and the critical month may vary between zones. This may have implications for the total cooling plant capacity required.

As noted above, different buildings will be more or less sensitive to solar gain. Deep plan, heavily over-shadowed, or windowless buildings will have least sensitivity, and so DRY-1 and DRY-2 would be more appropriate for testing their performance. Conversely, in shallow-plan, highly glazed buildings, solar gain will be very important, and performance would need to be tested using DRY-1 and DRY-3.

The initial choice of risk factor will change the severity of the test applied to the building design. This can be changed by the designer, but if the DRY were to become a formally endorsed weather data concept, it would be helpful for CIBSE to give guidance on the percentile to be used in different circumstances.

Finally, although all the previous discussion has been in the context of performance testing for periods of hot weather in the summer, the DRY can also be used to examine building performance during the winter; by choosing, for example, the 12.5 percentile, the performance may be assessed in cooler, drier and cloudier periods.

Summing up

COPSE has provided a new way of assembling weather data for the purposes of assessing the performance of a proposed building during the summer[10]. By comparison with the present DSY, the DRY provides much greater consistency between months, and much greater assurance that the weather data file will contain periods where the coincident values for temperature, solar radiation and humidity are representative of testing external conditions that need to be taken into account in the design, but are not at the extreme end of the spectrum of variability.

The DRY for a given location, timeframe and scenario is not a single dataset since it will vary according to how extreme a user wishes the weather to be in the design assessment; this will influence the choice of percentile in the distribution. Moreover, the critical month will vary according to the particular building or zone, orientation, function, etc. Hence the DRY is, rather, a methodology that provides a consistent way of selecting weather data for assessing building performance according to the parameters of interest: solar irradiance, air temperature or humidity.

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[10] *Watkins R, Levermore GJ, Parkinson JB, The Design Reference Year – a new approach to testing a building in more extreme weather using UKCP09 projections, Building Services Engineering Research and Technology – on line March 2012 at: http://bse.sagepub.com/content/early/2012/03/26/0143624411431170.abstract*

At present, use of the DRY would be a decision for an individual designer. However, should it become accepted as the way of assembling weather data for assessing summer-time performance, there would be a need for an organisation – presumably CIBSE – to provide guidelines for its use and the way that data from UKCP09 were used, so that designers were all working under the same "rules" and, in particular, were using the same weather data – whether based on observations or simulation – for a given location.

2b: Solar data

Examination of the characteristics of future solar radiation data produced by the Weather Generator that accompanied the UKCP09 projections showed that the generated data differed markedly in some respects from current solar data. It was not clear that these differences could be accounted for by physical changes in the atmosphere. The results pointed to a need for some modification of the weather generator and COPSE research informed subsequent changes in the procedure for modelling future solar radiation. These were incorporated in a revised Weather Generator issued in January 2011, when the contribution of COPSE researchers at Napier University to these changes was acknowledged[11].

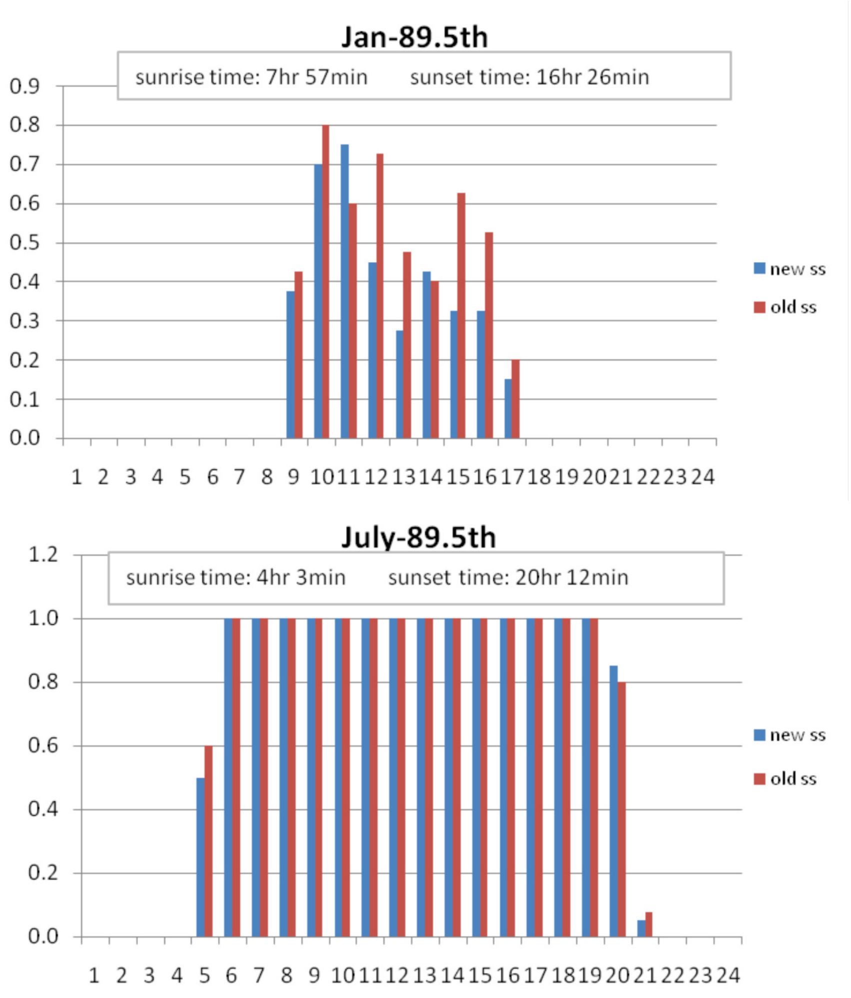

Figure 2.4: Comparisons of sunshine duration hours corresponding to the 89.5th percentile of daily total radiation for Heathrow. Note: old ss= UKCP09 data set, new ss= new UKCP09 data set.

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[11] *UKCIP. About the Weather Generator version 2.0. UK Climate Impacts Programme (2011) Available from: http://ukclimateprojections.defra.gov.uk/22580*

The changes principally related to the hours of sunshine and the diffuse radiation component of the total solar radiation. The first is illustrated by Figure 2.4 which shows the hours of sunshine through the day at Heathrow at 89.5% probability level in January and June. The effect of the changes is overall to reduce model-generated hours of sunshine, particularly at the beginning and end of the day, which produces a closer match with observations.

The second change is illustrated by Figure 2.5 which shows the proportion of diffuse radiation in the total radiation for two sites – Bracknell and Edinburgh – under different climate scenarios, and compares this with observational data. In all cases, the data refer to the 89.5% level of probability and to 13.00 hours in June. It can be seen that the earlier version of the Weather Generator projected a much lower proportion of diffuse radiation in future, i.e. on average much clearer skies, and that the revised version produces projections that correspond more closely to observed data.

Both original and revised Weather Generators project an overall increase in Global Solar Radiation by comparison with current levels. Figure 2.6 illustrates this for Bracknell during June, using generated data for a recent period (Control) and for 2030 Low Emission and 2080 High Emission scenarios. A note of caution is needed, however, concerning the very high increases at both ends of the day which stem from aspects of the model assumptions and process. This caveat, though, does not detract from the overall conclusion that future weather patterns are likely to be favourable for PV and other solar technologies.

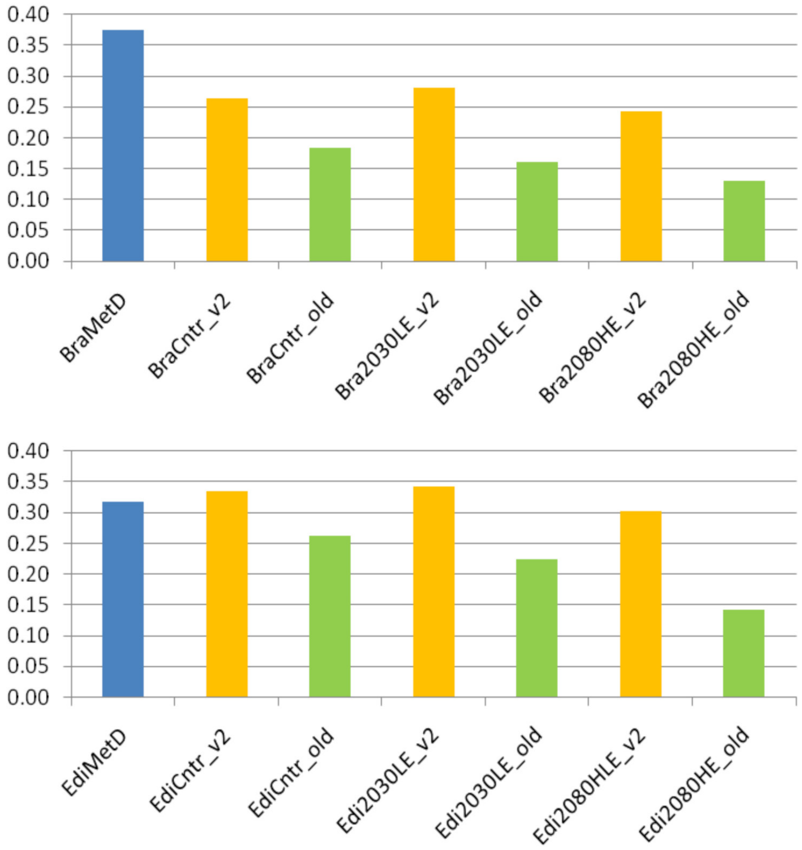

Figure 2.5: Ratio of diffuse to global irradiation (DRG) for June at 1300 hrs at 89.5th percentile; (a) Bracknell and (b) Edinburgh. Note: MetD= Meteorological Office data set, old= old WG control data sets, v2= WG version 2.0 data sets, LE= Low Emissions, HE= High Emissions.

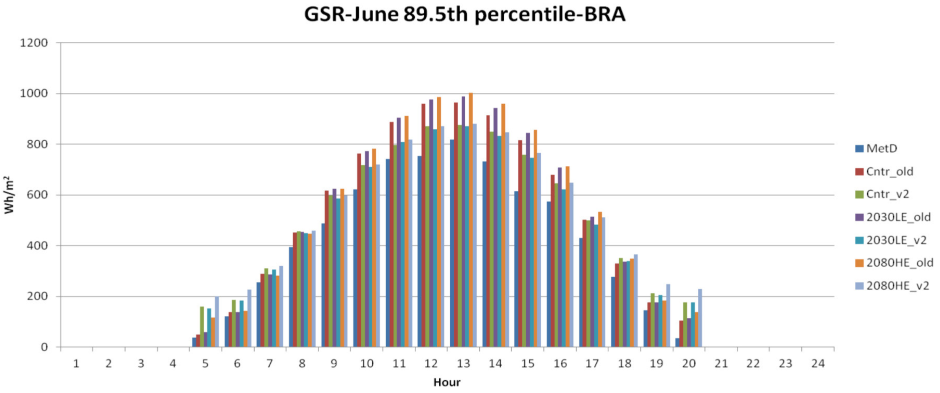

Figure 2.6: Global solar radiation (GSR) comparison for Bracknell.
Note: MetD= Meteorological Office data set, old= old WG control data sets, v2= WG version 2.0 data sets, LE= Low Emissions, HE= High Emissions.

3 Building performance in future climates

This Chapter provides an account of the research carried out under COPSE on the performance of existing buildings in future climates, using the files of future weather data described in Chapter 2. Since most of the building stock that will be in use in the second half of this century is already constructed, it is important to ascertain whether these buildings will continue to provide acceptable internal conditions, or whether extensive modifications will be required. The COPSE research covered the propensity of buildings to overheat in periods of hot weather, the impact of generally warmer climates on annual energy consumption, and the relationship between the external noise environment and the ability to cool a building through natural ventilation. The significance of the third study for future building performance is explained in Section 3c.

3a Overheating

Only a selection of the studies will be described here; the references 9 and 10 provide a fuller account of the research[12],[13].

Four contrasting existing buildings – an office building, a primary school, a hospital and a residential care home for the elderly – were modelled using EnergyPlus 6 software[14]. Thumbnail diagrams of the buildings are shown in Figure 3.1 while key physical details are in Table 3.1. With the exception of the office building (constructed in 1994), all were constructed recently. The buildings differed considerably in their patterns of occupation and the modelling took into account likely hours of occupancy, the number of people likely to be in the building, and the internal energy gains from lighting and electrical equipment, using widely accepted data[15].

All the buildings were naturally ventilated, the ventilation rate being set during the summer period at 4 air changes per hour – a typical value that might be expected for spaces mainly ventilated from one side with windows open on still, or virtually still, warm summer days. This rate was assumed to occur when the internal temperature exceeded 25°C and in addition was higher than the external air temperature. An additional infiltration allowance of 0.5 air changes per hour was assumed for the whole period of the simulation.

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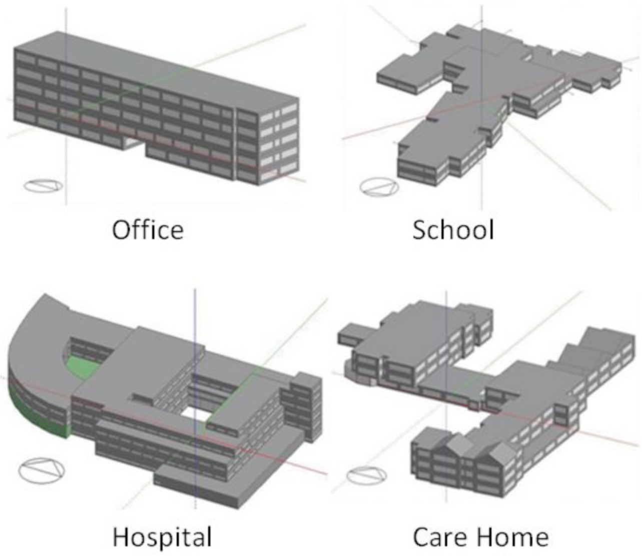
[12] *Du, H., Underwood, C.P. & Edge, J.S. (2012a). Generating design reference years from the UKCP09 projections and their application to future air conditioning loads.Building Services Engineering Research and Technology 33(1).*

[13] *Du, H., Underwood, C.P. & Edge, J.S. (2012b) Generating test reference years from the UKCP09 projections and their application in building energy simulations. Building Services Engineering Research and Technology. Doi: 10.1177/0143624411418132, 20pp.*

[14] *National Calculation Method Modelling Guide. Available at: www.ncm.bre.co.uk*

[15] *Energy Analysis and Tools – EnergyPlus Software. US Department of Energy – National Renewable Energy Laboratory. Available at: www.nrel.gov/buildings/energy-analysis.html*



Office

School

Hospital

Care Home

Figure 3.1: Thumbnails of case study buildings.

Table 3.1: Details of case study buildings

Building	Zones	Gross floor area (m2)	Treated floor area (m2)	Effective thermal capacity (kJm-2K-1)
Office	36	4269	2977	466
School	25	4870	2844	285
Hospital	145	21,897	12,786	259
Care Home	51	5683	5345	425

Each of the buildings was simulated using weather data taken to be representative of present conditions (the 'Control') and with weather data generated for a range of future emissions scenarios and for time periods centred on 2030, 2050 and 2080[16]. In addition, these simulations were repeated for three locations: London, Manchester and Edinburgh – thus the same building was modelled with weather data relevant for each of these locations. Only results for Manchester are presented here; Table 3.2 lists the symbols used in displaying these results.

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[16] *The Control dataset is based on weather data recorded in the period 1961–1990. Hence the time interval between the middle year of this band and the middle year of the 2030 band is 55 years, which is larger than the interval between the middle years of the other bands used in the analysis. This accounts for the significant difference between 'Control' and other data points in Figures 3.2 to 3.6.*

Table 3.2: Symbols for time periods and carbon emissions

Symbol	Meaning
C	Control data
3L	2030s Low carbon emission scenario
3M	2030s Medium carbon emission scenario
3H	2030s High carbon emission scenario
5L	2050s Low carbon emission scenario
5M	2050s Medium carbon emission scenario
5H	2050s High carbon emission scenario
8L	2080s Low carbon emission scenario
8M	2080s Medium carbon emission scenario
8H	2080s High carbon emission scenario

The risk of overheating was examined using two different percentiles in the distribution of external temperatures (see discussion of selection of weather data in Chapter 2). The first was 87.5%[17] because this is the risk level used by CIBSE in its tables of data for summer-time design assessment. The second was 99% in order to examine the impact of rising temperatures in situations where there is a need to minimise the risk of overheating. Some results from the four buildings are shown in Figures 3.2 and 3.3.

Figure 3.2 presents the percentage of occupied hours for which the internal temperatures exceed 28°C. It shows a rising trend throughout this century. Even at the 87.5 percentile level of risk, the office building exhibits sharp increases in the percentages of time during which discomfort might be expected, rising by 2050 to more than 15% of occupied hours under all carbon emission scenarios. Although the rise is not quite as marked for the primary school, there is still a clear increase in the proportion of time when high internal temperatures may inhibit learning. The traditional construction methods used in the care home, which give it a relatively high mass and a relatively small proportion of glazing, mean that temperatures exceed 28°C for less than 5% of occupied hours under the low emission projection, using the 87.5 percentile level of weather data. Although this level may still be too high for its elderly occupiers, the result does illustrate the difference that can be made through choice of construction measures. Similar conclusions apply to the hospital, partly because of its traditional high-mass construction and partly because of the high proportion of deep-plan spaces in this building which are not as influenced by future increases in solar radiation. The school example demonstrates that a sharp increase in the percentage of overheating hours (Figure 3.2) does not necessarily imply a high demand for cooling (Figure 3.3), because the school has spaces with low occupancy rates during periods when hot weather is most likely.

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[17] *Figures 3.2, 3.3 and 3.6 refer to the 85th percentile but in CIBSE nomenclature this is the 87.5 percentile.*

Figure 3.3 shows the cooling capacity per unit of floor area required to maintain each building at a conventional design maximum internal temperature of 28°C. These *cooling design loads* also show a steady rising trend through this century. The office building and care home show a near-tripling in average zone cooling design loads from the present to 2080 under the high emission scenario (85th percentile risk level). The trend for the hospital shows a lower rate of increase, although from a much higher base level; this is because internal heat gains attributable to equipment account for a larger proportion of the current cooling load than in the case of the other buildings. The school shows lower overall average design cooling loads and a much flatter rate of increase over time. This suggests that the high rate of increase in summer-time overheating in the school is attributable to a small number of spaces where the temperature is strongly influenced by external temperatures and solar radiation.

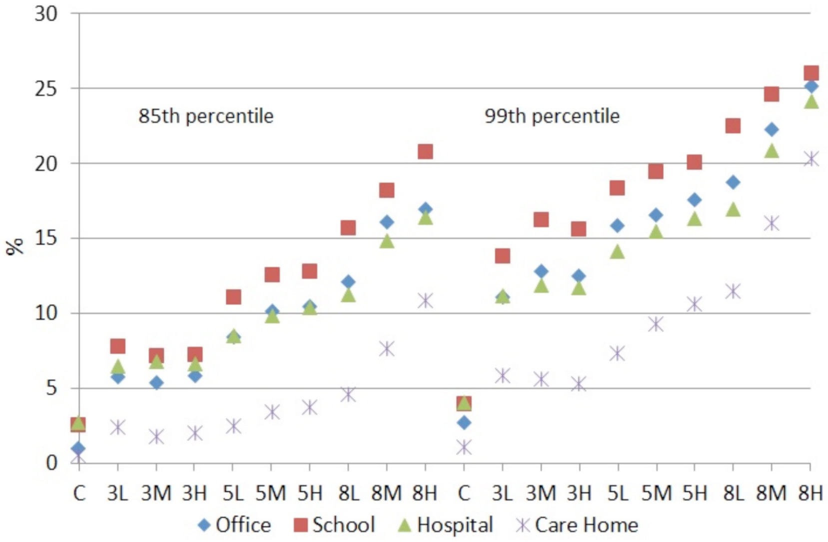

Figure 3.2: Summer-time overheating (Manchester) – a) Office b) School c) Hospital d) Care home.

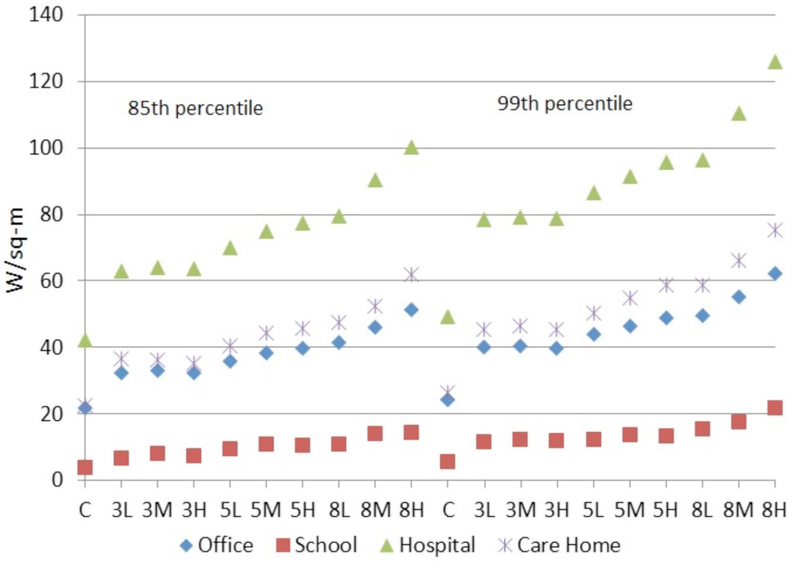

Figure 3.3: Cooling design loads (Manchester) – a) Office b) School c) Hospital d) Care home.

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In another study[18] undertaken within the COPSE programme, the cooling capacity required to maintain comfort conditions in a room with typical thermal properties was calculated for future time periods, under different emissions scenarios. This study took into account the decline in performance of cooling systems as external temperatures increase, and also the additional power consumed by fan systems when more heat has to be removed through existing ductwork. It concluded that a building designed to provide comfort conditions for 95% of occupied hours would need around 40% additional cooling capacity by the 2080s, and that up to five times the fan power would be required in the system to move air through the same ducting.

The outputs of COPSE research, some of which have been illustrated here, confirm that many buildings will require either substantial modification or the introduction of cooling systems (or both) if they are to continue to provide acceptable internal conditions in the future. Where cooling plant is already installed, it is likely to be replaced several times during the life of a building and at that time extra capacity and more efficient systems can be introduced, although increasing the size of air distribution systems may be more problematic. Where buildings rely at present on natural ventilation, the ability to install cooling plant may be restricted and this could prejudice the future use of the building. (Chapter 4 considers how the adoption of Adaptive Comfort principles may help to address this issue.)

The results also underline the importance of the choices made at design stage in new buildings, if these are to provide acceptable internal conditions over the whole of their service life. The choice of construction materials, massing, orientation and shading design, and the provision of space for possible future mechanical services all take on greater relevance as these cannot easily be modified during later refurbishments to combat the impacts of a warming climate.

3b Annual energy use

The energy required for cooling the four buildings in a typical year, under different climate scenarios, was estimated through the modelling process. The results (in terms of cooling energy consumption per unit area) are shown in Figure 3.4, for Manchester and also for London and Edinburgh. In each case, cooling energy shows a rising trend but the impact varies according to the type of building and the location. Under the high emissions scenario, cooling energy use in the office, care home and hospital buildings is predicted by the 2080s to be at least twice the present level. The school building shows the lowest annual rate of cooling energy increase owing to a large number of its spaces being within deeper-plan core areas and low internal casual heat gains due to equipment.

For each building type, the annual cooling energy use is higher (in some cases much higher) in London than in the northern cities of Manchester and Edinburgh. This reflects not only the difference in latitude but also the impact of the London 'Urban Heat Island' (see Section 2b) which raises the summer-time temperature in central London above that of surrounding areas.

Figure 3.5 shows results from a similar study of heating energy requirements. By contrast with cooling, however, this demonstrates a declining trend over the century. Annual energy use for each building is predicted to be lower in London than in the northern cities though the differences between locations are not as pronounced as is the case with cooling.

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[18] *Watkins, R. and Levermore, G.J. (2011). Quantifying the effects of climate change and risk level on peak load design in buildings. Building Services Engineering Research and Technology, 32(1), 9-20.*

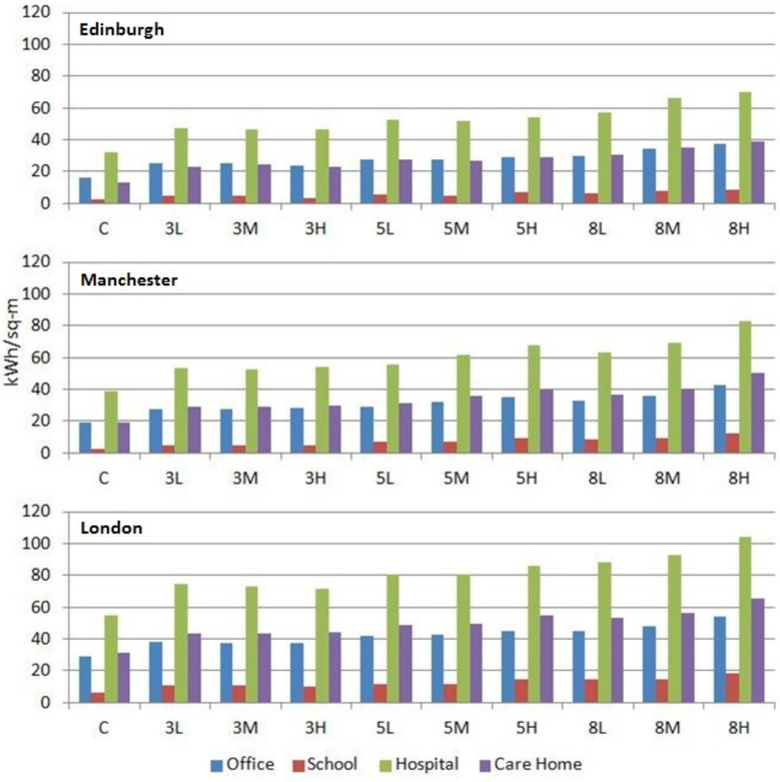

Figure 3.4: Annual cooling energy – a) Office b) School c) Hospital d) Care home.

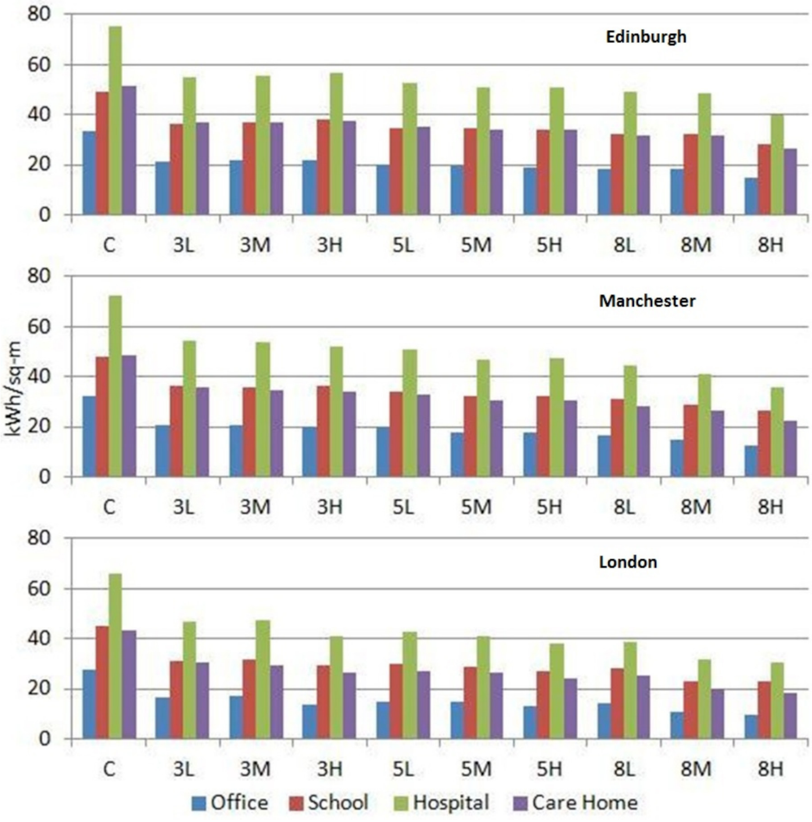

Figure 3.5: Annual heating energy – a) Office b) School c) Hospital d) Care home.

Although, the warming trend over the next decades will reduce annual energy use for heating of buildings, it makes little difference to the heating plant capacity that is required. This is illustrated in Figure 3.6, which shows the heating design load per unit of floor area for the four buildings under the same future climate scenarios as previously. The reason is that the weather data generated from the UKCP09 projections shows that winters will still have 'cold snaps' of the same intensity as at present even though average winter temperatures are higher. Thus decisions on plant sizing, which are based on the ability to maintain internal temperatures during such cold periods, are not greatly affected by future changes in the climate. However, they will of course be affected by measures taken to improve the thermal efficiency of both new and existing buildings, with consequent reduction both in the heating capacity required and in annual heating energy use.

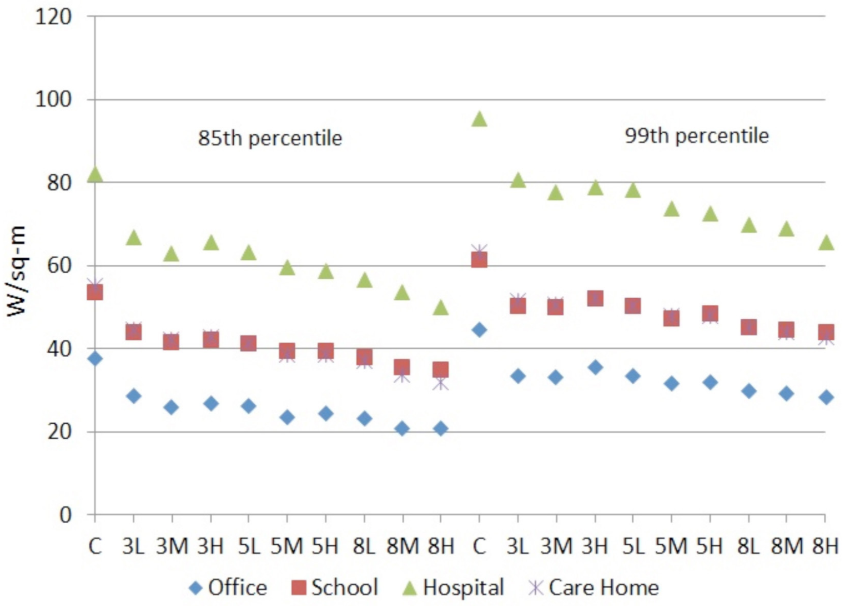

Figure 3.6: Heating design loads – a) Office b) School c) Hospital d) Care home.

The substantial increases in cooling energy use due to climate change are, however, unlikely to benefit from measures taken to reduce heating energy consumption and in some cases these may actually exacerbate the need for cooling. This reinforces the need for enhanced attention to the potential for over-heating during the design, and possibly to make provision for future cooling systems, so that building service lives are not shortened by the inability to combat over-heating.

COPSE research on the implications for national energy consumption of possible trends in energy use for heating and cooling of buildings is summarised in Chapter 6.

3c Ventilation and noise

Most buildings in the UK rely on natural ventilation to maintain comfortable internal conditions during period of lot weather, i.e. they have windows that can be opened. The internal conditions in such buildings depend upon the ability of occupants to open windows, the wind speed, wind direction and the external temperature. Building users are inhibited from opening windows if the external environment is noisy but may accept a degree of external noise for a small portion of the year if that reduces internal temperatures. Warmer conditions will tend to increase the proportion of time that windows need to be open. Thus some naturally ventilated buildings which on balance provide acceptable conditions because windows need to be opened for only a small portion of the year may become unacceptable for their occupants. These buildings will need either modification, perhaps with the installation of mechanical ventilation and cooling systems or, in the extreme, demolition and re-build.

The research carried out in COPSE included studies of how the need for window opening might change in future climates, and the relationship with the external noise environment. These studies showed that use of energy for cooling in buildings that are currently naturally ventilated for much of the year could increase significantly.

The future effectiveness of natural ventilation

Future wind speeds needed first to be estimated. The derivation of future wind speeds from the weather data generated from the UKCP09 climate projections was described in Section 2a. This method was used, but other estimates were also employed including alternative weather generators and accessing wind speeds obtained from the Regional Climate Model on which UKCP09 was partly based[19]. The results showed considerable variability in change factors from month to month, but were consistent with upper and lower bounds of the range indicated by the Regional Climate Model.

Dynamic thermal modelling using DesignBuilder was then employed to explore how these different estimates of future wind speeds affected the predicted ventilation rate of a typical office building (shown in Figure 3.7). It was found[20] that the estimates resulting from the dataset of the PROMETHEUS project[21] gave consistently higher ventilation rates than those from the COPSE dataset; this would be beneficial for avoiding the need for mechanical ventilation but at present it is not possible to say which estimate is likely to be more reliable as a predictor of future wind speeds.

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[19] *UK Met Office Hadley Centre. HadRM3-PPE-UK Model Data. (2009) Available from: http://badc.nerc.ac.uk/data/hadrm3-ppe-uk/*

[20] *Barclay, M., Sharples, S., Kang, J. and Watkins, R. (2011). The natural ventilation performance of buildings under alternative future weather projections. Building Services Engineering Research and Technology, 33(1): 35–50.*

[21] *Eames, M., Kershaw, T. and Coley, D. (2011). The creation of wind speed and direction data for the use in probabilistic future weather file. Building Services Engineering Research and Technology, 32(2): 143–158.*

Using these two weather datasets, the thermal performance of a small naturally ventilated office building equipped with passive cooling measures (shown in Figure 3.8) was investigated. The measure of comfort chosen was the percentage of occupied hours for which the internal temperature was above a defined comfort level – either a fixed 28°C as found in CIBSE guidance[22] or the 'adaptive comfort' temperature defined by CEN and British Standards.[23] Figure 3.9 shows the results from models using weather data representative of the present day, in 2050 and in 2080 under the UKCP09 High Emissions scenario. In all cases, the proportion of time for which internal temperatures exceeded the comfort threshold increased very significantly by 2080, calling into question whether natural ventilation would continue to provide overall acceptable environmental conditions without assistance from mechanical cooling systems during some part of the year, i.e. a 'mixed mode' approach to cooling.

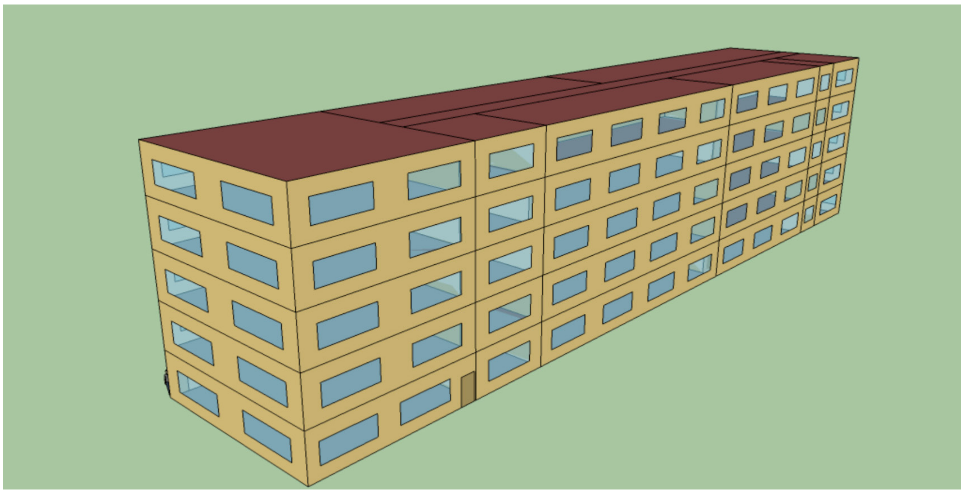

Figure 3.7: Sketch representation of the office building used to explore ventilation rates.

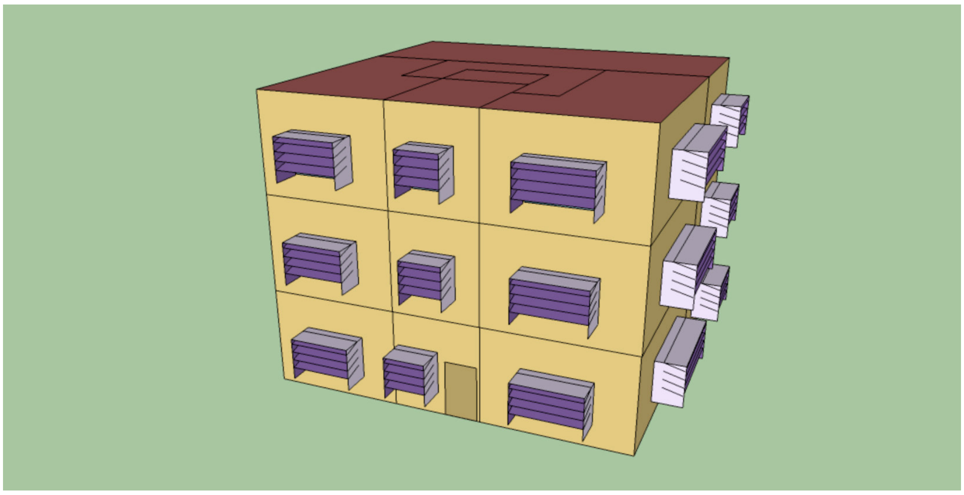

Figure 3.8: Sketch of small office building with passive cooling measures, such as solar shading, used to explore impact of window opening on internal temperatures.

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[22] *Chartered Institution of Building Services Engineers. CIBSE Guide A: Environmental design (2007)*

[23] *The concept of adaptive comfort is discussed in Chapter 4.*

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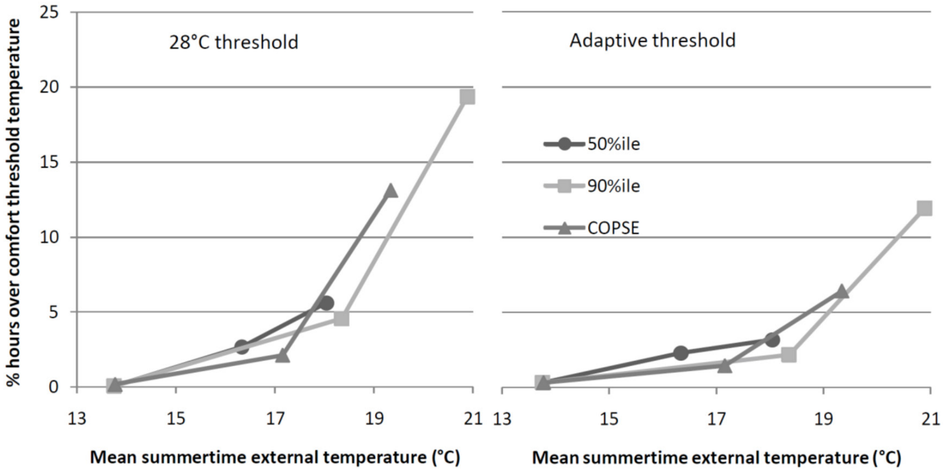

Figure 3.9: Percentage of occupied hours above thermal comfort threshold against mean summer temperature legend for two 50 and 90th percentiles of the PROMETHEUS DSY and the COPSE DSY.

The influence of external noise on ventilation rates

The combination of acoustic and ventilation performance in mixed mode buildings was explored through the use of noise maps which provide a guide to the external noise environment in any location[24]. From noise mapping, the external noise level at different points on the façade of a building may be calculated. Figure 3.10 shows a typical output from such a calculation; it illustrates that the exposure to external noise can vary considerably over the different faces of the building.

The thermal performance of this building was modelled in two contrasted locations in Manchester, in order to determine the energy that would be required for cooling in future climates. The degree of window opening was adjusted so that internal noise levels were close to a chosen tolerance level; this required modelling of the noise transmission through a window aperture[25]. Figure 3.11 shows that the average rate of use of energy for cooling increases markedly as the noise tolerance level decreases, with the two plots showing the influence of location. The figure also enables the impact of acoustic control measures to be estimated, since a measure that, for example, will reduce internal noise by 10dB(A) will reduce the rate of cooling required by the same amount as if the external environment were that much quieter.

The impact of future climates was also examined. Figure 3.12 shows how the average cooling energy rate increases in future for the same noise environment. In the model example, the increase between the present rate and that required in 2050 under the high emissions scenario was some 11kw. To maintain the cooling energy consumption at its present level would require a reduction in internal noise in excess of 10dB(A) through a combination of mitigation measures at the building and measures to reduce the noise generated by external sources (e.g. the introduction of quiet road surfaces).

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[24] *Barclay, M., Kang, J. and Sharples, S. (2012). Combining air borne noise mapping and ventilation performance for non-domestic buildings in an urban area. Building and Environment. 52: 68–76.*

[25] *Kang, J. and Li, Z. (2007).Numerical Simulation of an Acoustic Window System Using Finite Element Method. Acta Acustica united with Acustica. 93(1):152–163(12).*

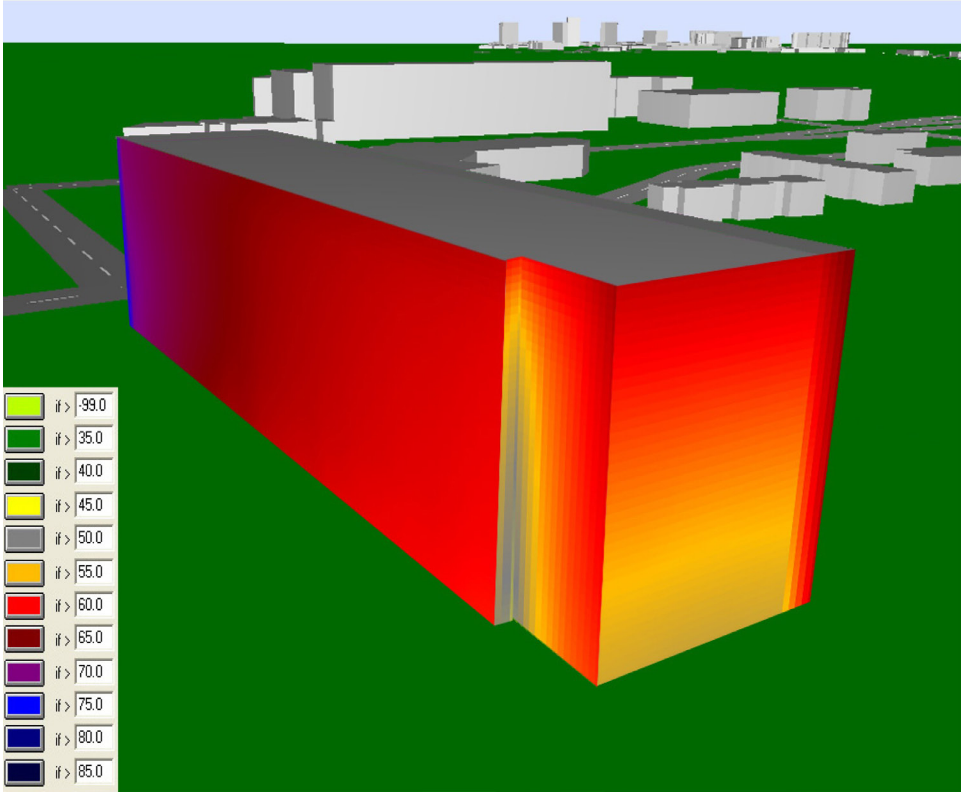

Figure 3.10: Noise mapping noise exposure pattern (Building 1, Manchester, high external noise level).

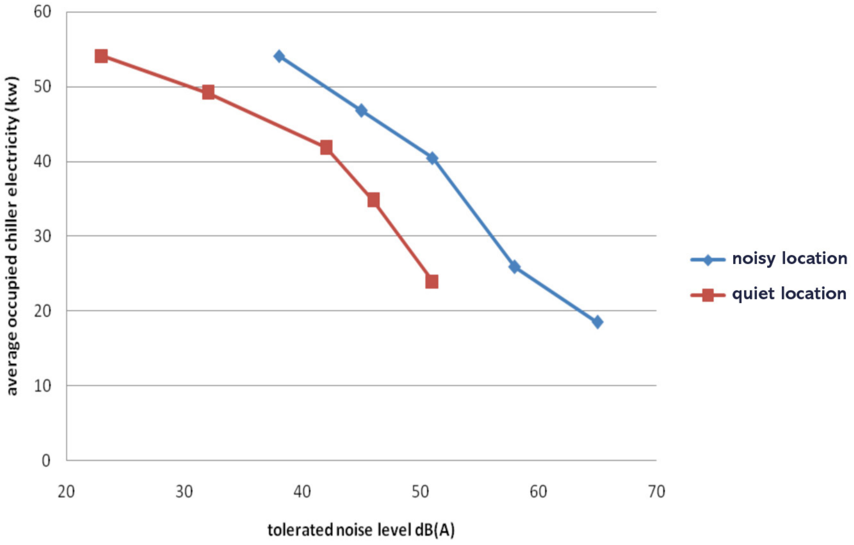

Figure 3.11: Relationship between cooling energy use in mixed mode building and the level of tolerance of noise in different noise locations (Red: quiet location; Blue: noisy location).

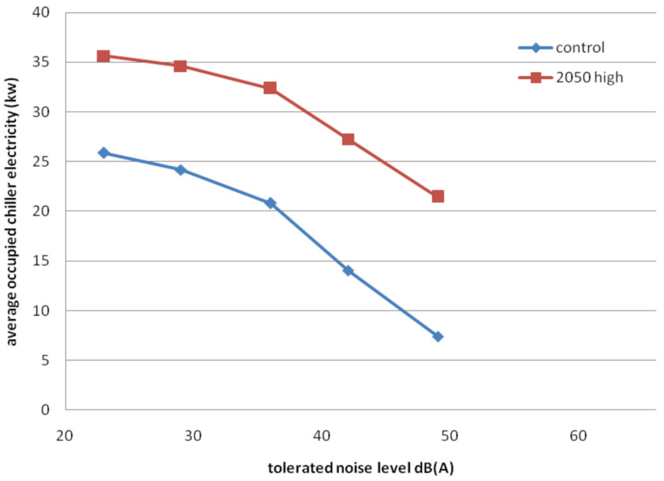

Figure 3.12: Relationship between cooling energy use in mixed mode building and the level of tolerance of noise, present and future climates (Control weather data and 2050 high emissions scenario).

4 Thermal comfort standards and implications for energy use for cooling

The concept of adaptive comfort

Adaptive Comfort is a the term used to describe the ability of building occupants to adapt to different environmental conditions, so that people feel comfortable after a change in their local environment after being exposed to the changed environment for a period. In the context of building design, this means that during a period of hot weather building occupants may feel comfortable with internal temperatures that are considerably higher than conventional 'comfort' conditions (e.g. the temperature to which buildings are often cooled in summer) after a day or two. In part, this is because they will open windows and adapt their clothing to the external conditions.

As with all measures of comfort, measures of Adaptive Comfort relate to conditions that will be considered comfortable by most building occupants, but because of the variability of individual responses to their environment, some building occupants will consider the conditions unsatisfactory.

It should also be stressed that Adaptive Comfort criteria relate only to buildings that are 'free-floating', i.e. there is no reliance on mechanical systems to maintain comfort conditions in summer. Occupants open windows, draw blinds and adjust clothing to maintain comfort conditions.

Because Adaptive Comfort criteria lead to 'comfort' temperatures that can be higher than those conventionally adopted as fixed control points in air-conditioning systems, they reduce the need for such systems to be installed. In particular, some existing buildings which otherwise would need to be refurbished with mechanical cooling systems can continue to rely on natural methods of ventilation. COPSE research[26] explored the impact, now and in the future, of changing to Adaptive Comfort criteria for design, using alternative approaches to the definition of Adaptive Comfort.

The adaptive comfort degree day

Two ways of arriving at a band of comfort temperatures using the principles of Adaptive Comfort have been incorporated into Standards[27,28]. However, these produce different upper and lower limits to the band and little guidance is available to policymakers, designers and energy managers to help them make an informed choice when choosing between standards. In order to address this, the COPSE research developed a novel metric, the Adaptive Comfort Degree-Day, which was then used to compare the potential energy savings from each approach.

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[26] *McGilligan, C., Natarajan, S. and Nikolopoulou, M. (2011). Adaptive Comfort Degree-Days: A metric to compare adaptive comfort standards and estimate changes in energy consumption for future UK climates. Energy and Buildings, 43(10): 2767–2778.*

[27] *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics – BS EN 15251:2007, CEN, Brussels, 2007/BSI, London, 2008.*

[28] *Thermal Environmental Conditions for Human Occupancy – ANSI/ASHRAE standard 55-2004, ASHRAE, Atlanta, 2004.*

The degree-day is a familiar concept to building services engineers. It is the sum of the mean daily internal-external temperature differences over the period of operation of the heating or cooling system, the internal temperature having been calculated taking into account the effect of internal thermal gains and solar heating[29]. Although these heat inputs fluctuate over the course of a day, they can be taken to have a constant average value and so raise the internal temperature by a constant amount. The resulting figure for degree days relates directly to the energy required by mechanical systems to maintain a defined, normally fixed, temperature which will result in a high proportion of the building occupants feeling comfortable.

Each degree rise in outdoor temperature, if maintained for a period which depends on the individual building, results in the same rise in internal temperature in the absence of any mechanical cooling system and so internal temperatures may be calculated directly from weather data. Figure 4.1(a) illustrates how average daily external temperatures rise and fall over the course of a summer. The shaded area is a measure of the cooling degree-days in a building where the internal temperature rises above a fixed upper bound for comfort temperature; alternatively, it is a metric for the cooling energy required over that period to maintain the building at the (fixed) comfort temperature. Since in the absence of a mechanical cooling system there is a direct relationship between the internal temperature of the building and the external temperature, the same curve (Figure 4.1(b)) also describes the internal temperature that would be achieved and the resulting shaded area shows what might be termed quasi- cooling degree-days.

However, the upper bound of the comfort band, as defined by Adaptive Comfort criteria, often exceeds the internal temperature in periods of hot weather, since it reflects the occupants' experience of progressively higher external temperatures. It follows a curve shown in Figure 4.1(c). The shaded area here represents the number of Adaptive Comfort Degree-Days (ACDDs). Studies undertaken as part of the COPSE project showed that this metric is a reliable indicator of the maximum saving in cooling energy use to be obtained from adoption of Adaptive Comfort criteria for determining the comfort temperature.

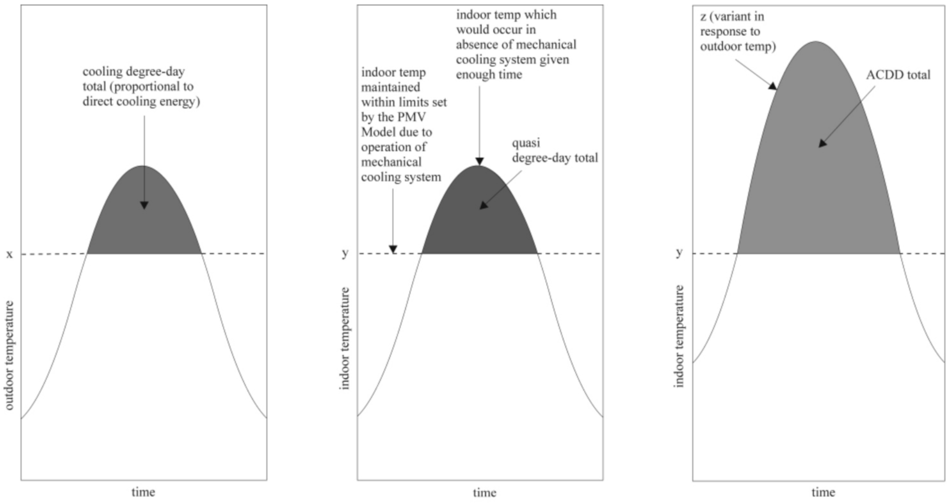

Figure 4.1: Derivation of the ACCD concept from the conventional cooling degree-day.

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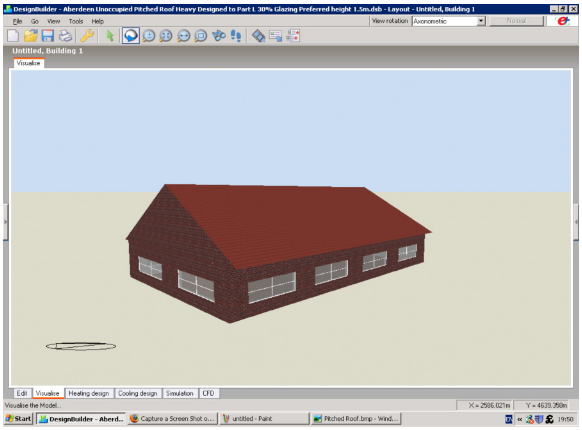
[29] *Chartered Institution of Building Services Engineers. (2006) Technical Memorandum 41: Degree-days: theory and application.*

In these studies, the cooling energy requirement and the number of Adaptive Comfort Degree Days were calculated for a mechanically-cooled, single storey office building (illustrated in Figure 4.2) of dimensions 15 x 25 x 3.5 m using five different construction types and five levels of glazing (10, 30, 50, 70 and 90%) in 22 different European locations. These ranged from Aberdeen (summer mean temperature 13.3ºC, annual direct normal solar radiation level 483 kWh/m^2) to Marseille (summer mean temperature 23.3ºC, annual direct normal solar radiation level 1504 kWh/m^2). Thus in total 550 annual simulations of energy use and internal temperatures were undertaken. The weather files used provided hourly data for the principal weather parameters (temperature, solar irradiance etc) while the modeling was carried out in DesignBuilder using EnergyPlus software[30].



View rotation: Axonometric

Visualise the Model...

X = 2586.021m Y = 4639.358m

Figure 4.2: An example of a building used in the modelling experiments – medium weight, pitched roof, 30% of wall surface glazed.

For each location, the comfort temperature through the year was recorded and the number of ACDDs returned by each location was calculated by two methods, first using category II of the European adaptive standard (EAS) and secondly using the 80% acceptability level of the ASHRAE adaptive standard (AAS)[31]. These two classes of standard are comparable since they both predict that 10% of occupants will be dissatisfied with the general internal temperature. Figure 4.3 shows, for one example of the 25 buildings, the very close relationship between the annual total cooling energy consumption and the number of ACCDs in each location. This figure was derived using the European standard but similar results were obtained with the ASHRAE standard. The correlation coefficient was in each case between 0.89 and 0.99, with an average of 0.97.

This research therefore showed that the ACDD was a good metric for annual cooling energy consumption for this building, and that by extension was a good metric for the potential energy savings to be made by relying on passive cooling measures and natural ventilation and using the adaptive comfort concept to judge the acceptability of internal temperatures instead of introducing air conditioning.

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[30] *US Department of Energy, Building Energy software Tools Directory – IWEC.*

[31] *An allowance was made for an average of a further 10% dissatisfaction that might occur because of local thermal discomfort, in addition to the general whole body 10% dissatisfaction. See G. Schiller Brager and R. de Dear, A Standard for Natural Ventilation. (2000) ASHRAE Journal 42 (10), pp21-28.*

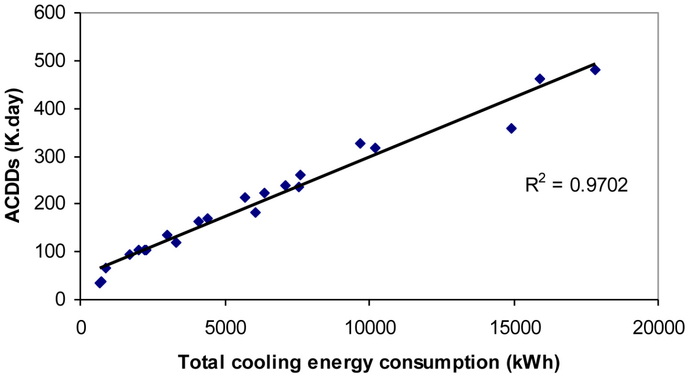

Figure 4.3: Correlation between annual number of cooling EAS ACDDs and total annual cooling energy consumption for the medium-weight building with 30% glazing.

Energy savings from the application of the ACDD concept in future climates

The way in which adoption of adaptive comfort criteria could result in reductions in cooling energy use in the future was explored through calculating the ACDDs under both the EAS and AAS standards using simulated future weather data derived from UKCIP09 data. These calculations were performed for three locations (London, Manchester, Edinburgh) and three future time periods (2020s, 2050s, 2080s). In addition, calculations were performed with future Test Reference Years as described in Section 2a.

The results are shown in Figure 4.4. They showed that, for each city, the potential savings achieved by an EAS-compliant building (bold line) would not be matched by its counterpart AAS-compliant building (dotted line) until decades later Indeed, in most cases savings derived from use of the EAS standard in the 2020s would not be matched by savings derived from the AAS standard until the 2080s or later. These findings reflect the higher upper limit of the thermal comfort zone in the EAS, which enables a greater number of buildings to use natural ventilation.

This research therefore produced a novel method for assessing the energy savings that could be made through the adoption of Adaptive Comfort criteria, if these showed that buildings could function satisfactorily without mechanical cooling systems. Further, it demonstrated that the use of the European standard for Adaptive Comfort resulted in potentially greater savings than the ASHRAE standard.

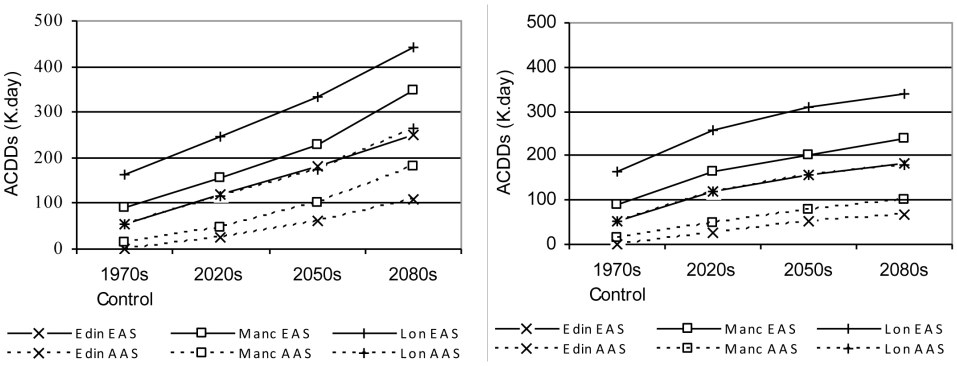

Figure 4.4: Annual number of cooling ACDDs for the AAS and the EAS for (a) High and (b) Low emissions scenarios for Edinburgh, Manchester and London for the 2020s, 2050s and 2080s.

5 Urban heat islands and canyons

The air temperature in an urban area is almost always higher than that in the surrounding rural area; this phenomenon is termed the Urban Heat Island (UHI). It arises for two principal reasons: first, built-up areas and rural areas gain heat from the sun and lose it to the atmosphere at different rates, the rural areas being exposed to more of the 'cold' sky while buildings in urban areas are less exposed to the sky and retain more heat in their structures; secondly, an urban area has many local sources of heat, notably buildings and vehicles, which raise the temperature of the surrounding air. The relative importance of these factors varies – in summer, solar radiation is the dominant influence while in winter, heat losses from buildings and traffic account for most of the effect. There are also diurnal changes; typically, in summer the UHI reaches a maximum (which can be up to 8°C in Manchester) during the night, as buildings and roads release heat absorbed during the day; in winter, this effect is less frequent although it can be more intense[32]. These variations are illustrated in Figure 5.1.

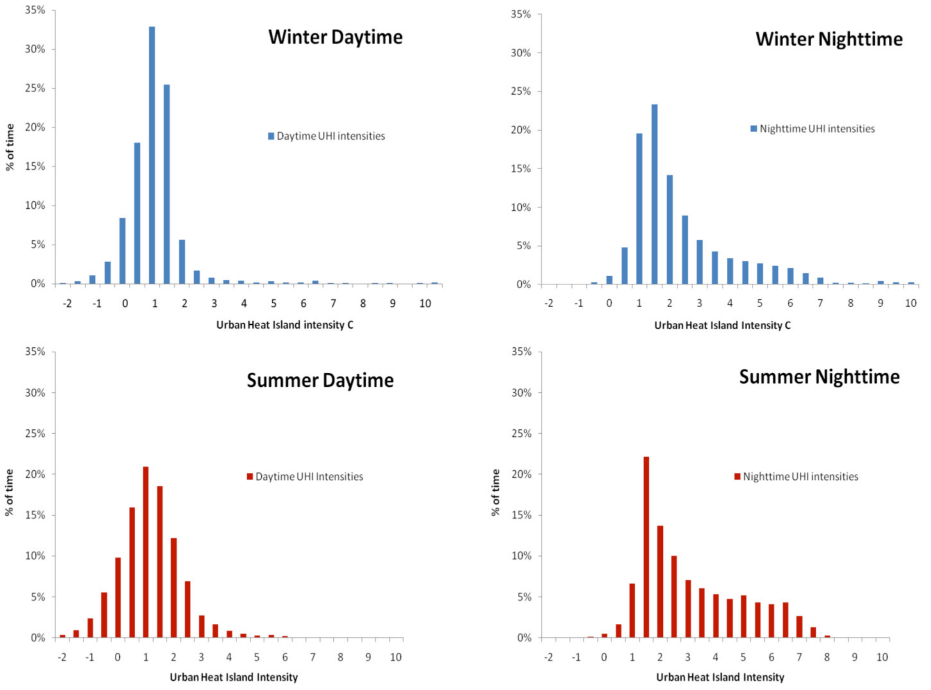

Figure 5.1: Distributions showing the magnitude of the Urban Heat Island in Greater Manchester in summer and winter.

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[32] *Levermore and Cheung, (2012) A low order canyon model to estimate the influence of canyon shape on the maximum Urban Heat Island effect. BSERT. Published online before print January 18, 2012, doi: 10.1177/0143624411417899*

A feature of the central parts of large urban areas is that they have 'street canyons'. Because of the height of the buildings lining the street, the view of the sky from ground level is restricted (Figure 5.2) and this influences the radiation heat exchanges that take place between buildings and the atmosphere, and therefore the scale of the UHI. Figure 5.3 illustrates how neighbouring buildings reduce radiation heat loss. A measure of the depth; width ratio of the street canyon is the Sky View Factor (SVF); this is essentially the proportion of the sky hemisphere that can be seen from ground level. COPSE research explored the influence of the SVF on the Urban Heat Island, using data from the Manchester urban area[33].

Figure 5.2: Hemispherical image of John Dalton Street, Manchester, using a Nikon FC-E8 Fisheye Lens.

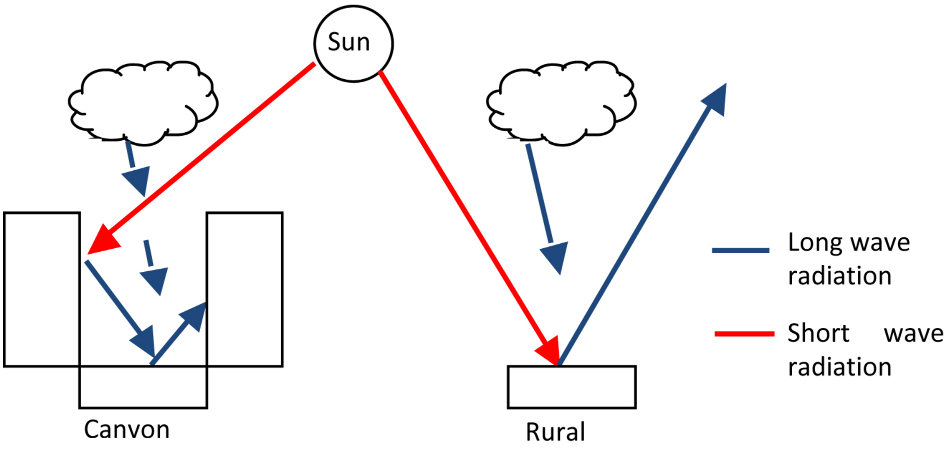

Figure 5.3: Illustration of heat exchanges between buildings in a street canyon, as compared with the heat loss in a rural area.

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[33] *H K W Cheung (2011). An Urban Heat Island study for building and urban design. A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Engineering and Physical Sciences.*

Monitoring urban temperatures

In order to characterise the Manchester UHI, air temperature sensors incorporating data loggers were installed at 59 sites in the Greater Manchester area, broadly on eight radial routes as shown in Figure 5.4. The sensors were mounted on lamp-posts at a height of 4 m (Figure 5.5) and recorded the temperature at 30 minute intervals. Data were collected from February 2010 to April 2011. The reference rural air temperature data came from the British Atmospheric Data Centre[34].

Figure 5.5: Sensor mounted on lamp-post.

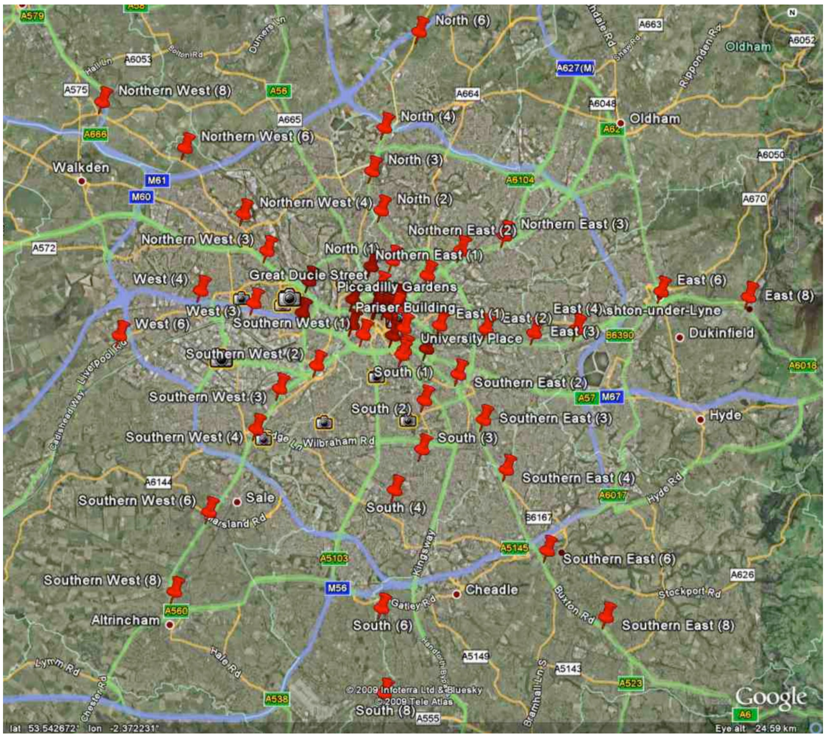

Figure 5.4: Map showing locations of sensors.

Because of its influence on heat loss through radiation to the sky the effect of the SVF is most marked on clear, calm nights and so from the complete dataset nights were identified when cloud cover at Manchester Airport was less than 25% and wind speed was lower than 2.5 m/sec, with the two conditions persisting for at least four hours. These data were then used in subsequent analyses.

Estimation of the Sky View Factor

The wide availability of high quality digital images enabled the research to utilise a new approach to estimating the SVF. As Figure 5.2 shows, photographs taken with a fish-eve lens provide a 360° perspective of the street canyon. This may then be analysed, to identify the white pixels which form the sky image, in contrast to those of other colours which relate to buildings. The proportion of white pixels in 37 annular rings which, together, make up the sky hemisphere is found and from that, the SVF is determined[35].

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[34] *British Atmospheric Data Centre, see: http://badc.nerc.ac.uk/home/*

[35] *Cheung, H.K.W. (2011). An Urban Heat Island study for building and urban design. A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Engineering and Physical Sciences.*

Tests showed that the resulting SVF did not change significantly if the camera was at one side or the other of the street, unless the building heights differed considerably from one side to the other. Neither was the SVF significantly affected by whether the camera was at ground level or head height, and so the height was standardised at 1.4 m.

The relationship between SVF and urban temperatures

Figure 5.6 shows, for the 59 sensor locations, a weak relationship between the SVF and the average UHI. The charts are based on data for clear and calm summer and winter nights respectively. As might be expected, UHI tends to increase as the SVF decreases, since the ability to lose heat through radiation reduces. But the effect is influenced by other factors, for example, the extent to which the buildings are heated during the day will depend upon the orientation of the canyon; there will be more extensive shading if it is East-West as compared with North-South. For deeper canyons (SVF less than 0.65), however, the relationship is stronger.

The UHI and building design

Designers need to take the UHI into account when assessing whether a building will be able to provide comfortable conditions in periods of hot weather without resort to mechanical cooling systems, and when estimating the annual energy use associated with such systems. Further, the rise in night-time temperatures attributable to the nocturnal UHI has implications for the comfort, and potentially for the health, of urban residents. Previous research led by Manchester University[36] investigated how the UHI in Manchester and Sheffield might be influenced by climate change and the measures that could be taken to mitigate the impact of increased temperatures. The COPSE research added to the understanding of the factors that influence the UHI. Combined with the future weather files discussed previously, it provides a better basis for assessing the performance of buildings in urban areas.

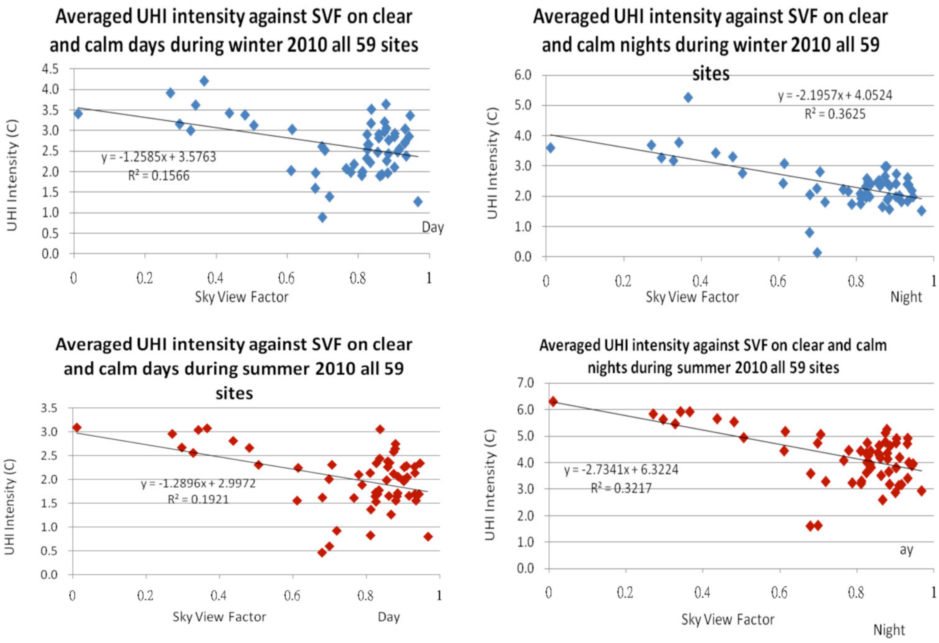

Figure 5.6: Relationship between UHI and Sky View Factor.

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[36] *SCORCHIO: Sustainable Cities: Options for Responding to Climate cHange Impacts and Outcomes (2007 to 2009). EPSRC grant EP/E017398/1. See: http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/E017398/1*

6 Implications of climate change for energy consumption in the national building stock

Heating buildings (space heating) accounts currently for some 16% of national energy consumption[37]. The research summarised in Section 3b showed that the rise in average winter temperatures expected as a consequence of climate change will reduce the energy required for heating, but the scale of reduction differs with the type of building. Other research undertaken within COPSE aimed to quantify the implications of this reduction for the national stock of buildings. To do this, it took a top-down view, considering the influence of temperature changes not on individual buildings but on heating energy consumption over a region.

Gas demand and space heating

Almost 80% of the energy used for space heating is provided by gas. Thus the relationship between daily average temperature and daily gas consumption can be used to predict daily gas demand during warmer winters. National Grid, which owns and operates the National Transmission System, publishes daily demand data for each of the thirteen geographic Local Distribution Zones (LDZs) which make up Great Britain (i.e. not including Northern Ireland). Stripping out the consumption that is not weather-dependent (e.g. industrial use), the residual daily gas consumption for a specified LDZ correlates strongly with the daily effective temperature[38] recorded at a weather station representative of the LDZ. This is shown in Figure 6.1; with the exact shape of the characteristic sigmoid curve being dependent upon a number of factors such as geographical latitude and whether the population is predominantly urban or rural.

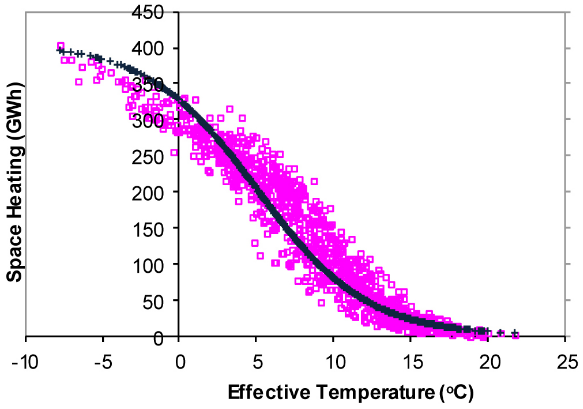

Figure 6.1: Relationship between Space Heating Gas Consumption for the North West LDZ and the Effective Temperature measured at Woodford for the period 2007–2010.

The principal area of interest is the left-hand section of the plot where consumption is high, since this represents most of the winter. In order to achieve a better relationship in that part of the curve, the curve was represented as a set of three lines, each with its characteristic slope (Figure 6.2). This provided the starting point for estimating regional heating energy demand in future climates.

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[37] *Department for Energy and Climate Change, London. Energy Consumption in the UK. www.decc.gov.uk/en/content/cms/statistics/publications/ecuk/ecuk.aspx*

[38] *A weighted "composite temperature" incorporating temperatures recorded on previous days.*

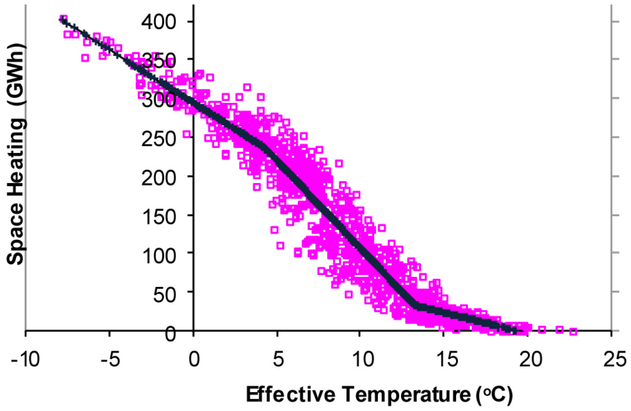

Figure 6.2: Segment Regression Analysis performed on Woodford/North West LDZ data.

Demand for space heating in future climates

Daily mean temperatures for future time periods, under different emission scenarios, and for a location typical of each of the 13 LDZs, were calculated from multiple runs of the UKCP09 weather generator. Each run produced 99 years of weather data and each average temperature was derived from 100 runs, i.e. 9900 years of weather data; in total over one million years of data were generated. From the resulting daily averages over the winter heating season, and the relationship between daily mean temperature and gas consumption, future levels of regional (LDZ) heating energy consumption could be calculated. The national heating energy consumption was then the sum of the 13 regional figures.

This study showed that, depending on the emissions scenario chosen, space heating energy demand in the present building stock fell by 16-18% in the 2030s with steady decline for the next 50 years, so that demand in the 2080s level was 27-43% lower than at present. These reductions are illustrated in Figure 6.3.

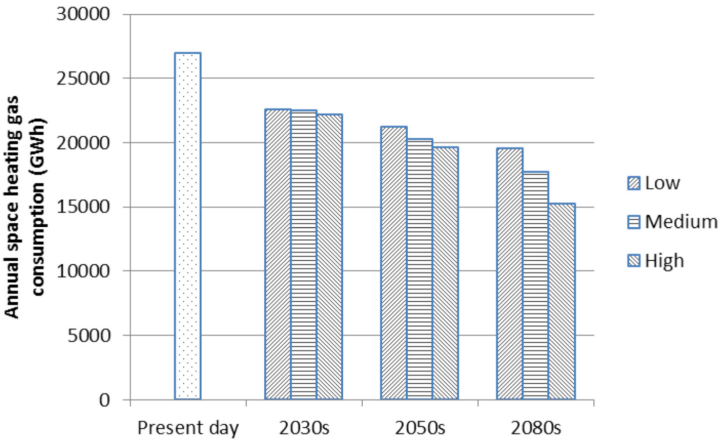

Figure 6.3: Reduction in Annual Space Heating Gas Consumption under Low, Medium and High Emissions scenarios.

These estimates assume no change in the building stock. But there will of course be changes in future decades, of which the most significant for heating energy use will be the introduction of energy efficiency measures in the present stock, the replacement of some of the present stock by new, more thermally efficient buildings, and the overall increase in stock expected over the next decades, in response to population pressures. Estimating the impact of these changes was outside the scope of the research, but the future daily averages derived through COPSE may be used in combination with consumption data revised to reflect stock changes to provide more realistic estimates of future heating energy consumption.

The research has shown, though, that irrespective of changes in the stock, climate change is likely to have a significant impact on space heating energy use.

7 Concluding observations

This report has summarised the coherent programme of research undertaken through the COPSE project. The core element in the project was the development of weather data files based on the most recent climate projections for the UK. These were then used to examine the potential impact of climate change on the design and operation of buildings over the coming decades. The scope was broad: thermal comfort – its implications for design and for the continued use of existing buildings, and how greater use of mechanical cooling system might be avoided; cooling and heating energy consumption both for individual buildings and over the national building stock; the relationship between ventilation, cooling requirements and the external noise environment; the characterisation of urban heat islands. The project was, arguably, unique in tackling such a range of issues.

COPSE research findings will, it is hoped, influence future building design, and policies towards the built environment, through a number of routes. In the first place, they add to the body of knowledge that can be drawn upon by designers, building owners and those responsible for regulatory and energy policies. More specifically, they are contributing to the current update of CIBSE Guide A, which is a key document for the design of building services.

The need to take account of potential changes in weather patterns, when these can be projected only on a probabilistic basis, poses challenges for designers and their clients. The assessment of risk – e.g. of overheating – becomes much more complex. COPSE has shown how weather files can be constructed that will assist such assessments and one consequence may be the development of weather data for the sizing of heating and air-conditioning plant by simulation rather than by the current method which has its original in manual calculations.

A complete (to date) list of COPSE publications is included in this report, as well as contact details of relevant research staff. There will in addition be five PhD theses ((two still to be examined). Because they relate to specific locations, time periods etc, the future weather data files are not contained in a database but are produced to order. They have already been used in relation to actual design exercises; included in the report is a Fact Sheet from the Technology Strategy Board's programme Design for Future Climate – Adapting Buildings illustrating the use of the COPSE weather files by a member of the Stakeholder Group.

With buildings accounting for a significant proportion of UK carbon emissions, and playing a key role in the health and welfare of the population, it is essential that they should be both efficient and comfortable, now and in the future. COPSE research has added to our understanding of the issues, and improved our ability to design and adapt buildings so that they will function effectively in future climates.

Outputs from COPSE

Publications

Temperature data and building design weather datasets

Watkins, R., Levermore, G.J. and Parkinson, J.B. (2012). The Design Reference Year – a new approach to testing a building in more extreme weather using UKCP09 projections. *Building Services Engineering Research and Technology*, online March 2012 at: http://bse.sagepub.com/content/early/2012/03/26/0143624411431170.abstract

Watkins, R., Levermore, G.J. and Parkinson, J.B. (2011). Constructing a future weather file for use in building simulation using UKCP09 projections. *Building Services Engineering Research and Technology*, Vol **32**(3): 293–299.

Levermore, G.J. and Cheung, H. (2012). A low order canyon model to estimate the influence of canyon shape on the maximum Urban Heat Island effect. *BSERT*. Published online before print January 18, 2012, doi: 10.1177/0143624411417899

Cheung, H., Levermore, G.J. and Watkins, R. (2010). A low cost, easily fabricated radiation shield for temperature measurements to monitor dry bulb air temperature in built up urban areas. *Building Services Engineering Research and Technology,* Vol **31**(4): 371–380.

Solar data

Tham, Y. and Muneer, T. (2011). Sol-air temperature and daylight illuminance profiles for the UKCP09 data sets. *Building and Environment*, **46**(6): 1243–1250.

Tham. Y., Muneer. T., Levermore, G.J. and Chow, D. (2011). An examination of UKCIP CP02 and CP09 data sets for the UK climate related to their use in building design. *Building Service Engineering*, **32**(3): 207–228.

Caliskan, N., Jadraque, E., Tham, Y. and Muneer, T. (2011). Evaluation of the accuracy of mathematical models through use of multiple metrics. *Sustainable Cities and Society*, **1**(2): 63–66.

Gago, E.J., Etxebarria, S., Tham, Y., Aldali, Y. and Muneer, T. (2011). Inter-relationship between mean-daily irradiation and temperature, and decomposition models for hourly irradiation and temperature. *International Journal of Low-Carbon Technologies*, **6**(1): 22–37.

Tham, Y., Muneer, T. and Davison, B. (2010). Estimation of hourly averaged solar irradiation: evaluation of models. *Building Service Engineering,* **31**(1): 9–25.

Tham, Y., Muneer, T. and Davison, B. (2009). A generalized procedure to generate clear-sky radiation data for any location. *International Journal of Low-Carbon Technologies*, **4**(4): 205–212.

Tham, Y., Muneer, T. and Davison, B. (2009). Evaluation of simple all-sky models to estimate solar radiation for the UK. *International Journal of Low-Carbon Technologies*, **4**(4): 258–264.

Building performance in future climates

Barclay, M., Kang, J. and Sharples, S. (2012). Combining noise mapping and ventilation performance for non-domestic buildings in an urban area. *Building and Environment*, **52**, 68–76.

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Barclay, M., Kang, J., Sharples, S., Wang, B. and Du, H. (2010). The challenge of balancing the demands for a comfortable thermal and acoustic built environment in a sustainable future. *Proceedings of the International Symposium on Sustainability in Acoustics*. Auckland, New Zealand.

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Adaptive comfort

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Datasets and other outputs

Matlab scripts forming the weather data generators developed at Northumbria University are available for Matlab users. Contact Professor Chris Underwood: chris.underwood@northumbria.ac.uk.

Test Reference Years and other building design weather data for future climates derived from UKCP09 data may be provided by the University of Manchester. Contact: Professor Geoff Levermore: geoff.levermore@manchester.ac.uk.

D4FC Factsheet 6:

University of Greenwich, Stockwell Street

Contact details

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General project information

Name of project:	University of Greenwich, Stockwell Street
Location of project:	London
Type of project:	New build
Cost of project:	£60m

Project team

Client:	University of Greenwich
Designer:	Heneghan Peng Architects
Contractor:	Unknown

Other organisations involved (and their role): Hoare Lea (M&E consultant), Alan Baxter (structural engineer), Fanshawe (cost consultant)

Project description

The project comprises the relocation of the School of Architecture and Construction, currently situated at Eltham, to Greenwich. It also creates a new learning resource centre on the same site, to improve its facilities and accommodate a growing numbers of students. The development will be undertaken on a brownfield site in Stockwell Street, Greenwich and proposes to provide 17 000m^2 of new buildings 10 000m^2 for the School of Architecture and Construction and 7000 m^2 for the learning resources centre

Project timescales and dates

Design and assessment period (pre-planning): project was submitted for planning in February 2011

Construction period (post-consent): construction is due to begin in summer 2011 and will take about two years

Operation and monitoring period: this will occur for 12 months post-completion

Further project details

1 What approach did you take in assessing risks and identifying adaptation measures to mitigate the risks?

- we held several workshops at which each member of the design team and the client attended. Climate related design and operational risks were identified and adaptations options and strategies developed. Each adaptation measure and its application to the University of Greenwich project was discussed
- where data was available further numerical modelling was undertaken otherwise a "what if" approach was taken.

2 How have you communicated the risks and recommendations with your client? What methods worked well?

- the client has been in attendance at each workshop and as such, is fully aware of all adaptation measures that will be recommended. The client has been involved in all areas of the design for the adaptation measures. Some of the students from the college are also getting involved outside of the workshops.

3 What tools have you used to assess overheating and flood risks?

- the University of Manchester were appointed to analyse the UKCIP09 data and to provide the team with the following:
  - design limit data for heating and cooling systems
  - design summer year (DSY) for overheating analysis for Greenwich for present, 2020s, 2040s 2080s. This data was used IES thermal modelling analysis software
  - test reference year (TRY) data energy use analysis for Greenwich for present, 2020s, 2040s 2080s.
  - peak rainfall data from the University of Manchester was given, in terms of mm/hr for storm water flooding risk calculations
- the TSB design checklist was developed further to aid discussion and structure the design analysis at the workshops.

4 What has the client agreed to implement as a result of your adaptation work?

- The adaptation measures were discussed with the client and it has been agreed to implement the following:
  - permanent flood protection to basement areas
  - add access control to the standby generator
  - include adaptable door frames for door dams
  - connect drainage system to the BMS
  - build-up above the attenuation tank to avoid flotation
  - an increase to the number of bike storage spaces
  - allow for an increase in plant and riser space
- this equates to a cost uplift of the original cost plant of £149 000 from £42 570 000 to a new total of £42 719 000.

5 What were the major challenges so far in doing this adaptation work?

- a large degree of uncertainty remains surrounding the design basis and the context in which the effects of climate change can be assessed. The availability of credible future weather data is fundamental to an analytical assessment of the impacts. The nonexistence or unreliability of specific data relating to key risk factors such as rainfall and wind reduces confidence in the analysis. As a result, clients and design teams are less

likely to commit to added expenditure in response to potential risks

- the UKCIP09 weather data has the potential to provide high resolution weather data for projects but as yet is generally unusable by the property sector.
- ultimately the implementation of adaptation measures will affect costs and this need to be balanced against budget
- the second major challenge was identifying the risks and briefing the design team. There was a degree of scepticism and initial defensiveness but gradually this was overcome.

6 What advice would you give others undertaking adaptation strategies?

- many of the adaptations and those of most significance are strategic in nature and affect the space planning and structure of the building. As such the climate related risks need to be identified and analysed at an early stage in the project
- based on the experience of the team the following design strategy could be adopted for other buildings:
    - measures that required structural alteration were recommended to be undertaken immediately irrespective of their actual required implementation time
    - measures that required changes to system or component capacity were only to be implemented when required but consequential structural and space planning issues were implemented (as in the first point)
    - each measure was considered in terms of its impact on the current design and modifications immediately introduced to facilitate a future retrofit
    - those measures that were identified but for which the UKCIP09 weather data provided no firm direction were assessed on their merits and measures introduced on a risk management basis. This particularly applied to the risk of flooding
    - adaptation measures for future years were triggered by the crossing of key thresholds such as thermal capacities of plant, indoor and external design criteria temperature criteria.
- ultimately the implementation of adaptation measures will impact upon costs. A building that is inherently flexible and “loose fit”, and has good passive design features, is likely to be easier and less costly to adapt over its lifetime.