MODELLING THE IMPACTS OF NEW UK FUTURE WEATHER DATA ON A SCHOOL BUILDING

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ABSTRACT

To investigate the impact of the new UK Climate Projections on building performance, a primary school building has been simulated with help of a dynamic building performance simulation package (EnergyPlus Version 6) using 4 sets of future test reference year data which were produced by the UK Chartered Institution of Building Services Engineers, Exeter University, Manchester University and Northumbria University respectively.

Indoor operative temperatures, heating and cooling energy demand of the sample building at three locations (Edinburgh, Manchester and London) under future climate conditions (time slices: 2020s 2030s, 2050s and 2080s; carbon emission scenarios: low, medium and high) were calculated to compare the impacts of four sets of future weather data on building performance.

INTRODUCTION

It is widely agreed that the increase of greenhouse gases emissions has caused, or at least contributed significantly to, the observed changes in global climate conditions. The Inter-governmental Panel on Climate Change fourth assessment report (IPCC, 2007) stated that world temperatures could rise by between 1.1 and 6.4 °C during the 21st century.

In the UK, designing buildings towards future climate conditions were widely implemented by building designers and building simulation practitioners. Hence, future weather data were used intensively for building simulation. The impact of the future warming of climate on building performance (such as thermal comfort conditions and heating/cooling energy consumption) has been predicted previously based on different climate model, however for the UK Climate Projection 2009 (the most comprehensive package of climate information for the 21st century to be made available for the UK to date), very few research has been done to investigate its impacts on buildings. As one of most important input parameter for building simulation, weather data directly influence the reliability and accuracy of simulation results; therefore, it is crucial to let practitioners understand the usage of appropriate future weather data for building simulation.

The UK Climate Projections

For the UK, two projections were made available in the last decade. The first one, the UKCIP02 climate change scenarios (UK Climate Impacts Programme, 2002) were generated in 2002 from a climate model developed by the Hadley Centre. In 2009, the latest version, the UK Climate Projections 09 (UKCP09), was released to supersede the UKCIP02 projections.

The UKCP09 Projections (Jenkins et al., 2009) indicated that the changes in summer mean temperatures were greatest in parts of Southern England (up to 4.2ºC (in range of 2.2 to 6.8ºC)) and least in the Scottish islands (just over 2.5ºC (in range of 1.2 to 4.1ºC)) from a 1970s baseline towards the 2080s (refer to the time slices definition in Table 1).

Table 1
Time slices definition

1970s	1960-1989
2020s	2010-2039
2030s	2020-2049
2050s	2040-2069
2080s	2070-2099

As a main product of the Projections, the UKCP09 Weather Generator (UK Climate Projections, 2010) can generate a set of daily and hourly future climate variables at different time periods (2020s to 2080s) and carbon emission scenarios (low, medium and high) for every 5km2 in the UK. For each specific location, time period and carbon emission scenario, 100 sets of 30-year period hourly and daily data could be generated by the Weather Generator to indicate 100 probabilities of future weather for 30-year period. The hourly climate variables were temperature, vapour pressure, relative humidity, sunshine hours, diffuse and direct horizontal radiation. This provided an opportunity to construct future weather files for building simulation.

Weather data for simulation

Due to the computational limit of most building simulation packages, there was a need to generate typical year data (also called test reference year data) from the Climate Projections Weather Generator' raw data (multi-year data).

The UK Chartered Institution of Building Services Engineers (CIBSE, 2009) released future hourly weather data (named CIBSE data) in 2008 which incorporated the UKCIP02 Projections, for three time lines (2020s, 2050s and 2080s) and for four carbon emissions scenarios (low, medium-low, medium-high and high). The method (Belcher, Hacker & Powell, 2005) used to create this CIBSE future weather data was to 'morph' the historical weather data, thus retaining historical weather patterns in the future data.

Due to the probabilistic feature of the UKCP09 Projections, for a specific location, time slice and carbon emission scenario, 3000 years hourly data (100 sets of 30 years data) were provided by the Weather Generator (UK Climate Projections, 2010). Researchers (Eames, Kershaw & Coley, 2011) at Exeter University created a method of generating five Probabilistic Reference Year data from a set of UKCP09 data. In their method, for each calendar month, 100 sets of typical month data were derived from 3000 months data, and then they were ranked in ascending order of monthly mean temperatures. Five months at 10th, 33rd, 50th, 66th and 90th percentile positions were then picked to construct five sets of Probabilistic Reference Year data. In this article, only the 50^{th} percentile data (named Exeter University data) were employed to do the building simulations.

Researchers (Watkins, Levermore & Parkinson, 2011) at Manchester University developed another method of generating one future test reference year data (named Manchester University data) from a set of UKCP09 data. The method followed BS EN ISO 15927-4:2005 (ISO, 2005) standard, but they directly applied the method to 3000 years data, rather than 20-30 years historical data.

A similar method (Du, Underwood & Edge, 2011) was implemented in Matlab by authors at Northumbria University to quickly extract a future Test Reference Year from UKCP09 data for a specific location, time slice and carbon emission scenario. This approach was more computationally efficient.

The Northumbria University dataset covered three time lines (2030s, 2050s and 2080s) and three carbon emissions scenarios (Low, Medium and High); whilst the Manchester University dataset only covered two emission scenarios (Low and High) for the 2020s, 2050s and 2080s. More detailed information about time lines and carbon emission scenarios of weather data from four organisations are listed in Table 2. The letters in column 2 of Table 2 were used to indicate time lines and emission scenarios in Figures 2-8.

The maximum daily global horizontal solar radiations of all typical year data at Edinburgh, Manchester and London from four organisations' datasets are plotted in Figure 2. There was a significant difference between the maximum values of three universities' data (derived from the UKCP09 Projections) and the values from CIBSE data (based on the UKCIP02 Projections). This might be attributed to the changing clarity of sky condition (Tham & Muneer, 2010) in the UKCP09 Projections.

Table 2
Weather data for simulation

WEATHER DATA FOR SIMULATION		
CIBSE	C	Control data (1983-2004)
	2L	2020s low carbon emission scenario
	ML	2020s medium low carbon emission scenario
	MH	2020s medium high carbon emission scenario
	2H	2020s high carbon emission scenario
	5L	2050s low carbon emission scenario
	ML	2050s medium low carbon emission scenario
	MH	2050s medium high carbon emission scenario
	5H	2050s high carbon emission scenario
	8L	2080s low carbon emission scenario
	ML	2080s medium low carbon emission scenario
	HL	2080s medium high carbon emission scenario
	8H	2080s high carbon emission scenario
Exeter Uni	C	Control data (1960-1989)
	3M	2030s medium carbon emission scenario
	3H	2030s high carbon emission scenario
	5M	2050s medium carbon emission scenario
	5H	2050s high carbon emission scenario
	8M	2080s medium carbon emission scenario
	8H	2080s high carbon emission scenario
Manchester Uni	C	Control data (1960-1989)
	2L	2020s low carbon emission scenario
	2H	2020s high carbon emission scenario
	5L	2050s low carbon emission scenario
	5H	2050s high carbon emission scenario
	8L	2080s low carbon emission scenario
	8H	2080s high carbon emission scenario
Northumbria Uni	C	Control data (1960-1989)
	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 annual maximum, annual minimum, annual mean, summer mean and winter mean dry bulb temperatures of test reference year data at Edinburgh, Manchester and London from four organisations (CIBSE, Exeter University, Manchester University and Northumbria University) are illustrated in Figure 3. The increase of annual mean and summer mean temperatures from four organisations' datasets were identical although their methods of generating typical year weather data were different. The maximum hourly temperature and winter mean temperatures from three universities (derived from the UKCP09 Projections) were generally lower than CIBSE data (based on the UKCIP02 Projections). Both projections show that the mean temperature in Edinburgh will be about 3 °C lower than the mean temperature in London, while the mean temperatures of Manchester lies between the temperatures of Edinburgh and London.

SIMULATION

Building

A recently built primary school (Figure 1) was selected for building performance simulation using the future weather data sets described in Table 2, because the users (age from 4 to 11) of the building are sensitive to extremes of thermal comfort which are very likely to occur in future according to climate projections.

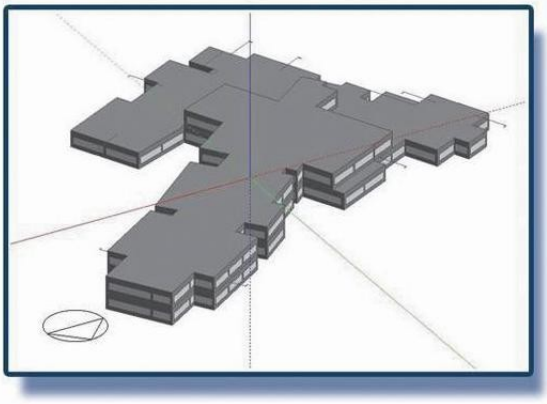

Figure 1 Primary school building

This two-storey building comprised of 25 zones which included 14 main occupied zones, such as meeting rooms, classrooms, offices and a library. The main occupied area was 3081.8 m^2 out of 4246.4 m^2 of gross floor area.

The occupancy densities and occupied period profiles of all zones were configured according to the UK National Calculation Method database (The Department for Communities and Local Government, 2010). For example, classrooms were occupied from 8:01 to 17:00 with difference occupancy densities at school term days.

Table 3
Building U-value and thermal capacity

	U-VALUE (W/m^2K)	KM (kJ/m^2K)
External wall	0.350	134.9
External roof	0.250	\
Groundfloor	0.257	\
Partition wall	1.690	126.1
Double glazing	2.725	\

The U-values and thermal capacities of the building material are shown in Table 3. The total solar transmission (Solar Heat Gain Coefficient, SHGC) of glazing was 0.742 and the area of glazing was 40% of the façade area.

Modelling assumptions

The same building was assumed to be located in three major cities in the UK: Edinburgh (55.95N, 3.34W), Manchester (53.36N, 2.28W) and London (51.48N, 0.45W) in order to compare the climate change impacts at different locations cross the UK.

A constant effective mean allowance for infiltration of 0.5 air changes per hour was applied to all zones, and additionally, an allowance for natural fresh air ventilation during occupied hours of 10L/s per person was applied for all the simulations.

Three simulations were conducted for the building at each specific location, timeline and carbon emission scenario. These simulations were ‘freefloat’ (no heating or cooling), heating and cooling conditions.

The ‘freefloat’ condition simulation was aimed to generate the summer, winter and annual mean indoor operative temperatures at occupied hours and the percentage of occupied hours over 28 ºC. Apart from the basic infiltration and fresh air allowance, 4 air changes per hour of natural ventilation were added when indoor air temperatures went over 25 ºC during the occupied hours and the indoor air temperatures were higher than the outdoor temperature. This assumes that users would open windows when they feel warm inside rooms.

For the heating and cooling simulations, profiles of all main occupied zones were configured according to the UK National Calculation Method database (The Department for Communities and Local Government, 2010). In brief, heating setpoints ranged from 18 to 22 ºC, and cooling setpoints ranged from 23 to 25 ºC depending on the usage of rooms.

To test the impact of different future weather data only on existing building, it was assumed that building materials, user behaviour and HVAC systems would be as they would be defined at the present time. Although it is debatable that this assumption could stand until 2080s because of the adaptive thermal comfort behaviour of occupancy, policy, economy and technology influence on occupancy. For this study, cooling and heating energy demand of each zone and the building were simulated. This energy demand does not include HVAC system energy consumption, because HVAC system is going to be replaced at 20-30 years cycle in future, and the efficient of system will change as well.

The usage of school is very unlikely to change in the future. The type of fuel source could influence total energy consumption, but it would not influence heating and cooling energy demand.

RESULTS AND DISCUSSION

Winter mean temperatures

Figure 4 shows results of indoor mean operative temperatures at occupied hours in winter for each zone and building at different locations, time slices and carbon emission scenarios. The occupied hours are working hours of weekdays in December, January and February, and they do not include Christmas (22nd Dec- 9th Jan) and middle term holiday (13th Feb- 20th Feb).

The top, middle and bottom rows show simulation results of the building at the Edinburgh, Manchester and London locations respectively.

The figure was broken into 4 columns to represent results from 4 organisations' datasets (CIBSE, Exeter University, Manchester University and Northumbria University, ordered from left to right in the figure).

Tests under the X axis indicate timelines and carbon emission scenarios (refer to Table 2).

The symbol 'x' in the figure indicates the mean temperature of one zone, and the bar in the figure indicates the mean temperature of the whole building. The pink, green and red bars in the figure highlight control, 2050 high emission scenario and 2080 high emission scenario results respectively which were common in the 4 organisations weather files.

This pattern of visualising the results was also used in Figures 5 and 6.

Figure 4 shows that results from the CIBSE control period were higher than other three control periods. This is because the CIBSE control weather data was historical recorded data from 1983-2004, whilst the other control data was simulated historical data for 1960-1989. For future timelines, results were identical, and they indicated that there would be a 2-4 ºC mean operative temperature increase inside the building in winter by the 2080s high carbon emission scenario.

Summer mean temperatures

Figure 5 shows results of indoor mean operative temperatures at occupied hours in summer for each zone and building at different locations, time slices and carbon emission scenarios. The occupied hours are working hours of weekdays in June, July and August. Middle term (29th May- 5th Jun) and summer holiday (24th July- 4th Sep) are not included.

For London, results from the UKCP09 Projections (three universities' datasets) are similar to results from the UKCIP02 Projections (CIBSE dataset), however, for Edinburgh, the UKCP09 Projections indicate warmer indoor conditions in summer than the UKCIP02 Projections.

The Figure also shows that overheating issues would be significant by the second half of this century, especially in London, because indoor summer mean operative temperature could reach 28 ºC.

Overheat percentages

CIBSE Guide A (CIBSE, 2006) recommends 1% of annual occupied hours over an operative temperature of 28 ºC as a criteria to assess the overheating risk of a school building. Figure 6 demonstrates the potential overheating situation for this building.

This figure shows that the duration of overheating by the end of this century would be 4 times that of current conditions.

Similar to summer mean temperature results, both UKCP09 and UKCIP02 Projections in London indicate similar overheat percentages, but for northern city (Edinburgh), UKCP09 indicate more overheat risks in late part of this century than UKCIP02. The overheat percentage from Exeter data is significantly higher than the percentage from other organizations.

Heating energy demand

Figure 7 shows the simulated annual heating energy demand for the building at different locations, time slices and carbon emission scenarios.

The blue bar indicates heating energy demand per gross floor area, and the blue and dark red bar together represent heating energy demand per treated floor area. The similar format was used in Figure 8 (for cooling energy demand).

Figure 7 shows a decreasing trend of heating energy demand. This would be one of benefits from a warmer winter in the future.

For control period, there is a difference between three universities' results and CIBSE's results due to the timeline difference. For future periods, the results are identical.

Cooling energy demand

Figure 8 gives the simulated annual cooling energy demand (sensible room load only) for the building at different locations, time slices and carbon emission scenarios. Sensible room load is the main cooling load for the UK buildings at this moment, and there is no evidence showing the change of relative humidity in future.

Both UKCIP02 (CIBSE data) and UKCP09 (three universities datasets) projections give identical results for the building in London, while the UKCP09 projections indicate more cooling energy demand in Edinburgh than UKCIP02 projections.

Figure 8 also shows that annual cooling energy demand could be tripled by the 2080s for the high carbon emission scenarios compared with the baseline results.

CONCLUSION

In this work, simulation results from four organisations' future test reference year data were compared. All of them show that summer overheating and higher cooling energy demand are very likely to occur in the second half of this century, though winter heating energy consumption could reduce.

In general, there is a good agreement among results from all weather data sets, although the CIBSE dataset and the three universities' datasets have slightly different predictions for the three cities due to geographical distribution. Three universities' test reference year results are identical although their methods of generating test reference year data are different.

This work provides an example for practitioners to understand the agreement and differences between four sets of future weather data, and it gives information for policy makers to choose appropriate weather data to conduct future proofed building design assessment.

Future work is required in four areas. First, a comparison of future Design Summer Year data and Design Reference Year data from four organisations will be conducted, as those data are important for peak load calculation and risk analysis. Second, more building types will be included as case studies, as they will give better understanding of how buildings perform in the future. Third, the adaptation towards future climate would be investigated. Fourth, user behaviour changes due to policy and economy factors will be investigated.

ACKNOWLEDGEMENTS

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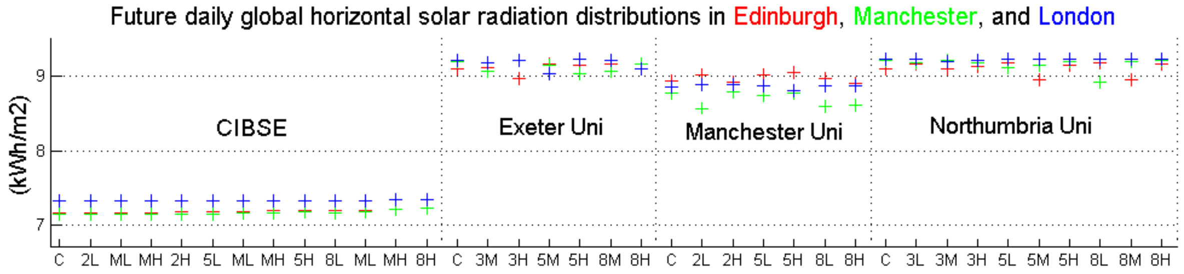

Figure 2 Maximum daily global horizontal solar radiation in Edinburgh, Manchester, and London

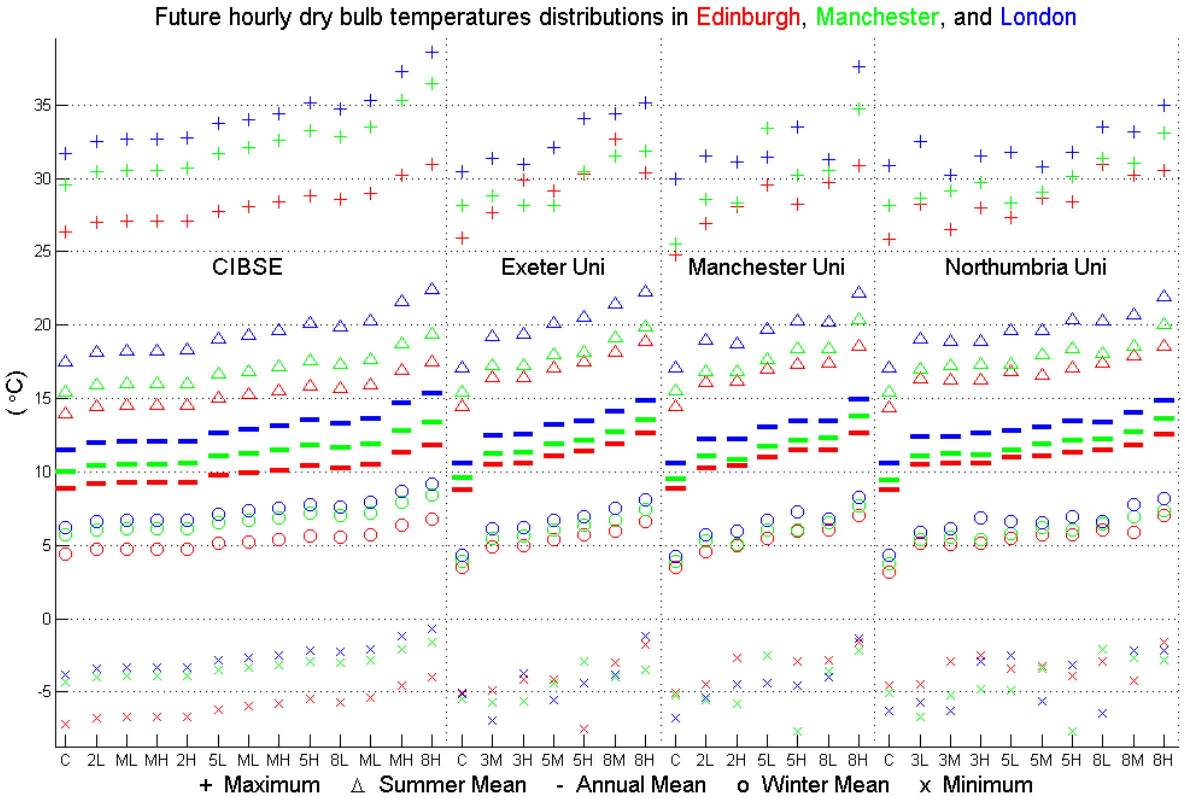

Figure 3 Hourly dry bulb temperatures distributions in Edinburgh, Manchester, and London

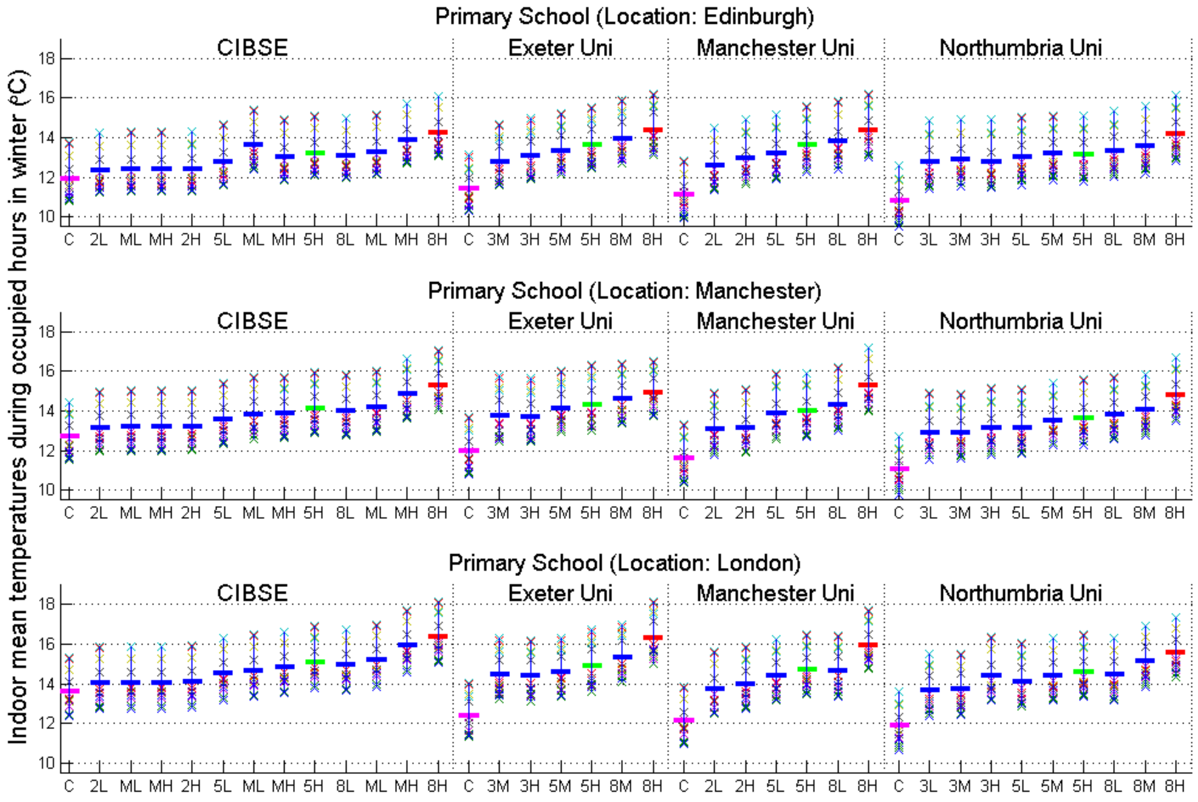

Figure 4 Indoor mean temperatures during occupied hours in winter

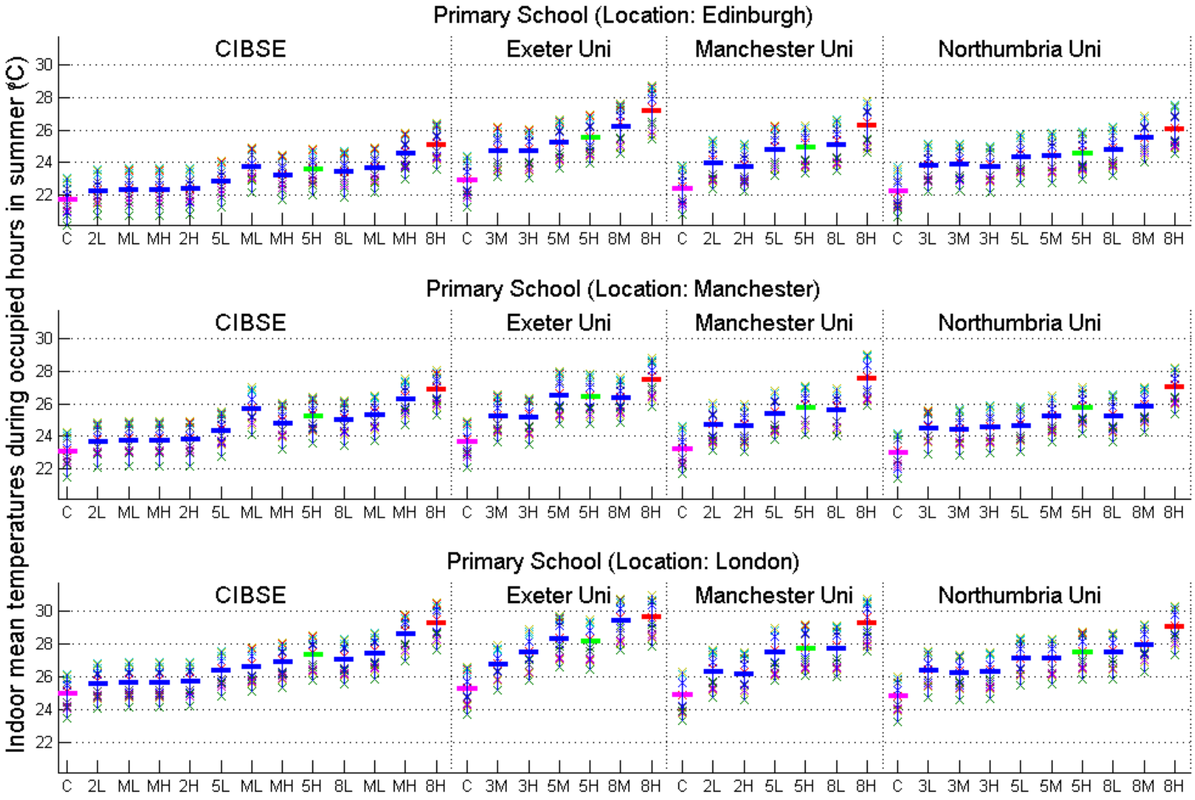

Figure 5 Indoor mean temperatures during occupied hours in summer

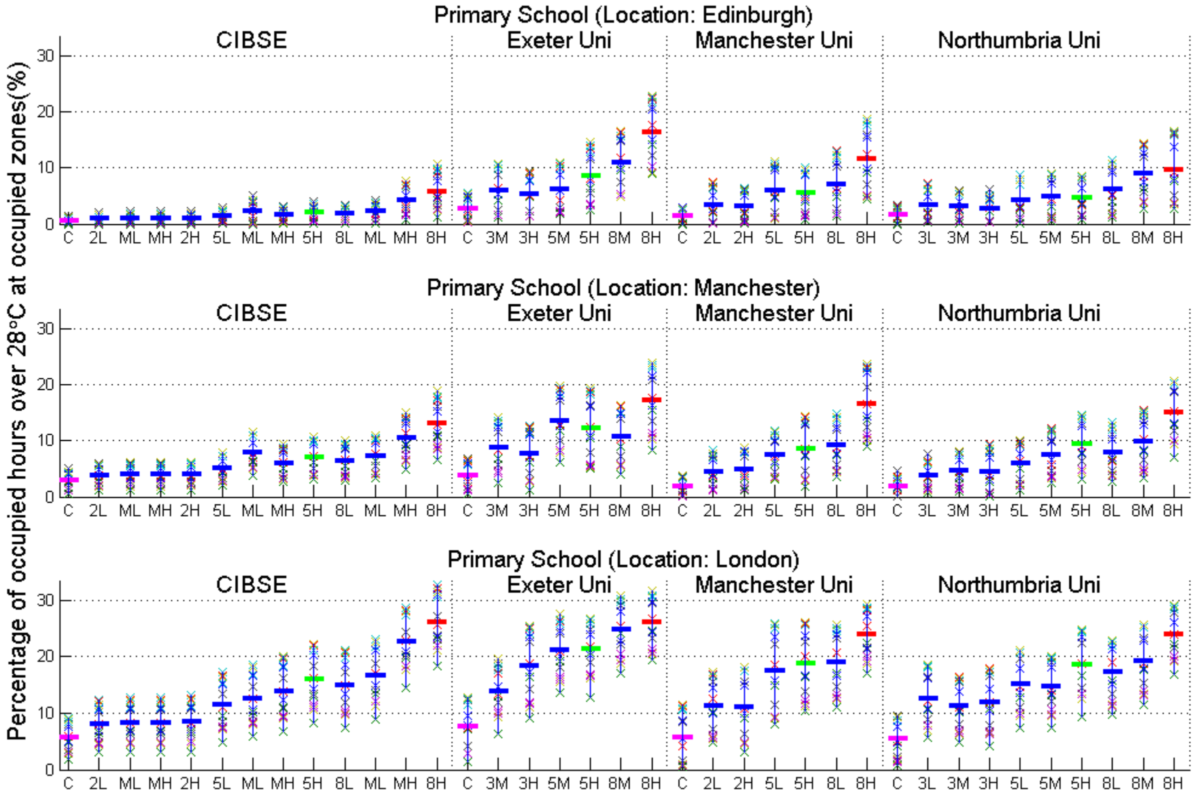

Figure 6 Percentage of occupied hours over 28 ^{o}C at occupied zones

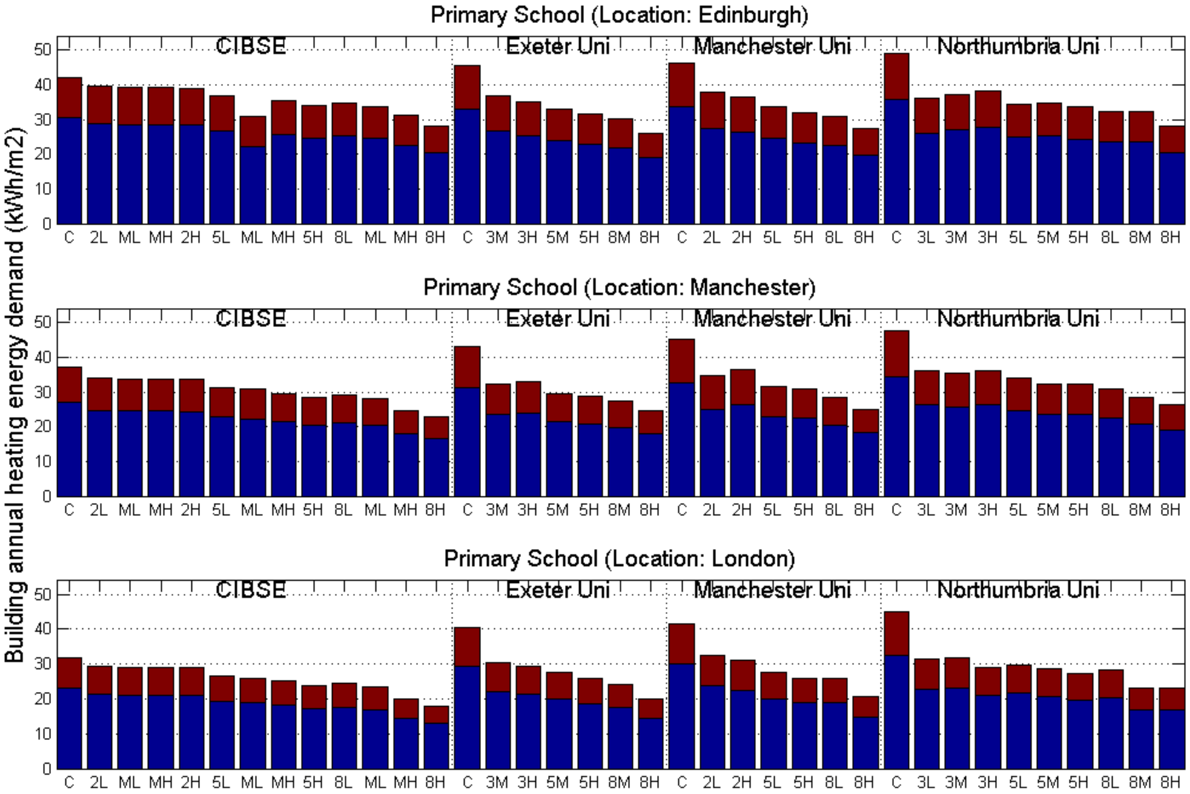

Figure 7 Building annual heating energy demand

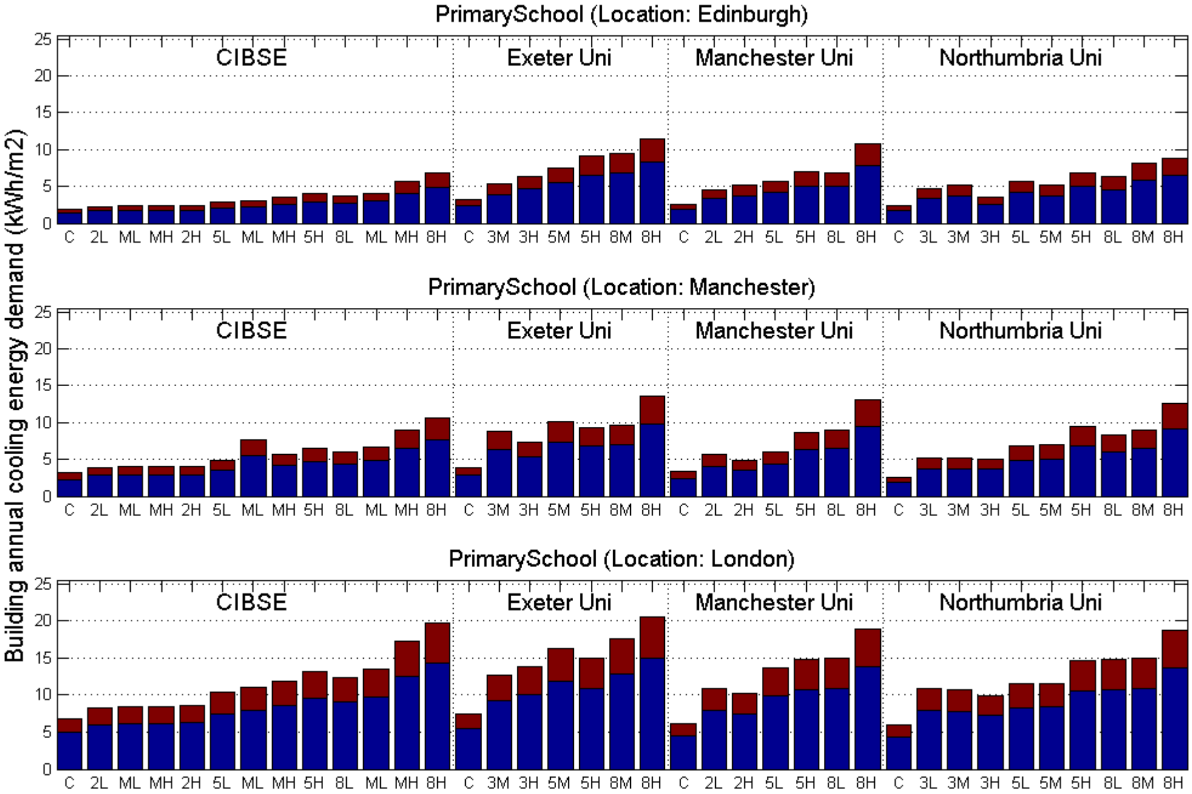

Figure 8 Building annual cooling energy demand