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Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century

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Abstract

This paper addresses the dual challenge of designing sustainable low-energy buildings while still providing thermal comfort under warmer summer conditions produced by anthropogenic climate change—a key challenge for building designers in the 21st century. The main focus is towards buildings that are 'free running' for some part of the summer, either being entirely naturally ventilated or mixed-mode (where mechanical cooling is only used when thought to be essential). Because the conditions in these buildings will vary from day to day it is important to understand how people react and adapt to their environment. A summary is made of recent developments in this area and of the climate data required to assess building performance. Temperatures in free running buildings are necessarily closely linked to those outside. Because the climate is changing and outside summer temperatures are expected to increase, the future will offer greater challenges to the designers of sustainable buildings aiming to provide either entirely passive or low-energy comfort cooling. These issues are demonstrated by predictions of the performance of some case study buildings under a climate change scenario. The examples also demonstrate some of the important principles associated with climate-sensitive low-energy design.

Keywords: Climate change; Thermal comfort; Low-energy buildings; Mixed-mode; Natural ventilation; Thermal mass

1. Introduction

There is little need to justify the drive to minimise the energy consumed by HVAC systems. Motivation may now appear to have moved from the desire to reduce costs and save scarce resources towards minimising the production of carbon dioxide which in terms of necessity is of much greater importance. It is however economic forces that will always dominate. Furthermore, the trend towards more ambitious architectural designs is stretching the ability of engineers to provide robust low-energy design solutions. It may be that the use of particular materials within the construction will help minimise consumption. It is however probable that the energy consumed during the life of a building will greatly exceed the embodied energy within the fabric and systems installed within the building and consequently a design that minimises energy consumption from the outset will be the most sustainable solution.

It has to be recognised that the HVAC plant will be replaced several times during the life of the building and also, to make things more difficult, the climate is changing. Therefore, a building and associated systems may take a number of different forms throughout the life of that building. It is probably impossible to predict the changes that that will be made to the HVAC systems; it is possible to make reasonable estimates of the climate over the next 80 years or so [1]. This has been done using computational models of the world climate system based on different scenarios for greenhouse gas emissions. For example in the UKCIP02 scenarios [1], the latest set of climate change scenarios for the UK produced by the United Kingdom Climate Impacts Programme, the projections for the Medium–High emissions scenario results in an increase in global temperature of 3.3 K by the 2080s. Table 1 presents the predicted increase in global temperature for the four UKCIP02 emissions scenarios and three time slices (each a 30-year period centred around the decade in question). In this paper we will restrict attention to the Medium–High emissions scenario, although at this time there is no particularly probability attached to any one of the four scenarios. However, comparisons can be made between the scenarios. For example, the level of projected global climate change in the 2080s under Low emissions is almost the same as that projected for the 2050s under Medium–High emissions.

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Table 1
UKCIP02 scenario global temperature changes under the four greenhouse gas emissions scenarios and three 30-year time slices through the 21st century

Time-slice	Low emissions	Medium–Low emissions	Medium–High emissions	High emissions
2020s	0.79	0.89	0.89	0.95
2050s	1.4	1.7	1.9	2.2
2080s	2.0	2.3	3.3	3.9

Using climate change scenarios it is possible, if some means can be found to modify the climatic data currently used for the prediction of energy consumption in buildings, to make a plausible estimate of the performance of the current plant and building under climate change. Recognising that retrofits will be made this approach is best used to test the 'robustness' of the original design.

A recent research project [2] looked at the impact of climate change on the performance of low-energy buildings in the United Kingdom. This study indicated, as might be expected, that good low-energy design offers the best 'future-proof' solutions. The study also highlighted four basic principles of low-energy and sustainable designs:

- switch off;
- spread out;
- blow away;
- cool.

That is, minimise heat gains (solar shade) and ensure internal equipment is switched off when not required ('switch off'). The impact of gains can be reduced by attenuating peaks by means of thermal mass ('spread out'). Ventilation systems should be properly controlled to ensure that gains are removed and not added to, for example, by not introducing outside air when that air is at a temperature greater than that in the building (other than that required to maintain air quality) ('blow away'). To this end a mechanical system may be preferable to a natural ventilation system. Finally if all else fails 'peak lopping' cooling will be required ('cool'). This is what is commonly called a 'mixed-mode' building is likely to become the sustainable building of the future.

In order to demonstrate some of the principles of low-energy design this paper uses a number of example buildings. These buildings, whilst based on actual buildings located in the United Kingdom have been simplified to demonstrate the main design features. Their selections were made by examining a number of post-occupancy design studies [3] and exemplars of what were thought to be good design. These examples demonstrate advanced natural ventilation principles, thermal storage, a novel low-energy cooling system and mixed-mode operation in the present UK climate and some possible future climates. In addition, to show that these types of buildings perform well the results of a post-occupancy survey on a mixed-mode building are described.

Low-energy designs, in particular natural ventilation, tend to be, by definition, more sensitive to changes in external climate conditions. It is therefore essential that the climate used to assess performance should provide a proper test of performance. Comfort targets are possibly even more important because the wider the range of permitted internal conditions the greater the scope for energy saving. Again it is important that realistic design conditions are set. The first section of the report presents a brief review of climate and comfort issues which is followed by a look at some of the features that affect the choice of particular low-energy design strategies. The case studies complete the paper.

2. Climate and comfort

A detailed discussion of these issues is beyond the scope of this paper. Climatic issues are discussed in great detail in CIBSE Guide J [4] and there are numerous publications on comfort criteria. This section presents an approach to determining internal design targets. The climatic conditions looked at here are for the assessment of the performance of the building and associated HVAC systems and not for the design of those systems. In this respect it is assumed that the only satisfactory way to assess building performance is by means of simulation. That is the use of a computer program that is capable of calculating performance over a complete year at a maximum of hourly intervals.

2.1. Climate

To reduce the effects of the natural interannual variability in the weather the World Meteorological Organisation defines climate to be a 30-year period whereas building services engineers use a single year for simulation modelling. It is therefore important that the year chosen is representative of the weather over a number of years. Such a year is commonly called a test reference year (TRY). The method used to select a TRY differs between countries (see for example CIBSE 2002 [4]); however, the objective is the same; to construct a set of 12 months that is representative of the past (say 20 years). This means that a TRY is unlikely to include extremes and therefore, while suitable for the prediction of energy consumption it is unsuitable for the purpose of assessing the performance of buildings under more onerous conditions. To do this requires a year that contains periods where temperatures are higher than average.

To address this issue the CIBSE have introduced the concept of the design summer year (DSY, CIBSE 2002 [4]). A DSY is a complete year for which the average temperature of the period April–September ('summer' (note that formal meteorological definition of summer is June–August) is at the centre of the upper quartile of rankings obtained from about 20 individual years; that is, from a set of 20 years, the DSY will be the third warmest according to the April–September average temperature. This means that there is approximately a 1 in 10 chance (assuming a non-changing 'stationary' climate) that a year will have April–September average temperatures exceeding that of