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Simulation of the future performance of low-energy evaporative cooling systems using UKCP09 climate projections

V.I. Hanby*, S.Th. Smith

Institute of Energy and Sustainable Development, De Montfort University, The Gateway, Leicester LE1 9BH, UK

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ABSTRACT

Recent activity in the development of future weather data for building performance simulation follows recognition of the limitations of traditional methods, which have been based on a stationary (observed) climate. In the UK, such developments have followed on from the availability of regional climate models as delivered in UKCIP02 and recently the probabilistic projections released under UKCP09. One major area of concern is the future performance and adaptability of buildings which employ exclusively passive or low-energy cooling systems.

One such method which can be employed in an integral or retrofit situation is direct or indirect evaporative cooling. The effectiveness of evaporative cooling is most strongly influenced by the wet-bulb depression of the ambient air, hence is generally regarded as most suited to hot, dry climates. However, this technology has been shown to be effective in the UK, primarily in mixed-mode buildings or as a retrofit to industrial/commercial applications.

Climate projections for the UK generally indicate an increase in the summer wet-bulb depression, suggesting an enhanced potential for the application of evaporative cooling. The paper illustrates this potential by an analysis of the probabilistic scenarios released under UKCP09, together with a detailed building/plant simulation of case study building located in the South-East of England. The results indicate a high probability that evaporative cooling will still be a viable low-energy technique in the 2050s.

1. Introduction

1.1. Background

The availability of climate projections together with methods for spatial and temporal downscaling has prompted increased research on simulating the future performance of buildings. The impacts of climate change on passively controlled buildings have been the focus of much of this work, but there are significant implications for buildings which rely on mechanical and mixed-mode solutions. The output of climate models cannot be used directly as an input to building and plant simulations, as the temporal resolution is on an annual, seasonal, or at most a monthly basis. Model outputs required downscaling to an hourly basis if the data are to be used in dynamic simulation programs.

One approach, developed in the UK, is to apply monthly scaling factors to actual weather years representative of a reference period, chosen to be as close as possible to the thirty-year period 1961–1990. This method, known as morphing, was applied to the output of the UKCIP02 [1] climate projections and resulted in hourly weather files for 14 locations in the UK. Morphing produced both Typical Reference Years (TRYs), used primarily for energy calculations, and Design Summer Years (DSYs) representing near-extreme hot periods to use in evaluating thermal comfort and overheating in naturally ventilated buildings [2].

The most recent climate projections (UKCP09 [3]) were produced by carrying out ensemble model runs and give probabilistic values for the change factors for the key variables; this makes it almost unavoidable to incorporate uncertainty in any analysis which makes use of the projections. The projections are based on three emissions scenarios, have output on a 25 km grid and cover the period 2010–2090 in seven decadal timeslices. A Weather Generator (WG) is also available [4] which constructs statistically plausible daily or hourly time-series on a 5 km grid. The weather generator was calibrated using real data from the period 1961–1990, hereafter referred to as the *control* period. Projections of future weather sequences, for a range of time slices and emissions scenarios, are referred to using the term *scenario*.

A high proportion of the existing non-domestic building stock will still be in use at the far time horizon of the climate projections,

* Corresponding author. Tel.: +44 (0)116 257 7980.
E-mail address: vhanby@dmu.ac.uk (V.I. Hanby).

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therefore it is timely to investigate their future performance and that of their environmental control systems in order to inform new designs and to investigate retrofit options. An important project which examined the future performance of a range of case study buildings was published by the CIBSE as Technical Memorandum 36 [5]. A comparison was made of the thermal performance of a range of buildings (including one office building with an evaporative mixed-mode system) using control weather files and files produced by morphing the control files using change factors produced by the UKCIP02 climate projections as noted above. The motivation for exploring the use of UKCP09 projections was as a result of their increased scientific rigour, such as additional carbon feedback cycles, together with the opportunity of obtaining a preliminary indication of the usefulness of output data in probabilistic form, which is intrinsic to the use of UKCP09 projections.

1.2. Climate change and building cooling loads

The cooling system of a building, whether 'natural' or mechanical, has to respond to internal and external heat gains. Whilst it is possible that internal gains might moderate in future, due to improvements in the efficiency of electrical and electronic equipment, the likelihood is that external gains will increase, putting increased pressure on the cooling system. In the case of systems which use mechanical cooling, the coefficient of performance might be expected to decrease. The projection of building cooling energy is subject to many uncertainties, including for instance future plant replacement and improvements in component performance. De Wilde et al. [6] have investigated methods of predicting future energy use taking into account many of the measurable uncertainties. In this study, we have restricted quantification of uncertainty to the influence of climate on building loads; we have assumed constant values over time for building properties, internal gains and plant performance parameters.

For a building with a mechanical or mixed-mode system, the important driving quantities are

- dry-bulb temperature;
- wet-bulb temperature (or an equivalent psychrometric variable); and
- solar radiation.

For passive and mixed-mode buildings wind speed (and possibly direction) is also important, but these quantities are not directly available from the UKCP09 WG. The current best estimates are that wind speeds are likely to decrease slightly until the 2050s, perhaps recovering to those prevalent in the control period by the end of the century [7], hence wind-driven processes such as infiltration and natural ventilation are unlikely to change to any significant degree. There has been considerable discussion as to how to cope with lack of wind speed data, including back-calculating daily wind speeds from the values of potential evapotranspiration (available as a daily mean value from the WG) and deriving hourly values from this figure [8], obtaining probabilistic wind speeds from a separate data source, the 11-member RCM [9] or the use of measured hourly data. In this work measured hourly values for wind speed and direction were used; the values were taken from the year 1985 which was found to be the closest to the long-term mean for London over the period 1976–1995.

Plume plots for summer (June, July and August) changes in dry-bulb temperature and downward short-wave radiation flux for London (grid square 1628, medium (a1b) emissions scenario) are shown in Fig. 1. The plots were generated at the 10% level of the cumulative distribution function (CDF), the 50% level (central estimate) and the 90% level.

The projections show that there is a 90% probability that the change in mean summer temperature by the 2080s will exceed 2.0 °C and a 10% probability that it will exceed 6.3 °C, thereby indicating that conduction and fresh air loads are likely to increase. The spread of uncertainty in solar radiation is interesting. There is a probability level of around 15% that the summer solar radiation will decrease, but it is most likely to increase over the century. This could increase the efficiency of active solar systems as well as solar gains to buildings.

Humidity levels also have implications for cooling loads as thermal comfort may be affected as well as any dehumidification energy used by the plant. Fig. 2 shows the predicted changes (as a percentage) of specific and relative humidity.

Although the summer specific humidity (base unit kg kg^{-1}) is predicted to rise over the century, the relative humidity is expected to decrease. This has implications not only for thermal comfort but also for the low-energy cooling systems that rely on the evaporation of water.

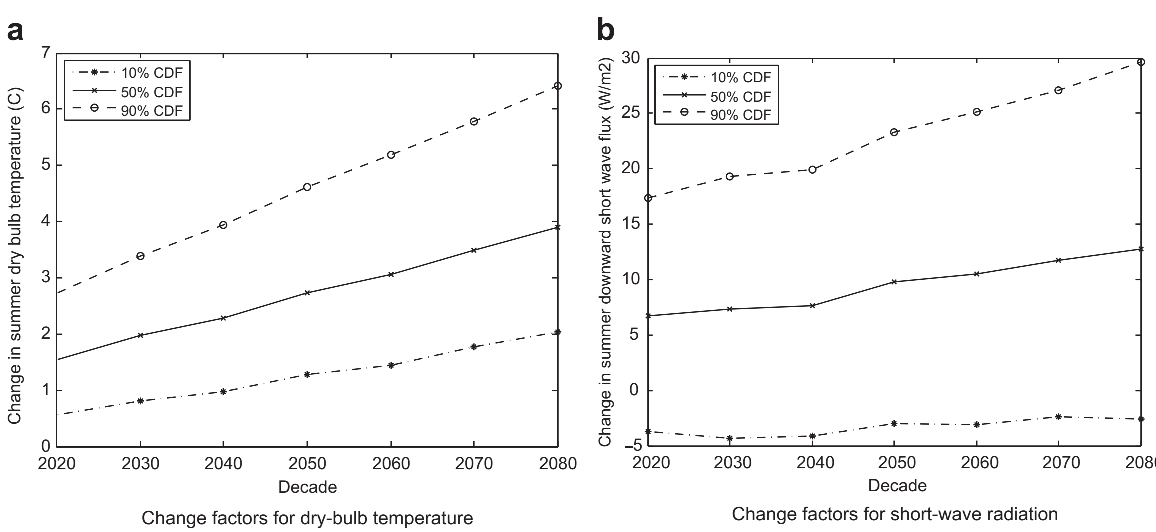

Fig. 1. Plume plot of change factors for dry-bulb temperature and solar radiation.