Energy and Buildings 43 (2011) 1723–1731

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Probabilistic climate projections with dynamic building simulation: Predicting overheating in dwellings

D.P. Jenkins[a,*], S. Patidar[b], P.F.G. Banfill[a], G.J. Gibson[b]

[a] Urban Energy Research Group, School of Built Environment, Heriot-Watt University, Edinburgh EH14 4AS, UK
[b] Maxwell Institute for Mathematical Sciences, School of Mathematical and Computer Sciences, Heriot-Watt University, Edinburgh EH14 4AS, UK

ARTICLE INFO

Article history:
Received 4 October 2010
Received in revised form 9 February 2011
Accepted 17 March 2011

Keywords:
Overheating
Building simulation
Climate change
Probability

ABSTRACT

This study, as part of the Low Carbon Futures project, proposes a methodology to incorporate probabilistic climate projections into dynamic building simulation analyses of overheating in dwellings. Using a large climate projection database, suitable building software and statistical techniques (focussing on principal component analysis), output is presented that demonstrates the future overheating risk of a building in the form of a probability curve. Such output could be used by building engineers and architects to design a building to an acceptable future overheating risk level, i.e. providing evidence that the building, with specific adaptation measures to prevent overheating, should achieve thermal comfort for the majority of future climate projections. This methodology is overviewed and the use of the algorithm proposed in relation to existing building practices. While the methodology is being applied to a range of buildings and scenarios, this study concentrates on night-time overheating in UK dwellings with simple and achievable adaptation measures investigated.

1. Introduction

The concept of "future-proofing" buildings against climate change, designing to account for predicted warming, is not in itself a new idea. Perhaps a more sensible approach would be to make buildings "future-sensitive" to predicted warming, with the different causes of overheating in buildings often being varied, making the term "future-proofed" somewhat misleading. However, previous studies [1,2] have been mostly concerned with deterministic descriptions of future climates, which imply a level of certainty to our understanding of climate predictions that does not really exist – though this approach has been unavoidable due to the information available for future climate descriptions. More recent climate descriptions, from the UKCP'09 programme [3] provide probabilistic projections of future climates for different scenarios and locations in the UK. These introduce the possibility of transferring the uncertainty of climate models across to, in this case, building performance predictions. Buildings could therefore, in theory, be designed with a spectrum of future climate possibilities in mind, endeavouring to ensure that the building will have a high probability of performing adequately within the lifetime of that building.

A major concern with building performance, in a warming climate, is the ability of the available systems and design features to cope with higher external temperatures (and, for some projections, higher solar gains). If the level of warming is such that the building overheats, or a cooling system becomes overloaded, then there will be a need to incorporate this into the existing design process. However, to understand the overheating risk in buildings it is usually necessary to carry out an appropriately detailed building simulation, ideally using dynamic simulation software. The problem thus becomes about managing detailed simulation exercises, with detailed climate descriptions, and making this process suitably efficient for carrying out in the design stage of a building project without dramatically increasing the length of that procedure. With such an algorithm, the designer can then look at adaptation choices (be they technology-, design- or behaviour-related changes) to reduce the future risk of that building "failing", i.e. overheating.

The Low Carbon Futures project [4], as part of the Adaptation and Resilience to Climate Change (ARCC) programme [5], is investigating this area with an aim of providing a procedure that could be adopted by the building industry. This involves analysing the available climate data, carrying out appropriate building simulations for specific building types, and then providing a means of incorporating the results into a manageable format. The latter step will require input from building professionals to ensure that the project is describing something that has relevance to the building design sector – this requirement will be met by a series of focus groups within the project, gathering information about current practices and feedback around methods proposed by the project team.

* Corresponding author. Tel.: +44 0 1314514637.
E-mail address: D.P.Jenkins@hw.ac.uk (D.P. Jenkins).

0378-7788/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2011.03.016

To demonstrate the approach being adopted, this paper will describe the work carried out for a domestic building case-study. The project is also looking at other building variants, including school and office buildings, which may require mechanical systems or more advanced forms of natural ventilation.

2. UK climate projections '09

Future climate projections have previously been available in deterministic format, using morphing algorithms that can be applied to current climate file descriptions [6]. This project, and other projects within the ARCC programme, use the probabilistic climate projections provided by UKCP'09 [3]. Rather than providing, for example, single test reference years for a future climate, this format of climate projections allows a user to access a "Weather Generator", which can produce 10,000 climate files for a given scenario. From this a number (up to 100 at a time) of statistically equivalent 30-year time series projections can be downloaded which describe a specific future scenario (e.g. low-emission, 2020–2049) for a specific location (based on a grid map of the UK). The weather variables are generated at hourly scales and include: total hourly precipitation (mm), mean hourly temperature (°C), vapour pressure (hPA), relative humidity (%), sunshine fraction (of an hour), downward diffuse radiation and direct radiation (both W/m^2).

If downloading 100 time-series, then each run will produce 3000 (30 years × 100 files) equally probably representative climate years at an hourly resolution. The information that can be produced by the Weather Generator tool is therefore potentially vast and, in practice for any real building design project, will require some degree of simplification for use with building simulation software (such as ESP-r), while maintaining the essential features that are important for defining the hourly climate conditions. This is described in Section 4.1.

The timelines looked at for this study are 2020–2049, 2040–2069 and 2060–2089 (referred to as "2030s", "2050s" and "2080s" respectively). All three "low", "medium" and "high" emission scenarios are investigated, with these definitions referring to assumptions used within UKCP'09. With two locations used in the building modelling (Edinburgh and London), this provides a total of 20 climate scenarios, including a baseline "current" climate (from 1960 to 1990 data) in both locations.

3. Accounting for overheating in building simulations

As will be discussed in Section 6, the objective is to provide an algorithm that can cope with a wide range of overheating definitions. This is important as changing the building, or activity within the building, can change the definition of overheating that is most appropriate for that scenario. Also, overheating and thermal comfort definitions have a tendency to change over time, as the research community gains a greater understanding of the relationship between occupants and buildings [7].

Non-domestic buildings, without air-conditioning, are often stated as having summer operative indoor comfort temperatures of 25 °C [8]. The same level is used for living areas in dwellings, though bedroom summer comfort is reduced to 24 °C (mainly due to the effect of bedding). If the criterion of overheating is then looked at, the same reference suggests benchmarks of 28 °C for non-domestic buildings and then 26 °C for dwelling bedrooms, with the respective areas said to overheat if such temperatures are exceeded for 1% of the occupied hours. Air-conditioned spaces are then subject to different conditions, with the interaction between occupant and control of a mechanical system of vital importance. Taking this a step further, the concept of adaptive comfort [9] can be introduced into building simulation [10] in an attempt to replicate field studies of how occupants of buildings can alter their comfort temperature depending on, among other factors, external temperature.

Although this latter effect will not be considered in this study (as it is more applicable to non-domestic buildings in the UK), the concept of thermal comfort in a domestic building is still non-trivial. It is useful, at this point, to define the original objective of the project; namely, to investigate the periods for which the building might no longer be providing the level of comfort required such that the occupant will attempt to adapt in some way (if such options exist). "Adapt", in this sense, could simply be the opening of a window or, in more extreme cases, purchasing a domestic cooling unit. It has been suggested elsewhere [11] that the time when adaptation is most limited is at night when the occupant will be trying to sleep and would, by choice, not want to move to another room or outside to feel more comfortable. Therefore, an appropriate (though not the only) metric for overheating in a dwelling for this study might be the periods for which the night-time bedroom temperature exceeds a certain threshold. Quantifying this internal temperature threshold is also non-trivial as it is likely to vary with the perception of the occupant, level of clothing/bedding and other climate conditions (such as humidity). This paper will be using 23.9 °C as the threshold temperature beyond which the occupant might wish to adapt or change their circumstances [11,12]. The number of hours above 23.9 °C that the bedroom is modelled to experience will thus be compared across different scenarios, and compared to a current baseline.

This technique will clearly rely on the suitability of the building simulation software (in this case ESP-r [13]) to model such temperature profiles. While a model can never be a substitute for empirical data, the difference between modelled outputs for various scenarios can be useful for identifying the trends affecting, in this case, overheating in buildings and suitable adaptation options. It is, however, important to have software that can account for the thermal response of the building in suitable way, i.e. a dynamic rather than steady-state calculation.

This discussion suggests that any tool used to predict overheating needs to be versatile enough to accommodate many different definitions of overheating. Also the tool will incorporate the results, or in effect predict the results, of many simulations. To account for this, the regression analysis presented in Section 6 attempts to predict hourly temperature profiles and not only generic overheating metrics across seasons. It is assumed that if such a regression tool can suitably predict hourly temperatures then it should be suitable for predicting various definitions of overheating, based on those hourly temperatures.

4. Generating simulation output

4.1. Random sampling

As described in Section 2, the source of climate projections (i.e. the Weather Generator) provides 3000 equally probable representative climate years at an hourly scale for the desired period of 30 years of time. The first step in statistically processing this climate information is to use a random sampling algorithm to select a single year from each of the 100 time series of 30 year duration, to generate a representative sample of size 100 from the distribution of future climates. These 100 hourly climate data files, for each of the previously described 20 scenarios, provide the input for the building simulations. However, despite this reduction in the climate data input, this will still involve 2000 hourly simulations to represent the breadth of this data for a single building description. As this building then undergoes adaptation changes (requiring re-simulation), there is still a need to abbreviate the