Simple statistical model for complex probabilistic climate projections: Overheating risk and extreme events

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ABSTRACT

Climate change could substantially impact the performance of the buildings in providing thermal comfort to occupants. Recently launched UK climate projections (UKCP09), clearly indicate that all areas of the UK will get warmer in future with the possibility of more frequent and severe extreme events, such as heat waves. This study, as part of the Low Carbon Futures (LCF) Project, explores the consequent risk of overheating and the vulnerability of a building to extreme events. A simple statistical model proposed by the LCF project elsewhere has been employed to emulate the outputs of the dynamic building simulator (ESP-r) which cannot feasibly be used itself with thousands of available probabilistic climate database. Impact of climate change on the daily external and internal temperature profiles has been illustrated by means of 3D plots over the entire overheating period (May–October) and over 3000 equally probable future climates. Frequency of extreme heat events in changing climate and its impact on overheating issues for a virtual case study domestic house has been analyzed. Results are presented relative to a baseline climate (1961–1990) for three future timelines (2030s, 2050s, and 2080s) and three emission scenarios (Low, Medium, and High).

1. Introduction

Experiments based on an advanced scientific methodology and general circulation models (GCM), commonly known as global climate models, reveal that there is an exponential increase in the global concentration of greenhouse gases [1]. According to a UK Climate Projections (UKCP09) [2] briefing report, central England's temperature has already increased by 1 °C since the 1970s and this increase is most likely due to anthropogenic emission of greenhouse gases [3]. This excessive addition of the greenhouse gasses in the atmosphere is warming up the Earth's surface causing climate change and thus altering the weather pattern. Climate change could hasten species extinction, cause coastal flooding, and lead to more frequent and severe storms and extreme temperature events such as heat waves. Such extreme temperature events could cause catastrophic losses to both human and natural systems and thereby have dramatic ecological, economic and sociological impact [3–8].

For the UK, projections for future changes to climate are provided by the UK Climate Projections (UKCP09) and are available in probabilistic format to address the uncertainty associated with future climate change. To include a measure for the uncertainty, these climate projections are generated by multiple simulations of global climate models (in particular HadCM3 [9]) combined with a new methodology designed by the Met Office. The projections also include the results of other IPCC [1] climate models, and are constrained by observations of past climate. Thus to describe just any single future climate scenario a range (in fact thousands) of possible climates are available where each climate has a certain probability of occurring.

Extreme events, by definition, are in the tails of such probability distributions. Interestingly, events in the tail of the distribution are the ones that change most in frequency of occurrence as the distribution shifts due to global warming [10,11]. The work presented in this paper will focus on the potential impact of future climate changes on the frequency of the extreme temperature regimes (heat wave) and how this could influence the overheating issues in the UK's domestic house sectors.

The suite of probabilistic climates projection available from UKCP09 for a London location at three future timelines, namely 2030's, 2050s, and 2080s, including a baseline [1960–1990] has been carefully analyzed to quantify the future change in the frequency of extreme heat events. The impact of extreme heat

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events on indoor comfort temperatures of a domestic building case study has been assessed by means of a simple statistical model proposed by the Low Carbon Futures (LCF) project [12] elsewhere [13,14]. This simple statistical tool is mainly based on multiple regression techniques and could efficiently emulate the outputs of traditional dynamics building simulation software ESP-r [15], which cannot be practically used with thousands of potential climates available for each future scenario.

This project is sponsored by the Adaptation and Resilience in a Changing Climate (ARCC) Programme [16], looking at possible methods, i.e. adaptations, for coping with a future climate.

2. Methodology

To analyze complex probabilistic climate information and to generate corresponding indoor temperature profiles for a case study dwelling, an elegant regression tool has been developed by the LCF project which is described in detail elsewhere [14]. The simple regression tool which is based on data reduction methods such as Principal Component Analysis (PCA) and multiple regressions is validated at an hourly scale to provide a close match (within a range of 1 °C) for the outputs of dynamic building simulation software (ESP-r). More details on the development procedure of the regression tool are found elsewhere [13].

This section should present a brief description of probabilistic climatic information available from UKCP09, profiles of the domestic building case study simulated with ESP-r, and a short note on the regression tool which has been employed to emulate outputs of ESP-r for quantifying extreme heat events and its impact on overheating issues in the case study building. A short review on the possible definitions of the heat wave is also included.

2.1. Probabilistic climate projections and regression tool

The UKCP09 provides climate change information focused on the UK. The projections are presented for seven 30 years time periods ("2020s" denoting as 2010–2039, "2030s" denoting 2020–2049, …, up to "2080s" denoting 2070–2099), and at three different future greenhouse gas emissions scenarios represented as "High", "Medium" and "Low". These projections are based on change relative to a baseline time period (1961–1990) and, by means of a *Weather Generator* (WG) [17] tool, are available at an hourly temporal resolution with a 5×5 km^2 spatial resolution for any user defined UK location.

For the work presented in this article, climatic information has been downloaded from UKCP09's WG tool for a London location corresponding to all three greenhouse gas emissions scenarios and at three future time periods, namely 2030s, 2050s and 2080s, including baseline. Notably for any user specified future scenario, the WG tool could provide at least 3000 equally probable hourly climate files (each climate file represents a prototype climate year for that scenario) in the form of 100 statistically equivalent time series, where each of the time series is equally probable and of 30 years in length. For each of the future scenarios under investigation a representative sample of 100 climate years is formed by means of a random sampling algorithm, which selects one year randomly from each of the 100 time series.

To formulate the regression tool, a 3-bedroom cavity-wall house with a total floor area of 144 m^2 has been simulated with ESP-r for one randomly chosen climate file from the 100 available climate years (additional information on the virtual case study building can be found elsewhere [18]). The regression tool is based on the concept of underpinning the existing relationship between available climate variants and the indoor temperatures, where each climate variant first need to be carefully analyzed and simplified by

means of PCA. The model has been formulated to capture indoor temperature profiles during the period of May to October only. To allow time-based sensitivity analysis, the idea of segmented modeling has been applied and data fitted in parts, namely a) May–June; b) July–August; and c) September–October, to cover the entire period (May–October) [13].

A regression tool which could be formulated from the one climate file had been validated across all the available 100 climates files and corresponding to all different future scenarios as described above. Moreover, the proposed statistical regression tool has been demonstrated to efficiently estimate the outputs of ESP-r at an hourly scale within a single degree centigrade for up to 90% of the entire dataset [13,14]. Thus, it is reasonable to consider an application of the proposed simple and efficient regression tool for quantifying frequency of heat waves and analyzing overheating issues in that context.

2.2. Heat waves and overheating

Research conducted by Met Office clearly shows that even in the UK heat waves could be lethal, when hotter summers are predicted in foreseeable future [19]. There is no universal definition of a heat wave, however a heat wave could be considered as a prolonged period of excessively hot weather accompanied by high humidity, where temperatures are outside the normal climate pattern for that period [20]. For the UK, the Met Office defines summer heat wave duration as "the sum of days with daily maximum temperature more than 3 °C above 1961–90 daily normal for ≥ 5 consecutive days (May–October)" [21].

As stated previously, extreme events formulate tails of the probability distribution and therefore for the present study of heat waves and overheating analysis, it is essential to consider all 3000 climates corresponding to each available future scenario. An initial analysis of 3000 baseline climate files identified 15.6 °C as the daily normal temperature for 1961–1990. For each climate file daily normal temperature has been averaged over the overheating period and then again averaged over all equally probable 3000 climate years.

Thus, *summer heat wave duration* could be defined as – "*sum of days with daily maximum temperature more than 18.6 °C for 5 or more days during May–October*". In this context, to examine the impact of heat waves on indoor temperatures, two overheating criterion had been designed and compared with corresponding heat wave durations:

Overheating criterion 1 – "Sum of the days with average of night time (11pm – 7am) bedroom temperature more than 24 °C for 5 or more days during May–October".

Overheating criterion 2 – "Sum of the days with average of night time (11pm – 7am) bedroom temperature more than 28 °C for 5 or more days during May–October".

Notably, overheating criteria 1 and 2 are designed by the author and are mainly motivated from the Met Office definition of summer heat wave in order to compare the influence of external climates on the indoor comfort temperatures.

3. Result

Following the above definition of a heat wave and overheating criteria, some key results has been presented in this section for a London location.

3.1. External and internal temperatures

An analysis of external and internal temperatures are performed at an hourly scale and presented at daily scale corresponding to