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# Simple future weather files for estimating heating and cooling demand

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ABSTRACT

Estimations of the future energy consumption of buildings are becoming increasingly important as a basis for energy management, energy renovation, investment planning, and for determining the feasibility of technologies and designs. Future weather scenarios, where the outdoor climate is usually represented by future weather files, are needed for estimating the future energy consumption. In many cases, however, the practitioner's ability to conveniently provide an estimate of the future energy consumption is hindered by the lack of easily available future weather files. This is, in part, due to the difficulties associated with generating high temporal resolution (hourly) estimates of future changes in air temperature. To address this issue, we investigate if, in the absence of high-resolution data, a weather file constructed from a coarse (annual) estimate of future air temperature change can provide useful estimates of future energy demand of a building. Experimental results based on both the degree-day method and dynamic simulations suggest that this is indeed the case. Specifically, heating demand estimates were found to be within a few per cent of one another, while estimates of cooling demand were slightly more varied. This variation was primarily due to the very few hours of cooling that were required in the region examined. Errors were found to be most likely when the air temperatures were close to the heating or cooling balance points, where the energy demand was modest and even relatively large errors might thus result in only modest absolute errors in energy demand.

## 1. Introduction

Global warming is apparent and there is general consensus that even by dramatic reductions in the global anthropogenic emissions of greenhouse gasses, adaptation action will be necessary to address those impacts that are already unavoidable. While substantial reductions in $CO_2$ emissions can be achieved from optimized energy use in buildings, present and future constructions require to be taken into account the changing climate conditions, including increased risk and intensity of extreme events such as floods, strong winds and heat waves. Unsurprisingly, there is a strong interest in predicting the effects of the expected future climate warming on the built environment in terms of developing appropriate adaption and mitigation strategies [1–3]. In this context, there is a particular need from property owners and facilities managers for estimates of the future energy demand for heating and cooling [4].

The energy demand of buildings, both now and in the future, can be quantified in a variety of ways. Common methods utilize (i) Heating Degree Days (HDD) and Cooling Degree Days (CDD) from which fuel consumption is directly inferred [5–7], (ii) total energy consumption or heating and cooling demand [8,9], (iii) relative changes in energy demand [10,6], or (iv) $CO_2$ emissions, which are a function of energy consumption and supply source [10]. Other factors directly related to buildings' thermal performance can be quantified by metrics as suggested by de Wilde [11], i.e. (i) peak demand of a building [12] (ii) peak demand on the grid [13] (iii) and the overheating risk in different types of buildings [14–16]. In this article we consider the relative change of the energy demand using both a degree day method and a dynamic simulation tool.

To determine the annual energy demand of a building, we require a weather file that describes the typical weather

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conditions at the building's location, as well as information on the structure and usage of the building. A typical weather file is usually constructed from real, measured data, the details of which are discussed in Section 2.1. To determine the *future* annual energy of a building requires a future weather file, i.e. a projection of the weather at some time of interest in the future. Research in constructing future weather files has received significant interest recently, and this work is summarized in Section 2.2.

Despite the significant interest, there is evidence that future weather files are often not readily available in many regions. For example, Jentsch et al. note the lack of availability of approved climate change weather files for simulation programmes [15]. This is supported by Jones and Thornton who also comment that the lack of availability of weather data is a serious impediment to undertaking climatic modelling to assess the impact on agriculture [17].

The lack of available future weather files is, in part, due to the difficulty in acquiring future weather projections within a sufficiently localized region and at the hourly temporal resolution required by standard weather file formats. To produce such data typically requires downscaling global circulation models to regional levels, e.g. using regional climate models, followed by detailed analyses to assert the quality of the projections. This work requires expert knowledge of climatology and is typically conducted at dedicated research centres and national meteorological institutes. A wide range of global and regional climate projections provided by different climate modelling groups may be extracted from international multi-model inventories like the CMIP5 (Coupled Model Intercomparison Project) and CORDEX (Coordinated Regional Climate Downscaling Experiment) data centres, however, typically at coarse temporal (daily) and spatial resolutions (25–50 km).

In this study we investigated the implications of temporal resolution on future simulations of buildings' energy demand. To address this issue we used a simple "change-based" method for constructing future weather files, e.g., adding an estimated annual increase in air temperature to an existing weather file, and we then considered whether the results provide useful estimates of a building's future energy demand. We investigated how estimates of a building's energy demand differ based on different future weather files constructed using coarse (annual), medium (monthly) and fine (hourly) temporal resolution data of air temperature change. In this study we only considered a single parameter, outside dry bulb temperature, of a future weather file, i.e. other parameters such as humidity, solar irradiation, precipitation and wind speed were not considered. However, we note that the work of [18] suggested that "… with a +10% change in proposed future values for solar radiation, air humidity or wind characteristics, the corresponding change in the cooling load of the modelled sample building is predicted to be less than 6% for solar radiation, 4% for RH and 1.5% for wind speed, respectively". Similarly, as noted in Ref. [19] even though the thermal comfort of a building depends on many different weather parameters such as outdoor dry bulb temperature, relative humidity, wind speed and solar irradiation the most significant weather parameter that has the strongest correlation with the internal thermal comfort is the outside air temperature during warm periods. Also, Kershaw et al., who investigated internal temperatures and energy usage in buildings, pointed out that the external air temperature is a major driver of the internal temperature [16].

The emphasis of the present work was to investigate how well a future weather file was able to predict future energy demand, whereas broadly speaking, previous work has been concerned with how "realistically" a future weather file models the expected weather. Thus, our focus in this paper was on the application of future weather files rather than on climate modelling. Of course, we expect more "realistic" future weather files to provide accurate estimates of energy demand. However, as we previously discussed, the creation of these files can be difficult or at least impeded by the lack of available data. If simpler future weather files can produce very similar estimates of a building's energy demand, this will facilitate the modelling of future energy demand by practitioners.

In the following we first briefly review how historical weather files are created (Section 2.1) and categorize different methods to construct future weather files. Three common ways are discussed for constructing future weather files with annual, monthly and hourly temporal resolution (Section 2.2). In Section 2.3 we describe the commonly used methods to estimate the energy demand of a building, such as the degree-day method and dynamic building simulations. In Section 3 we investigated the sensitivity of a building's energy demand to three different methods of calculating a future weather file, where the calculations were based on the abovementioned coarse (annual), medium (monthly) and fine (hourly) estimates of future air temperature changes obtained from a regional climate model. We used the degree-day [20] analysis, which is independent of any specific building model, and the sensitivity is measured based on the change in the number of heating and cooling degree-days resulting from the analyses. For comparison we also investigated the sensitivity of three dynamic simulation models to the differently constructed future weather files. These three building models were (i) an existing naturally ventilated historical building, (ii) the same building renovated to have an air tight envelope, windows with improved thermal properties and naturally ventilated and (iii) the same building renovated as (ii), where the ventilation is provided by mechanical ventilation, and the heat-losses due to ventilation are recovered. Section 4 discusses the experimental results. Finally, Section 5 summarizes our findings and discusses some possible lines of future research.

## 2. Construction of weather files

This section outlines how current weather files are constructed based on historical observations of weather parameters as well as how future weather files are constructed and used to provide estimates of the energy demand of buildings.

### 2.1. Historical weather files

A weather file consists of a variety of parameters that vary with the type of weather file. The most common weather files are (i) the Example Weather Year (EWY) developed by Chartered Institution of Building Services Engineers (CIBSE) [21] and mostly used in UK. (ii) the Typical Meteorological Year (TMY) developed in 1978, which is mostly used in the USA, (iii) the International Weather Year for Energy Calculation (IWYEC) developed and used by ASHRAE in the USA and other global locations, (iv) the Test Reference Year (TRY) and Design Summer Year (DYS) developed by the CIBSE and used in Europe, and (v) the Design Reference Year (DRY) developed by Ref. [22] and used in Denmark and 20 other countries.

In this paper we used data from a Design Reference Year (DRY), which comprises 25 parameters. The DRY was chosen as the base line for our experiment mainly because of our knowledge of how the files were created as well as availability. Each parameter is assigned hourly values for a period of one year, i.e. the temporal resolution is hourly, and thus a DRY file contains 8760 values for each parameter. The construction of data in a DRY file is similar to

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