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Estimating the impact of climate change and local operational procedures on the energy use in several supermarkets throughout Great Britain

M.R. Braun [a,*], S.B.M. Beck [a], P. Walton [b], M. Mayfield [c]

[a] Department of Mechanical Engineering, University of Sheffield, UK
[b] Marks & Spencer, London W2 1AS, UK
[c] Department of Civil and Structural Engineering, University of Sheffield, UK

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ABSTRACT

Possible changes in gas and electricity consumption in supermarkets throughout Great Britain have been investigated for the 2030s in order to assist decision makers with choices relating to energy use. In addition to this, two operational procedures, which vary between supermarkets, were investigated to see if a link between them and differences in energy consumption could be established. To achieve these aims, seven similar supermarkets were identified and their data analysed to derive their energy signatures through simple and change point regression analysis. These models were then combined with data from climate change prediction project UKCP09 for different probabilities (10%, 50% and 90%) of temperature increase in order to calculate changes in future energy use. In addition it was investigated if a linear regression model between the selected operational procedures and electricity use could be established.

The results showed that, compared with the base period 1961–1990, the mean values of the annual average temperature for these seven supermarkets was predicted to rise by 2.0 °C or 20% for the central estimate. This led to an estimate of an increase in average electricity consumption of 2% and an average drop in the gas usage of 10%. The result also showed that differences in operational practices seem to have little impact on the in-store energy use. Differences in gas use models between stores can be more credibly explained by the building volume.

1. Introduction

The main purpose of a supermarket is the sale of goods and services from suppliers to end users for their personal use [1]. While engaging in this activity a supermarket interacts with other organisations, the natural environment and the community it is located in. One example of this interaction is the use of energy supplied by utility companies; the UK sector that supermarkets belong to accounting for approximately 3% of total electricity use [2]. Through this energy usage and other emissions, supermarkets have an impact on the environment, e.g., the emission of greenhouse gases (GHG). Tassou et al. [2] reported that UK supermarkets and similar organisations are responsible for 1% of the total UK GHG emissions. The bilateral interaction with the community not only includes employing people, but also their staff influencing how the supermarket is operated, thus having an impact on its energy consumption.

In addition to the atmospheric interaction described in the previous paragraph, there is also a possible feedback loop through the changing climate affecting supermarkets. Therefore this paper investigates how climate change may alter the energy use in this type of building, especially as supermarkets are considered buildings with a high energy use intensity (EUI) [2]. As this research covers a number of supermarkets the possible effect of differences in operational procedures is also considered.

The literature review section of this paper establishes that, although the effect of climate change on energy use in different building types has been investigated for different locations in the UK and around the world, no such investigation has been performed for supermarkets located in the climatic regions in Great Britain. Therefore this paper remedies this situation by using the seven research steps described in Section 3. These steps cover the identification of seven similar grocery supermarkets throughout Great Britain and follow on with a description of how the energy consumption and temperature data were prepared to arrive at statistical models for future gas and electricity use prediction. This section also comments on the examined operational procedures.

* Corresponding author.
E-mail address: dtp11mrb@sheffield.ac.uk (M.R. Braun).

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The next section showing the results of the model development and application explains that for four out of the seven identified supermarkets electricity consumption could be model as change point models, whereas for gas data only linear regression models were required. These models were then used together with data from the climate change predation project UKCP09 to estimate future gas and electricity use. Section 5 shows that the spread of predictions for various locations in Great Britain was comparable to that of other types of building. The final section summarises the overall conclusions for the two research questions regarding dependency of energy use on climate change and local operational procedures.

2. Literature review

Probably one of the earliest works which described an investigation into the effects of climate change on energy use in buildings is the report to the US Congress by Loveland and Brown in 1989 [3] in which they detailed their research into five building types located in six US cities. They used computer programme based one hourly transient thermal network simulations and a climate change scenario for which the atmospheric CO_2 had doubled. The researchers found that, regardless of whether the building was internal load dominated or skin load dominated, the cooling demands would rise greatly. Although the authors reported a drop in heating loads, they concluded that this would not compensate for the increase in cooling, so an overall increase in energy use could be expected. That this interest has been sustained can be seen by a paper by Wang and Chen [4] from 2014 in which the authors essentially updated the research introduced in [3]. These researchers simulated nine types of building with EnergyPlus, a building simulation software package based on the heat balance approach [5], for fifteen cities located in all seven US climate zones. Their research, which used morphed weather data based on the atmospheric-ocean general circulation model HadCM3, showed that the magnitude of the impact would be more dependent on the building type than on location. Regarding spatial dependency the authors reported that for the warmer climate zones the energy use would increase, whereas for the colder zones the energy demand would drop. Another example of this continued interest is the review of a significant number of climate change impact studies by Li et al. [6]. Their paper reported that the degree day method and building simulation approach were the most popular study methods and that whether the reduction in heating demand would outweigh the increase in required cooling depended on the climate under consideration.

Although all of the works referred to above reported on a number of building types, none of them included supermarkets. This seems to be the general situation with climate change impact assessments on building energy use. However, Tassou et al. [2] reported that the UK sector that supermarkets belonged to accounted for approximately 3% of total electricity use and 1% of total GHG emissions. These statistics show that the question of how changing climate may alter the energy consumption in supermarkets deserves attention, especially because they can be classed as high energy intensity buildings due to their peculiar refrigeration systems and lighting requirements [2].

An exception to the situation described in the previous paragraph is the work by Braun et al. [7] in which the researchers investigated the impact of the changing climate on the gas and electricity requirements of a single UK supermarket by means of multiple regression models. The expected energy consumption for the 2040s was based on the climate change prediction UKCP09 [8] and reported a significantly larger drop in heating demand than increase in cooling load. However, work on an office building involving five cities throughout Great Britain [9] and residential dwellings in four cities in the UK [10] suggests that the change in energy use may well be location dependent and therefore studying only one supermarket may have been insufficient to draw conclusions for the whole of the UK.

To remedy the deficiency shown above this study primarily aims at exploring the change in supermarket energy use owing to climate change at various locations in the UK. As it has been shown that occupant behaviour should be included in building energy models [11], this work also investigates if a statistically significant relationship between two operational procedures, which may vary between supermarkets, and energy use can be established. To do this, it is more advantageous to analyse actual buildings rather than use software building models as the human factor is implicitly included. To be relevant to decision makers in supermarkets, the time horizon is relatively short (the 2030s).

3. Study method

Potential modelling methods which may be employed to achieve the aims of this research are highlighted in, e.g., [6] and can be divided into data-driven and deterministic tools [12,13]. The most popular approaches according to [6], the degree day method and using building simulation software, were deemed unsuitable for this research. The main reason for rejecting building simulation software packages based on the heat balance equation was that they are unsuitable for large volumes [14]. In addition, it was judged that the calibration effort was considerable [15] without using the software package's main strength namely evaluating of different design options (for instance, Leach et al. [16] evaluated 78,000 software models with different design options in their case study). CFD based software tools are capable of solving the equations for fluid flow thus providing estimates of the spatial distribution of airflow, pressure, temperature etc. more accurately. This being the case, they have been used for building simulations to compare, for example, the thermal comfort provided by diverse HVAC. However, CFD tools by themselves are unable to calculate the energy consumption of buildings as they are unable to calculate the heat transfer through opaque structures [17]. The other popular deterministic tool mentioned in [6], the degree day method, was also considered inappropriate as these make use of what is called the balance point temperature, which is the outside temperature at which the inside heat gain and the thermal losses cancel each other out for a specific set-point temperature and therefore for this temperature no heating is required [12]. However, the supermarkets investigated here require heating all year round because of the cold aisle phenomenon [18] and therefore no balance point temperature could be established.

In contrast with deterministic tools, data driven methods employ input and output data to generate an energy signature model relating these two [19,20]. For a pilot study multiple linear regression analysis was used [7], but the correlation between the predictors was a cause for concern [21]. During this case study, it was noted that the coefficient of determination for a simple linear regression model for the gas data was reasonably high. However, the electricity data showed non-linear behaviour with a section relatively independent of temperature. This type of electricity usage pattern had been successfully modelled by change point regression models [22,23]. In order to develop time efficient yet useful models it was decided to utilise a simple regression model where possible and a change point regression model where necessary.

As shown in Fig. 1 the study method ultimately chosen was divided into seven steps of which the first two were concerned with the selection of comparable supermarkets. When this search began the sponsoring company reported a chain of 766 stores in the UK (of which 243 were franchised) [24] and divided them into different categories. The store format which had the highest