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Using regression analysis to predict the future energy consumption of a supermarket in the UK

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HIGHLIGHTS

- Energy consumption of supermarket depends more on temperature than humidity.
- Multiple regression analysis is a flexible tool to consider for energy use prediction.
- Results show dramatic reduction in gas use and modest increase in electricity use.

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ABSTRACT

The change in climate has led to an interest in how this will affect the energy consumption in buildings. Most of the work in the literature relates to offices and homes. However, this paper investigates a supermarket in northern England by means of a multiple regression analysis based on gas and electricity data for 2012.

The equations obtained in this analysis use the humidity ratio derived from the dry-bulb temperature and the relative humidity in conjunction with the actual dry-bulb temperature. These equations are used to estimate the consumption for the base year period (1961–1990) and for the predicted climate period 2030–2059.

The findings indicate that electricity use will increase by 2.1% whereas gas consumption will drop by about 13% for the central future estimate. The research further suggests that the year 2012 is comparable in temperature to the future climate, but the relative humidity is lower. Further research should include adaptation/mitigation measures and an evaluation of their usefulness.

1. Introduction

With the founding of the IPCC in 1988 [1] the idea of anthropogenic climate change really entered the scientific arena so that, currently, the vast majority of researchers working in this area believe that the climate is changing and that this is fundamentally man-made [2]. That the issue of global warming has also reached politics is evident by the coming into force of the UN framework convention on climate change [3] in 1994 [4]. All of this has added to the interest in assessing the impact of climate change on various aspects of society, including on energy consumption in buildings.

Some of those assessments examine specific countries such as the UK. Jenkins et al. [5], for example, use a software model of a four-story office building to investigate five locations in the UK to see how the change in climate will affect the energy demand for heating and cooling in 2030. These researchers find that the energy demand, although in part location dependent, is primarily heating dominated. Their study also includes the assumption that office equipment and lighting will be more efficient (so producing less waste heat) in the future which will increase the demand for heating. However, they conclude that the temperature increase due to climate change will mitigate this to a degree. Gupta and Gregg [6] evaluate the effect of climate change on four types of dwelling located in Oxford, UK, by means of the simulation software IES. They find that thermal discomfort will rise significantly with climate change, especially in flats.

A number of other studies are summarized by Li et al. [7] who point out the two main approaches: the degree-day method and simulation techniques. Most of the papers in that review study office buildings and homes. The authors find that the predicted warming will result in a reduced heating load and an increased cooling load. This translates into a reduction in energy use for

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colder climates and an increase in electricity consumption for warmer climates.

In addition to the degree-day method and simulation, other approaches have been used. One example is the paper by Schrock and Claridge [8] in which the authors use a simple regression model of the ambient temperature to investigate a supermarket's electricity use. The use of multiple linear regression analysis allows the inclusion of any desired variable. This technique is used by Lam et al. [9] who study office buildings in different climates in China. These researchers include 12 input variables covering building parameters, building loads and the HVAC system in their regression model and find that predictions largely agree with building software simulation. Another example is Chung et al. [10] who investigate the energy use intensity of supermarkets by means of such diverse variables as operational schedule, number of customers, lighting control, employee behaviour and maintenance factors, but explicitly exclude outdoor climate. Braun et al. [11] employ multiple regression analysis to investigate timer settings, night cover effectiveness together with indoor and outdoor temperature and humidity on the electricity consumption of a supermarket. The more complex principal component analysis is used by Lam et al. in [12] for office buildings. This technique allows the same flexibility as multiple regression analysis, but is not restricted by its underlying assumptions (for more details see 2.3 Multiple linear regression analysis).

Owing to their refrigerated shelves, supermarkets are quite different from other commercial buildings. Consequently, there are a number of documents published relating to modelling their energy consumption. One example is Suzuki et al. [13] who model the refrigeration system and energy flow of heat sources of a supermarket in Japan for one-hour increments. The authors find that the refrigeration equipment accounts for about 60% of the total energy demand and that the air leakage of the open refrigerated shelves has a considerable effect on this demand. The paper by Arias and Lundqvist [14] presents their software *CyperMart* which focuses on different refrigeration systems. Although the software uses also climate data as inputs, the intended users are not those researching climate change impact, but designers and technicians. The work of Bahman et al. [15] uses a moisture balance equation and the humidity ratio w to infer the indoor relative humidity in a supermarket. This, in turn, is used to simulate the energy use. Their results suggest that the indoor relative humidity is strongly correlated with the total energy consumption, i.e. the lower the indoor humidity, the lower the total energy use.

There are two documents which relate to the carbon footprint of supermarkets in the UK. The first is a report by ENDS Carbons [16], which looks at supermarkets as a whole, from direct to indirect CO_2 emissions. However, it does not quantify the impact of climate change on supermarkets. The second document is a paper by Jenkins [17] in which the author uses a software model to evaluate different carbon-saving measures of a "standard UK supermarket". This research does not explicitly model the refrigeration systems which may have the effect of insufficiently capturing the main difference between supermarkets and other retail buildings.

The review above suggests that there will be an impact of the changing climate on the energy consumption of supermarkets and that relative humidity is likely a parameter which needs including in addition to outside temperature (see for instance [15,18]). Although some researchers examined supermarkets' CO_2 emissions, none have reported on the impact of future climate on their energy use. Therefore this paper focuses on predicting the change in energy consumption of a grocery supermarket for the 2040s by using the outside temperature and relative humidity data to perform a multiple regression analysis. The 2040s (rather than the end of the century) were chosen because (a) the lifespan of a refrigeration system is typically 15–20 years and (b) this research is aimed to be relevant to present day strategic decision makers in designing and operating current and prospective supermarket buildings and systems, and whose own lifetime might very well include the 2040s.

2. Study method

The supermarket studied and the methodology of the analysis and modelling is detailed in this section. As Fig. 1 indicates, this assessment is based on the actual consumption data, dry-bulb temperature and relative humidity records for 2012. This data was divided into two data sets to be used in a multiple linear regression analysis to generate two equations, one for electricity and one for gas. Thereafter these equations were used to estimate the consumption for the base period (1961–1990) which then was compared with the estimated consumption for the future period (2030–2059, also called the '2040s').

The study method used here may have certain limitations because it does not consider any other weather parameters, such as solar radiation or wind, or any future technical advances and building improvements. Furthermore it assumes that any change in footfall is negligible. Notwithstanding that, this method yields meaningful results in an easily realisable way.

2.1. Supermarket

The supermarket (see Fig. 2), which opened in July 2010, is located in the UK Yorkshire and Humber region, close to the city of Hull. It is at the larger end of the mid-range store size with a sales area of 1266 m^2 (see also Table 1) and an electric energy use density for 2012 of about 460 kW h/m^2 pa which, according to Tassou et al. [19], is about half the expected value. The supermarket sells mainly food and some general merchandise. In addition, it also has a café/restaurant and a small bakery.

The main energy consumers are the 240 kW condensing gas boiler (which serves the cold aisle heating, the general heating and the hot water system) and the two remote refrigeration R404/CO_2 plants of nominally 80 kW and 60 kW cooling capacity. These two plants are responsible for refrigerating about one third of all the shelves on the sales floor and the cold room. The three freezer cabinets in the sales area are self-contained and the freezer room is connected to two small freezer units outside.

The breakdown of electricity use in Fig. 3 is based on the consumption data from sub-meters for the first half of 2012 and is typical for supermarkets [20,21]. This figure shows that about half of the electricity consumption is made up of essentially weather independent loads such as lights (lights are also fitted to the refrigerated shelves). The consumption of the other half, i.e. HVAC and refrigeration packs, is more directly related to the weather.

2.2. Weather and consumption data

The datasets for the regression analysis are based on consumption and weather data for the whole year 2012. The temperature and relative humidity was downloaded in 15-min increments from a sensor situated on the north side of the supermarket. The gas and electricity consumption for the whole supermarket was readily available from the company's energy website. This data was downloaded in hourly readings and then summed for each week.

The temperature and humidity data for the base year was downloaded from the MET office website [22]. These values are monthly, long term averages for the period of 1961 to 1990 for the 25 km square containing Hull. The same two weather variables were also obtained for the same square from the UKCP09 website [23] by downloading monthly predictions for the high emissions