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Effects of building energy optimisation on the predictive accuracy of external temperature in forecasting models

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ABSTRACT

The practice of using external temperature as a predictor of energy consumption in commercial buildings is well understood and it has been shown that this predictor is the most important when compared to other weather-based factors. In the literature, where a study has shown the external temperature not to be sufficiently accurate in forecasting energy usage by statistical methods, more predictors can be added to derive a more accurate forecasting model. The influence of the operating efficiency of the building on this accuracy has not been properly explained. This may be because of a lack of internal performance data for the building under review.

This study has been developed to examine the effects of building operating efficiency on the forecasting accuracy of a statistical model by isolating external temperature as the sole predictor. The mechanism used to demonstrate the effects of the building's operating efficiency on the merit of using solely external temperature as a predictor is linear regression between external temperature and energy usage data.

The study was carried out on two buildings of differing scale, occupational use and construction techniques. Using revised operational schemes involving more carefully controlled energy consumption and by monitoring local external temperatures, the relative accuracy of the various regression models is seen to be enhanced significantly following the efficiency programmes. The study has also facilitated an examination of the relative contributions to forecasting model accuracy resulting from energy efficiency actions taken in both buildings compared to the use of various external temperature indices.

1. Introduction

It has been reported that in Europe and the US, approximately 20% of total energy usage is consumed in the commercial building sector and 50% of this is used by heating, ventilation and air-conditioning (HVAC) plant [1,2]. This would imply that 10% of all energy consumed on these two continents is used solely in the provision of occupant comfort in commercial buildings. Estimates indicate that the trend of rising energy use in the commercial building sector is predominantly due to the expansion of HVAC systems in new buildings [3]. Evidence also suggests that HVAC is the predominant source of peak load, particularly in warm climates [4]. There exists a growing imperative to reduce this energy demand, if possible.

As part of this effort to help understand and reduce energy usage in buildings, substantial research work has continued into various forms of energy forecasting models. Building energy forecasting and simulation have been separately developed and have their origins in very different research areas. The forecasting of building energy usage has relied primarily on statistical methods to learn or ‘be trained’ on past usage data while the simulation procedures rely on the thermal transfer characteristics of the building's internal and external envelopes. These models are generally broken down into a number of categories, including, engineering, statistical and neural networks [5–7]. Katipamula et al. [8] explain that regression analysis of energy usage in buildings was becoming popular given the complexity and time-consuming nature of simulation. In response to the complexity of simulation, simplified temperature range frequency or bin methods and degree-day methods have also been proposed, with some good results for certain building types [9].

The statistical methods usually involve data analysis of past energy usage coupled with some influencing parameters such as weather and/or internal space or plant temperatures. In some of the seminal research in the area of building energy forecasting, external temperature has been shown to be the most influential of

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these parameters [10–13], and the particular window of external temperatures used to form the average daily external temperature has also been shown to be important [14]. Occupancy has also been used to increase the model's accuracy [15]. Auto-regressive time series models such as ARIMA [16] and Fourier series [17] have also been successfully applied to predicting heating and cooling energy usage.

ASHRAE has provided a useful summary of the forecasting methods and their dependent variables [18]. In all cases, the external temperature is used as the main predictor. It is important to understand why this main predictor may or may not add significantly to the model accuracy. For any given building under examination, researchers may find a relationship between heating and/or cooling energy usage and external temperature which can result in highly variable levels of forecasting accuracy. Several statistical methods have been used by numerous researchers presenting results showing varying levels of correlation between building energy consumption and the external temperature but little, if any, discussion has been presented as to why this should be the case for that particular building with that particular energy data. Lazos et al. [19] have presented a useful summary of this work. Whether the HVAC plant operating within the building in question is delivering occupant comfort in an efficient manner is a complex question but it should be considered if the predictive strength of these correlations between energy usage and weather parameters can be better explained. This is a particularly important point when considering the analysis methods available to non-technical operations or facilities management personnel. It would help overall plant efficiency and energy reduction in the existing building stock, if simple, yet effective methods are developed to facilitate non-technical personnel in energy usage and building efficiency analysis.

In this study, with selected buildings, the changing predictive relationship between external temperature and energy usage is explored before and after energy efficiency programmes are carried out. As far as it is possible to tell from the existing literature, this type of study has not been carried out before. It is of interest to show how the level of operational efficiency of the interaction between plant and envelope in a particular building can have a significant effect on the accuracy of an energy forecasting model. Given the HVAC plant within any building is designed to provide suitable levels of occupant comfort temperatures [18,20], the question has been posed as to whether the operating efficiency of this plant directly affects the accuracy with which external temperature can be used to forecast energy usage in a statistical model.

ASHRAE [18] has produced a comprehensive summary of the various building energy forecasting methods and within that summary, simple linear regression (SLR) energy prediction models which are solely dependent on external temperature are classified as very fast to implement, useful for energy savings calculations and with low accuracy results. While it is difficult to argue with this ASHRAE classification, this study seeks to explore if HVAC plant operational efficiency may be one reason why these SLR forecasting models should be considered of low accuracy. While external temperature may not be considered accurate as the sole predictor, it is included in almost every type of building energy forecasting model described in the literature and international guidance documents. The objective of this study is to provide some insight for future building energy forecasting studies by showing that operational HVAC efficiency should be considered when formulating an energy prediction model.

1.1. Study objectives

The study has focussed on the operation of HVAC plant in delivering suitable occupant comfort space temperatures and sufficient fresh air in two modern Western European buildings constructed within the past 15 years. The study has specifically excluded changes to occupant behaviour and analysis of other energy uses in commercial buildings such as lighting, small power, office equipment and refrigeration. The effects of solar gain have also been excluded, but future studies will include this important parameter. When analysing energy usage in these buildings, it is of interest to determine the effects of the implementation of energy efficiency programmes on the predictive accuracy of external temperature. For this reason, SLR has been used to isolate the effects of external temperature alone.

The aims of the study are as follows:

- Determine the forecasting accuracy of SLR models of HVAC plant energy usage when the buildings were first examined prior to any efficiency measures being implemented
- Apply unique energy efficiency programmes to the pilot and test buildings, describe the major changes made to the operation of both sets of plant and present the cumulative effects of the efficiency programme on overall HVAC energy usage
- Compare the pre- and post-efficiency programme energy usage figures, drawing conclusions relating the changes in the amount of variance in the SLR relationship to the increasing efficiency of HVAC comfort temperature delivery
- Confirm the relative importance of the availability of locally recorded external temperature in these SLR analyses

2. Methodology

This study is focussed on HVAC use within two commercial buildings chosen for the study, one pilot (P1) and one test building (T1), the latter to test the robustness of the conclusions from the pilot building. Both buildings have a building management system (BMS) installed which controls the plant delivering occupant comfort throughout the year. As this study is different in its' objectives and purpose insofar as the predictor is being examined rather than the outcome of the modelling, it is difficult to directly compare the methodology used in this study with those going before.

The methodology used in the study has been kept as simple as possible and can be summarised as follows:

- Gather the relevant energy usage data from each building prior to any efficiency intervention, over the full heating (P1) and cooling season (P1 and T1) and the external temperature data over the same period (both local and weather service, if possible)
- Examine the SLR models of energy usage with external temperature as the sole regressor with accompanying statistical measures of the Coefficient of Determination (R-Sq), root mean square error (RMSE) and the coefficient of variation of RMSE (CV (RMSE))
- Devise and implement energy efficiency programmes in each building with the specific objective of increasing the efficiency of how the HVAC plant delivers appropriate comfort levels
- Repeat the creation of SLR models for energy usage data following the completion of the efficiency programme
- Compare the before and after SLR models in terms of forecasting accuracy with the aforementioned statistical measures
- With external temperature interval data sourced locally from the buildings and from the national weather service, confirm the relative contributions of the efficiency programmes and the various temperature indices