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Development of hybrid numerical and statistical short term horizon weather prediction models for building energy management optimisation

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ABSTRACT

Modern building system optimisation frameworks are able to utilise forecasts of generation and load to achieve financial and energy savings. To that end, weather variable predictions of various horizons are particularly useful, as major components of the energy system depend directly or indirectly on prevalent weather conditions. Instead of obtaining weather prediction inputs from an external entity, such as a meteorological office this work proposes the use of a hybrid model that is able to generate localised predictions for ambient temperature, relative humidity and wind speed. A weighted regression and an autoregressive process were implemented in order to develop two hybrid models. The models produce forecasts in a horizon of six hours ahead, with an hourly temporal resolution and are based on two components. The persistence component assumes stationarity of the conditions in the atmosphere, while the numerical component downscales synoptic scale weather observations to a localised region. In this study the persistence will be used as both the reference model to determine the skill of the numerical and the hybrid models, as well as an input component with decreasing weighting for the hybrid models. The hybrid models show notable improvements in skill over both individual components up to 38% for temperature, 28% for relative humidity and 9% for wind speed respectively. More frequent update of reference component inputs, improved the accuracy of the hybrid models even further. Specifically, when the update intervals of the reference component occurred twice as often, the predictions improved by up to 50% compared to the original models. Furthermore, the hybrid models were adjusted to develop forecasts useful for building energy system management, such as the occurrence of a sudden change or a peak temperature. This novel approach is relatively simple to implement and unlike previous works, focuses on high spatial resolution regions and metrics tailored to the optimisation framework of energy management of buildings.

1. Introduction

The energy management of commercial buildings is often associated with the prediction of the load and, where available, onsite generation from renewable sources. Accurate forecasting information may assist in minimising the energy costs and adding value to the generated energy, especially during peak load periods. In previous work [1], it was concluded that the accuracy of such forecasts can be increased when using weather variable inputs. This is due to the fact that a primary source of unpredictability is the Heating Ventilation and Air Conditioning (HVAC) load and its peaks, which vary according to the evolution of weather conditions [2–4]. Specifically, in studies where optimisation and control frameworks utilised weather inputs, savings in energy costs of up to 30% were reported compared to a deterministic approach without weather inputs.

An extended review of weather forecasting techniques was conducted in previous work [1]. The importance of accuracy was highlighted in the review paper, as errors in weather predictions tend to pass on - often magnified – to higher tier modules responsible for predictions and control of load and demand response measures. Typically, building control systems are receiving predictions from external entities, such as weather

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stations, however it was found that studies with onsite weather forecasts reported improvements in accuracy. The reason for this, is that often the stations are not in close proximity to the building and thus there are differences in the magnitude and temporal evolution of the weather variables [8]. In addition to being able to capture the microclimate of the building site, onsite generated forecasts were found to have advantages, such as ability to integrate directly in a broader control system and generation of tailored outputs. Hence, it was concluded that there is potential value in developing localised weather predictions.

Short-term horizons of up to few hours ahead are regarded as the most valuable by the literature, as they are associated with peak load prediction and scheduling of energy flows [5–7]. However, day ahead horizons are also valuable especially for buildings with the ability to utilise their thermal mass to control the discharge of energy. Numerical weather predictions based on atmosphere dynamics equations have been proposed as appropriate high accuracy models for such horizons [1,5,9–12]. However, there are limitations to these techniques, since they may be resource intensive and time consuming to run.

Based on the findings discussed in the review paper [1] and summarised above, there is potential for adding value to the energy management systems of commercial buildings via a lightweight localised weather prediction model. The work in this study attempts to add value to the energy management of a building by developing a variety of useful weather forecasts, specifically predictions of air temperature, relative humidity and wind speed of up to 6 h ahead. The advantage of 6 hourly intervals is that the use of recent weather observations can be used to improve overall accuracy. Furthermore, it is a horizon that has been used in existing control strategies as it allows for both a reasonable time frame to develop optimal energy management plans, and a margin for adjustments if needed [13,14]. Air temperature and relative humidity directly affect the heat exchange between the building and the environment as well as the HVAC load. Temperature and wind speed also affect the capacity to generate energy onsite from distributed generation systems, where available. Finally, wind speed may affect ventilation effectiveness depending on the building design.

The aim of this paper is the development of a hybrid numerical and statistical regression prediction model, which may operate as a part of a broader control and optimisation framework of building energy management. The justification of such a hybridisation is to combine the advantages of individual numerical and regression prediction models. Specifically, numerical models perform better in instances of strong gradients, while regression models enable the utilisation of existing patterns in weather.

The hybridisation was based on the outputs of two base components: a reference component which is obtained from onsite observations and assumes that the state of the atmosphere remains unchanged during the next hours and a numerical prediction component, which is able to downscale synoptic data to generate localised forecasts. The model requires onsite weather observations for the statistical post processing, however since many buildings do not have access to weather monitoring it could run with inputs from external entities. This is considered as a significant benefit as the numerical prediction component can generate simulations from synoptic scale data at any location and hence provide the basis for the final outputs.

Two approaches were then followed for the development of the hybrid model: a weighted regression and an autoregressive model with external outputs. Furthermore, the effects of updating the reference component inputs more frequently were investigated. All versions of the base and hybrid models were assessed in terms of their accuracy, requirements and limitations.

The paper begins with a review of relevant recent studies in order to contextualise the proposed algorithms. The details of the development and parameterisation of the hybrid models, as well as their constituent base models is described in section 3. Section 3 also describes the acquisition process and characteristics of data used in this study. The following part (section 4) includes a range of results and useful findings from the simulations, which are discussed and evaluated extensively in section 4. Additionally, there is a discussion of the limitations and next steps in the context of the development of a complete prediction and optimisation model.

2. Background

A considerably large part of control systems responsible for the energy management of buildings is based on analysing outputs from physical models. These models are able to account for a range of factors, such as the building structural composition, the building geometry, and the interactions with its surroundings. While the amount of inputs, architecture and layers used to model the building and its zones vary, variables such as the temperature and relative humidity are vital to ensure efficient management of the load and occupancy comfort. Model predictive control (MPC) systems are control frameworks that typically incorporate weather variables to locate optimal solutions of an objective function, considering boundaries for occupant comfort, energy tariffs and the structure/geometry of the zones in short term horizons [15,16].

Accurate information about the evolution of the weather is involved in:

- Adjusting the dynamic optimisation of HVAC set points according to the weather conditions and building zone dynamics [16–20]. Most of these methods attempt to operate the HVAC system at the point of maximum efficiency (lowest energy costs) for a certain horizon and within well-defined boundaries of thermal comfort.
- Predictions of building load, as besides occupancy patterns the ambient temperature and relative humidity greatly affect the HVAC load (which in turn is a major component of commercial building load) [19,21–25]. Of particular interest in most of these studies are the predictions of peaks in building load, which are often associated with high energy costs.
- Predictions of onsite energy generation (where available): solar generation is directly affected by incident radiation and is negatively affected by higher temperatures and cloud formation [26–33]. Furthermore committing on site cogeneration or trigeneration sources may be optimised with predictions of building load on a day ahead horizon [34–36].
- Enabling preconditioning (night-control) processes to shave mid-day peaks by shifting some of the load to low tariff off-peak times [37–41]. Preconditioning of a building is based on the principle of using the building's thermal mass to shift some of the load from the middle of the day to the night before and hence achieve peak and energy cost reductions (assuming that the temperature difference is sufficiently high between day and night).
- Enabling various demand response measures: MPC systems are able to respond to hourly energy prices more efficiently with accurate weather inputs [34,42–45].

Savings in terms of reduced energy consumption and costs compared to a business as usual scenario with a rule based control system, can be realised in a range of ways from the above processes (often in parallel). More details about the design, application and performance of such models utilising weather information can be found in previous work [1]. The cost and energy savings results vary