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Load forecasting of supermarket refrigeration

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HIGHLIGHTS

- Novel study of models for short-term supermarket refrigeration load forecasting.
- Data from supermarket in village in Denmark and weather forecasts are used.
- Non-linear dependencies and operation in different regimes are found.
- Time adaptive non-linear regime shifting models are applied.
- White noise residual are obtained for short horizons validating the models.

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ABSTRACT

This paper presents a novel study of models for forecasting the electrical load for supermarket refrigeration. The data used for building the models consists of load measurements, local climate measurements and weather forecasts. The load measurements are from a supermarket located in a village in Denmark. Every hour the hourly electrical load for refrigeration is forecasted for the following 42 h. The forecast models are adaptive linear time series models. The model has two regimes; one for opening hours and one for closing hours, this is modeled by a regime switching model and two different methods for predicting the regimes are tested. The dynamic relation between the weather and the load is modeled by simple transfer functions and the non-linearities are described using spline functions. The results are thoroughly evaluated and it is shown that the spline functions are suitable for handling the non-linear relations and that after applying an auto-regressive noise model the one-step ahead residuals do not contain further significant information.

1. Introduction

Nowadays there is an increased focus on the studies concerning the integration of renewable energy sources into existing energy systems. In 2020 the national goal is that 50% of the electrical energy consumption in Denmark should be covered by wind energy and hence the development of a Smart Grid is of high priority in Denmark. This development is going to ensure an optimal coherence between the fluctuating energy production from renewables and the energy consumption. The study presented in this paper is carried out as part of iPower, which is a Danish collaboration platform including 32 partners, universities and research institutions as well as industrial companies from various countries. The idea of iPower is to develop an intelligent and flexible energy system, a Smart Grid, that can handle a fluctuating power generation, by enabling increased flexibility in the power load such that it better can follow the generation of wind power and thus decreases the need for grid and reserve capacity investments. The ability for the power consumers to contribute with flexibility is a key issue and one of the challenges is to create application-configurable control schemes for the industrial consumption side. An industrial consumer, that could provide flexibility is the Danish supermarkets, they are using a large amount of electricity on lightning, cashiers, refrigerators and coolers, etc. In many of the proposed Smart Grid setups in the literature load forecasting is an important part of the control schemes [1]. In a particular setup with a thermal storage unit, here an ice-storage for energy buffering, load

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forecasting is essential as basis for optimization. Furthermore, the models can potentially be applied for fault-detection and performance monitoring of refrigeration systems.

Many approaches to load forecasting are found in literature, however no studies were found which specifically consider forecasting of load for refrigeration in the resolution of the present case. Braun et al. [2] builds a multiple-linear regression model based on weekly average values and find non-linearities in the load dependency of ambient temperature. For load forecasting of at hourly resolution different kinds of data-driven modeling methods are typically used from parametric models, such as ARIMA and ARMAX models, and over to fully non-parametric methods, such as kernel based methods, Support Vector Machines (SVM) and Artificial Neural Networks (ANN). An adaptive ARMA model is used by Chen et al. [3] to forecast 24 h electrical load and concludes that adaptivity improves forecasting performance significantly. To further encompass non-linearities Charytoniuk et al. [4] and Fan and Hyndman [5] propose semi- and non-parametric regression models, the latter building on inputs from calender variables, lagged load observations, and past and predicted ambient temperature, emphasizing the importance of using relevant inputs to improve the forecasts. Espinoza et al. [6] applies support vector machines to forecast electrical load of an HV–LV substation, Penya et al. [7] compare an ARIMA model with ANNs for forecasting of electricity load of a HVAC system for an office building and Jain et al. [8] propose support vector regression to forecasts energy consumption for a multi-family house. Datta et al. [9] apply an ANN model for prediction of the total electrical load for a supermarket, which is more or less the same as the present problem of predicting the refrigeration load, since a high share of the total load is for refrigeration. Combined methods to forecasting especially for dealing with non-linearities and heteroscedasticity have been suggested, Tan et al. [10] combines wavelet transform with ARIMA and GARCH models, and Fard and Akbari-Zadeh [11] presents a combined method based on several of the commonly used methods. Finally, regime switching models are applied widely in forecasting to deal with systems operating in multiple regimes, i.e. systems exhibiting different dynamics and input relations depending on inputs, states and time: for electricity prices see [12], for wind power see [13,14], and for wind speed see [15].

Halvgaard et al. [16] use heat load forecasting as part of an economic Model Predictive Control (MPC) for providing demand response using a hot water tank for thermal energy storage, in the same way load forecasting for refrigeration can be used with an MPC and an ice storage tank, see [17]. The subject of flexible power consumption in refrigeration systems has a huge potential, see for example Hovgaard et al. [18] and Shafiei et al. [19].

This paper presents a novel study of time series models for forecasting the electrical load from supermarket refrigeration. Such a study was not found in existing literature. This particular case is important, since electrical loads for refrigeration can be made flexible using the heat capacity of the system or additional ice storage tanks. Furthermore, the features, e.g. input dependencies, dynamics and non-linearities, which needs to be taken into account for this particular case, are presented in detail in the paper. The data used for building the forecast models are hourly load measurements, local measured ambient temperature and numerical weather predictions (NWPs) for a summer period of 3 months (May, June, July). The forecast models are adaptive linear time series models which are fitted with a computationally efficient recursive least squares (RLS) scheme. Every hour the hourly load for refrigeration for the following 42 h is forecasted. The dynamic relations between the inputs and the load are modeled using linear transfer functions and non-linearities are handled with spline functions. The refrigeration system operates in two regimes: one during opening hours and another during closing hours, which is modeled by a regime switching model. Different approaches to predicting the regime is applied: one simply by using the fixed opening and closing hours and another more automatized approach where a forecasted diurnal curve is used. The results are thoroughly evaluated with a statistical analysis of the residuals showing that nearly systematic information is removed proving that only marginal improvement will be possible. Finally, a discussion further elucidate the features needed to be taken into account for supermarket refrigeration load forecasting and suggestions for further studies are presented.

2. Data

The data used in the study consists of measurements from a supermarket located in a village in Denmark. The local measured load and ambient temperature are used together with NWPs.

2.1. Electrical load for refrigeration and local temperature measurements

The load measurements are the electrical load of the compressors of a trans critical CO_2 refrigeration system which provides cooling to four low and seven medium temperature cooling units. The period acquired is from May 1st to August 1st 2012. The measured time series are hourly averaged values in kW and are denoted by

$$\{Q_t, \quad t = 1, \ldots, N\}$$

Local measured ambient temperature is also hourly average values, in °C, denoted by

$$\left\{T_t^{\mathrm{a,obs}}, \quad t = 1, \ldots, N\right\}$$

where $N = 2208$. A plot of data is found in Fig. 1, where it can be seen that a few parts of the time series are missing. There are two larger gaps of one to two days length, as well as a few other smaller gaps. From the plot it is clear that the load change over time and it seems change with the same pattern as the ambient temperature. In Fig. 2 a period of five days is plotted. It is clearly seen that the system operates in two regimes, which are identified as closing and opening hours, where at closing hours the load is lower than opening hours. This is mainly because the supermarket is closed at night, and the cabinets without doors are covered by isolation material. Also high frequency peaks are seen in the opening hours, which could be related to defrosting of the low temperature cabinets, that is scheduled in the morning and evening, individually for the different types of low temperature cabinets. For more detailed information about the system, see [20].

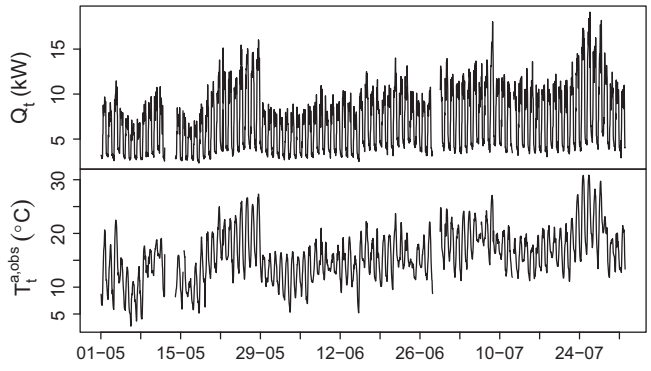

Fig. 1. Time series plot with hourly average values of the load and the local ambient temperature.