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Short-term prediction of electric demand in building sector via hybrid support vector regression

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HIGHLIGHTS

- Wavelet decomposition and SVR were combined to constitute this hybrid model.
- A hotel and a mall were selected to present stationary and non-stationary features.
- We predicted the hourly electric demand intensity in two practical buildings.
- The modeling adaptability regarding building types was carried out by comparison.
- This model is applicable for further model-based smart building energy management.

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ABSTRACT

Reliable and highly-generalized prediction models of short-term electric demand are urgently needed for the building sector, as the crucial basis of sophisticated building energy management. Advances in metering technologies and machine learning methods provide both opportunities and challenges for modified approaches. With multi-resolution wavelet decomposition (MWD) as a preprocessing from the point of view of signal analysis, the hybrid support vector regression (SVR) model was applied in two case study buildings to predict the hourly electric demand intensity. Taking ten-dimensional parameters of 29 workdays as the training sample, this model was carried out in a mall and a hotel, the consumed electric demand sequences of which represented the stationary and non-stationary series respectively.

By comparisons between the hybrid SVR and the pure SVR, results indicated that the introduction of MWD can always improve the predicting accuracy for the hotel, while it is not necessary for the mall. Specifically, the similar steady level around 0.65 W/m^2 of absolute error was obtained for the mall and the hotel buildings, when ε was lower than 0.1. At the same time, the steady quantitative values of relative errors tended to be around 4% and 6% respectively for the hotel and the mall. Based on the limited historical readings, this paper offers an on-line prediction method of short-term electric demand, which is applicable for the further smart energy management.

1. Introduction

As a major contributor of greenhouse gas emissions, it is estimated that the building sector accounts for around 40% of the total global energy resources [1]. Specifically, the increasing development of smart grid and high penetration of integrated renewable energy resources ask for more flexibility from the energy system [2], in order to match the temporal and spatial differences between supply and demand sides. For such elaborately-designed distributed energy systems, a crucial focus is the precise deploying schedules of multi-resource energy according to the dynamic energy demand, which generally asks for hourly granularity in order to achieve the dynamic energy management of multi-systems. However, variability caused by renewable generation from supply side, and the various consumption patterns are making it more challenging to achieve efficient systematic operation and maintain the balance between generation and consumption [3]. To solve this problem, two issues should be taken seriously namely: accurate and highly-generalized prediction modeling of short-term energy demand, and establishment of a reliable and

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Nomenclature

ANN	artificial neural network
SVR	support vector regression
SRM	structural risk minimization
WD	wavelet decomposition
HEDI	hourly electric demand intensity
MWD	multi-resolution wavelet decomposition
FT	Fourier transform
a, b	temporal scales, shift translation
Ai, Di	appropriate part, detail part after wavelet decomposition
$\alpha_i^* - \alpha_i$	network weights
ε	*error threshold / training tolerance*
C	*regularization term*
SVM	support vector machine
ERM	empirical risk minimization
RE	relative error (%)
DMAE	daily mean absolute error (W/m^2)
DMAPE	daily mean absolute percentage error (%)
DRMSE	daily root mean square error (W/m^2)
DAMPE	*daily amendatory mean percentage error (%)*
E_{mi}	measured hourly electric demand intensity (W/m^2)
E_{pi}	predicted hourly electric demand intensity (W/m^2)
RE_{hy}	hourly relative errors of the hybrid SVR with MWD (%)
RE_{pu}	hourly relative errors of the pure SVR without MWD (%)
$RE_{hy\_0.1}$	relative error of the hybrid model when ε equals to 0.1 (%)
$HEDI_{hy}$	hourly electric demand intensity of the hybrid model (W/m^2)
$HEDI_{pu}$	hourly electric demand intensity of the pure model (W/m^2)

flexible model of multi-energy flow [4]. The former is the research orientation of this paper.

Thus, accurate energy consumption prediction in various classified buildings and then at the next regional scale, should be brought in a logic relation. However, it should be noted that the energy consumption or electric demand series show totally different features due to various operation timetables and building types, which in turn enhance the difficulty of accurate prediction. For instance, because of the obviously periodic and seasonal regular patterns, the energy sequences of malls and office buildings can be well predicted even with sub-hourly granularity [5]. However, buildings like hotels and event venues show non-stationary electrical temporal features due to the endogenous parameters, such as the instantaneous consumers' activities in hotels or stochastic events [6], and the exogenous parameters, such as the dynamic meteorological conditions [7]. Unlike the stationary sequences with apparent tendency rules, the non-stationary principle can be hardly caught with traditional methods and was rarely discussed before. As a result, it is of great realistic significance to figure out the modeling adaptability and provide corresponding prediction results according to the specific characteristics of each building type.

In terms of adopted approaches, energy prediction models in building sector consist of physical simulation modeling [8] and statistical analysis [9]. However, because of their mathematical essence, each approach has a corresponding applicable scope and also weaknesses when concerning the limited representation of various aspects of buildings. For example, as a white-box model, the establishment of a physical model needs quantities of detailed attributes as the input, which are usually not easy to obtain access in China, let alone the practical complicated operation timetables of hotels and venue buildings. On the other hand, the pure black-box models are not well accepted by engineers, mainly because of the poor explanation behind black-box and the sacrifice of building physical insight [10]. Furthermore, the deep learning function of traditional black-box models depends excessively on limited historical data, due to the well-used empirical risk minimization (ERM) principle. Consequently, as stated in Ref. [11], if without auxiliary feature extraction or data selection from the original sequences, the generalization of such methods is quite limited in most practical cases. As a result, hybrid prediction models have attracted more attentions nowadays, especially when combined with artificial intelligence based techniques, such as artificial neural network (ANN) and support vector regression (SVR). Due to its superior handling of nonlinear relationship, these intelligent approaches are being applied worldwide in multitudinous fields [12]. Along with data explosion resulted from smart metering and various sensors, the extended hybrid approaches modified from machine learning techniques are highlighted in the field of metering-based forecasting [13,14].

Actually, there are already some hybrid models regarding short-term electrical consumption prediction. For example, the well-known ANN was frequently discussed to be connected with the fuzzy logic, gradient based learning techniques and so on [12]. Meanwhile, based on the structural risk minimization (SRM), SVR models are believed to obtain a globally optimal solution, instead of the local extremum and poor explanation ability behind the black box in ANN [12,15]. Consequently, SVR modeling is increasingly considered in fields of mode recognition and regression estimation [16,17]. In addition, other than the studies conducted on applicable ranges [18] and optimization [19], the hybrid SVR approaches have also attracted more attentions nowadays. Zhang [20] carried out a weighted SVR model, the weighting values of which were determined with the help of differential evolution algorithm. Furthermore, due to its sensitive extraction of high-frequency features, wavelet decomposition (WD) was utilized to achieve the wavelet neural network [21,22] and the wavelet ARIMA [23] in the field of electric demand prediction. At the same time, SVR was also combined with WD to realize better forecasting accuracy in fields of export trade prediction [24] and stock index prediction [25]. However, there are rarely studies currently on the combination of SVR and WD in the field of short-term energy prediction for individual buildings, let alone the classified buildings with different temporal sequences specifically. Furthermore, in the previous combination of SVR and WD in other fields, the function of WD can be concluded as decomposition based on frequency recognition, then the ANN or SVR models are established for each decomposed sequence independently. In other words, the introduction of WD serves only as the preprocessing and reconstruction of independent predicted results in these models. However, it should be noticed that such combination is not sufficient for SVR, the independent variables of which could largely affect the modeling quality. Hence, the role WD plays in prediction needs to be further explored.

Accordingly, in this paper, a hybrid SVR model connected with WD was applied to predict the hourly electric demand intensity (HEDI) in a mall and a hotel, which show stationary and non-stationary operated characteristics respectively. The model

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