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Energy consumption prediction of air-conditioning systems in buildings by selecting similar days based on combined weights

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ABSTRACT

Accurate modelling and prediction of energy consumption of the air conditioning system is crucial for improving decision making. A method for predicting the energy consumption of air-conditioning systems is proposed in this paper. Based on the same weather type (sunny, cloudy, overcast, or rainy) and day type (workdays or holidays), the similarity errors using the combined weight method and the baseline errors of similar working conditions are calculated with this method. These conditions include outdoor temperature and lighting and plug power, then, similar days are determined within a certain similar error range. In addition, the air-conditioning energy consumption in these similar days is regarded as that in the predicted days. The similarity errors in selecting similar days are acquired by efficiently combining subjective weights, objective entropy weights, and correlation coefficients. To verify the accuracies of the predicted energy consumption using similar days method based on combined weights, a simulation was performed by eQUEST. According to the simulation example of measured data in an office building, it is proved that the proposed prediction method with high forecast accuracy can select similar days with a high degree of similarity under non-catastrophic weather conditions, and offer promise for wider engineering application.

1. Introduction

Buildings account for about 19.1% of the total energy use in China. One of the priorities is the large public building power consumption, which a quarter of total building energy consumption. The energy consumption of the air conditioning systems accounts for 40–60% (or even higher) of total energy consumption in large public buildings [1–3]. Therefore, accurate modelling and prediction of energy consumption for air conditioning system are crucial for improving decision making since it could facilitate grid design and operation of building.

In this regard, predicting building energy consumption has drawn a lot of research attention in recent years [4,5]. Engineering methods, statistical methods, and artificial intelligence methods were used to implement predictions of building energy consumption [6]. Al-Homoud [7] reviewed two simplified methods: one is the degree day method, the other is a bin method which is also known as the temperature frequency method. White and Reichmuth [8] attempted to use average monthly temperatures for predicting monthly building energy consumption. Bauer and Scartezzini [9] proposed a regression method to handle both heating and cooling calculations simultaneously by dealing with internal, as well as solar and gains. In the work of Cho et al. [10], a regression model was developed from 1-day, 1-week, 3-monthes measurements, which lead to prediction errors in the annual energy consumption of 100%, 30%, and 6%, respectively. ANNs are the most widely used artificial intelligence models in the application of building energy prediction [11–14]. This type of model is good at solving non-linear problems, and definitely it is an effective approach for this complex application. SVMs are increasingly used in research and industry. They are highly effective models for solving non-linear problems even with small quantities of training data. Many studies of these models have been conducted on building energy analysis in the past five years [15–19]. From the above studies, it can be seen that much work has been done on the modelling and prediction of energy consumption. However, in the cited literature, the similar day method is one of the simplest and oldest load forecasting methods which are still used for load forecasting [20,21] or selecting proper input data for other methods [22,23]. This paper aims to improve the efficiency of simple similar day method based on weather type (sunny, cloudy, overcast and rainy) and day type (workdays and holidays), coupled with the combined weight method.

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In this paper, the basic idea of energy consumption prediction for air-conditioning systems by selecting similar days based on combined weights is introduced, then the process of calculating the weighting coefficients is given. Furthermore, an example was analysed in detail so as to verify its function. A simulation verification is performed by eQUEST in Section 4, while the last section contains a brief summary about the results.

2. Methodology

2.1. Factors affecting energy consumption in air-conditioning systems

For the same building, there are various factors influencing the energy consumption of air-conditioning systems, such as climate, time, and factors inside the building.

Climate factors and conditions have a significant influence on the energy consumption of air-conditioning systems. These factors mainly include outdoor temperature, relative humidity of the outdoor air, wind direction and speed, solar radiation intensity, cloud cover, and precipitation. Among them, the last four can be synthesised into weather type (sunny, cloudy, overcast, or rainy).

For those time factors affecting the energy consumption of air-conditioning systems in buildings, they mainly contain seasonal variations, namely, weekly cycles (workdays and holidays), and daily cycles (working time and non-working time). The energy consumption of air-conditioning systems presents a significant periodicity. In general, the energy consumption in winter and summer has a remarkable growth compared with that in spring and autumn in any year. In addition, the energy consumption of air-conditioning systems, at run time, greatly differs from that on non-workdays within a given week. Similarly, the energy consumption during the working week showed significant disparities with those at non-working time.

For factors inside buildings, time factors influencing the energy consumption of air-conditioning systems in buildings were mainly comprised of indoor lighting power, equipment power, and the number of personnel. However, the extent of effect of these factors on the energy consumption depends on various conditions, including building types, volume and internal and external patterns.

Climate and time factors, as well as those inside buildings exert a significant influence on the energy consumption of air-conditioning systems. Considering this, the study selects similar days by regarding weather and workday types, outdoor temperature, and lighting and plug power as variables of similar working conditions.

2.2. Basic idea of energy consumption prediction by selecting similar days based on combined weights

A method for predicting the energy consumption of air-conditioning systems is proposed in this paper. Based on weather type (sunny, cloudy, overcast, or rainy) and day type (workdays or holidays), the similarity errors using the combined weight method and the baseline errors of similar working conditions are calculated with this method.

The basic idea of energy consumption prediction for air-conditioning systems by selecting similar days based on combined weights is outlined as follows:

1) With the given day types and weather types for comparison, the outdoor temperature and lighting and plug power, and air-conditioning systems on contrasting days are extracted hourly from 0:00 to 23:00 every day and taken as baseline values. By doing this, the outdoor temperature vector $x_{t,0}$, the vector $x_{lp,0}$ of lighting and plug power, and the vector $x_{ac,0}$ of electricity consumption by air-conditioning systems on contrasting days are formed as followings:

$$x_{t,0} = \left[x_{t,0}(1), x_{t,0}(2), \cdots, x_{t,0}(23), x_{t,0}(24)\right], \tag{1}$$

$$x_{lp,0} = \left[x_{lp,0}(1), x_{lp,0}(2), \cdots, x_{lp,0}(23), x_{lp,0}(24)\right], \tag{2}$$

$$x_{ac,0} = \left[x_{ac,0}(1), x_{ac,0}(2), \cdots, x_{ac,0}(23), x_{ac,0}(24)\right]. \tag{3}$$

2) The date data of referential historical days with same day types as those of contrasting days are selected. Then the data of lighting and plug power in those days with same day types are extracted hourly from 0:00 to 23:00 every day. By using these baseline values, the $n_{lp} \times 24$ dimension date electricity vector $x_{lp,1}$ for lighting and plug power on those days with same day types is formed. The combined weight θ_{lp} of electricity consumption data as the baseline values on those days with same day types is determined:

$$x_{lp,1} = \begin{bmatrix} x_{lp,1}(1,1) & x_{lp,1}(1,2) & \cdots & x_{lp,1}(1,24) \\ x_{lp,1}(2,1) & x_{lp,1}(2,2) & \cdots & x_{lp,1}(2,24) \\ \vdots & \vdots & \ddots & \vdots \\ x_{lp,1}\left(n_{lp},1\right) & x_{lp,1}\left(n_{lp},2\right) & \cdots & x_{lp,1}\left(n_{lp},24\right) \end{bmatrix}. \tag{4}$$

3) The date data of referential historical days with same weather types as those of contrasting days are selected. The outdoor temperature data in days with same weather type are extracted hourly from 0:00 to 23:00 every day and taken as baseline values. Therefore, the $n_t \times 24$ dimension vector $x_{t,2}$ of outdoor temperature in the days with same weather type is generated and then the combined weight θ_t of lighting and plug power as baseline values in the days with same day type is determined:

$$x_{t,2} = \begin{bmatrix} x_{t,2}(1,1) & x_{t,2}(1,2) & \cdots & x_{t,2}(1,24) \\ x_{t,2}(2,1) & x_{t,2}(2,2) & \cdots & x_{t,2}(2,24) \\ \vdots & \vdots & \ddots & \vdots \\ x_{t,2}(n_t,1) & x_{t,2}(n_t,2) & \cdots & x_{t,2}(n_t,24) \end{bmatrix}. \tag{5}$$

4) The days with same day type and weather type are selected hourly from 0:00 to 23:00 every day and taken as baseline values to extract the data of outdoor temperature, electricity consumption for lighting and plug, and air-conditioning systems in those days with same day type. In this way, the $n \times 24$ dimension vector $x_{t,3}$ of outdoor temperature, the $n \times 24$ dimension electricity consumption vector $x_{lp,3}$ for lighting and plug and the $n \times 24$ dimension electricity consumption vector $x_{ac,3}$ for air-conditioning systems with same day types are formed as below:

$$x_{t,3} = \begin{bmatrix} x_{t,3}(1,1) & x_{t,3}(1,2) & \cdots & x_{t,3}(1,24) \\ x_{t,3}(2,1) & x_{t,3}(2,2) & \cdots & x_{t,3}(2,24) \\ \vdots & \vdots & \ddots & \vdots \\ x_{t,3}(n,1) & x_{t,3}(n,2) & \cdots & x_{t,3}(n,24) \end{bmatrix}, \tag{6}$$

$$x_{lp,3} = \begin{bmatrix} x_{lp,3}(1,1) & x_{lp,3}(1,2) & \cdots & x_{lp,3}(1,24) \\ x_{lp,3}(2,1) & x_{lp,3}(2,2) & \cdots & x_{lp,3}(2,24) \\ \vdots & \vdots & \ddots & \vdots \\ x_{lp,3}(n,1) & x_{lp,3}(n,2) & \cdots & x_{lp,3}(n,24) \end{bmatrix}, \tag{7}$$