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Normative Building Energy Models for Buildings with Intermittent Air Conditioning System Operation – Applicability and Accuracy

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ABSTRACT

Intermittent air conditioning (AC) system operation is quite common in developing countries, which is featured by turning on/off air conditioning systems to meet dynamic building loads. Due to the inherent uncertainty and vast variation in intermittent AC operation behavior, it is quite challenging to model the energy performance of buildings with this kind of operation. Normative models have the advantages of simplicity and fastness, and can achieve good accuracy when modeling the energy performance of existing buildings. This paper presents a systematic study to evaluate the applicability of normative methods for buildings with intermittent AC operation. In this study, five government office buildings in Qingdao city with different AC operation behavior were chosen as the testing cases. The results show that multiple operation behavior exists in the investigated buildings, and normative methods are less accurate when predicting the energy performance of buildings with intermittent AC operation.

KEYWORDS

Intermittent AC operation, Normative methods, Energy performance

INTRODUCTION

The past thirty years have evidenced a dramatic increase of energy consumption in public buildings in China. It is estimated that China's commercial buildings consumed 26.4% of overall building energy consumption in the building sector in 2012 (BERC 2014). Recently, Chinese government has set ambitious targets in reducing the energy consumption in public buildings. The energy efficiency policies in China's 12th five year plan aimed at reducing the energy use intensity in ordinary commercial buildings (area less than 20,000 square meters) by 10%, and that in large scale commercial buildings (area larger than 20,000 square meters) by 15% (MOF and MOHURD 2012). This implies a significant number of public buildings to be retrofitted.

To identify good candidates for energy retrofit, building energy simulation methods are quite useful. Generally, building energy simulation models refer to models that are implemented in computer languages, and able to approximate energy consumption behavior of real buildings. Because of its prediction power, building energy simulation models have been widely used in building energy saving applications, such as energy retrofit (Teres-Zubiaga et al. 2015), low carbon building design (Reda et al. 2015), and building system optimal control (Sun et al. 2013), etc. In terms of the modeling principle, these methods can be classified into three categories: black box method, gray box method, and white box method (Li et al. 2014).

In general, white box methods are transparent and require zero training data, but needs more effort when modeling existing buildings (Li et al. 2014). Therefore, to identify the energy retrofit targets from a list of candidate buildings, white box method is not an economical choice. To solve this problem, normative method - a simplified white box method - is proposed.

Augenbroe and Park developed a normative energy modeling tool (GSAToolkit) based on the NEN 2916 standard, and have applied it to assess the performance of federal buildings in United States (Park & Augenbroe 2003). Later on this tool is refined based on a set of international standards (including EN ISO 13790 standard, EN 15241 standard, etc.), and renamed as 'EPSCT' toolkit (Lee et al. 2013). Heo further showed that this normative model is able to mimic the dynamic energy consumption behavior of existing buildings, and can give reliable suggestions regarding optimal energy retrofit solutions (Heo et al. 2012).

The following content presents the results of a study conducted to verify the accuracy of normative building energy simulation models when applied to public buildings with intermittent AC operation. Firstly, the characteristics of the buildings used as test cases are introduced; secondly, the evaluation framework deployed in this study is described; thirdly, the identified key parameters through calibration of all test cases are summarized; fourthly, the model validation results are presented; finally, conclusion remarks are given.

Characteristics of the test case buildings

Qingdao city is located near the Yellow sea in northern China, featured by a monsoon oceanic climate with a relatively long winter period and a short summer period. In this study, five government office buildings in Qingdao city were selected as the test cases, whose information is shown in Table 1. All five buildings are Large Public Buildings (LPB), with area larger than 20000 m^2. The heating and cooling sources for these buildings are municipal Combined Heating and Power (CHP) companies, and electricity driven chillers/heat pumps. The terminal units of these buildings are mainly fan coil and fresh air systems, except that Bldg. 3 is equipped with some additional split AC units. For all five buildings, detailed hourly electricity metering data is available, therefore it is possible to analyze their AC operational behavior.

Table 1. *Information of test case buildings*

Index	*Area (m^2)*	*Stories*	*HVAC System*	*Cooling source*
1	32970	21	fan coil + fresh air	Centrifugal chiller
2	42600	15	fan coil + fresh air	Centrifugal chiller

3	44909	15	fan coil + fresh air +split unit	Centrifugal chiller
4	27000	11	fan coil + fresh air	Water source heat pump
5	60826	28	fan coil + fresh air	Centrifugal chiller

To understand the AC operation behavior, a Decision Tree (DT) based analysis was performed. In this analysis, five input variables were selected: month of year, day of week, hour of day, day type, and outdoor dry-bulb temperature, and the power consumption of the cooling plant was used as the single output variable (there is no heating power plant). To simplify the analysis, power consumption data is discretized into two groups: those above 5% of the maximum power consumption and those below the 5% threshold.

Two distinct operational behavior have been found among the testing buildings. The first behavior is strictly schedule based, as seen in Fig. 1. Cooling plants are shut down from Jan to June and from Sep to Dec, the only operation period is from July to August. Furthermore, chillers are turned on only on working days and in working time (from 7am to 4pm). The second behavior is less predictable, as found in Bldg.3 and shown in Fig. 2. The cooling/heating source may be turned on at any time of the year, except for March, May, and June. In terms of daily operation, the system has two discrete operation periods: from 8am to 4pm, and from 8pm to 11pm. In sum, this analysis shows that while the AC system of Bldg. 1, 2, 4, and 5 are operated in a strict schedule based way, that of Bldg. 3 shows an intermittent pattern and less predictable.

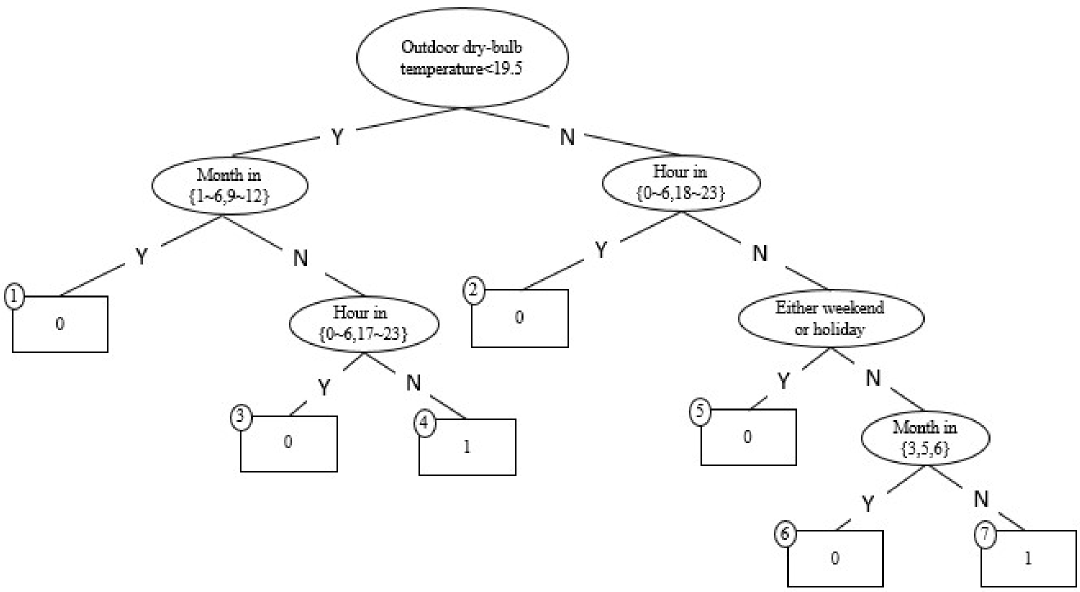

Figure 1. *DT analysis of AC operational behavior in Bldg. 5*

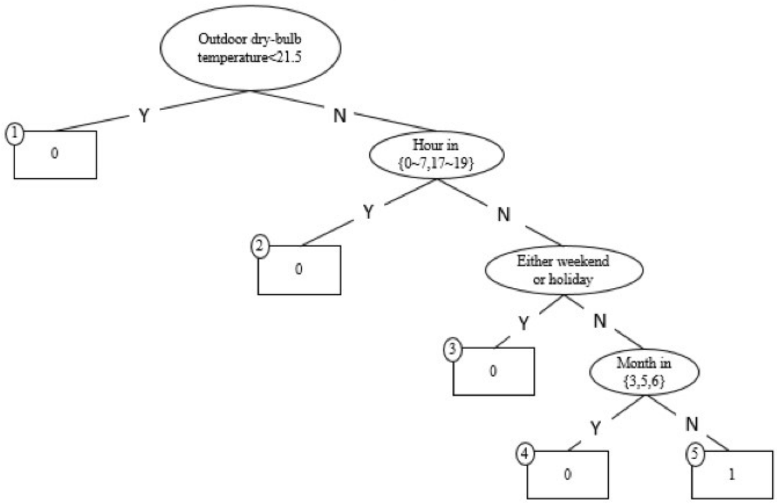

Figure 2. *DT analysis of AC operational behavior in Bldg. 3*

Evaluation Methods and Results

To evaluate the applicability and accuracy of normative energy simulation models, the following framework is established (as shown in Fig. 3). As the first step, the information of the test building is collected, including the basic building information and two-year energy consumption data (one year for training and the other for testing). Secondly, normative model is established and calibrated based on the first year training data. If the preset accuracy criteria is satisfied, the established building model is further tested with the second year testing data. Finally, the agreement between the predicted second year energy consumption and the actual data is taken as the indicator, suggesting the applicability of the normative model to the test building.

To evaluate the agreement between predicted energy consumption and actual energy consumption, two indices were deployed: index of agreement *d* and coefficient of variation of the root mean squared error (*CV-RMSE)*, which are defined as the following:

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}\left(|P_i - \overline{O}| + |O_i - \overline{O}|\right)^2} \quad (1)$$

$$\mathrm{CV(RMSE)} = \frac{\sqrt{\sum_{i=1}^{n}(O_i - P_i)^2 / n}}{\overline{O}} \quad (2)$$

where O_i denotes the observed value, P_i denotes the prediction results in month *i*, $\overline{O}$ represents the average value of metering data. Index of agreement *d* ranges from 0 to 1, the larger *d* suggests a better agreement. Root mean square error CV (RMSE) is opposite to d, with lower values expressing better fit between the model and data. If CV (RMSE) is less than 15%, models are declared to be calibrated (ASHRAE 2002).

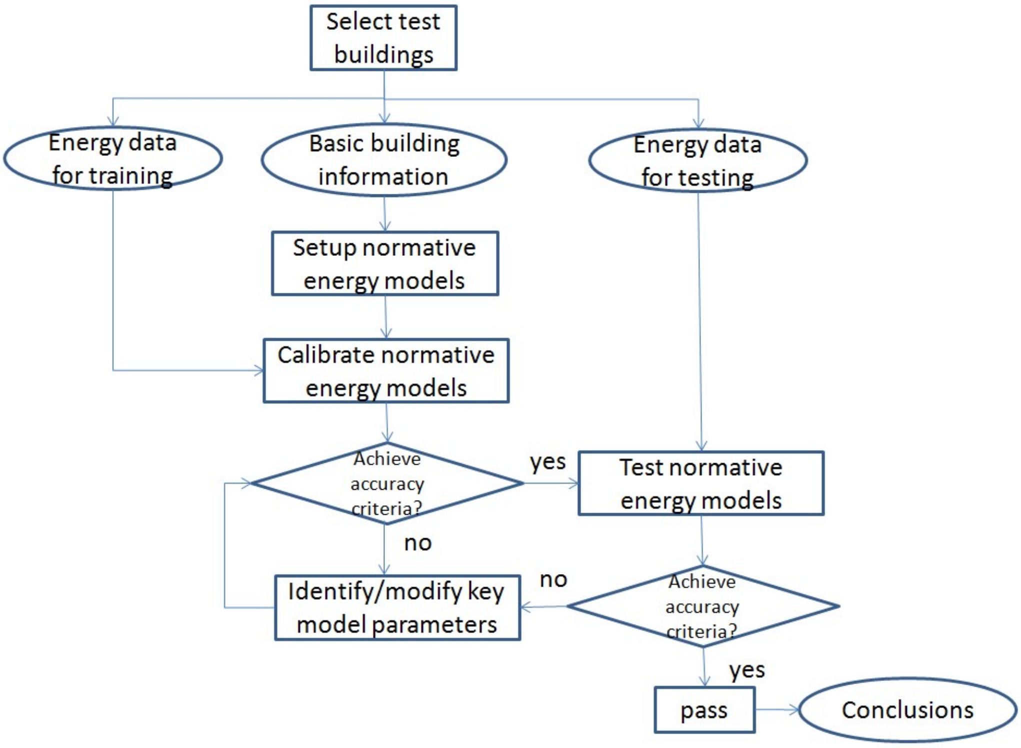

Figure 3. *Evaluation framework of normative energy models*

Table 2 presents the prediction accuracy of normative models for test buildings. It can be seen that except for Bldg. 3, all other buildings are predicted with a satisfactory accuracy, the CV-RMSE index in both calibration and testing cases falls below 15%. In general, the agreement index *d* is between 0.90 and 0.96, and the CV-RMSE value falls between 10% and 14%.

Table 2. *Prediction accuracy of normative methods for test buildings*

	Calibration		*Testing*	
Index	*d*	*CV-RMSE*	*d*	*CV-RMSE*
1	0.94	0.11	0.90	0.13
2	0.92	0.10	0.90	0.12
3	0.77	0.20	/	/
4	0.94	0.13	0.93	0.14
5	0.96	0.10	0.91	0.12

CONCLUSION AND IMPLICATIONS

Normative models have the advantages of transparence, simplicity and fastness, therefore are suitable to identify energy retrofit targets among a large number of buildings. This study presents the accuracy of normative models when applied to buildings with intermittent AC operation. The results show that the AC operation behavior has a significant impact on the prediction performance of the normative method. For buildings with continuous AC operation, the performance of normative method is satisfactory; however, for those with less regular operation behavior, the performance is questionable. Therefore, to apply normative methods to predict energy demand of existing buildings, it is important to understand the operation behavior of the building. Further study is needed to develop energy prediction methods for buildings with intermittent AC operation.

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