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Improving the accuracy of energy baseline models for commercial buildings with occupancy data

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HIGHLIGHTS

- We evaluated several baseline models predicting energy use in buildings.
- Including occupancy data improved accuracy of baseline model prediction.
- Occupancy is highly correlated with energy use in buildings.
- This simple approach can be used in decision makings of energy retrofit projects.

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ABSTRACT

More than 80% of energy is consumed during operation phase of a building's life cycle, so energy efficiency retrofit for existing buildings is considered a promising way to reduce energy use in buildings. The investment strategies of retrofit depend on the ability to quantify energy savings by "measurement and verification" (M&V), which compares actual energy consumption to how much energy would have been used without retrofit (called the "baseline" of energy use). Although numerous models exist for predicting baseline of energy use, a critical limitation is that occupancy has not been included as a variable. However, occupancy rate is essential for energy consumption and was emphasized by previous studies. This study develops a new baseline model which is built upon the Lawrence Berkeley National Laboratory (LBNL) model but includes the use of building occupancy data. The study also proposes metrics to quantify the accuracy of prediction and the impacts of variables. However, the results show that including occupancy data does not significantly improve the accuracy of the baseline model, especially for HVAC load. The reasons are discussed further. In addition, sensitivity analysis is conducted to show the influence of parameters in baseline models. The results from this study can help us understand the influence of occupancy on energy use, improve energy baseline prediction by including the occupancy factor, reduce risks of M&V and facilitate investment strategies of energy efficiency retrofit.

1. Introduction

The buildings sector consumes 40% of the total primary energy in the United States [1], and the consumption has continued to increase, particularly in developing countries [2]. The buildings sector is thus responsible for a quarter of the total global greenhouse gas (GHG) emissions [3], and this proportion can reach around 50% in the United States (U.S.) with adverse impact on global environment, healthcare, and economy [4]. Furthermore, in the life cycle of a building, more than 80% of energy consumption occurs during the actual operation stage, rather than the construction stage [5]. Therefore, improving the energy efficiency of existing buildings is a key issue for reducing the total energy consumption and GHG emissions.

Energy efficiency retrofit for existing buildings is considered a promising method to achieve the target of energy savings [6]. Numerous previous studies indicated energy retrofit can significantly benefit the environment, society, and economy by improving energy efficiency [6,7], reducing emissions [8,9], controlling resource usage [10], enhancing the reputation of building owners [11], improving the health and productivity of occupants [12,13], reducing operation costs [14], increasing rent and occupancy rates [15,16], and creating job opportunities [17].

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Owing to the significant benefits on energy conservation and other aspects of society, energy efficiency retrofit has been emphasized around the world. For example, the U.S. government passed the Energy Policy Act (EPA) of 2005 and Executive Order (EO) 13,423, which require that 15% of the total number of existing buildings should be retrofitted to improve energy efficiency by 2015 compared with the 2003 baseline. Approximately 30 billion US dollars are assigned to conduct energy efficiency retrofit of existing buildings and facilities [7]. Incented by the policies, the market to provide energy efficiency services through energy service companies (ESCOs) has been blooming in the last decade [8].

Energy performance contracting (EPC), which is a financing package provided by ESCOs, is a commonly used market mechanism to implement energy efficiency retrofit. EPC includes energy savings guarantees and associated design, implementation and operation services [2,9]. The profit (or the payment to ESCOs) of an EPC is mainly from the amount of energy cost savings after retrofit. The energy savings can be defined as the difference between how much energy the building consumed after retrofit, and how much it *would have* consumed without the retrofit. The former can be obtained from utility meters, and the latter, which is referred to as the energy use "baseline", is not measurable but can only be obtained by prediction. The accuracy of the baseline prediction can significantly impact the energy saving assessment, investment return and payback period. Furtherly, it can likewise impact the investment strategies and development of the building retrofit market.

The whole process of predicting baseline and assessing energy saving is called "measurement and verification" (M&V) [10]. The mechanism of M&V approaches is first monitoring the energy use of buildings, then developing mathematical models trained by observed data, and finally predicting baseline of energy use based on the developed models. Xia and Zhang [10] present a mathematical description of the M&V problem and cast a scientific framework for the basic M&V concepts, propositions, techniques and methodologies. Mathieu et al. [11] proposed a regression-based model to predict baseline electricity consumption of commercial buildings and industrial facilities. Coughlin et al. [12] evaluated the performance of three average-based models for baseline. Granderson et al. [13] proposed an automated M&V method for evaluating model performance. Granderson and Price [14] summarized five baseline models, including both average-based models and regression-based models, and compared the predictive accuracy of these models with several metrics. More complex mathematical models of M&V have been emerged, including multivariate regression models, exponential smoothing models, neural network models, and Fourier series models [15–18].

Uncertainty of M&V models is important, since not only the value of the baseline, but also the accuracy and reliability of the prediction are critical to energy efficiency retrofit. It provides the stakeholders (e.g., ESCOs, building owners, facility managers) the information of investment risk, which is critical in decision making. For example, if the post-retrofit energy use will be 30% lower than the baseline, but the uncertainty exceeds 30%, it is then very risky to invest in this retrofit project. Walter et al. [8] emphasized the influence of uncertainty and assessed uncertainty of M&V for 17 buildings by calculating the percent differences between predicted baseline and observed data. The results showed there was considerable uncertainty in baseline prediction: 5 out of 17 buildings had more than 20% uncertainty, and in an extreme case it was more than 60%.

The occupancy rate is a key uncertainty factor of M&V. Numerous previous studies indicated that the occupancy rate had significantly positive correlation with the energy use in buildings [19–26]. Occupants in buildings influence energy use in buildings in three major ways [27]: (1) sensible and latent heat gains from occupants, (2) occupants' need of thermal comfort, visual comfort and indoor air quality, and (3) occupant behavior and interactions with building systems and controls [28,29]. In addition, in commercial buildings, the occupancy rate may increase after energy retrofit, due to lower utility bills, better indoor environment and higher social reputation [30–32]. Miller et al. [33] indicated the office buildings with green features will have 2–4% occupancy rate premium. Wiley et al. [34] specified that the office buildings with LEED certification will increase up to 16–18%. Therefore, if the occupancy rate is changed after energy retrofit, the baseline of energy use should be adjusted.

Although a number of previous studies emphasized the importance of occupancy factor in predicting the baseline, few studies, if not none, used occupancy factor in baseline prediction models, probably due to the highly stochastic activities and data limitation. Therefore, several research questions related to M&V remain to be answered: Does occupancy rate significantly impact the accuracy of baseline prediction? If yes, how to quantitatively evaluate the impact on prediction accuracy? How is the influence of occupancy on baseline models compared to that of other impact factors (e.g., outdoor air temperature, day of week), stronger, weaker or equal? Is it feasible to improve prediction accuracy of energy baseline by using occupancy data? Nowadays, most commercial buildings have access control system, which can obtain occupancy data in short time intervals. These data provide a new opportunity to deeply analyze the impact of occupancy on the accuracy of baseline prediction.

To address the aforementioned questions, this study proposes a novel method to quantitatively evaluate how accuracy of energy baseline models is improved by including the occupancy factor. Different from previous models, the proposed model of this study considers the occupancy data as independent variables rather than external uncertainty, shown in Fig. 1. Although influence of occupancy has been emphasized by numerous previous studies, traditional models have not included occupancy data in the functions of energy prediction. Therefore, in traditional models, occupancy is an external uncertain factor, which can negatively impact the accuracy of energy prediction. Contrarily, in this study, the occupancy data is considered as an independent variable so that the influence of occupancy can be fitted by the function and evaluated by the prediction results. The results of this study showed the accuracy of energy prediction is improved. From theoretical perspective, including occupancy data can improve the prediction accuracy, since the uncertainty of occupancy factor can be controlled and reduced, and less uncertainty can improve the prediction accuracy.

The results of this study reveal that the influence of occupancy on the accuracy of energy prediction. In addition, since the performance of models varies across hours and systems, the proposed method zooms into the hourly performance and different systems (i.e., HVAC, lighting, plug load and total load) of baseline models. Another important feature of this work is it only uses simple algorithm, excluding complex mathematical processing, and the input data is available in most commercial buildings. That means the proposed method is relatively easy to be implemented, and can be well adopted for practical projects. The results of this study can help us understand the quantitative influence of occupancy on energy use and energy baseline models.

2. Methodology

2.1. Framework of evaluating occupancy impact on baseline prediction

The methodology to evaluate occupancy influence on baseline prediction comprises of four steps, illustrated in Fig. 2.