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Analysis of energy efficiency retrofit scheme for hotel buildings using eQuest software: A case study from Tianjin, China

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ABSTRACT

Hotel buildings generally consume more energy than other types of public buildings, so measures should be adopted to reduce their energy demands. Energy retrofit measures (ERMs) were explored by eQuest software, using the example of an existing four-star hotel in Tianjin, China. The study investigates predictive accuracy for the major factors in the energy consumption of hotel buildings. The results indicate that the schedules of internal loads have the most significant impact on the accuracy of the model for hotel buildings, followed by occupancy rate and coefficient of performance (COP) of the chillers. A retrofit scheme was formulated and its energy-saving potential was evaluated by the calibrated model. Post-implementation monitoring was carried out, and the similarity between model predictions and the actual outcomes of the retrofits confirms that the calibrated model provides a highly accurate forecast of the energy-saving effects of the building energy efficiency retrofit (BEER) scheme.

1. Introduction

The energy consumption of buildings has always accounted for a large proportion of total societal energy consumption. With increasing standards of living, more stringent demands for thermally comfortable buildings are being made, which result in higher energy consumption. In 2010, building energy consumption accounted for nearly 20.9% of total energy consumption in China [1]. As a major building type, public buildings can greatly influence the level of energy consumption by buildings. Public buildings (excluding heating energy in northern China) accounted for 25.6% of building energy consumption [1]. Among public buildings, hotels are unique for several reasons: (I) hotel buildings operate 24 h per day and have continual cooling or heating demands; (II) hotels combine different functions and facilities, such as guest rooms, restaurants, business centers, etc. A high-quality indoor environment may be requested by guests; (III) domestic hot water (DHW) is required 24 h per day. As a result, hotel buildings typically have higher energy consumption than other types of public buildings. The mean annual power consumption in total and for air-conditioning systems is more than 1.34 and 2 times greater for hotel buildings than for other types of public buildings [2,3]. Therefore, it is significant to promote energy efficiency measures for public buildings, especially hotel buildings.

With rapid development of BEER, retrofit measures have been implemented to conserve energy in existing buildings. Meanwhile, numerous studies have examined the energy-saving potential of retrofit measures and have estimated the energy consumption of buildings following retrofits. Energy simulation software is widely used in such studies, and plays an increasing role in BEER analysis. Zhu [4] evaluated the energy-saving potential of three ERMs made through a conventional energy auditing process by eQuest. The three recommendations were evaluated separately, and the simulation results indicated that, despite significantly reducing energy consumption, Energy Star rating could only be guaranteed by combining all three strategies. Although it is a time-consuming and resource-intensive task to build a feasible model, eQuest is a valuable technique for assisting facility managers in assessing BEER proposals. Neto and Fiorelli [5] applied EnergyPlus simulation software and an artificial neural network to predict the energy consumption of an office building. The findings demonstrated that realistic input data are beneficial for a reliable model. The schedules of internal loads and equipment characteristics are more significant for an accurate office model that uses parametric analysis. Ke et al. [6] created an eQuest simulation model to examine the

Abbreviations: ERMs, energy retrofit measures; COP, coefficient of performance; BEER, building energy efficiency retrofit; DHW, domestic hot water; MBE, mean bias error; RMSE, root mean square error; ECMs, energy conservation measures; HVAC, heating, ventilation, and air-conditioning; MEP, mechanical, electrical and plumbing; C_V (RMSE), coefficient of variation of the root-mean-squared error; CON, conference room; EIFS, exterior insulating finishing system; WSHP, water-source heat pump; CSWD, Chinese standard weather data; TMY, typical meteorological year; EER, energy efficiency ratio.

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Table 1
Building physical attributes.

Building name	Air-conditioned area (m^2)	Number of floors	Construction date	Building type
Main building	15792	16	1985.5	Guest room
Wing	2639	4	1985.5	Dining and entertainment
Entertainment center	8000	6	1998.8	Entertainment (electronic game room, bath center)
West building	2799	5	1985.8	Express hotel
Conference center	1816	2	1998.8	Conference center
Power station	276	2	1985.5	Equipment room and office

energy-saving performance contract of an office building by using IPMVP option D. Using actual electricity consumption data, the model was calibrated via yearly mean bias error (MBE) and root mean square error (RMSE). The calibrated model was used to examine the effects of changes in energy consumption parameters on overall energy consumption. They found that illumination density had the greatest impact on energy consumption. Therefore, retrofitting proposals should prioritize lighting systems in order to effectively reduce overall energy consumption in office buildings. Pan et al. [7] used calibrated energy simulation to analyze energy performance in a case study of a high-rise commercial building. A DOE-2 model was created for the building and system characteristics. The model was then calibrated until statistical indices complied with relevant standards and guidelines. The calibrated model was used to evaluate the energy-saving potential of energy conservation measures (ECMs). Pedrini et al. [8] described the basic methodology for energy modeling and calibration when analyzing building energy performance by computer simulation software. The methodology comprises three main steps: (I) baseline energy modeling based on design plans and documentation; (II) walk-through and audit stage for input parameters such as internal loads, their schedules, and cooling and heating set points; (III) end-use energy measurements for fine-tuning the operation schedules and internal power density. More than 15 office buildings in Brazil were studied using this method. The results indicated that the schedule descriptions had the most significant impacts on the accuracy of the model for office buildings.

Numerous factors need to be taken into consideration to determine the applicability of a BEER proposal, of which the primary factors are generally the investment cost of the retrofit scheme and the associated energy conservation potential. Therefore, accurate prediction of the energy-saving potential of the BEER scheme is necessary. A four-star hotel building in Tianjin was chosen as a BEER project to predict energy conservation potential using eQuest software. Through the process of calibrating the baseline model, the major factors affecting the accuracy of the prediction of hotel buildings' energy consumption are studied. The results are conducive to modeling hotel buildings in similar studies.

2. Baseline model development

2.1. Description of buildings

The hotel consists of six buildings with a gross floor area of more than 36,000 m^2 and air-conditioned area of about 31,000 m^2. Detailed information for the six buildings is shown in Table 1. Two of the buildings (entertainment center and conference center) were constructed in 1998, whereas the others date from 1985. The heating, ventilation, and air-conditioning (HVAC) system comprises two different refrigeration systems. One system (system #1) includes two 930 kW centrifugal chillers working in parallel operation mode, whereas the other (system #2) comprises one 700 kW and one 627 kW screw chiller operating in parallel. In winter, a coal-fired boiler (capacity 2.1 MW) with a backup supplies hot water to the air-conditioning system. Three constant-frequency pumps, operating in parallel with a backup, serve the chillers in chilled-water and cooling-water cycles. In winter, the chiller water-pumps function as hot water pumps. The hotel adopts a primary air fan-coil system to maintain indoor comfort levels. The coal-fired boilers, which supply hot water to the air-conditioning system, also supply DHW to the guest rooms throughout the year.

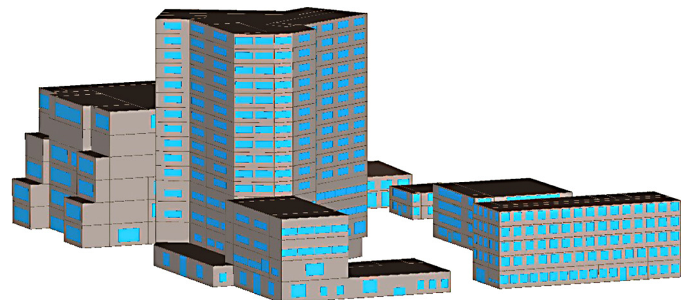

Fig. 1. Geometric representation of the hotel (northeast view).

2.2. Baseline energy modeling

Data are available on whole-building energy use, but there is no detailed breakdown of energy consumption by sub-system, such as annual HVAC, heating, and cooling. To identify energy-intensive components of the various systems in the hotel, the most common approach is to develop an energy simulation model to predict the energy performance of the buildings and the energy conservation potential of the BEER schemes.

A model of the hotel is created in eQuest, with reference to the steps for calibrated simulation described in ASHARE Guideline 14-2002 [9]. As a quick energy simulation tool and latest version of DOE-2, eQuest has been widely used in evaluating the energy performance of buildings and predicting the energy-saving potentials of ERMs.

2.2.1. Geometric modeling

In order to ensure the reliability of the simulation, a detailed geometric model of the buildings was developed from the actual building plans. The building layout was determined from architectural drawings, and the model accounted for the azimuth of the buildings. Three-dimensional (3D) models of the hotel are shown in Figs. 1 and 2. Rather than defining the window-to-wall ratio, the window layout was determined according to the architectural plans. The structure of the buildings consisted of a frame shear wall with bricks or aerated concrete blocks. The envelope properties are shown in Table 2. The overall heat transfer coefficient (U-value) can be calculated by consulting a design manual [10]. For thermal zoning, the model referred to the actual zoning indicated by the HVAC plans instead of simple core-vs.-perimeter zoning that helped automatically zone the model in eQuest. A HVAC zone consists of a group of conditioned spaces that share a common thermostat. After the thermal partition, the thermal zones consist of core, perimeter, and plenum spaces with conditioned and unconditioned types. Some simplifications were made as follows: (I) the conditioned spaces that shared similar magnitude and schedule of