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Energy consumption comparison analysis of high energy efficiency office buildings in typical climate zones of China and U.S. based on correction model

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ABSTRACT

Actual operation energy consumption of the high energy efficiency buildings built and operated in China and U.S. has been quite different than expected. This paper compares actual energy consumption to expect high energy efficiency office buildings in U.S. and China. Considering the different indoor design temperature, climate conditions and operated period between the compared cases in the two countries impact on the building energy consumption, correction model was built to eliminate the influence of the three factors on the comparison result and put the comparison analysis of high energy efficiency office buildings in the two countries into the same level. Regard to building general information and climate condition, four pairs of buildings in typical climate zones of China and U.S. were selected to compare the building energy conservation technology and building energy consumption based on a large scale of investigation and testing. After corrected, the energy consumption data are analyzed, including total energy consumption, and sub-metering energy consumption such as heating, cooling, lighting, office equipment, etc.. The energy saving technologies applied in these four pairs of buildings was also compared to explain energy consumption differences.

1. Introduction

Buildings account for a significant proportion of the total energy and carbon emissions worldwide, and play an important role in formulating sustainable development strategies [1]. China and the United States are the two largest energy-consuming countries [2]. In recent years, a large scale of high energy efficiency buildings have been built and operated encouraged by both Chinese and U.S. government, which were usually labeled as certain ranks in U.S. or certain Stars in China. In these buildings, different kinds of energy saving technologies were applied; however, actual operation energy consumption of these buildings has been quite different than expected. The real operation energy consumption of these demonstration projects has seldom been paid close attention to.

Through a large scale of investigation, test and simulation, four pairs of office and other commercial buildings from typical climate zones in China and U.S. were respectively selected to compare building energy consumption differences between the two countries. The energy saving technologies applied in these four pairs of buildings were also compared to explain the reason for energy consumption differences.

Decisions taken in the early stages of architectural design have an important impact on energy demand and efficiency [3]. In this design phase, architects and engineers need to manipulate common concepts that reveal the influence of indoor design temperature, climate conditions and operation period on energy consumption which were also greatly different between U.S. and China. When the energy consumption data of the buildings in the two countries was obtained, directly comparison without regard to the three factors would cause deviation. In order to reduce or eliminate this deviation, it is necessary to establish a correction model.

Unquestionably, different indoor design temperature would cause different building energy consumption. The design and operations of energy systems are key issues for matching energy supply and consumption [4]. Aktacir [5] investigated the influence of different outdoor design conditions on air conditioning systems and found that the selection of outdoor design conditions is a very critical step in calculation of the building cooling loads and design capacities of air conditioning equipments. Korolija [6] studied the relationship between building heating and cooling load and subsequent energy consumption with different HVAC (Heating, Ventilating & Air-Conditioning) systems. The indoor design temperature in U.S. cases was

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more comfortable than that in China cases mentioned in this paper. In summer, indoor design temperature in U.S. cases were 2 °C lower than that in China cases, and in winter, indoor design temperature in U.S. cases were 2 °C higher than that in China cases. The base temperatures were different between China and the US, and it is not unreasonable to use the same base temperatures for both countries [7]. To allow for the differences in indoor design conditions, correction factors were adopted. American sacrifice a lot of energy consumption on the road of pursuing comfortability.

The same as indoor design temperature, the climate conditions also greatly influence the building energy consumption [8,9], which mainly concentrated in HVAC energy consumption while the influence on lighting energy consumption and office equipment energy consumption could be negligible. Li et al. [10] found that the outdoor climatic conditions developed for cooling load estimation via the simulations are less stringent than the current outdoor design data and approaches adopted by local architectural and engineering practices. Joseph [11] used computer package DOE-2.1E to investigate the influences of different weather data sets on the thermal and energy performance of cooling dominated office buildings in Hong Kong through computer building energy simulation techniques. Seventeen weather data sets from 1979 to 1995 were used for the computer simulation. The objective was to investigate the likely diversity in computer predictions based on different weather years. Predictions of annual cooling loads, peak cooling loads and annual electricity consumption were found to differ by up to about 14%. Zogou and Stamatelos [12] provided a comparative discussion on the effect of climatic conditions on the design optimization of heat pump systems and showed that climatic conditions significantly affect the performance of heat pump systems, which should lead to markedly different strategies for domestic heating and cooling, if an optimization is sought on sustainability grounds. Bulut [13] used the current outdoor design data locally used and the new data presented in their studies in order to evaluate the influence of the weather data set on the heating and cooling load. They found up to 25% and 32% differences between the cases considered for cooling and heating loads, respectively. Bruno Bueno [14] built a model used in a series of parametric analyses to investigate the impact of the Urban Heat Island effect on the energy consumption of buildings. For residential buildings in summer, a 5% increase in cooling energy demand can be expected per 1 K increase in the maximum Urban Heat Island effect (usually at night), which in another view proved the influence of climate on building energy consumption.

However, the operation period could not only influence the HVAC energy consumption [15,16] but also influence the lighting and office equipment energy consumption. Beerepoot [17] found that energy performance regulations have been successful in conserving energy. Santin [18] found that occupant characteristics and behavior significantly affect energy use (4.2%).

So, it is necessary to correct the influence of indoor design temperature, climate conditions and operation period on building energy consumption. And it is more reasonable to correct the submetering energy consumption in turn rather than correct the total energy consumption directly. In this paper, the building energy consumption data in China was made as reference and the building energy consumption data in U.S. was corrected.

2. Correction model

In the stage of design and operation, a variety of factors will have an effect on energy consumption. For example, if the operation period is changed, such as intermittent operation or continuous running, the energy consumption of the same building would be changed [15–18]. Also, if the indoor design temperature is changed, the energy consumption would be changed [4,5]. Moreover, if the same building located in the different climate zones, even if the operation period and indoor design temperature are unaltered, the energy consumption would be different [19–21].

Indoor design temperature, climate conditions and operation period have significant impact on building energy consumption exist objectively. Building energy efficiency technologies are not corrected in the model because these technologies applied in these four pairs of buildings were compared to explain the reason for energy consumption differences.

So it is necessary to consider these objective factors which have obvious significance for building energy consumption, such as indoor design temperature, climate condition and operation period. This correction model is designed to eliminate the influence of the three factors on building energy consumption. This way can make the comparison results more scientific than former correction. This paper focused on comparing the energy consumption data of high energy efficiency office buildings in typical climate zones of U.S. and China based on the recommended correction model.

2.1. Indoor design temperature correction factor

The indoor design temperature which have effect on building energy consumption include indoor air design temperature and outdoor calculated temperature which are also important parameters for energy efficiency of buildings. Indoor and outdoor design conditions corresponding to different frequency levels of probability for several locations in the United States and around the world are developed by the American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc [22]. Literature [23] expounded the relationship between indoor design temperature and calculated load.

According to the heat transfer calculation method of building envelope for heating in winter, the heating indoor design temperature energy consumption correction factor could be defined as follows:

$$\eta_{ho} = \frac{t_{hiCi} - t_{hoCi}}{t_{hiAi} - t_{hoAi}} \tag{1}$$

η_{ho} – Heating indoor design temperature energy consumption correction factor;
t_{hiCi} – Heating indoor design temperature of case *i* built in China, °C;
t_{hoCi} – Heating outdoor calculation temperature of case *i* built in China, °C;
t_{hiAi} – Heating indoor design temperature of case *i* built in U.S., °C;
t_{hoAi} – Heating outdoor calculation temperature of case *i* built in U.S., °C

The cooling indoor design temperature energy consumption correction factor could be defined as follows:

$$\eta_{co} = \frac{t_{ciCi} - t_{coCi}}{t_{ciAi} - t_{coAi}} \tag{2}$$

η_{co} – Cooling indoor design temperature energy consumption correction factor;
t_{ciCi} – Cooling indoor design temperature of case *i* built in China, °C;
t_{coCi} – Cooling outdoor calculation temperature of case *i* built in China, °C;