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Correlation analysis of energy consumption and indoor long-term thermal environment of a residential building

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Abstract

In China, energy consumption (EC) obtained by simulation is usually used as an indicator to assess residential building performance at the design phase. For free running buildings, due to the absence of heating/cooling equipment, EC may not be an appropriate indicator and using EC as a measure of building thermal performance may cause misleading at the design phase. In this paper, thermal discomfort rate (TDCR) was proposed as an indoor long-term thermal environment indicator, and was used to analyze the difference of building performance caused by using different evaluation indicators. Results showed that there existed a strong correlation between EC and TDCR when changing envelope design, but the trend and sensitivity may be different. Therefore, using EC to assess the thermal performance of free running buildings at the design phase may lead to poor indoor thermal environment. The results in this paper can be used to guide building design and energy-saving policy making.

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Keywords: correlation; sensitivity; energy consumption; thermal environment; building envelope; residential building

1. Introduction

In China, the energy use in the building sector is dominated by the residential buildings, whose final energy consumption increased by nearly 30% between 2000 and 2012, reaching more than 15 EJ. The residential sub-sector

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represents roughly 85% of the total building sector final energy consumption in China (including estimated biofuels use), with the remainder consumed in the other services sub-sector (commercial and public buildings 3 EJ) [1]. This urges to reduce the energy consumption in buildings, mainly in the residential ones.

In China, energy consumption (EC) obtained by simulation is usually used as an indicator to assess the residential building performance at the design phase. However, the surveys [2] showed that there are many residents that do not rely on air conditioning or heating facilities to improve the indoor thermal environment when outdoor climate is moderate. Some residents still only use the window ventilation or fans to meet their demand, even if the indoor temperature exceeded the standard requirements. Due to the absence of heating/cooling equipment, EC may not be an appropriate indicator for free running buildings and using EC as a measure of building thermal performance may cause misleading. The purpose of this study is to analyse the effects of the envelope design parameters on energy consumption of mechanical heated/cooled buildings and long-term thermal environment of free running buildings. Furthermore, the research on the correlation and difference between these two evaluation methods are the focus of this paper.

In recent years, many studies have focused on the evaluation of long-term thermal environment of residential buildings, but most of them were interested in how to enhance the building thermal environment by optimizing the envelope design. Thermal and energy performance of residential buildings were optimized by combining sensitivity analyses and simulation-based optimization in the Argentine Littoral region [3]. An optimization procedure that adopts the 'Long-term Percentage of Dissatisfied' to support the design of a net zero energy building located in a warm climate was proposed [4, 5]. Long-term discomfort indicators based on Fanger and adaptive comfort model were proposed to assess the thermal discomfort of a reference free-floating building in 16 different climatic zones of California [6]. A detailed review of long-term discomfort indices proposed in literature is given in [7].

In this paper, a typical dormitory building model in Changsha, China, was established and simulated by EnergyPlus software [8]. An indicator of long-term thermal environment called thermal discomfort rate (TDCR) was proposed and used to evaluate the indoor thermal comfort condition. Then the correlation between EC and TDCR indicator was analysed under different envelope designs. In addition, the sensitivities of these two indicators to envelope design were also discussed.

2. Methodology

2.1. Indicator to evaluate indoor long-term thermal environment

The more frequent cooling or overheating, indicates that the worse the building thermal environment. In this paper, thermal discomfort rate (TDCR) was proposed to evaluate the indoor long-term thermal environment. TDCR was calculated through the following procedures [9]:

1) After the simulation was complete, the indoor operative temperature range was divided into several subintervals. Then the number of temperatures (N_i) that fall in each subinterval can be obtained.

2) Based on the consideration of the degree of overheating and overcooling, the weighting factors $W_{w.i}$ and $W_{s.i}$ were introduced and calculated by

$$W_{w.i} = (t_l - t_{o.i})/(t_l - t_{\min}) \tag{1}$$

$$W_{s.i} = (t_{o.i} - t_u)/(t_{\max} - t_u) \tag{2}$$

where $t_{\max}$ and $t_{\min}$ are the maximum and minimum annual ambient temperature [^{o}C], t_u and t_l are the upper and lower limits of the thermal comfortable temperature [^{o}C], which were defined as 16^{o}C and 28^{o}C in this study [9].

3) Then the TDCR indicator for winter and summer was calculated:

$$\mathrm{TDCR}_w = \sum_{i=t_{\min}}^{t_L} N_i \times W_{w.i} \tag{3}$$