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Field study on energy economic assessment of office buildings envelope retrofitting in southern China

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ABSTRACT

Energy consumption of buildings accounts for more than 37.3% of total energy consumption while the proportion of energy-saving buildings is just 5% in China. In this paper, in order to save potential energy, the building envelope retrofitting is considered. An office building in Southern China was selected as a test example for energy consumption characteristics. The base building model was developed by TRNSYS software and validated against the recorded data from the field work in six days out of August-September in 2013. In addition, with a design of numerical simulation, sensitivity analysis was conducted for energy performance of building envelope retrofitting; six envelope parameters were analyzed for assessing the thermal responses. Results show that significant energy savings are obtained for the thermal transmittance (U-value) of exterior walls, infiltration rate, ventilation and shading coefficient, of which the sum relative sensitivity is about 91.06%. The results are evaluated in terms of energy and economic analysis. On the other hand, it appears that the cost-effective method improves the efficiency of investment management in building energy.

1. Introduction

According to the announcement of ASHRAE Handbook HVAC Applications, building sector is responsible for more than 40% of the global end-use energy consumption (ASHRAE Handbook-HVAC Applications, 2011). As the second largest building energy user around the world, China ascends first in residential energy consumption and ranks third in commercial energy consumption (International Energy Agency (IEA), 2007). The final energy consumption in Chinese buildings grew by 37.3% in 2015; if this trend continues, the energy use could increase by 70% in 2050 (Department of Energy statics, National Bureau of Statics of China, 2015; International Energy Agency (IEA), 2015; Tsinghua University, 2015).

It is reported that 33% of all global carbon emission could be attributed to existing buildings, while newly buildings only accounted for a limited proportion (Kelly, 2009). It is broadly recognized conducting cost-effective retrofits on existing buildings exerts it crucially to achieve the goals of green buildings; this is due to the large ratio of existing buildings to new constructions (Koester, Eflin, & Vann, 2006; Huang, Niu, & Chung, 2011). Effective reform or more stringent energy-efficiency standard would embrace the retrofitting market of building energy conservation. The "Green Building Action Plan" released by the Chinese central government stated that the total floor area of retrofitting existing buildings will reach 570 million square meters by 2015 in China (General Office of the State Council of the People's Republic of China, 2013; Zhou, Zhang, Wang, Zuo, & He, 2015). However, there are insufficient regulations which fix minimum thermal requirements in office buildings, thus it is significant to enhance the existing buildings' energy efficiency.

Technology and management are the vital impact factors that influence the effectiveness of building energy retrofitting (Gao & Tang, 2010). Reference literatures of technology in the related area concerned about the thermal insulation materials (Al-Homoud, 2005; Asadi, Silva, Antunes, & Dias, 2012; Jaehun & Jehean, 2016). Some studies focused on the windows replacement and thermal performance (Bojic, Yik, & Sat, 2002; Stegou-Sagia, Antonopoulos, Angelopoulou, & Kotsiovelos, 2007). Different building environmental assessment tools by occupants or life cycle phases of buildings were also analyzed in (Happio & Viitaniemi, 2008; Ng, Chen, & Wong, 2013). Some literatures researched the energy-saving potential in the way of retrofitting residen-

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Nomenclature

EPS	Expanded polystyrene
ESMs	Energy-saving measures
inf.	Infiltration rate
NPV	Net-present-value
SC	Shading coefficient
U_{frame}	Thermal transmittance of frame
U_{glass}	Thermal transmittance of glass
U-roof	Thermal transmittance of roof
U-value	Thermal transmittance
U-window	Thermal transmittance of window
U-wall	Thermal transmittance of wall
vol.	Volume of workplace

tial building envelope to reduce the ventilation losses (Cetiner & Edis, 2014; Dall'O', Galante, & Pasetti, 2012). Many of the studies were based on theoretical calculation. Additionally, the approach of dynamic calculation and monitoring studies guarantees the possibility of further research (Cantin, Burgholzer, Guarracino, Moujalled, Tamelikecht, & Royet, 2010; Martin, Mazarrón, & Canas, 2010); TRNSYS is one of the appropriate tools, which bridges the gap between predicted and actual building energy performance (Buratti, Moretti, Belloni, & Cotana, 2013; Terziotti, Sweet, & McLeskey, 2012; Yu, Haghighat, Fung, 2015). As to the management aspects, the application of energy saving measures usually needs to be supported by economic assessments. Gero et al., for example, proposed a multi criteria model and explored the trade-offs between the building thermal performance and capital cost of the building (Gero, Neville, & Radford, 1983). Goodacre et al. applied a cost-effective method to assess the potential scale of the benefits from upgrading heating and hot-water energy efficiency in English buildings (Goodacre, Sharples, & Smith, 2002). A desired efficiency label at the minimum cost with the multi-objective optimization method was obtained (Asadi, Silva, Antunes, & Dias, 2012; Tadeu, Alexande, & Tadeu, 2015). Different envelope retrofitting methods were also evaluated the results under an economical Net-present-value (NPV) approach (Terés-Zubiaga, Campos-Celador, González-Pino, & Escudero-Revilla, 2015).

However, although the methods of envelope retrofitting have been extensively studied, there is little information available about the capacity of energy saving in office building envelopes; and literature about the comprehensive way of evaluating the retrofits in building energy is still insufficient in Southern China. In this study, 27 combined energy-saving measures (ESMs) have been applied with TRNSYS software to enhance the efficiency of office building envelope. These measures are exterior walls insulation, infiltration repairs and windows replacement. Some important contributions in this paper are found, including that the daily energy demand is well recorded for the usage of model checking. On the other hand, unlike the traditional retrofits, the sensitivity factor of the envelope that signifies the capacity of energy saving in different envelopes is applied, playing a key role in combining diverse ESMs. Moreover, these combined scenarios' results are evaluated under an economic and energy analysis, which is useful for the future building energy-efficient retrofitting practices and the policy-making in southern China.

2. Methodology

2.1. Approach of the study

A prevailing approach has been applied throughout this paper; the studied building is treated as open systems considering interactions between the dwelling and the environment. This approach is based on the integration of monitoring studies and simulation methods. The researched building was monitored in order to calibrate the simulation model; the building was retrofitted in different ways and the results were evaluated in terms of energy and economic analysis. Similar approaches have been explained and used in Terés-Zubiaga et al. (Nikolaidis, Pilavachi, & Chletsis, 2009; Terés-Zubiaga, Martin, Erkoreka & Sala, 2013; Terés-Zubiaga et al., 2015).

2.2. Case study selection

In this study, a multi-office building named Jicheng Mansion (JCM), which is located in Tianhe District of Guangzhou, China, has been selected as the reference building. The building was constructed in 2003, a specific construction period in which a significant number of similar office buildings had been built up before legislative acts on building energy conservation was carried out. The appearance of the reference building is described in Fig. 1.

The 10-storey building has a net conditioned floor area of 612 m^2, of which the overall floor area is 6120 m^2. The ceiling height of this building is 33.6 m, and the window-wall ratio is 0.3. The building is mainly consisted of reinforced concrete. The window is composed of single glass.

2.3. Monitoring study

In sure of obtaining data to calibrate the building simulation model, the reference building JCM has been monitored. The building has four external walls, oriented South, West, North and East. Obviously, there are three thermal zones in each floor, i.e., the Storage with two toilets, the Workplace and the Staircase with an elevator. The Workplace is the conditioned thermal zone, with a net floor area of 456 m^2; the other two rooms are unconditioned thermal zones. The building outline is depicted in Fig. 2.

Fig. 2 shows the outline of each floor. As to Workplace, the south wall is an interior wall without solar heat gain. The office building is equipped with a central air-conditioning system. Southern China is located in a subtropical area, and the refrigeration season is yearly from May to November, thus cooling demand is solely concerned in this case. Due to the rated refrigerating capacity of the air-conditioning system, the chiller supplies cooling load for 7 floors, and the 1st, 5th and 9th floors are not equipped with air conditioners.

The data of the inlet water temperature, outlet chilled water temperature and flow rate of chilled water were recorded from the

Fig. 1. General view of JCM.