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Challenges for energy and carbon modeling of high-rise buildings: The case of public housing in Hong Kong

Wei Pan*, Hao Qin, Yisong Zhao

Department of Civil Engineering, The University of Hong Kong, Haking Wong Building, Pokfulam, Hong Kong, China

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ABSTRACT

Buildings are a main contributor to energy consumption and carbon emissions. The approach of low energy or low carbon building has been widely adopted. However, there exist challenges for energy and carbon modeling, particularly of high-rise buildings in high-density urban environments. The aim of this paper is to examine the challenges and develop strategies for energy modeling of high-rise buildings drawing on the case of public housing in Hong Kong. The paper reviews the knowledge barriers to the use of building energy analysis software and proposes a workflow to incorporate energy simulation into the design stage. Considering the urban environmental factors that may contribute to biased results of energy simulation, the technical issues during the conversion of data from BIM model to energy simulation software are investigated. Thermal zones and user behaviors are also examined as technical and subjective assumptions could lead the simulation to a wrong direction. The examined challenges and developed strategies will help achieve building energy simulation and carbon emission estimation of high-rise buildings in Hong Kong with efficiency and accuracy and also inform practices in other relevant urban settings.

1. Introduction

Buildings together contribute to over a third of world's energy consumption and carbon emissions (Pan and Garmston, 2012). Buildings in Hong Kong account for almost 92% of electricity use and 60% of greenhouse gas (GHG) emissions in the city (EMSD, 2014), far exceeding the world averages. Hong Kong now has roughly 2671,900 stocks of living quarters as at end-October 2014 (HKCSD, 2014) with substantial annual increases. Tackling GHG emissions from buildings is an important strategy for achieving government goals for substantial GHG emission reductions and long-term sustainability in Hong Kong. In particular, the HKSAR Government has pledged to achieve a reduction in carbon intensity of at least 50–60% on the 2005 baseline by 2020 (ENVB, 2010). The Environmental Protection Department and Electrical and Mechanical Services Department (EPD and EMSD, 2010) of the Government have developed and implemented a set of guidelines to account for and report on GHG emissions and removals for commercial, residential or institutional buildings in Hong Kong.

Previous research has concluded that the operational carbon emissions have the major share of the life cycle carbon emissions of the building (Atmaca and Atmaca, 2015). It is therefore vital to estimate the operational carbon emissions of buildings in early design stages and alert the designer to refine their designs should the estimated carbon emissions of the building exceed specification. It has been indicated that building energy analysis (BEA) software can be used to calculate the operational carbon emissions based on the simulated building energy consumption and relevant carbon conversion factors (Tettey et al., 2014; Peng, 2015; Oladokun and Odesola, 2015; Mata et al., 2013). However, challenges exist in the modeling process. There is a lack of knowledge of the usability, interoperability and accuracy of BEA software. This knowledge gap is coupled with the paucity of understanding of the uncertainties in the BEA of buildings and occupant behaviors in the complex high-rise high-density urban environment.

The aim of this paper is thus to examine the challenges and develop strategies for energy and carbon modeling of high-rise buildings. The research was carried out through literature review and technical analysis to examine the challenges. The examined challenges were contextualized and demonstrated using a real-life project case study with a 40-storey public residential building in Hong Kong as a typical high-density urban environment under hot-and-humid subtropical climatic conditions. In addressing the

* Corresponding author at: Postal address: The University of Hong Kong, Haking Wong Building, Pokfulam, Hong Kong, China. Tel.: +852 28592671; fax: +852 25595337.
E-mail address: wpan@hku.hk (W. Pan).

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Table 1
Definitions of high-rise buildings.

Source	Definition
National Fire Protection Association 101®, Life Safety Code, 2012 edition	A high-rise building is a building more than 23 m in height, measured from the lowest level of fire department vehicle access to the floor of the highest occupiable story
Council on Tall Buildings and Urban Habitat	A tall building is a building of perhaps 14 or more stories (i.e. or over 50 m in height); A super-tall building is a building over 300 m in height, and A mega-tall is a building over 600 m height
Code of practice for minimum fire service installations and equipment and inspection, testing and maintenance of installations and equipment (Fire Services Department HK, 2012)	Any building of which the floor of the uppermost story exceeds 30 m above the point of staircase discharge at ground floor level

challenges the paper develops relevant strategies before conclusions are drawn.

2. High-rise buildings and building energy modeling approaches

The definitions of high-rise or tall buildings measured by meters or number of storeys vary in different regions or countries (Table 1). The definition provided by the Hong Kong Fire Services Department refers a high-rise building to one, of which the uppermost storey exceeds 30 m above the point of staircase discharge at ground floor level.

Due to the scarce land resource suitable for urban development in Hong Kong, high-rise buildings are the dominant building type in the city. Qin (2015) conducted a comprehensive survey of the residential buildings built in Hong Kong from 2003 to 2013 and found that the buildings ranged from 8 to 65 storeys with the median value being 32 storeys which is affiliated with the building height around 100 m. Based on the definition above, almost all of the residential buildings in the urban areas of Hong Kong are high-rise. Therefore, high-rise buildings are a most important component of the building sector in Hong Kong for achieving energy and carbon reductions.

Due to the rapid development of computer technology, BEA is widely adopted in research and real practice worldwide. Various software/tools are used in the simulation of energy performance of different building types and building parts. A large number of such previous studies were about energy modeling or simulation of low-rise buildings holistically (e.g. Almeida et al., 2015; Bambrook et al., 2011; Carrilho da Graça et al., 2012; Cellura et al., 2015; Deng et al., 2011; Fong and Lee, 2012; Méndez Echenagucia et al., 2015; Shoubi et al., 2014; Tettey et al., 2014), and some focused on modeling of building parts (e.g. Chan and Chow, 2013; Chan et al., 2009; Ihara et al., 2015). Some others were carried out of high-rise buildings (e.g. Bojić et al., 2002; Bojić and Yik, 2005, 2007; Chan, 2015; Chen et al., 2008; Cheung et al., 2005; Lee et al., 2015; Peng, 2015; Sozer, 2010).

The approaches to energy modeling of high-rise buildings adopted in previous studies vary (Table 2), but there appear to be several common ones: (1) modeling one or multiple flats of an intermediary storey (Bojic et al., 2001; Bojic et al., 2002); (2) modeling one typical storey (Bojić, 2006; Bojić and Yik, 2007); (3) modeling three representative floors, i.e. ground, middle and top floors (Chen et al., 2008); (4) modeling representative flat(s) of all storeys (Chan, 2015); (5) modeling all storeys without surroundings (Peng, 2015); and (6) modeling all storeys with surrounding environment (Sozer, 2010).

The simplification of building geometry such as the first and second approaches listed has been most widely adopted, as these approaches can greatly reduce computation time. However, the accuracy of simulation results based on such simplification is questionable. Also, ignoring the presence of adjacent buildings (Burnett et al., 2005) imposes uncertainty on simulation results. In short, there is a great diversity of modeling approaches for high-rise buildings in BEA, which calls for a set of widely accepted rules to simplify the process while ensuring accuracy.

In addition, there is still a lack of use of systems approaches for modeling high-rises. The simulation of design strategies is normally carried out in a separate manner, rendering the building's systems features overlooked. For example, previous studies normally focused on one strategy, e.g. the usage of solid oxide fuel cell tri-generation system (Fong and Lee, 2014), district cooling systems (Chow et al., 2004), and secondary loop chilled water (Ma et al., 2008). However, the interdependence between building fabric, building services systems and renewable energy remain largely unknown.

The purpose of modeling buildings' energy consumption is to inform design decision making. However, current practices of modeling high-rises for achieving low or zero carbon still encounter significant challenges in supporting design decision making. The topmost challenge is the absence of a common zero carbon definition for high-rise buildings. It is of great importance to clarify the scope of energy consumption in the definition, e.g. the lighting appliances and plugs, usage of renewable energy (see Pan and Ning, 2015). For example, if lighting appliances are excluded from the definition (e.g. in the UK), the use of energy-efficient lightings may not be prioritized in energy modeling. Another challenge exists with occupant behaviors. A number of previous studies have revealed the relationship between building energy performance and occupant behaviors (Haas et al., 1998; Branco et al., 2004; Lindén et al., 2006; Guerra-Santin and Itard, 2010). However, although buildings' energy performance regarding building envelope and interior systems can be simulated using many simulation software/tools, quantifying energy use from occupancy is still a challenge. Interactions between occupants and building systems such as thermostats, windows, lights and blinds can have a significant impact on the total energy use of a building. Some researchers have argued such impact can be up to a factor of 30% (Andersen et al., 2007). A further challenge resides with the lack of specific requirements for renewable energy for high-rise buildings, which might impede the uptake of such technologies in the modeling. For high-rise buildings the use of renewable energy is of critical importance to achieving the net zero of energy use and carbon emissions.

3. Challenges to energy/carbon modeling of high-rise buildings and the case in Hong Kong

3.1. Challenges in BEA process and software

3.1.1. BEA software

After more than five decades of development, technology of building energy simulation has been well established. There exist numerous building energy simulation tools. US Department of Energy lists more than four hundreds building energy simulation tools on their website, among which many perform whole building energy simulations. However, there are still many issues with the use of BEA software in the building design stage (Attia et al., 2012). Most of the BEA software/tools are only designed for engineers without considering the usability by architects. Crawley et al.

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