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An object-oriented energy benchmark for the evaluation of the office building stock

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A R T I C L E I N F O

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A B S T R A C T

Energy benchmarking is useful for understanding and enhancing building performance. The aim of this research is to develop an object-oriented energy benchmarking method for the evaluation of energy performance in buildings. Statistical analysis of the four-year monitored energy consumption data for office buildings was conducted. The results show that the energy use intensity follows the lognormal distribution with the Shapiro–Wilk normality test. Based on the lognormal distribution, the energy rating system for office buildings has been established. An object-oriented energy use intensity quota determination model has been developed. This research provides practical tools that enable decision-makers to evaluate a building's energy performance and determine the energy benchmark.

1. Introduction

China is one of the largest energy consumers in the world. In 2014, China generated 24% of the world's electricity while consuming 21.2% of the world's total final consumption and emitting 28.2% of the world's CO_2 emissions from fuel combustion (IEA, 2016). The total energy consumption of construction and operation in the Chinese building sector accounts for 36% of the total energy consumption in China (THUBERC, 2016). Building energy consumption associated carbon emission has drawn major concern nationally and internationally. China has a distinctive building classification system with buildings classified into two major groups: civil and industrial. Civil buildings are divided into residential buildings and public buildings. The public buildings are further classified into office, commercial and hotel buildings along with buildings in major sectors such as education, health, communication and transportation (see Fig. 1).

A nationwide large-scale investigation into energy efficiency of buildings carried out over ten years ago recognized that government offices and large-scale public buildings were to be the key focus of China's energy efficiency reform (Liang et al., 2007). Public buildings are more energy intensive compared to residential buildings. Especially, the energy use intensity (EUI) of large-scale public buildings (those with more than 20,000 m^2 floor area) is 10–20 times higher than that of urban residential buildings (MOHURD, 2014). According to the study by Tsinghua University Building Energy Research Center (THUBERC, 2016), in 2014 energy consumed within public buildings accounted for more than 27% of total energy consumption in buildings. China has set an ambitious target of reducing carbon dioxide emissions by 60%–65% per unit of GDP based on the 2005 baseline by 2030 (Department of Climate Change, 2015). The public building sector, with its enormous potential for energy saving and emission reduction, has been targeted for energy conservation in order to achieve the national goal (MOHURD, 2017). Legislation had recommended compulsory compliance with building standards and codes for the new buildings (Yao et al., 2005). However, this posed great challenges for the existing buildings, 95% of which were “highly-energy-consuming" (Xu et al., 2009). Therefore, building retrofitting strategies, including improvement of building envelope performance; application of renewable technologies; improvement of the efficiency of energy systems; and intelligent operation and energy management, were to be considered by central and local authorities to achieve the carbon-reduction targets while maintaining a comfortable and sustainable built environment. In practice, two questions remain: What is the distribution of energy performance in the current building stock? How can the decision-makers evaluate and rank the energy performance of buildings within the stock to identify, prioritize, and target buildings for retrofitting? Energy benchmark is a useful measure for understanding and enhancing building performance.

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Nomenclature

Symbols

A	building gross floor area [m^2]
d	natural logarithm of the building EUI [kWh/m^2]
D	building EUI [kWh/m^2]
E	hourly electricity consumption [kWh]
EXPF(x)	expectation function of lognormal distribution
f(x)	probability density function of the lognormal distribution
GD	gross building EUI [kWh/m^2]
CDF(x)	cumulative distribution function of the lognormal distribution
r	the planned stock gross floor area increase rate [%]
S	building energy saving percentage compared to baseline year energy consumption [%]
SA	stock gross floor area in baseline year (gross floor area for office buildings) [m^2]
UEXPF(x)	updated expectation function of the lognormal distribution
PSA	planned stock gross floor area in the future [m^2]
v	target building EUI [kWh/m^2]
Φ	cumulative distribution function of the standard normal distribution
μ	mean value of the natural logarithm of EUI [kWh/m^2]
σ	standard deviation value of the natural logarithm of EUI [kWh/m^2]

Abbreviations and acronyms

CDD	cooling degree day
EUI	energy use intensity
HDD	heating degree day
HSCW	hot summer and cold winter
HVAC	heating, ventilation and air conditioning
GFA	gross floor area
CPBECMP	Chongqing public building energy consumption monitoring platform

Subscripts

t	t^{th} hour of the year

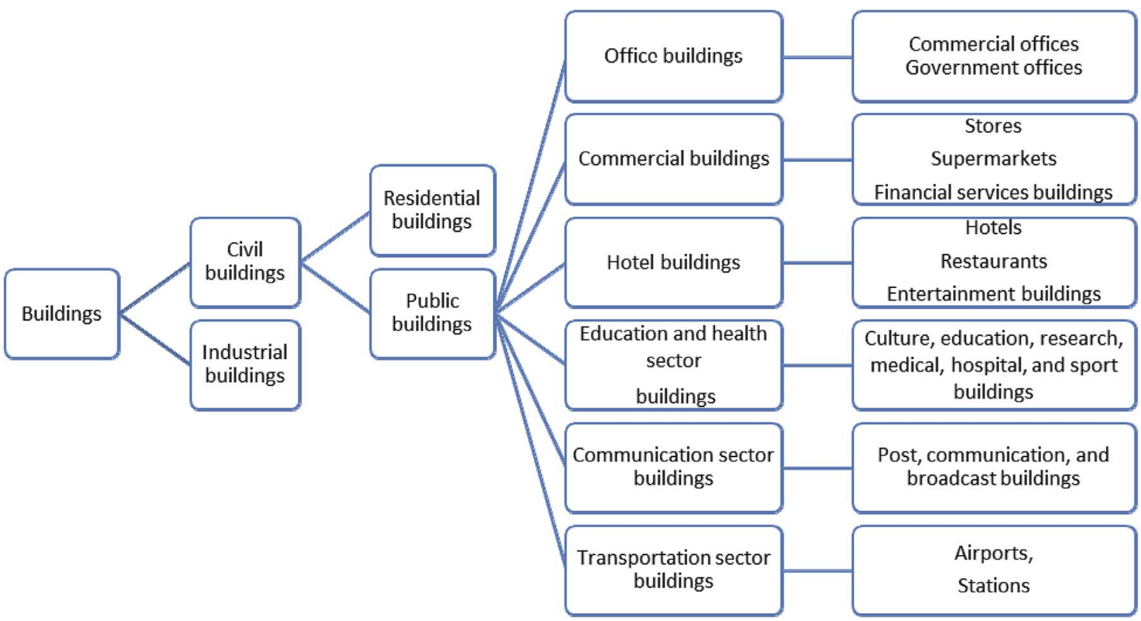

Fig. 1. Chinese building classification (Yao et al., 2016b).

The aim of this research is to develop an object-oriented energy benchmarking method which could be used for the evaluation of energy performance in the building stock and for deciding on actions for improvement. Using this new method, local authorities will be able to set up realistic and scientifically-sound energy benchmarks to reduce carbon emissions from buildings and minimize their environmental impact. The framework of the paper is presented in Fig. 2.

2. Literature review

The establishment of realistic benchmarks and quota mechanisms requires two main steps: the collection of energy consumption data and building energy benchmark setting.

2.1. Building energy performance data

To set a reasonable building energy benchmark for a group of buildings sharing the same function, a detailed analysis of building energy performance is needed. No matter what methodology is used, adequate, valid, and reliable data are essential. The data sources for building energy consumption are twofold: actual performance data collected by surveying or monitoring and simulation data generated from computer models. The computer simulation software can be used to calculate building energy consumption (Boyano et al., 2013; Gao et al., 2014; Pomponi et al., 2015; Xu et al., 2013; Yao et al., 2016a), but a performance gap exists between predicted or simulated energy use and actual energy use (Burman et al., 2012, 2014; de Wilde, 2014; Menezes et al., 2012; Salehi et al., 2015; Wilde and Jones, 2014). Onsite measured data is favored for the evaluation of the actual energy performance of buildings.

First conducted in 1979, the Energy Information Administration (EIA) in the United States continuously carries out national surveys and collects information including energy-related building characteristics and energy usage data for commercial buildings, the Commercial