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An Investigation on Energy Consumption of Public Buildings in Chongqing, China

Xinyi Li[#1], Qin Li[#2], Baizhan Li[#3], Runming Yao[*#4]

 # National Centre for International Research of Low Carbon and Green Buildings,
funded by MOST, Chongqing University

Faculty of Urban Construction and Environmental Engineering, Chongqing University,
Campus B, Shapingba District, Chongqing, China, 400000

* School of the Built Environment, University of Reading

Engineering Building, School of the Built Environment, University of Reading, Whiteknights,
P.O Box 219, Reading, RG66AW, UK

[1]amylee_lixinyi@163.com

[2] muzishuixin_1013@163.com

[3]baizhanli@cqu.edu.cn

[4]r.yao@reading.ac.uk

Abstract

Global climate change is one of the most important environmental issues that human have ever faced. China is taking an active role in reducing carbon dioxide emission in order to alleviate the climate change process. Building sectors contribute for 30% of carbon emission and 27.5% of total energy consumption in China. There is an urgent need for improving building energy efficiency to achieve carbon reduction. New buildings are legislated by national standards and regulations to secure a relatively high level of energy efficiency. However, the diversity of architectural design, system operation and management make it a big challenging to achieve energy efficiency in existing buildings. Existing researches have already investigated the building retrofit technologies and strategies. However, information on the current building stocks is even more important due to its impact in decision makings of retrofit strategies. This paper investigates the energy consumption of public buildings in Chongqing, China. Building energy consumption data collected from Chongqing public building energy consumption monitoring platform was analyzed by SPSS software. The data collection and analysis are focused on governmental office, general office, hotel buildings and shopping mall. Statistical hypothesis test, using log-normal P-P plot and Shapiro–Wilk test, reveals that the annual energy consumption densities of these types of building are log-normal distributed.

Keywords – Building energy consumption; Public buildings; Hypothesis test

1. Introduction

Global climate change is one of the most important environmental issues human has ever faced, and the greenhouse gas (including carbon dioxide as the primary greenhouse gas emitted through human activities) contributes significantly to global climate change [1]. To reduce greenhouse gas emissions and slow down the climate change process remains a worldwide challenge. China is paying great attention and working actively on reducing greenhouse gas emissions. After the implication of a series of climate change actions, carbon dioxide emissions per unit of gross domestic product (GDP) is 33.8% lower than the 2005 level by 2014. The new national goal set for 2030 is to lower carbon dioxide emissions per unit of GDP by 60% to 65% from that of 2005 level [2]. Building sectors contributes to 30% of carbon dioxide emissions and 27.5% of total energy consumption in China [3, 4]. Therefore, the improvement of energy efficiency is urgently required. New buildings are legislated by national standards and regulations to secure relatively high energy efficiency[5]. However, the diversity of architectural design, system operation and management makes it challenging to achieve energy efficiency in existing buildings. Civil building in China has been classified into public building and residential building. The energy consumption density of public building is much higher than residential building. The energy consumption density of large-scale and small-scale public buildings are of 10-20 times and 5-8 times higher than that of urban residential buildings respectively [3]. Public buildings accounts for 20% of total floor area but they consumed 26% of total energy in China [6]. Therefore, in recent years, research attention had been paid on public buildings in aspect of energy policy and technology implementation. The knowledge of the energy consumption in existing public building stock is the fundamental information needed by policy makers to set up energy benchmark. This paper presents a study on investigation of public building energy consumption in Chongqing, China.

2. Research Method

2.1. Large-scale Survey

The method of large-scale survey on building energy consumption has been applied in many developed countries. First conducted in 1979, the Energy Information Administration in United States carried out a national sample survey that collected energy-related building characteristics and energy usage data on the commercial buildings, namely Commercial Buildings Energy Consumption Survey (CBECS)[7]. In the United Kingdom, the Department of Energy and Climate Change (DECC) set up the Building Energy Efficiency Survey (BEES) and the National Energy Efficiency Data-Framework (NEED) for building energy consumption data collection and energy efficiency analysis[8, 9]. The large-scale energy consumption data collection started relatively late in China, the existing building energy consumption studies were mainly based on small-scale survey and measurement [10-13]. The representative of subjected buildings is unclear which makes the application of their results quite limited. Beginning in 2007, the Minister of Housing and Urban-Rural Development (MOHURD)

built up the Chinese national statistical system of energy consumption for public buildings based on the large-scale data collection. The method was used to collect both basic building information (including name, year of complement, function, floor area et al.) and building energy consumption information[14]. Nowadays, thanks to the fast development of the IT industry, the measuring and monitoring system which enables the real-time data collection becomes realistic. Chongqing is one of the pilot cities using the monitoring system to obtain energy consumption in public buildings. Electricity is the main energy used in Chinese public buildings[6]. Therefore the electricity is the only measured energy in monitoring platform. The Chongqing platform was completed in 2012 and served to dynamically monitoring the electricity consumption of buildings. A preliminary paper was published in 2015 on the energy consumption of governmental office buildings in Chongqing [15].

2.2. Monitoring Platform

The Chongqing public building energy consumption monitoring platform monitored 207 public buildings in 2012 with an overall floor area of 5.5 million square meters. The data collected includes building basic information and hourly electricity consumption. In this pilot project, only governmental office, general office, hotel buildings and shopping mall were studied in detail. The numbers of the surveyed building and total floor areas are shown in Fig. 1. The governmental office building has the largest building number and highest total floor area, whilst the hotel building has the lowest total floor area but of the second largest building number.
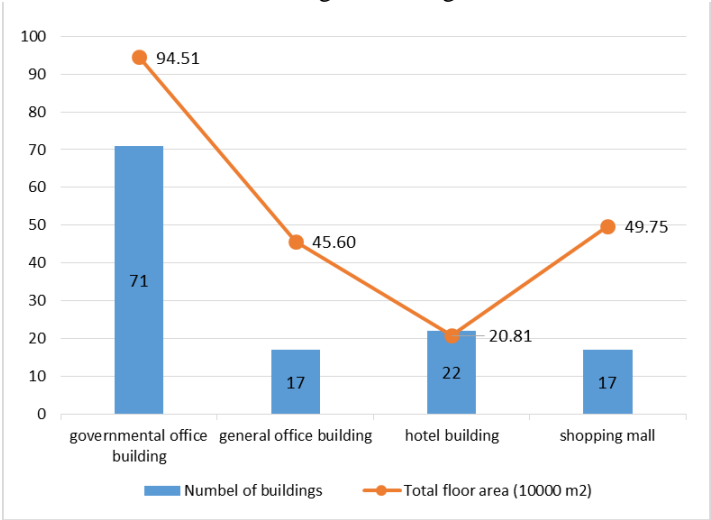

Fig. 1 The number and total floor arae of different building types

2.3. Data Analysis

Annual Energy Consumption

The annual energy consumption of each building can be calculated using (1),

$$D = \frac{\sum\limits_{t=1}^{8760} E_t}{A} \tag{1}$$

Where,
A is the building total floor area (m^2),
D is the annual building energy consumption density (kWh/m^2),
E_t is the hourly electricity consumption at the tth hour of the year (kWh).

The annual energy consumption density distributions of different building types are presented in Fig. 2.
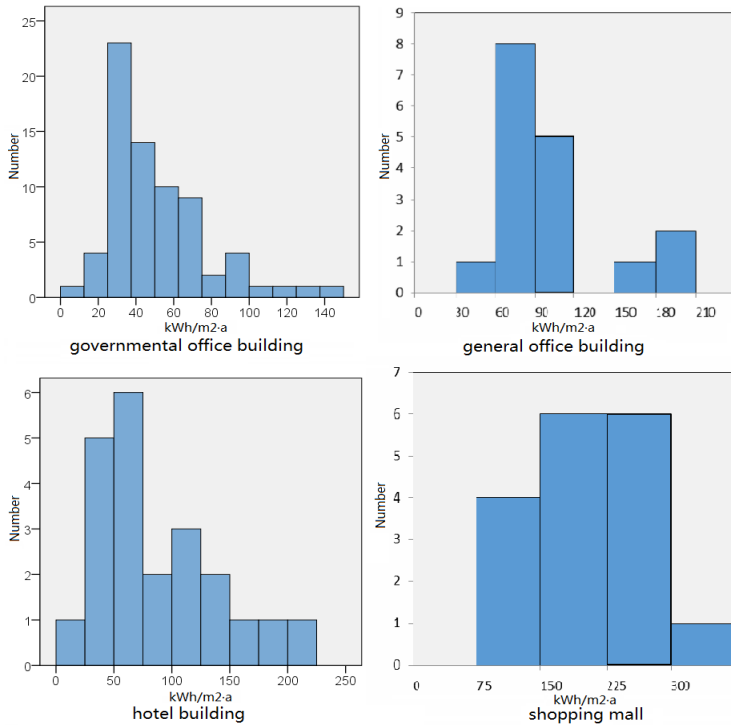

Fig. 2 The annal energy consumption density distribution of different building types

Statistical Hypothesis Test

From the Fig. 2 we can see that the annual energy consumption densities are non-negative and their distributions are skewed to the left. This indicates that the annual energy consumption density may have the log-normal distribution. Therefore, the hypothesis test has been used to check the annual energy consumption density distribution of different building types. The hypothesis couple set for all the building types shown as following,

The null hypothesis H_0: the natural logarithm of annual energy consumption density is normally distributed;
The alternative hypothesis H_a: the natural logarithm of annual energy consumption density is not normally distributed.

The natural logarithm of annual building energy consumption can be calculated using (2):

$$d = \ln D \qquad (2)$$

Where,
d is the natural logarithm of annual building energy consumption density,
D is the annual building energy consumption density (kWh/m^2).

SPSS software was used to conduct the hypothesis test including P-P plot and Shapiro–Wilk test. P-P plot is used to assess the likelihood that the natural logarithm of annual energy consumption density "d" complies with a normal distribution. The comparison line is the 45 ° line where the theoretical cumulative probability and empirical cumulative probability is equal. If all the points fall on this line, it indicates an equal distribution between the natural logarithm of annual energy consumption density "d" and the normal distribution. P-P plot has the merit of intuitively appealing, but it subjectively relies on informal human judgment to accept or reject the null hypothesis.

The Shapiro–Wilk test is a test of normality in frequentist statistics, and it was used to determine whether the natural logarithm of annual energy consumption density "d" follow the normal distribution. The most commonly used significance level α=0.05 has been set up, which indicated that level of confidence for our Shapiro–Wilk test result is 95%. If the p-value is bigger than the significance level α, the null assumption should be accepted and it's reasonable to believe that the data of natural logarithm of annual energy consumption density "d" is normally distributed. The mean value and standard deviation of the samples were also calculated.

3. Result and Discussion

Based on the method described above, SPSS package has been used for statistical analysis. The P-P plots of the natural logarithm of annual energy consumption density

for the four types of public building are shown in Fig. 3. From the figure we can see that all the points are falling on or close to the 45 ° comparison line. This indicates the normal distribution of the natural logarithm of annual energy consumption density by visual judgment.
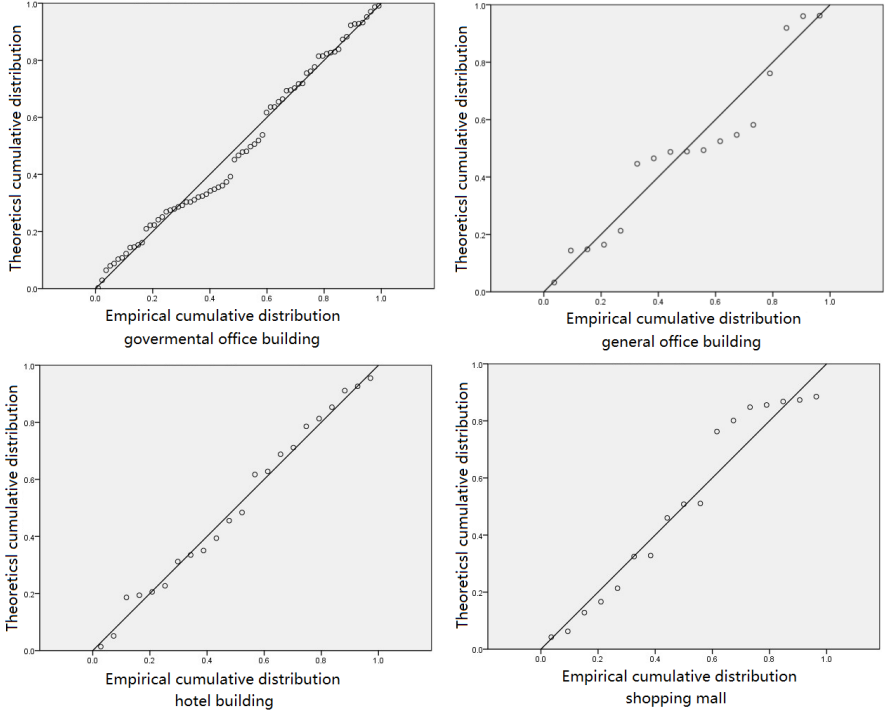

Fig. 3 The P-P plots of natural logarithm of annual energy consumption density for different building types

The result of Shapiro–Wilk test is presented in Table 1. All building types have passed the Shapiro–Wilk test with p-value greater than 0.05 indicating that the natural logarithm of annual energy consumption density "d" for governmental office, general office, hotel buildings and shopping mall are normally distributed. This further proved that the annual energy consumption density of the above building types are log-normal distributed, and their detailed distributions are as following,

For governmental office building, $D \sim \ln N (3.8354, 0.487^2)$
For general office building, $D \sim \ln N (4.1071, 0.536^2)$
For hotel building, $D \sim \ln N (4.3179, 0.626^2)$
For shopping mall, $D \sim \ln N (4.7983, 0.533^2)$

Table 1. The result of Shapiro–Wilk test for natural logarithm of annual energy consumption density "d"

Statistic result \ Building type	Governmental office building	General office building	Hotel building	Shopping mall
Shapiro–Wilk p-value	0.685	0.276	0.907	0.098
Mean value	3.8354	4.1071	4.3179	4.7983
Standard deviation	0.487	0.536	0.626	0.533

The probability density function describes the relatively likelihood for the random variables to take on a given value, the probability of the random variates falling within a particular range of values is given by the integral of this variable's probability density function over the range. It provides a vivid information on the variable distribution. The probability density function of energy consumption density for different building types are shown in Fig. 4. From the Figure we can see that different types of building present different distributions. The governmental office building has the smallest energy consumption density variation range, while the hotel building has the biggest energy consumption density variation range. Moreover, shopping mall is more likely to have high energy consumption than any other building types in this study.
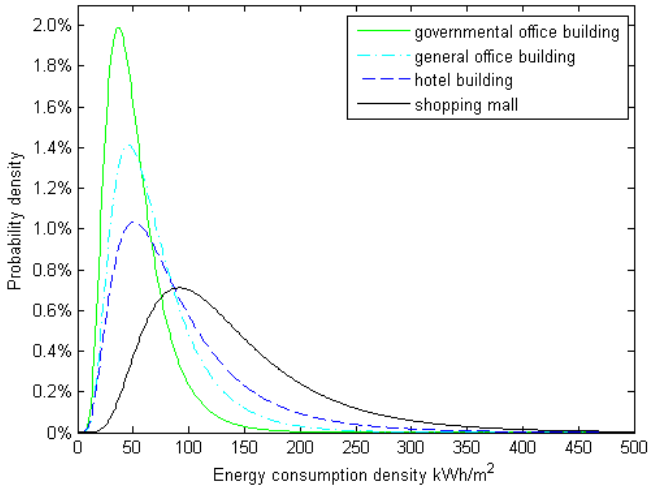

Fig. 4 The probability density of energy consumption density for different building tyupes

Cumulative probability function describes the probability of variable takes on a value less than or equal to stated X-axis value. With known log-normal distribution for annual energy consumption density of governmental office, general office, hotel buildings and shopping mall, their cumulative probability functions were drawn and presented in Fig. 5. The cumulative probability function can be used to determine the

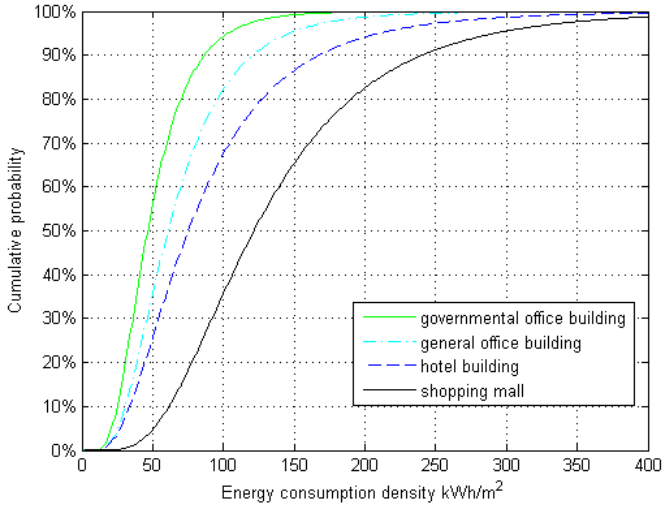energy consumption density level of a randomly selected building comparing to building stock of the same type.

Fig. 5 The cumulative probability of energy consumption density for different building types

4. Conclusion

This paper presents a statistical analysis of the data collected from a pilot monitoring platform for public building energy consumption survey in Chongqing, China. The annual energy consumption density of the four types of public buildings including governmental office, general office, hotel buildings and shopping mall were analyzed. The annual energy consumption density complies with the log-normal distribution. The cumulative probability of energy consumption density for different building types provides useful reference to the determinations of energy consumption density level of a randomly selected building.

Acknowledgment

References

[1] EPA. *Causes of Climate Change.* United States Environmental Protection Agency; 2015. Available from: http://www3.epa.gov/climatechange/science/causes.html.

[2] Department of Climate Change. *ENHANCED ACTIONS ON CLIMATE CHANGE: CHINA'S INTENDED NATIONALLY DETERMINED CONTRIBUTIONS*. National Development & Reform Commission of China, 2015.

[3] MOHURD. *Report of Chinese Building Energy Efficiency Development-Existing Building Retrofit.* Beijing: China Architecture & Building Press; 2014.

[4] Yang, C., Li, X., Zhou, H. Strategic path and countermeasures for the low-carbon development of buildings in China. *Building energy efficiency*. 7 (2015) 107-111.

[5] MOHURD. *Design standard for energy efficiency of public buildings GB50189-2015*. 2015.Ministry of Housing and Urban-Rural Development, People's Republic of China.

[6] Cheng, Y., Huang, L., Yue, Z.-R., Sheng, J.-X. Study on Energy-Efficient Retrofit of Public Buildings in Ningbo City. 2013 Fourth International Conference on Digital Manufacturing and Automation (Icdma)2013. p. 1268-1271.

[7] EIA. *COMMERCIAL BUILDINGS ENERGY CONSUMPTION SURVEY (CBECS).* U.S. Energy Information Administration; 2015. Available from: http://www.eia.gov/consumption/commercial/about.cfm.

[8] DECC. *Building Energy Efficiency Survey (BEES).* Department of Energy & Climate Change; 2013. Available from: https://www.gov.uk/government/collections/non-domestic-buildings-energy-use-project.

[9] DECC. *National Energy Efficiency Data-Framework (NEED)*. 2013. Available from: https://www.gov.uk/government/collections/national-energy-efficiency-data-need-framework.

[10] Chao, Z., Dong, L., Xiao-jie, Z., Shu-hui, L., Hui, Y., Ya-wen, W., et al. Energy Consumption and Energy Saving Potential Analysis on Office Building of Higher Education in Shanghai. *Building Energy & Environment*. 32 (2013) 37-40.

[11] Tang, H., Ren, J., Guo, B., Zhao, X., Long, E. Energy Consumption survey and Energy Saving Potential Analysis for goverment Office Buildings in Guangzhou. *ENERGY CONSERVATION*. (2008) 30-32.

[12] Zhisheng, L., Guoqiang, Z., Dongmei, L., Sheng, M., Xuhong, L., Lixin, L. Energy Consumption Features for Large-scale Public Office Building In Greater Guangzhou, P.R.China. *Journal of Chongqing Jianzhu University*. 30 (2008) 112-117.

[13] Fang, L., Wei-qing, C., Xiao-qing, Z., Shu-rong, Y., Yun-fei, D. Survey and Analysis on Energy Consumption in Official Buildings in Guangzhou. *BUILDING SCIENCE*. 23 (2007) 57-60.

[14] Ding, H., Liu, H., Wang, L. Preliminary analysis of the energy statistics in civil buildings. *HV&AC*. 39 (2009) 1-3.

[15] Li, Q. An Analysis of Electricity Consumption in Government Office Building Based on Energy Consumption Monitoring System. *Urban Development Studies*. 22 (2015) 1-5.