Energy and Buildings 127 (2016) 499–511

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

The performance and analysis of office building energy consumption in the west of Inner Mongolia Autonomous Region, China

Shilei Lu[a,*], Shaoqun Zheng[a], Xiangfei Kong[b]

[a] School of Environmental Science and Technology, Tianjin University, Tianjin 300072, China
[b] School of Energy and Environmental Engineering, Hebei University of Technology, Tianjin 300401, China

ARTICLE INFO

Article history:
Received 26 December 2015
Received in revised form 4 April 2016
Accepted 3 June 2016
Available online 6 June 2016

Keywords:
Building energy consumption
Office building
ANOVA
Inner Mongolia

ABSTRACT

The large public building energy consumption (BEC) is the focus of Building Energy Saving, therefore, it is necessary to study the characteristics of BEC to find out the important factors affecting BEC. For this purpose, 27 office buildings in the west of Inner Mongolia Autonomous Region were studied, based on statistical analysis of the researched basic information and energy consumption bill of these buildings. This paper focused on the determination of the significant factors affecting the total and subentry energy consumption intensity (ECI) of office building, as well as the establishment of standardized linear regression models between these selected factors and total and subentry ECI. Firstly, eleven continuous variables, three independent categorical variables, and the climate factor were selected and analyzed the impact on total and subentry ECI by statistical software SPSS20.0, in order to find out the significant influencing factors. Then based on the results of curve fitting, standardized models of total and subentry ECI and their respective significant impact factors were established using multiple linear regression analysis. The regression results showed that the electricity use percentage of the total equivalent electricity consumption was an important factor affecting the total ECI of office building in the west of Inner Mongolia Autonomous Region. Finally, univariate analysis of variance (ANOVA) was conducted between the three independent categorical variables and the total and subentry ECI, and the results showed that these factors had no significant effect on the ECI of office building. Process of the regressive model establishment and the results of analysis of variance could both guide us to propose more targeted energy saving measures.

1. Introduction

In recent years, with the continued growth in people's living standards and the rapid development of economy, the corresponding building energy consumption (BEC) has been growing sharply. According to the statistics, BEC has accounted for 20% approximately in the total energy consumption [1]; furthermore the proportion will increase to 25% by 2020 [2]. Moreover, Energy consumption per unit area of the large public building is about 10 times that of ordinary residential buildings. According to the statistics, office building is one of the largest energy intensive typology, adding retail building which account for over 50% of the total energy use among public buildings except domestic buildings [3]. Furthermore, the office building area has grown sharply: at the end of 2007, China office building area has reached 890 million m^2, accounting for the total area of public building by 17.1%; and the power consumption was about 172.6 billion kWh, accounting for the total electricity consumption in public building by 24.1% [4]. In recent years, new office buildings have been increased continuously. Moreover, because of the higher thermal comfort, the requirement of environmental comfort level is still growing, air-conditioning installation and utilization rate of office buildings are much higher than residential buildings. Therefore, the energy saving potential in public building is enormous, and energy-saving task is urgent.

China is a country with a vast territory, its climate and geographical features are various. The climate, economic, architectural forms etc. in different cities are different, leading to characteristics of public BEC varying. To explore the current state and characteristics of BEC in China, a large number of scholars have being studied the public BEC. Zhou et al. [5] researched the assessment impact of various scenarios on the energy use in commercial buildings in China taking use of a detailed terminal-use energy model. In his study, the results showed that commercial energy use is undervalued by

* Corresponding author.
E-mail address: lvshilei@tju.edu.cn (S. Lu).

http://dx.doi.org/10.1016/j.enbuild.2016.06.008
0378-7788/

Nomenclature

BEC	Building energy consumption
ECI	Energy consumption intensity
LS	Lighting system
HVAC	Heating ventilation and air conditioning system
IES	Indoor equipment system
ISS	Integrated service system
SSR	Special service region
PN	People number of energy use
GFA	Gross floor area
ACA	Air conditioning area
SRA	Special service region area
PACA	Percentage that the air condition area accounts for the GFA
PSRA	Percentage that special service region area accounts for the GFA
$HDD_{obs1,2,3}$	The observation heating degree-days in the observation year of Bayan Nur, Ordos City, and Wuhai City respectively
$CDD_{obs1,2,3}$	The observation cooling degree-days in the observation year of Bayan Nur, Ordos City, and Wuhai City respectively
$HDD_{std1,2,3}$	The standard values of heating degree-days from the standard weather data of Bayan Nur, Ordos City, and Wuhai City respectively
$CDD_{std1,2,3}$	The standard values of cooling degree-days from the standard weather data of Bayan Nur, Ordos City, and Wuhai City respectively
$\eta_{HDDclt1,2,3}$	The correction coefficients of heating degree days of Bayan Nur, Ordos City, and Wuhai City respectively
$\eta_{CDDclt1,2,3}$	The correction coefficients of cooling degree days of Bayan Nur, Ordos City, and Wuhai City respectively
ECI_{HVAC}, ECI_{LS},ECI_{IES}, ECI_{ISS}, ECI_{SSR}	the equivalent electricity consumption intensity of HVAC, LS, IES, ISS, SSR systems respectively
$ECI_{Heatingobs1,2,3}$	The observed heating energy consumption intensity in the observation year of Bayan Nur, Ordos City, and Wuhai City respectively
$ECI_{Coolingobs1,2,3}$	The observed cooling energy consumption intensity in the observation year of Bayan Nur, Ordos City, and Wuhai City respectively
$ECI_{Heatingclt1,2,3}$	The climate normalized of the observed heating energy consumption intensity in the observation year of Bayan Nur, Ordos City, and Wuhai City respectively
$ECI_{Coolingclt1,2,3}$	The climate normalized of the observed cooling energy consumption intensity in the observation year of Bayan Nur, Ordos City, and Wuhai City respectively
$ECI_{HVACclt1,2,3}$	The climate normalized ECI_{HVAC} in the observation year of Bayan Nur, Ordos City, and Wuhai City respectively
$ECI_{obs1,2,3}$	The observation building energy intensity in the observation year of Bayan Nur, Ordos City, and Wuhai City respectively
ECI_{norm}	the normalized building energy intensity
$ECI_{HVACnorm}$ $ECI_{IESnorm}$, $ECI_{ISSnorm}$	the normalized ECI_{HVAC}, ECI_{IES}, ECI_{ISS} respectively
ITE	Indoor thermal environment
IAQ	Indoor air quality
OEM	Organization of energy management
MES	Metering of energy systems
IEM	Implementation of energy management

approximately 44% in China's current statistics, and the energy intensity of more commercial buildings would increase. Tsinghua University [6] studied the distribution characteristic of the public BEC, based on the investigation and analysis of BEC in Beijing, Shanghai, and Shenzhen. Liu [1] and Li [7] respectively conducted an investigation about energy cost of numerous public buildings, and acquired the characteristics of the energy use and energy consumption level of each type of public buildings in Chongqing. Among them, some scholars have studied the energy use of office buildings. Zhang and Ding [8] investigated and analyzed the BEC of the government office building in Chongqing, and finally acquired the energy utilization characteristics of government office building in Chongqing. Founded on energy audit, Zhang et al. [9] studied the energy structure and energy use character of a large office building in Beijing, as well as summarized the energy characteristics of the office building. Liang et al. [10] conducted a sample survey of 15 high-rise office buildings in Shenzhen, and found that the key to energy-saving was to reduce the energy consumption of equipment, lighting and air conditioning. Xiao et al. [11] from Building Energy Research Center of Tsinghua University analyzed the office building energy consumption in several provinces and municipalities. Based on a cluster analysis, they found a unique dual sector distribution feature existing in office building in China, which was different from a single-peak distribution characteristic in Japan and the US. By summarizing previous work, it is found that most energy audits are carried out in tropical and temperate climate zones, causing the data of public BEC in the cold climate zone is few, especially in the Inner Mongolia autonomous region. Inner Mongolia Autonomous Region is located in north of China, and its longitude span is large. The west region of Inner Mongolia mainly Includes Bayan Nur, Wuhai City, Ordos City and Alxa League, and most area of these cities belong to the Severe Cold Area. This area has a long and cold winters, causing its heating days are long; while the diurnal temperature difference is large during summer. In order to better understand the status of office building energy consumption in the west of Inner Mongolia Autonomous Region, as well as to better tap the energy save space of office building, a detailed energy audit for Bayan Nur, Ordos City, Wuhai City office building totaling 27 office buildings were carried out.

There are mainly two methods to analyze building energy consumption: one is the classic method, and the other is data-driven method [12]. The first method is to solve the building energy consumption when the input parameters, system architecture and system parameters of the building are given. However, in the second method, the input and output parameters of the building are known, and the purpose is to solve the relationship between building energy use and its influence factors. Obviously, the second method is more suitable for public building energy use analysis. According to the application, the data-driven method is divided into three categories: model calibration method, gray-box approach and the empirical method (or black box model method), which have all been researched. Model calibration methods take use of simulation software to build architectural models, and then adjust the input conditions to make the simulation results consistent with the measured energy consumption. In most cases, it is not enough by means of model calibration method, so researchers often combined it with regression analysis approach. Asadi et al. [13] took