Study Influencing Factors for Energy Consumption of Office Buildings in Severe Cold and Cold Region, China

Zequn Ding¹, *, Hongqing Zhu¹, Weiyu Zhou², Junliang Liu¹ and Zhigang Bai¹
¹State Nuclear Electric Power Planning Design & Research Institute, Beijing 100095, China
²Urban Gas & Heat Research Institute, North China Municipal Engineering Design & Research Institute Co., Ltd, Tianjin 300384, China

*Corresponding author e-mail: dingzequn@tju.edu.cn

Abstract. The paper analyzed and studied the factors that affect the energy consumption of office buildings, and some suggests were put forward according to the analysis. Through orthogonal experiment the research selected the exterior wall heat transfer coefficient, exterior window heat transfer coefficient, lighting power density, electricity density, air conditioning system form to analyze and study. Although the ranking factors affecting two models are different, but through the analysis found that the air conditioning system is the greatest impact factor, followed by the lighting equipment, after that is envelope.

1. Introduction
There are mainly two methods to analyze building energy consumption: one is the investigation and research, the other is energy consumption simulation. For building energy consumption data, the investigation and research is the most direct and most reliable method. However, the main shortcomings of the survey research are heavy workload and long cycle. So many scholars choose simulation software to analyze buildings energy consumption situation.

The energy consumption simulation software has been used in some areas of theoretical analysis and research for analysis energy consumption by many scholars at home and abroad. Zhang Wenjie [1] of the Harbin Institute of Technology by using tool eQUEST to simulate a building and new model that has applied energy efficient measures annual energy consumption. Hunan University Li Qing [2] using Energy consumption simulation analysis and simulation software DeST to analysis a complex commercial building, including a detailed analysis of the load characteristics, construction and influencing factors, the typical room load, and also according to the above analysis and put forward the measures for energy saving from the typical room. Tan Xiaoyan [3] and Chen Gaifang [4] of Chongqing University respectively use DeST to simulate the energy consumption of a typical office building and office building, and analyze the influence factors and then put forward the energy saving measures.

S.E. Chidiac [5] et al. Through the use of energy consumption simulation software to did architectural studies such as location, size, operation, building envelope, electrical, air conditioning and ventilation system performance, single or multiple factors for the construction of energy-saving effect. Nelson Fumo [6], using EnergyPlus benchmark model to simulate to get the coefficient, a simple method is put forward, through the application of a series of predetermined coefficient, data consumption of electricity
and fuel bills monthly, estimated an hour of electricity and fuel energy consumption. And the method has been applied to a hypothetical building located in Atlanta and Meiili Dean, and in these two cases, the error in estimating the energy consumption per hour is 10%. Fumo [7] Nelson also uses EnergyPlus software to analyze the energy consumption of CHP (combined heat and power) system and economic model. Ke et.al [8] examine the Energy-Saving Performance Contract (ESPC) of an office building by applying IPMVP Option D in combination with the energy analysis model established for the building by eQUEST simulation software to calibrate energy consumption simulation results using actual electricity billing data.

2. Method

2.1. Target buildings and Building description
Two typical public buildings were selected in the paper according to need of research in the Severe Cold and Cold Region. One is the government office building and another is non-governmental office building. In Model 1 architecture, 3 floor underground is parking garage, layers 1-2 mainly for commercial use and 3-12 layers mainly for office. In Model 2 architecture 1-8 layers mainly for offices and meeting rooms. Basic situation of 2 buildings can be seen in table 1 and the models of 3D in Fig. 1.

![Model 1 and Model 2](image)

**Figure 1. Building models of 3D**

2.2. Orthogonal Experiment Design and results
There are lots of influence factors on energy consumption of office buildings, generally can be divided into two parts, the external cause and internal cause. The external cause refers to the various kinds of interference of indoor thermal environment, which include two parts of the inner disturbance and outside disturbance. Inner disturbance refers to the change of the human body and equipment heat, moisture dissipation, and lighting heat dissipation of the room inside. Outside disturbance refers to the weather factors, mainly including the change of outdoor air temperature, humidity, and solar radiation intensity, wind speed and direction, etc. Internal cause is mainly refers to the condition of the building itself, including building orientation, palisade structure parameters such as structure, shape coefficient.

Office building energy consumption composition mainly includes the energy consumption of air conditioning, lighting, equipment, the influence of the factors corresponding to that are the influence factor of air conditioning, lighting, and equipment energy consumption.

The paper mainly studies the following factors that affect the energy consumption of office buildings: window-wall ratio, wall type, window type, occupancy density, lighting equipment load, roof type, shading coefficient and indoor set temperature, air index and air conditioning system forms, the chiller COP. Because only confirm the influence degree of various factors on the results, so select two representative index, and selected two typical building by using orthogonal test (L12).
Although the order of influence factors of two buildings are different, but through the analysis results can be found that the air conditioning system in the form of the influence of the two buildings is the largest, highest degree, followed by lighting density, followed by the building envelope. So, the paper will focus on analysis these factors.

3. Results and discussion

3.1. Exterior wall
The heat through the wall structure entering the room is mainly from two parts: the convection heat transfer between the outdoor air and the enclosure structure, and the solar radiation heat transfer through the wall. According to the research, five different heat transfer coefficients of the external walls are selected for simulation and analysis. The influence on the total energy consumption is shown below.

![Figure 2. Variable of energy consumption, electricity consumption and gas consumption for heating in different exterior wall U-values](image)

With the increase of exterior wall heat transfer coefficient, the heating energy consumption of total annual, electricity and gas of Model.1 and Model. 2 increased basic in liner, and the effect of different exterior wall heat transfer coefficient for the total energy consumption, electricity and gas consumption is obvious.

3.2. Lighting power density
According to the results of orthogonal test for Model.1 and Model.2, the lighting power density factor is the second factors following the air conditioning system factors. Five groups of different lighting power density have been selected to do the simulation analysis, respectively.

For Model.1 and Model.2, with the increase of lighting power density, total energy consumption and power consumption close to linear growth, and the gas consumption present straight decline. This is mainly due to the heating season, with the increase of the power density of the lighting, the heat capacity of the equipment increased, so that the gas consumption reduced and the required design temperature achieved. For the cooling season, the indoor design temperature is low, and needs to consume more power, so electricity consumption increased.
Figure 3. Variable of energy consumption, electricity consumption and gas consumption in different lighting power density

3.3. Air-conditioning system
Ground source heat pump (GSHP) is one of the most current technology of renewable energy use of air conditioning cold and heat source, therefore, ground source heat pump has been set as cold and heat source (with variable air volume air conditioning system) and compared with the constant air volume air conditioning system (CAV) and variable air volume air conditioning system (VAV) and variable refrigerant volume air conditioning system (VRV), the simulation results as below.

From Figure 4 it can be clearly seen, the building's total energy consumption and electricity consumption of Model.1 is smaller than that of CAV, VAV, little bigger than that of VRV and the building's total energy consumption and electricity consumption of Model.2 is smaller than that of CAV, VAV and VRV. The constant air volume all-air system is the largest energy consumption, of which the fan energy consumption is too large. For the heating period of Model.1 and Model.2, the minimum energy consumption is the use of ground source heat pump system. For Model.1, the energy consumption of using ground source heat pump system is slightly higher than VRV in other months, but the energy-saving effect of ground source heat pump system is still obvious in general.

With different air conditioning system energy consumption simulation, it can be found that air conditioning system had a huge impact on building energy consumption and overall, the energy efficiency of ground source heat pump system is still quite obviously.
4. Conclusions and Suggestions
With the increase of exterior wall heat transfer coefficient, the total annual energy consumption and electricity and gas consumption of two models increased with near-linear; with the increasing of the exterior window heat transfer coefficient, total annual energy consumption and gas consumption increased with near-linear, but the electricity consumption is decreased; with rise of the lighting power and office equipment density, the total annual energy consumption, electricity consumption have a linear growth trend, but the heating gas consumption decreased. For Model.1, the cold and heat source of air conditioning system is heat pump which has less energy consumption than (CAV) and (VAV), slightly higher than the (VRV). For Model.2, the cold and heat source is ground source heat pump which can consume lower energy consumption than the other three kinds of air conditioning system.

According to the analysis of the results, it can be found that the main factors affecting the energy consumption of buildings are building envelope, lighting equipment, office equipment and air conditioning system. Therefore, few suggestions can be put forward:

1) With the heat transfer coefficient of the exterior walls minimized from 2.5 W/(m² • k) to 0.5 W/(m² • k), the total energy consumption can be reduced about 10%, and the energy consumption also reduce obviously with the decrease of heat transfer coefficient of the exterior wall.

2) With the application of energy saving lamp, the lighting power density can be decreased from 14 W/m² to 6 W/m², the total energy consumption can be reduced by more than 16%.

3) Compared with CAV and VAV, the building's total energy consumption and electricity consumption with GSHP can be reduced by 40%, so it is important to choose the right and reasonable air conditioning system under suitable conditions, and the high energy consumption air conditioning system such as constant air volume full air system should be adopted as little as possible.

4) Other energy saving measures, such as improving the energy management system, developing good energy habits, and using renewable energy as much as possible, should also be taken seriously.

Acknowledgments
This research was funded by the State Nuclear Electric Power Planning Design & Research Institute Support Key Project under grant numbers 100-KY2020-QYK-N01. Beijing Municipal Science and Technology Project under grant numbers Z171100000317004.

References
[1] Zhang Wen-jie. Analysis of Public Buildings Energy-Saving Potential Based on Energy Simulation [D]. Harbin Institute of Technology, 2012.
[2] Li Qing. Energy Consumption Simulation and Energy-Saving Analysis on Public Buildings at Changsha District [D]. Hunan University, 2013
[3] Tan Xiao-yan. Survey and Research on Energy Consumption of Office Buildings in Chongqing [D]. Chongqing University.2008.
[4] Chen Gai-fang. Research on Energy Efficiency and Energy Consumption Simulation of Public Buildings in Chongqing [D]. Chongqing University. 2007.
[5] S.E. Chidiac, E.J.C. Catania, E. Morofsky. Effectiveness of single and multiple energy retrofit measures on the energy consumption of office buildings [J]. Energy, 2011, 36 (8): 5637-5652.
[6] N. Fumo, P. Magro, R. Luck. Methodology to estimate building energy consumption using EnergyPlus benchmark models [J]. Energy and Buildings, 2010, 42 (12): 2331–2337.
[7] N. Fumo, P. Magro, L. Chamra, Energy and economic evaluation of cooling, heating, and power systems based on primary energy [J]. Applied Thermal Engineering, 2009, 29 (13): 2665–2671.
[8] Ming-Tsun Kea, Chia-Hung Yeh, Jhong-Ting Jian. Analysis of building energy consumption parameters and energy savings measurement and verification by applying eQUEST software. Energy and Buildings, 61 (2013): 100–107.