

ANALYSIS OF BUILDING ENERGY EFFICIENCY STRATEGIES FOR THE HOT SUMMER AND COLD WINTER ZONE IN CHINA

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ABSTRACT

In this paper, three typical cities (Shanghai, Changsha and Chongqing) in the hot summer and cold winter climate zone of China was selected to study and the energy consumption of a model building in these three locations was simulated by eQuest software. After comparing the result, the differences among them were shown in this paper. From the viewpoint of building energy consumption, solar radiation may be a positive factor in winter but negative in summer. With simulating and analyzing the influence of exterior window shades and building orientation on cooling/heating load and the amount of energy consumption of the model building in Changsha, the optimal overhang depth, fin depth and building orientation were obtained. Finally, based on the results obtained, some design strategies for energy efficiency buildings in the hot summer and cold winter zone are proposed.

KEYWORDS

Energy efficiency strategies, Energy consumption, Exterior window shades, Building orientation,

INTRODUCTION

Most modern buildings depend on conventional energy excessively, which are critical for those buildings using artificial lighting and mechanical HVAC systems. In China, the building with high energy consumption and low efficiency is the main reason of energy shortage. At present, building consumes 26.7% of commercial energy in China (Siwei Lang 2004). Building energy efficiency is known as one of the most effective measures in recent years, and now so hot that attracts a large amount of research attention in the field of heating, ventilating and air conditioning (P. Thollander et al. 2005, M. Bojic and F.Yika 2005, S.M.Deng and J.Burnett 2000). In addition, due to the rising cost of energy, looking for efficient ways of building operation, such as load management (D.V. Bush et al. 2002) or renewable energy (E. Vine et al. 2000), have become more and more important for facility managers.

The hot summer and cold winter zone is the important region in China because of its typical climate character. The zone in forms of high temperature and humidity in summer and low temperature in winter mainly refers to the region along the Yangtze River valley, where not only

cooling energy consumption is large for summer, but also has large heating energy consumption in winter. It is known that solar radiation has an important effect on HVAC loads of buildings. Because solar radiation is depend on azimuths of envelope, the heat gain on the surface of envelope constructions is different for different azimuths. Taking a rectangular building facing to south for example, the optimization of all year solar heat gain was studied in reference (Tang Mingfang 2002, Tang Mingfang 2001). The results indicate that the larger the ratio of length to width and the ratio of height to width of buildings, the more solar heat gains on exterior envelope constructions. But it is not the case in the summer, while it has a smallest solar heat gain. For example, in the areas near north latitude 30°, the suitable ratio of length to width and ratio of height to width of buildings are 2.0~2.3, 2.1~2.4, respectively (Tang Mingfang 2002, Tang Mingfang 2001). Besides, many energy efficiency measures such as thermal insulation, building orientation, special roof system, shading device and so on (V.Cheng et al. 2005, A. Dimoudi et al. 2006, Long Enshen et al. 2005, Yang Zhao et al. 2005, Fang Lin et al. 2002), were studied in this climate zone. However, few of these studies are quantitative or integrated.

In this paper, a model building in hot summer and cold winter climate zone was established and simulated by eQuest software. The difference of energy consumption is analyzed for the three cities (Shanghai, Changsha and Chongqing). Furthermore, the influence of building orientation, blind seasons and exterior shading device for windows on HVAC loads and energy consumption is simulated and analyzed for Changsha. On the model building, an optimization model is established comprehensively considering building orientation, blind seasons and exterior shading device for windows. Finally, some strategies for energy efficiency design are suggested.

METHODOLOGY AND MODEL

BUILDING

Methodology

Computer-based simulation is accepted by many researchers as a tool for evaluating building energy consumption. There are many different types of computer-based simulation tools that are available for performing whole-building simulation, e.g. DeST, DOE-2, Energyplus, and so on. In this paper, the program eQuest based on DOE-2.2 is adopted as a

tool for energy consumption analysis. EQuest, a quick energy simulation tool, is “a sophisticated, yet easy to use, freeware building energy use analysis tool level”. That is the main reason for adopting eQuest software in this study (Yimin Zhu 2006).

An introduction of the model building

The model building studied in this study is an office building with about 5000m² building area. According to the research findings of reference (Tang Mingfang 2002, Tang Mingfang 2001), the ratio of length to width and ratio of height to width of buildings are set to be 2.2 and 2.0, respectively. And the geometrical dimensions are 33m long, 15m wide, 30m high, 3m room height and 10 storeys.

The base model building in this paper faces to south, whose area ratio of windows to wall is 38% for south, 28% for north and 30% for east and west. The HVAC system is 2-pipe fan-coil units with fresh air system, and the screw water chiller and oil boiler was selected as the refrigeration and heating equipment. In order to simplify the process of modeling with few changes about result, the whole building plane is divided into 4 perimeter zones and 1 core zone. That is the regular zoning method using in eQuest software. And each perimeter zone depth is set to be 3m. The area ratios of rooms in different function are showed in Table 2. Moreover, the remainder area (about 4%) in forms of affiliated building area is not conditioned. The infiltration air is set to be 0.3 vol/h in the perimeter zones and 0.01 vol/h in the core zones, which are defaulted by the eQuest software according to the building type. Modeling process mainly includes the establishing of geometrical model, inputting of building envelope parameter and setting of interior loads, schedules and HVAC systems. The geometrical model of the building is shown in Fig.1.

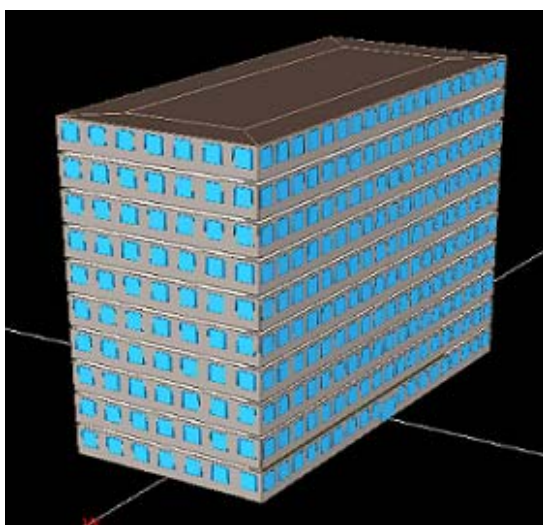


Fig.1 Geometrical model of the building

Building envelope settings

Traditional building envelope was selected in the model building, and the parameters of building envelope are showed in Table 1.

Table.1 Building envelope parameters

ENVELOPE CONSTRUCTION	U-VALUE (W/m ² · K)	ABSORPTANCE
Exterior wall	1.90	0.55
Interior wall	3.10	0.7
Roof	3.05	0.7
Ground floor	1.08	0.6
Internal floor	4.88	0.6
Window	5.43	—

Interior loads and schedules

The settings of building interior loads and schedules referred to “Design Standard for Energy Efficiency of Public Buildings GB50189-2005”, and the some important parameters are showed in Table 2.

SIMULATION RESULTS AND DISCUSSION

Characteristics of HVAC loads and energy consumption in different cities

By using corresponding meteorological data, the model building was simulated for Shanghai, Changsha and Chongqing, respectively. All year HVAC loads and peak loads for each city are showed in Fig.2 and 3.

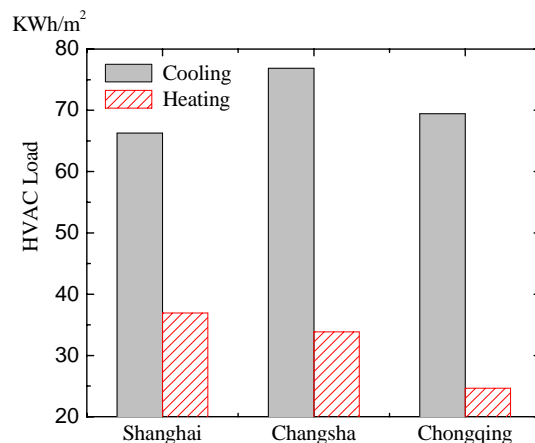


Fig.2 HVAC loads in the three cities

As showed in the Figs, the cooling load is 76.85kWh/m², 69.46 kWh/m² and 66.27 kWh/m² for Changsha, Chongqing and Shanghai, respectively, and 36.95 kWh/m², 33.86 kWh/m² and 24.66 kWh/m² for the heating load for Shanghai, Changsha and Chongqing, respectively. The result indicates that Changsha’s climatic condition is a disadvantage for

Table.2 Interior loads and schedules

SPACE NAME	AREA RATIO (%)	PERSONS (m ² /p)	LIGHTING (W/m ²)	EQUIPMENT (W/m ²)	SCHEDULE	TEMPERATURE SETPOINTS (°C)	FRESH AIR (m ³ /h-p)
Office (General)	45	4	11	20	8:00-17:00	26/20	30
Office (Private)	15	8	18	18	8:00-17:00	26/20	30
Corridor	15	50	5		8:00-17:00	26/20	30
Lobby	8	14	11	5	8:00-17:00	26/20	30
Conference room	8	2.5	11	5	8:00-17:00	26/20	30
Restrooms	5	19	9	—	8:00-17:00	26/20	30

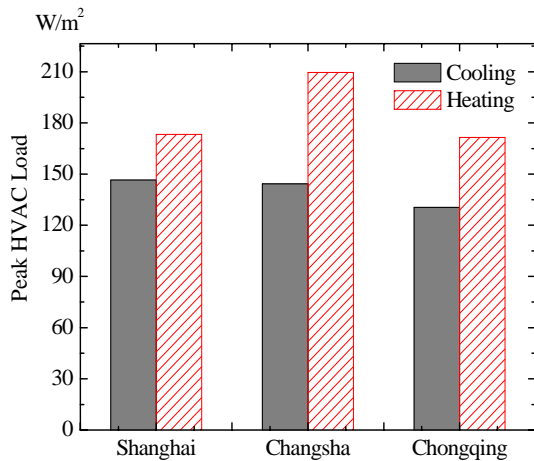


Fig.3 Peak loads in the three cities

reducing energy consumption of HVAC system in buildings, and it is obvious that the cooling load is biggest and heating load is also huge. Because of lower latitudes and locating in the inland area, the cooling load of Changsha and Chongqing is larger than that of Shanghai. The heating load of Chongqing is the smallest, and the reason may be that Chongqing locates in the place so called “Sichuan Basin” and its climate is hardly affected by the cold wind from the north in winter. The heating load of Changsha is smaller than that of Shanghai, but the peak heating load is not the case. One reason for this phenomenon is that Shanghai is near the ocean and water can regulate surrounding air temperature.

The above analysis shows that although the three cities are all in the same climate zone of hot summer and cold winter, the differences of their HVAC loads and energy consumption for same building are comparatively notable. For the HVAC system design and building efficiency research, these differences should be considered according to the local geographic position and microclimate environment.

Orientation optimization

In above analysis, the orientation of the base model building is set to due south, and the selection of the ratio of length to width and the ratio of height to width is the result of considering solar radiation.

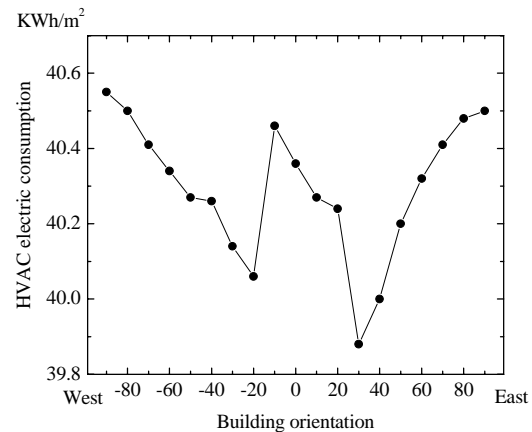


Fig.4 Interrelation of electric consumption and building orientation

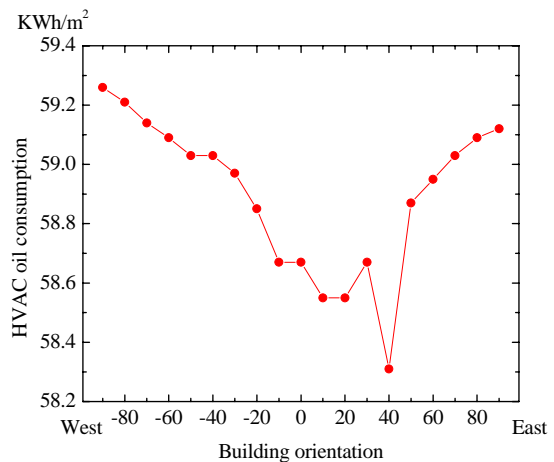


Fig.5 Interrelation of oil consumption and building orientation

In order to analysis the influence of orientation of the model building on its energy consumption in Changsha, the influence of a set of building orientations on HVAC energy consumption is analyzed by change orientation from due east to due south, and then to due west (step by 10°). The simulation results are shown in Fig.4 and 5. As shown in Fig.4 and 5, all year HVAC energy consumption is relatively small when the model building faces to due south. To certain extent, it indicates the base model building select a better orientation qualitatively. But it is obvious that south is not the best building orientation from the above results. And the optimum building orientation limits range from south by east 10° to 45° in Changsha. The model building consumes oil only in winter, so low oil consumption indicates small heating load. The uneven distribution of meteorological data such as solar radiation, wind speed in the space and time, is the main reason for the variation of heating load with different building orientation.

Blind season optimization

The blind is a very convenient and adjustable shading device for windows. In order to analyze the influence of blind on HVAC loads and energy consumption, three cases (all year no blind, blind for summer and winter, blind only for summer) are simulated for Changsha. The results are showed in Fig.6.

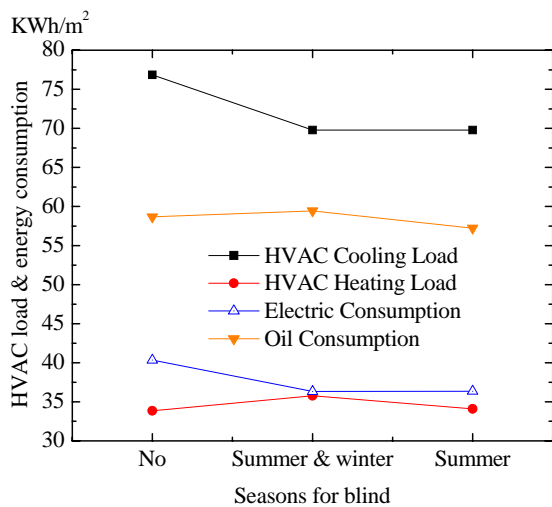


Fig.6 blind seasons and their energy consumption

It shows the blind is an effective way to reduce HVAC loads and energy consumption in summer. In winter, the heating load and oil consumption will increase when the blind is used. So it can be concluded that the blind is very suitable only for summer, but not for winter and transition season in Changsha.

Exterior shading optimization for windows

Changsha locates in the middle-latitude area, and the solar altitudinal angle is high for summer and low for winter. So the exterior shading of south windows

influences on HVAC loads and energy consumption greatly. Horizontal window shading device is the important exterior shading facilities considering the summer and winter conditions. So the horizontal exterior shading device is primarily studied for south windows. In addition, the solar radiation is large for east and west windows, and the exterior shading maybe also have some influence on HVAC loads and energy consumption for north windows. Vertical north window exterior shading device and multiform east & west window exterior shading device are also simulated here.

In the simulation by eQuest, the overhang depth of horizontal shading device for south windows was adjusted from 0 to 1.2m (step by 0.1m), and the results are showed in Fig.7. As shown in Fig.7, the cooling load and electric consumption gradually decrease with the increase of the depth, but the heating load is different. At the same time, the falling rate is slower when the depth is over 0.6m. Above analysis indicates that the overhang depth really not the longer, the better. And the optimum depth is range from 0.4m to 0.6m.

Fig.8 shows the interrelation of north window fin depth and HVAC loads. With the increasing of fin depth, the cooling load is decreasing and the heating load is increasing, and the falling rate is higher for the cooling load when the fin depth is range from 0.1m to 0.3m. So, it is obviously that about 0.3m fin depth is the most suitable.

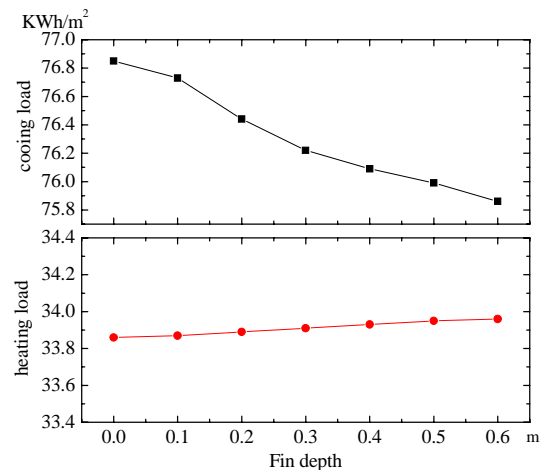


Fig.8 Influence of fin depth on HVAC loads

Table.3 shows the HVAC loads and energy consumption on the condition that overhang depth is 0.8m and fin depth is 0.4m for east and west windows. As Table.3, these shading devices are not effective. For the exterior shading device of east and west windows, the movable repelling board is suggested.

Integrated optimization for the base model

Above analysis shows there are some energy efficiency potentials in many aspects for the base model building. In the paper, the base model building has been optimized in the aspects of building

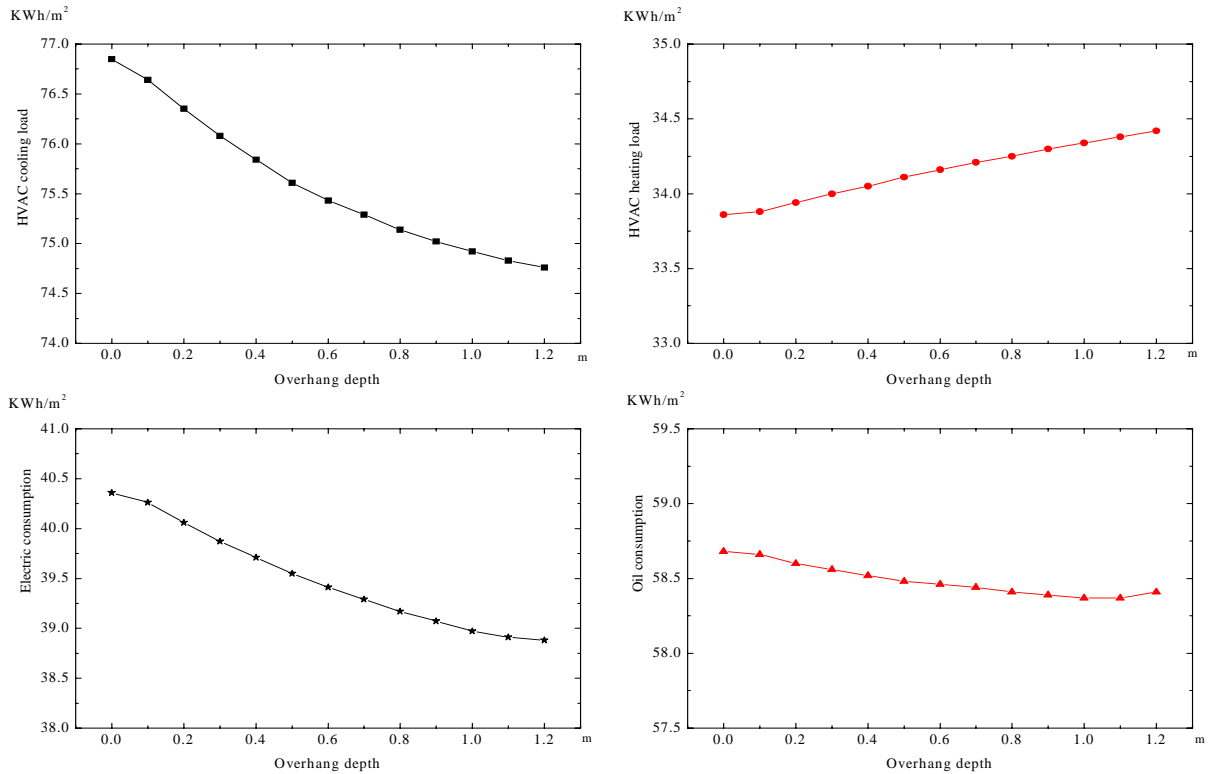


Fig.7 Influence of overhang depth on HVAC loads and energy consumption

orientation and window shading device. Through calculation and analysis, a new model building has been obtained with south by east 35° for the building orientation, blind only for summer, 0.5m overhang depth for south windows and 0.3m fin depth for north windows. The HVAC loads, energy consumption and energy efficient rate are shown in Table.4.

Obviously, the potential is very large in reducing total load and HVAC electric consumption. On the whole, the new model can save 10.98% HVAC electric consumption and 1.96% oil consumption in

contrast to the base model. It can also be concluded that the window shading is a very important measure to reducing HVAC cooling load, and the building energy efficiency is even more effective when the movable repelling board is applied to east and west windows. Besides, the additional thermal insulation on building exterior envelope constructions such as exterior wall and roof may contribute to building energy efficiency greatly.

Table.3 Exterior shading effect of east and west windows

MODEL	HVAC COOLING LOAD	HVAC HEATING LOAD	ELECTRIC CONSUMPTION	OIL CONSUMPTION
Baseline (kWh/m ²)	76.85	33.86	40.36	58.68
Overhang 800mm (kWh/m ²)	75.57	34.03	39.62	58.46
Fins 400mm (kWh/m ²)	76.01	34.00	39.98	58.69

Table.4 Characteristics of integrated optimization model

	TOTAL COOLING LOAD	TOTAL HEATING LOAD	ELECTRIC CONSUMPTION	OIL CONSUMPTION
Baseline (kWh/m ²)	76.85	33.86	40.36	58.68
New model (kWh/m ²)	69.36	34.54	35.93	57.53
Energy efficient rate (%)	9.75%	-2.01%	10.98%	1.96%

CONCLUSION

The study has indicated that computer-based simulation is a powerful technique to analyze building energy consumption and find out the optimal energy-efficiency design strategies. In this paper, HVAC loads and energy consumption of a model building are analyzed quantitatively in the hot summer and cold winter zone of China. According to the study, some energy efficiency design strategies are suggested as following.

(1) For the HVAC system design or the building efficiency research of different locations, sometimes even in the same climate zone, the variation of geographic location and microclimate environment should be paid more attention.

(2) In China, south is a good orientation for the building, but maybe not the best. This study indicates orientation range from south by east 10° to 45° is proper for the model building in Changsha.

(3) Window shading is very important and also effective in reducing cooling load and energy consumption. This study indicates that the blind is suit only for summer; the overhang depth range from 0.4m to 0.6m is proper for the south window; the proper fin depth of the north window is about 0.3m; and the movable repelling board is very fit for east and west windows.

There are many factors influencing on the building energy consumption, and each factor has their own specific properties. An integrated optimization of the building design will be effective in reducing HVAC loads and energy consumption.

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