IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Optimization of passive design measures for residential buildings in Chinese hot summer and cold winter areas

To cite this article: Xinzhi Gong *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **310** 022058

IOP Conf. Series: Earth and Environmental Science **310** (2019) 022058 doi:10.1088/1755-1315/310/2/022058

Optimization of passive design measures for residential buildings in Chinese hot summer and cold winter areas

Xinzhi Gong[1,] *, Chenyang Jia[1], Yilei Yu[2], Chuancheng Li[3]

[1] Guangxi Key Laboratory of New Energy and Building Energy Saving, Guilin University of Technology, Guilin 541004, China

[2] Graduate Institute of Building and Planning, National Taiwan University, Taipei 100, China

[3] Department of Architecture, Wuhan University of Technology, Wuhan 430072, China

* gxinzhiglut@126.com

Abstract. Passive design, which includes several passive design strategies like shading devices and insulated envelop, is the most economical effective strategy for reducing energy consumption inside residential buildings. To investigate the impact of passive design on building thermal performance, a representative city Wuhan in Chinese hot summer and cold winter areas was selected for optimum analysis. The design parameters required for the climate of Wuhan using the Climate Consultant Software and passive strategies were analysed through the DesignBuilder Software in this paper. The results show that the optimization of passive design could reduce the annual primary energy by 52.2%. It will guide the architect in his choice of appropriate passive measures directly for the hot summer and cold winter region in China.

1. Introduction

With the rapid development of economy and the increase of people's living standard, a significant portion of the energy is consumed by today's residential buildings. In China, residential building sector consumed 192.7 million tons of standard coal in 2003, which accounted for 11.3% of the total primary energy used in the nation and continuously rise to 17.2% in 2006[1]. Every year, approximately 34.1% of total energy in building sector is used for household space heating[2]. These facts emphasize that residential building sector has become a key energy end user.

The hot summer and cold winter area of China is the coldest area in the same latitude in the world. It is hot and humid in summer and cold and wet in winter in this region. Over the last 15 years, the diffusion of individual heating facilities has led to a 575 times growth of residential heating energy consumption in this region, constituting a major contributor to the increase of residential energy consumption and associated carbon emission of China. It is worthwhile investigating the energy conservation of dwellings in Chinese hot summer and cold winter areas and scrutinizing the driving forces behind that.

In order to alleviate the growing building energy demand, it is widely accepted that passive design is the most economical effective strategy to reduce thermal load of residential buildings[3]. It was reported by measurements that passive design buildings can save more than 50% of total primary energy consumption[4]. In previous investigation, some passive design measures were optimized based on the orthogonal method and the listing method for each of Chinese representative cities[5]. It analyzed the interactive effects between parameters and their best combination. Gong claimed that the most significant parameter is external wall insulation thickness and the second significant parameter is shading depth among the 7 passive design measures: wall thickness, roof insulation thickness, external wall insulation thickness, window wall ratio, glazing type, orientation and sunroom/ shading. Fu and Xiao revealed that building orientation, bodily confidence and window wall ratio can be seen as useful indexes for the studies focusing on building energy saving[6]. A good passive design with the objective of minimizing the energy demand for comfort involves all the various aspects of building design like insulated envelop, passive solar heating, shading, and so on[7].

This paper chooses a representative city Wuhan in Chinese hot summer and cold winter areas, shows the climate of the city and identifies its suitable strategies on buildings by using the Climate Consultant Software, then develops a simulation model and outlines simulation methods by listing method, calculates the primary energy consumption of passive design building models by using the dynamic simulation program of DesignBuilder Software, and finally, compares them to the baseline case, in order to optimize the combination of passive strategies and clarify the trends of passive design strategies application.

2. Methods

The research uses two methods: firstly, started with using Climate Consultant Software to understand several aspects of climate in the Wuhan city and the required passive parameters needed to achieve thermal comfort in buildings. Secondly, the listing method, which studies one parameter at a time while keeps other parameters fixed as the standard level, is used to further analyse the optimal level for each passive strategy[8]. In the second step, the primary energy consumption of the model is calculated by the dynamic simulation program DesignBuilder. It can assess the performance of the building.

2.1. Climatic characteristics and design parameters

Wuhan city, which is located at the center of the hot summer and cold winter region, has very cold winter and quite hot summer. The lowest average temperature appears in January below 1 °C (33.8 °F), while the highest average temperature usually occurs in July and August over 28 °C (82.4 °F). The annual precipitation is large and the average annual humidity is very high around 78%.

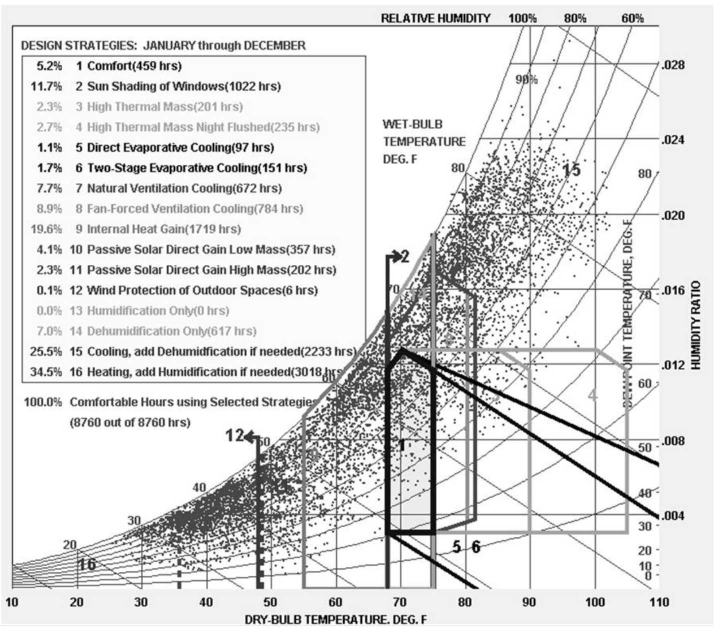

Figure 1. Comfortable zones using different strategies

In order to understand the climate of the city and its strategies on buildings, the Climate Consultant Software was used to read the graphs of the climate. Based on the Climate Consultant Software, figure 1 shows that several parameters such as sun shading or windows (11.7%), internal heat gain (19.6%), cooling (25.5%) and heating (34.5%) are recommended to achieve human thermal comfort. Therefore, this paper integrated 5 parameters of passive strategies: shading devices, insulated walls, insulated roofs, glazing types, and windows to wall ratio to the proposed designing order to evaluate the impact of each parameter on the indoor thermal load for Chinese hot summer and cold winter areas. This study will help architects understand and select their priorities of the parameters as per its impact on building performance.

2.2. Control parameters and levels for simulation

The baseline case (Case 0) represents a standard practice of building construction where levels of parameters are based on the design standard for energy efficiency of residential buildings in hot summer and cold winter zone (JGJ75-2012). To achieve the most valuable parameters for thermal comfort in summer and winter, 5 parameters identified by the Climate Consultant Software were arranged in different cases with different levels for simulation, as shown in Table 1.

For the 4 levels from level 0 to level 3, the heat transfer coefficient of the parameter roof insulation thickness in this paper is 0.381 W/(m^2·K), 0.233 W/(m^2·K), 0.168 W/(m^2·K), 0.144 W/(m^2·K), respectively. For the 5 levels from level 0 to level 4, the heat transfer coefficient of the parameter external wall insulation thickness is 0.962 W/(m^2·K), 0.750 W/(m^2·K), 0.483 W/(m^2·K), 0.242 W/(m^2·K), and 0.148 W/(m^2·K), respectively. For the 5 levels from level 0 to level 4, the heat transfer coefficient of the parameter glazing types is 2.346 W/(m^2·K), 1.798 W/(m^2·K), 1.778 W/(m^2·K), 1.514 W/(m^2·K), and 1.064 W/(m^2·K), respectively. The 5 levels of the parameter window wall ratio are 0.35, 0.2, 0.3, 0.45, 0.6, respectively, from level 0 to level 4. This paper also discusses the 4 shading devices: the blind with high reflectivity slats, the louvers with 0°, 30° and 60° angles, the overhangs with 300 mm, 600 mm and 900 mm depth, and the side fins with 300 mm, 600 mm and 900 mm depth.

In this investigation, if the five 5-level parameters for a city are fully matched, the number of simulative cases will be 5^5 = 3125, which is too large to operate. In order to optimize the passive design by manageable number of simulation cases, this paper utilizes the listing method to analyze the optimal level for each parameter with a total of 5 levels, and then, determine and validate the optimal combination of passive design strategies.

Table 1. Control parameters and their levels for optimization of passive design

Case	Parameters	Level 0	Level 1	Level 2	Level 3	Level 4
1	A: Roof insulation thickness	50 mm	100 mm	150 mm	180 mm	-
2	B: External wall insulation thickness	15 mm	25 mm	50 mm	120 mm	210 mm
3	C: Glazing type	Double	Double Low-E	Triple	Double Low-E with inert gas	Triple Low-E with inert gas
4	D: Window wall ratio	0.35	0.2	0.3	0.45	0.6
5	E: Shading device	None	Blind	Louvre	Overhang	Side fins

2.3. Simulation model and system description

A simple box model with a window is used to simulate the indoor thermal conditions. It has floor area of 16 m^2 (4 m × 4 m) and floor-to-floor height of 3 m. The basic envelope material of the box model is concrete. The annual primary energy of the model is calculated by the dynamic simulation program of DesignBuilder Software. It can estimate heating/ cooling loads, indoor temperatures, and humidity for the whole building, taking into consideration the complete heat, air, and moisture features. The 8760 hourly records of the typical year weather data for the Wuhan city developed by Tsinghua University is used for simulation. The total internal heat sources (human body, electric appliances, etc.) are assumed equal to 3.58 W/m^2. Air conditioning system (COP= 3.0) is the only energy consumer in the model, which controls indoor temperature above 18 °C in winter and below 26 °C in summer for a whole year on a 24 h basis. Indoor relative humidity is controlled at the high peak 60% and the low peak 40%. Ventilation change rate is 0.5 h^{-1}.

3. Results

3.1. The optimal level of passive strategies by listing method

To validate the passive design of residential buildings in Chinese hot summer and cold winter areas, the most valuable parameters for thermal comfort were identified firstly by the Climate Consultant Software, and the primary energy consumption of levels' variation for each parameter were compared with the baseline case (case 0) by the listing method. Level 0 of each parameter is based on the currently energy saving standard of China. With the levels from 1 to 4, the heat transfer coefficient of passive strategies is reduced gradually. The optimal level of each parameter is representing the lowest result in those of the five levels, which can comprise the optimal combination of minimum annual primary energy consumption. Figure 2 obviously illustrates the variation of the annual thermal load of each parameter.

Roof insulation thickness changes have a distinctive effect in Chinese hot summer and cold winter areas. As shown in figure 2(a), under the condition of setting the roof insulation thickness from 50 mm to 180 mm, primary energy consumption descends by 4.5% from 529.6 kWh/ (m^2· yr.) to 505.7 kWh/ (m^2· yr.).

By external wall insulation thickness increasing from 15 mm to 210 mm, the primary energy consumption of residential buildings reduces greatly, then gradually approached to 0 kWh/ (m^2· yr.) when the external wall insulation thickness ascends continually, as shown in figure 2(b). Increasing the external wall insulation thickness from 15 to 210 mm can lead to a sharp decrease in the thermal load reduction rate around 44% from 529.6 kWh/ (m^2· yr.) to 296.3 kWh/ (m^2· yr.).

As shown in figure 2(c), the impact elements of energy saving by the parameter glazing type are thickness, coating and multilayer. The triple-glazing with a low-emissivity coating and inert gas (heat transfer coefficient =1.514 W/ (m^2·K)) is the optimal level for residential buildings in Chinese hot summer and cold winter areas, which can reduce primary energy consumption by 3.0% from 529.6 kWh/ (m^2· yr.) to 513.5 kWh/ (m^2· yr.). While the double-glazing with a low emissivity coating and inert gas (heat transfer coefficient =1.064 W/ (m^2·K)) is also a good choice, which could decrease primary energy consumption by 2.14%.

Large effects of window-wall ratio on thermal load in hot summer and cold winter areas are demonstrated by this investigation. Figure 2(d) shows that when window-wall ratio is increased from 0.2 to 0.6, the primary energy consumption ascends about 3.9% from 539.8 kWh/ (m^2· yr.) to 518.5 kWh/ (m^2· yr.) for Wuhan.

Four types of shading devices were simulated in the study. Figure 2(e) shows that the primary energy consumption variations of the blind with high reflectivity slats, the louvers, the overhangs, and the side fins. In the four types of shading devices, the louver blades and the overhangs are suitable for residential buildings. The louver blades with 60° is the best option for Wuhan city. It could decrease quarterly primary energy consumption by 7.8% from 67.0 kWh/ (m^2· yr.) to 61.7 kWh/ (m^2· yr.) in summer.

3.2. Energy saving performance on optimum analysis of passive strategies

According to the results of primary energy consumption of the cases arranged in Table 1, values of the optimal levels for the parameters roof insulation thickness, external wall insulation thickness, glazing type, window wall ratio and shading devices are determined respectively as 180 mm, 210 mm, Triple-glazing with a low-emissivity coating and inert gas, 0.6 of window wall ratio, and louver blades with 60°. Among these passive strategies, the external wall insulation thickness and the shading device are the most significant parameters.

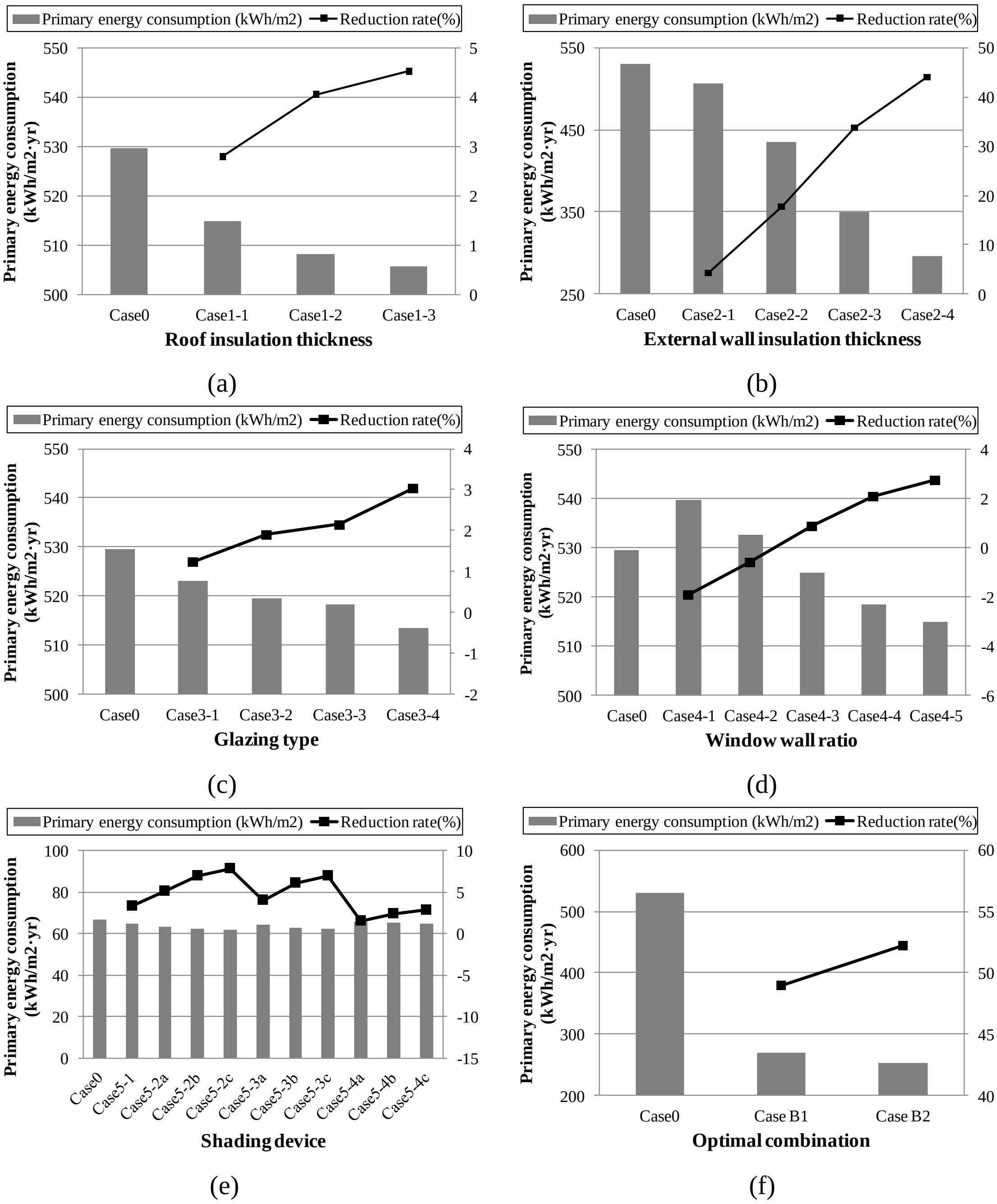

Figure 2. Annual primary energy consumption of different parameters and the optimal combination

In order to know the optimal combination, two cases combined with the optimal levels are simulated. The case B1 combines 180 mm of roof insulation thickness, 210 mm of external wall insulation thickness, Triple-glazing with a low emissivity coating and inert gas, 0.6 of window wall ratio, and no shading. The case B2 adds the shading device of louver blades with 60° based on the case B1. Figure 2(f) shows that the annual primary energy of the case-B1 combination is 270.17 kWh/ (m^2· yr.). It could reduce the primary energy by 49.0% compared with the base line. The case B2 consumes primary energy around 253.1 kWh/ (m^2· yr.), which could reduce primary energy by 52.2% compared with the base line.

4. Conclusions

In this paper, an approach, based on the passive strategies analysis by the Climate Consultant Software and the listing method by using the DesignBuilder Software, has been introduced to optimize five passive energy-saving measures: roof insulation thickness, external wall insulation thickness, window wall ratio, glazing type, and shading devices; on building thermal load performance for Chinese hot summer and cold winter areas.

It indicates that the external wall insulation thickness and shading devices are the two most important parameters on the annual primary energy consumption in Chinese hot summer and cold winter areas. Insulation acts as a barrier to heat flow, reducing heat loss in winter to keep the house warm and reducing heat gain in summer to keep the house cool. With the increase of the roof and external wall insulation thickness, primary energy consumption is reduced significantly. The double or triple glazing with a low-emissivity coating are good options in this region. By using these glazing, increasing window wall ratio could decrease primary energy consumption. A contribution of primary energy consumption reduction in summer was achieved as a result of using shading devices, especially using louvers.

This investigation finds that with the optimization, the passive design could reduce the annual primary energy of the building considerably, approximately 52.2%. Achievement of optimal thermal comfort with less energy consumption is the basic aim of this paper. All the different cases are analyzed in order to suggest the best passive design for temperature climate. For conclusion, it can be suggested that the lives of people can be improved by providing them with the effective passive designs.

Acknowledgements

This work was supported by the Project of Guangxi Key Laboratory of New Energy and Building Energy Saving [Grant No. 17-J-21-9], the Project of Teaching Reform Research of Guangxi Province of China [Grant No. 2018JGA176], and the Natural Science Foundation of Hubei Province of China [Grant No. 2015CFB532].

References

[1] Chen, S., Li, N., Guan, J., Xie, Y., Sun, F., Ni, J. (2008) A statistical method to investigate national energy consumption in the residential building sector of China. Energy and Buildings, 40: 654-665.
[2] THUBERC. (2018) 2018 Annual report on China building energy efficiency. Beijing: China Architecture & Building Press (in Chinese).
[3] Sadineni, S.B., Madala, S., Boehm, R.F. (2011) Passive building energy savings: a review of building envelope components. Renewable Sustain Energy Reviews, 15: 3617-3631.
[4] Chen, X., Yang, H. (2017) A multi-stage optimization of passively designed high-rise residential buildings in multiple building operation scenarios. Applied Energy, 206: 541-557.
[5] Gong, X., Akashi, Y., Sumiyoshi, D. (2012) Optimization of passive design measures for residential buildings in different Chinese areas. Building and Environment, 58: 46-57.
[6] Fu, X., Xiao, Y. (2008) Building Energy-Saving Technology at Hot Summer and Cold Winter Area in China. Chongqing: Chongqing University Press. (in Chinese).
[7] Aksoy, U.T., Inalli, M. (2006) Impacts of some building passive design parameters on heating demand for a cold region. Build and Environment, 41: 1742-1754.
[8] Wei, J., Zhao, J., Chen, Q. (2010) Optimal design for a dual-flow window for different climate regions in China. Energy and Buildings, 42: 2200-2205.