# Study on the comprehensive energy performance of different shading systems in China

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# Study on the comprehensive energy performance of different shading systems in China

**X Li[1], JQ Peng[1*] and C Curcija[2]**
[1] College of Civil Engineering, Hunan University, Changsha 410081, China
[2] Windows and Envelope Materials Group, Lawrence Berkeley National Laboratory, United States
E-mail: jqpeng@hnu.edu.cn

**Abstract.** This study evaluates the impacts of different shading systems on the comprehensive energy performance of buildings in China. Firstly, simulation models for four shading systems were developed using THERM, WINDOW and EnergyPlus. Then, four shading systems with different qualities, setting modes and baseline window systems were defined and simulated. Two cities, Beijing and Guangzhou, were selected as representative cities for heating-dominated and cooling-dominated regions in this study. Finally, the comprehensive energy performance, including cooling electricity consumption, heating electricity consumption and lighting electricity consumption for buildings with different shading systems were analysed. The results show that in Beijing, the most suitable shading system is roller shade with D quality (the combination of performance parameters), H (half shading) setting mode and low-e glazing system, while in Guangzhou, the most suitable shading system is roller shade with A quality, F (Full shading) setting mode and low-e glazing system. Besides, buildings in Beijing with suitable shading systems can achieve at least 20% energy saving potential (including air conditioning and lighting electricity consumption) compared with buildings without shading systems and the corresponding figure for Guangzhou is 50%. The conclusions of this study provide a reference for design and selection of shading systems in different regions in China.

**Keywords:** shading systems, comprehensive energy performance, qualities, setting modes

## 1. Introduction

The energy consumption for civil buildings accounts for about 20% of the total energy consumption of our society in China [1~3]. With the rapid development of modern construction industry and significant improvement of people's living standard, the proportion of building energy consumption to the total energy consumption of our society will continue to increase. Therefore, building energy conservation has become an important issue in the strategy of sustainable development in China.

Windows are the most energy-consuming part among the enclosure structures of buildings [4, 5], however, the installation of suitable shading systems can effectively reduce the heat gain of external windows in summer, thereby reducing the cooling load of air conditioning, which is of great significance for building energy conservation [6]. At present, the traditional shading systems for residential buildings in China mainly consist of cellular shades, fixed awnings, roller shades, horizontal louvered blinds and so on. The shading systems will have a significant impact on buildings' cooling load, heating load and indoor lighting distribution. Therefore, this paper analyses the impacts of different shading systems on buildings' comprehensive energy performance, including cooling electricity consumption in summer, heating electricity consumption in winter and lighting electricity consumption for the whole year.

## 2. Methodology

### *2.1. Simulation Model*

The simulation model established in EnergyPlus was based on a typical residential apartment in China. The whole apartment was divided into four zones viz. living room, bedroom, kitchen and bathroom. There were two windows on each orientation of north, east and west while the south side of the apartment was set with three windows. The size of each window is 1.6m (height) * 1.5m (width) and the material of the window frame is aluminum alloy. Moreover, the shading systems were mounted on the upside of each window in the east, south and west. Taking the fixed awnings as an example, the model established in EnergyPlus is shown in figure 1.

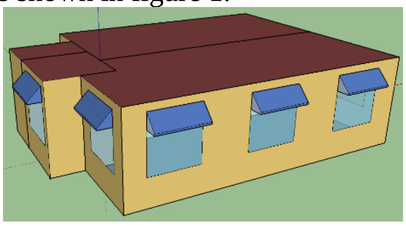

**Figure 1.** The fixed awnings model in EnergyPlus

The detailed process for establishing different shading systems is seen in figure 2. The design and heat transfer calculation of the aluminum alloy frame was conducted in THERM. Then, the files generated by THERM were imported in WINDOW. And the IDF file of the whole window, containing the data of the aluminum alloy frame, the baseline window system and the shading system, was derived from WINDOW. Finally, the IDF file of the whole window was integrated with the whole building's IDF file and run in EnergyPlus.

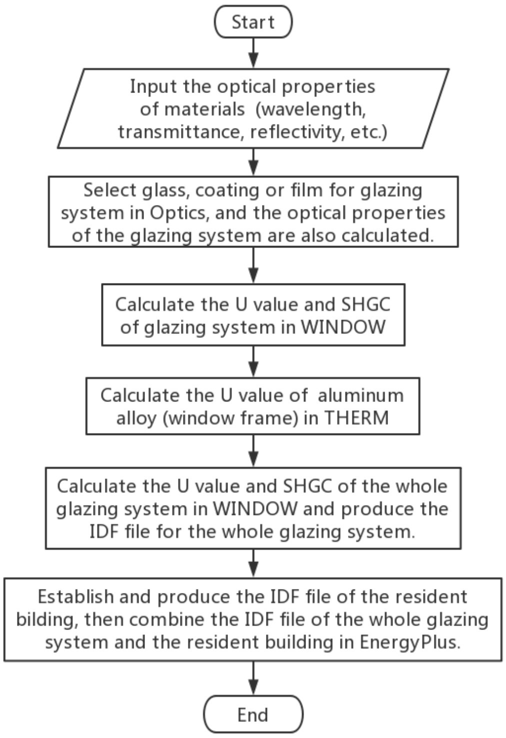


**Figure 2.** Modelling and integrating of traditional shading systems for buildings

The heat transfer model was employed to simulate the hourly heating and cooling load and the daylighting model was used for simulating the electricity consumption of artificial lighting, besides, the lighting control points were set in the middle of each area with a height of 0.75 m. The illumination level and lighting density were set to be 300 lux and 9W/m$^2$, respectively.

*2.2. Qualities and setting modes for shading systems*

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The shading systems selected in this paper mainly consist of cellular shades, roller shades, fixed awnings and horizontal louvered blinds. Three baseline windows (double clear glazing system, low-e glazing system and single clear glazing system) were selected to compare the energy-saving potential of different shading systems under various glazing systems. In addition, four “qualities” were defined to represent a wide variety of heat transfer and daylighting performances. Although the parameters for each quality are developed with the intent that quality A has the best performance and qualities B, C, and D are continuously “worse”. It is recognized that the overall energy outcomes are not necessarily going to be “Best” to “Worst”. The definition of qualities can be seen in table 1.

**Table 1.** Definition of qualities and setting modes for shading systems

| Shading type | Quality | Emis sivity | Reflect ance | Transm ittance | Open ness | Conductivity, k, (W/m·K) | Gap (mm) | Cell Side length (mm) | Thick (mm) | Tilt angle (˚) | Remark |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fixed awnings | A | 0.1 | 0.8 | 0.0 | | | | | | | F |
| | B | 0.9 | 0.6 | 0.0 | | | | | | | F |
| | C | 0.9 | 0.4 | 0.05 | | | | | | | F |
| | D | 0.9 | 0.02 | 0.50 | | | | | | | F |
| Roller shades | A | 0.1 | 0.8 | 0.0 | 0 | 0.10 | 0 | | | | F<br>H |
| | B | 0.9 | 0.7 | 0.1 | 0.02 | 0.10 | 0 | | | | F<br>H |
| | C | 0.9 | 0.5 | 0.2 | 0.05 | 0.15 | 3 | | | | F<br>H |
| | D | 0.9 | 0.05 | 0.5 | 0.3 | 0.5 | 12 | | | | F<br>H |
| Cellular shades | A | 0.1 | 0.8 | 0 | | | 0 | 19 | | | F<br>H |
| | B | 0.9 | 0.65 | 0.2 | | | 3 | 19 | | | F<br>H |
| | C | 0.9 | 0.45 | 0.25 | | | 3 | 15 | | | F<br>H |
| | D | 0.9 | 0.1 | 0.5 | | | 12 | 10 | | | F<br>H |
| Horizontal louvered blinds | A | 0.2 | 0.9 | 0 | | 0.08 | | | 3 | 0 | F / 0 ˚ slats<br>H / 0 ˚ slats |
| | | | | | | | | | | 45 | F / 45 ˚ slats<br>H / 45 ˚ slats |
| | | | | | | | | | | -45 | F / -45 ˚ slats<br>H / -45 ˚ slats |
| | | | | | | | | | | 90 | F / 90 ˚ slats<br>H / 90 ˚ slats |
| | B | 0.9 | 0.75 | 0 | | 0.2 | | | 0.2 | 0 | F / 0 ˚ slats<br>H 0 ˚ slats |
| | | | | | | | | | | 45 | F / 45 ˚ slats<br>H / 45 ˚ slats |
| | | | | | | | | | | -45 | F / -45 ˚ slats<br>H / -45 ˚ slats |
| | | | | | | | | | | 90 | F / 90 ˚ slats<br>H / 90 ˚ slats |
| | C | 0.9 | 0.6 | 0.6 | | 0.2 | | | 0.2 | 0 | F / 0 ˚ slats<br>H / 0 ˚ slats |
| | | | | | | | | | | 45 | F / 45 ˚ slats<br>H / 45 ˚ slats |
| | | | | | | | | | | -45 | F / -45 ˚ slats<br>H / -45 ˚ slats |
| | | | | | | | | | | 90 | F / 90 ˚ slats<br>H / 90 ˚ slats |
| | D | 0.9 | 0.1 | 0 | | 160 | | | 0.2 | 0 | F / 0 ˚ slats<br>H / 0 ˚ slats |
| | | | | | | | | | | 45 | F / 45 ˚ slats<br>H / 45 ˚ slats |
| | | | | | | | | | | -45 | F / -45 ˚ slats<br>H / -45 ˚ slats |
| | | | | | | | | | | 90 | F / 90 ˚ slats<br>H/ 90 ˚ slats |

As EnergyPlus cannot simulate the energy performance of half shading systems, the whole window was divided into two small and equal windows to analyse the energy performance of half shading systems. The upper half of the window was defined as window1 while the lower half of the window was defined as window2 and the size of the whole window is 1.6m (length) * 1.5m (width), thus the sizes of the divided windows are all 1.6m (length) * 0.75m (width). The shading systems were modelled in their three deployment states: when window1 and window2 were not deployed shading systems, this mode was defined as O (Open); When window1 was deployed shading system, window2 was not deployed shading system, this mode was defined as H (Half shading); When Windows1 and window2 were all deployed shading systems, this mode was defined as F (Full shading). For fixed awnings, F and O setting modes were adopted, while for cellular shades, roller shades and horizontal louvered blinds, H, F and O setting modes were adopted. Therefore, for fixed awnings, the combination of qualities and setting modes are AF, BF, CF, DF, while for cellular shades and roller shades, the combination of qualities and setting modes are AH, AF, BH, BF, CH, CF, DH, DF. For horizontal louvered blinds, the slat angle also should be considered, and defined 0° (perpendicular to the wall), 45° (the upper half of the window facing out), -45° (the upper half of the window facing in), 90° (parallel to the wall) as 1, 2, 3, 4. Therefore, the horizontal louvered blinds possess 32 layout methods, which are A1H, A1F, A2H, A2F, A3H, A3F, A4H, A4F, B1H, B1F, B2H, B2F, B3H, B3F, B4H, B4F, C1H, C1F, C2H, C2F, C3H, C3F, C4H, C4F, D1H, D1F, D2H, D2F, D3H D3F, D4H, D4F.

## 3. Results and discussion

Figure 3 to figure 5 compare the comprehensive energy performance of four traditional shading systems with different setting modes, qualities and glazing systems in Beijing and Guangzhou. It can be seen that the shading systems with suitable qualities and setting modes will show better energy performance while the shading systems with bad qualities and setting modes will consume more electricity compared with the O setting mode. For three baseline window systems in two regions, the heating electricity consumptions and lighting electricity consumptions of shading systems with H setting mode are all less than that with F setting mode, while the cooling electricity consumptions of shading systems with H setting mode are all more than that with F setting mode.

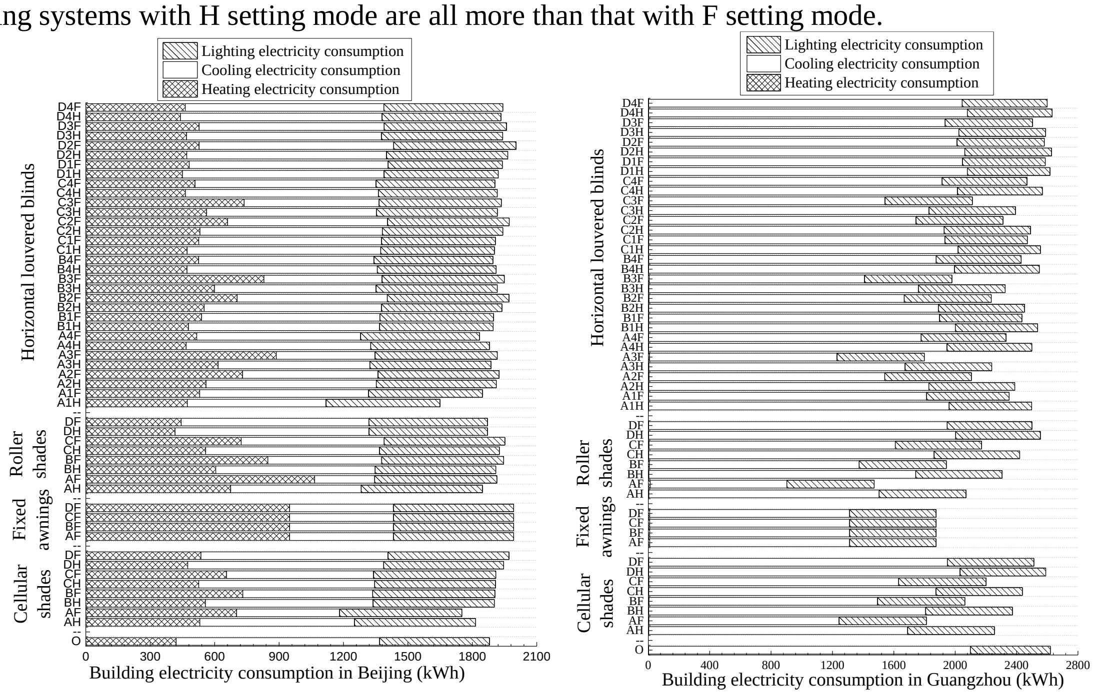


**Figure 3.** Building energy consumption for double clear glazing system

Besides, In Beijing, the total electricity consumptions of shading systems with F setting mode are all generally less than that with F setting mode for double clear glazing system and low-e glazing system, while for single clear glazing system, the total electricity consumptions of shading systems with F setting mode are all generally more than that with F setting mode. However, in Guangzhou, the total electricity consumptions of shading systems with F setting mode are all generally more than that with F setting mode for three baseline window systems. Besides, the impacts of setting modes and qualities on the energy performance of fixed awnings in two regions are not very obvious while this impact is pretty sensitive for cellular shades, roller shades and horizontal louvered blinds. And for low-e glazing system, the impacts of setting modes and qualities on energy performance of different shading systems are less significant than that for double clear glazing system and single clear glazing system.

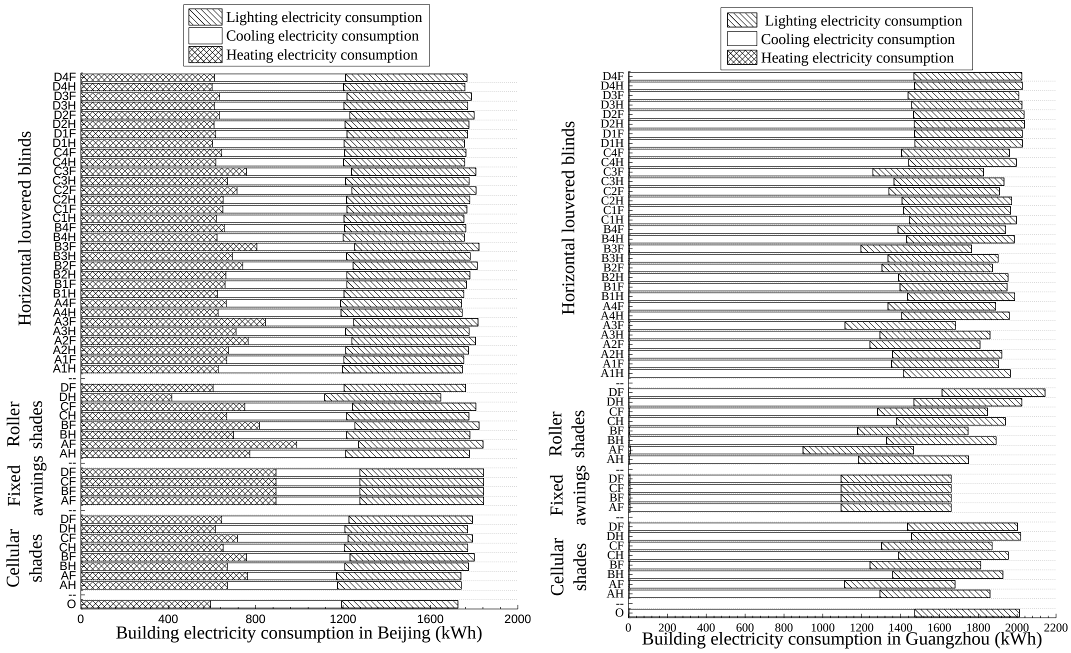


**Figure 4.** Building energy consumption for low-e glazing system

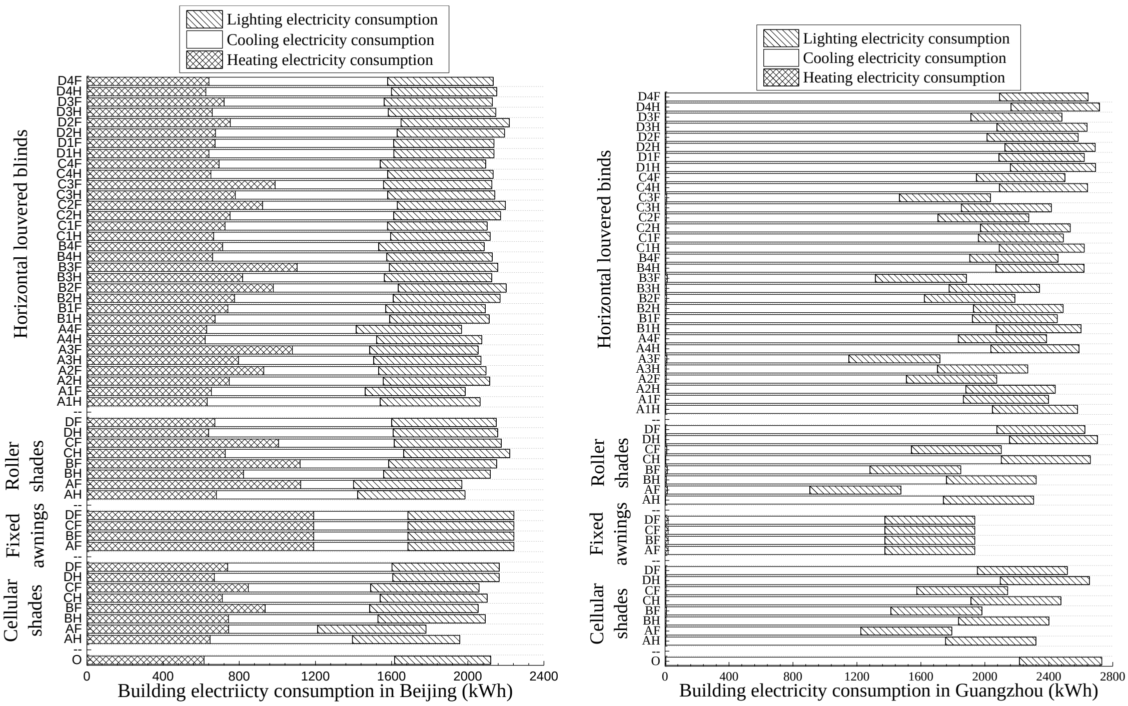


**Figure 5.** Building energy consumption for single clear glazing system

From figure 3, it is seen that for double clear glazing system in Beijing, the most suitable shading system is horizontal louvered blinds with A quality, H setting mode and 0° slat tilt, the corresponding heating electricity consumption is 473.28kWh, cooling electricity consumption is 645.51kWh, lighting electricity consumption is 530.4kWh and the total electricity consumption is 1649.19kWh. Compared with buildings without shading systems, the energy saving potential for buildings with horizontal louvered blinds is 15.54%; In Guangzhou, the most suitable shading system is roller shades with A quality and F setting mode, the corresponding heating electricity consumption is 4.07kWh, cooling electricity consumption is 1500.75kWh, lighting electricity consumption is 569.32kWh and the total electricity consumption is 1472.25kWh. Compared with buildings without shading systems, the energy saving potential for buildings with roller shades is 50.43%.

Figure 4 shows that for low-e glazing system in Beijing, the most suitable shading system is roller shades with D quality and H setting mode and compared with buildings without shading systems, the energy saving potential for buildings with roller shades is 24.67%; In Guangzhou, the most suitable shading system is roller shades with A quality and F setting mode and compared with buildings without shading systems, the energy saving potential for buildings with roller shades is 50.60%. Figure 5 shows for single clear glazing system in Beijing, the most suitable shading system is cellular shades with A quality and F setting mode and compared with buildings without shading systems, the energy saving potential for buildings with cellular shades is 18.59%; In Guangzhou, the most suitable shading system is roller shades with A quality and F setting mode and compared with buildings without shading systems, the energy saving potential for buildings with roller shades is 50.33%.

## 4. Conclusions

In this paper, the comprehensive energy performance of four types of shading systems with different qualities, setting modes and baseline window systems were analysed, and the main conclusions obtained were listed as follows.

1. The shading systems with suitable qualities and setting modes showed excellent energy-saving potential. Besides, the impacts of setting modes and qualities on the energy performance of fixed awnings were not obvious while this impact is pretty sensitive for cellular shades, roller shades and horizontal louvered blinds.
2. In Beijing, the most suitable shading system is roller shades with D quality, H setting mode, and low-e glazing system while in Guangzhou, the most suitable shading system is roller shades with A quality, F setting mode and low-e glazing system.
3. Compared with buildings without shading systems, buildings with suitable shading systems can save at least 20% and 50% energy (including air conditioning and lighting electricity consumption) in Beijing and Guangzhou, respectively.

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