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Solar shading performance of window with constant and dynamic shading function in different climate zones

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ABSTRACT

Window is a basic building element that can significantly influence the indoor thermal and lighting environment, in evaluating the shading performance of a window system with shading device, the solar heat gain coefficient (SHGC) is of key factor. This paper analyzed the optimal constant solar heat gain coefficient (SHGC) in several typical climate zones in USA and China, the SHGC values were compared according to their latitudes. Based on a grid shading configuration for window, the optimization of grid pitch for energy saving was conducted. The optimal SHGC decreases gradually with the decrease of latitude, the effect of shading device becomes more obvious. The window with optimal SHGC could reduce total building load up to 37.8% in selected USA cities and 24.8% in selected China cities. For the same city and grid pitch, more than 6 times difference emerges from summer to winter. The minimum geometrical shading coefficient (GSC) of grid shading increases with the decrease of latitude.

1. Introduction

Building energy saving have been put effort in a long time since buildings consume about 40.6% of total energy use (Philipp et al., 2014), where heating, cooling and electrical lighting requirement results in energy consumption of building significantly. The window is an important part of building envelope, it usually brings a certain heat load from solar radiation while it allows light passing through, and properly leads to overheating in summer, hence the cooling load increases. The main disadvantage of clear glass window is that it cannot provide enough thermal resistance and usually leads to very high cooling load in summer. For well thermal comfort performance and operation efficiency, one way for improving the performance of window is to enhance heat insulation. The window with air layer has been proved to be capable of increasing insulation significantly. Almeida et al. studied natural convection in a window (Almeida and Naylor, 2011). With an attic radiant barrier system, the cooling load was reduced around 16% in daytime hours, and there was overall 9% reduction during five-day period (Moujaes and Brickman, 1998). Aydin analyzed the thermally optimal air-layer thickness between double-pane windows (Aydin, 2000). Although the air layer could bring thermal insulation, most of window with air layer could not lower both the annual heating and cooling demand as well. But by combining typologies or changing the system settings according to the particular situation, a substantial overall improvement over the traditional insulated glazing unit with exterior shading is possible (Saelens et al., 2003). Glazing panels have to be combined with shading systems. Curtains, blinds and similar are most widely used shading devices. The shading devices are more and more employed to reduce solar radiation passing through window in hot seasons.

Solar heat gain coefficient (SHGC) is key factor for evaluating the shading performance of a window system with shading devices, which refers to the solar energy transmittance of a window. The usual shading configuration could be divided into two types: fixed shading and moveable shading, which depends on whether it could achieve constant or dynamic SHGC. In most of the previous researches, SHGC was regarded as a constant parameter. Appelfeld et al. studied four types of window: micro structural perforated shading screen (MSPSS), clear glazing, woven roller shade, and venetian blind. They got a constant normal-incidence SHGC of 0.37, 0.62, 0.35, and 0.49 respectively (Appelfeld et al., 2012). Ismail presented a thermal analysis on a simple window with single glass panel. From the study, solar heat gain coefficient for a simple glass window (3 mm thickness) was about 0.91; the parameter was stable during 80 min (Ismail, 2003).

The impact of window system on building energy consumption in specified location or climate zone had been conducted before by

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some researchers. The effect of advanced glazing and overhangs on the solar energy transmitted into or lost from the room through the fenestration areas had been evaluated for typical residential buildings in Tehran (Ebrahimpour and Maerefat, 2011). The energy savings from applying solar window films in a commercial building with large, curtain wall areas in Shanghai, China were analyzed (Yin et al., 2012). Building-integrated photovoltaics (BIPV) are photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facade (Steven, 2010). By considering the meteorological condition in Hong Kong, the energy performance of the shading-type BIPV claddings with different surface azimuth angles, in terms of electricity generation and cooling energy consumption reduction was analyzed (Sun et al., 2012). Kim et al. proposed an experimental configuration of an external shading device which can be applied to apartments in South Korea. To verify the advantage of the external device (Kim et al., 2012). Mandalaki et al. defined the geometrical parameters that will be incorporated to the overall characteristics of the optimal fixed shading device and proposed new fields of development for the BIPV technologies (Mandalaki et al., 2012). Aldawoud investigated the performance and the effectiveness of electro-chromic glazing to prevent solar radiation from entering a conditioned space and compared their performances with those of conventional fixed exterior shading devices in hot, dry climate (Aldawoud, 2013). Nikoofard et al. studied the effect of external shading on household energy requirement for heating and cooling in Canada (Nikoofard et al., 2011). In previous researches, energy consumption of window with constant SHGC and air layer in specified location were studied widely. However, seldom research focused on the interaction between climate conditions and optimal constant SHGC.

Optimized windows can reduce energy consumption for space heating, cooling and electric lighting. An energy efficient window should take on multiple functions: it can reduce solar heat gain in summer so as to decrease the cooling load, while allow solar radiation go into room as much as possible like clear glazing window in winter. The window should also be capable of utilizing daylight and providing outdoor view for occupants. Obviously, the windows with constant SHGCs cannot completely meet these requirements. The windows with complex shading configurations can cut down lighting and cooling energy consumption significantly, which are described as complex fenestrations system (CFS) (Li et al., 2008).

The moveable shading configuration can adjust the solar radiation amount according to the outdoor radiation intensity. The roller shading integrated an automatic active shading control strategy had been studied, which could operate following an adjustable schedule with the variation of transmittance from 10% (shade closed) to 100% (shade opened) (Tzempelikos and Athienitis, 2007). Carbonari et al. reported the experimental evaluation performed on a dynamic shading system based on liquid layer sliding within dedicated glass stratification (Carbonari et al., 2012). Nielsen et al. quantified the potential of dynamic solar shading façade configurations by using integrated simulations that considered several requirements, including the energy demand, the indoor air quality, the amount of daylight available, and visual comfort (Nielsen et al., 2011).

The application of moveable shading configuration is limited by its complexity and reliability. The dynamic shading effect comes true from the control strategy such as "open-close mode". Although fixed shading configuration has no advantage in thermal efficiency, it is still more widely used compared with moveable shading configuration. The solution for this issue is to develop the fixed shading configuration with dynamic shading effect, which will improve the overall performance of window significantly. Actually, some fixed shading configurations could show dynamic shading effect. Some researchers have conducted the studying about this field. Datta studied external fixed horizontal louvers with different slat lengths and tilts, and found that for Milan 70% of heat gain is cut off in summer, while only 40% is cut off in winter (Datta, 2001). Sherif et al. presented an external perforated window Solar Screens, and studied the optimal size and depth of screen. The study indicated that perforated screen provide an excellent shading performance in hot climate zone (Sherif et al., 2012a). However, they did not take the thermal insulation function into account. Kim and Giles proposed a grid shading structure, which is similar to perforated solar screen, integrated into double glazing window, and tried to address the thermal insulation and shading function of window in the meantime. The grid shading configuration is essentially the combination of horizontal and vertical blinds, which can adjust the solar heat gain with the change of sun zenith and azimuth angle. The shading configuration shows obvious dynamic shading effect as the sun moves on (Kim, 2009). The SHGC of such configuration is different between summer and winter, even more between morning and afternoon. The grid shading configuration integrated air layer could benefit from both the thermal insulation and dynamic shading effect, it is potential in energy saving. The research on the suitability and optimization of grid shading configuration in different climate conditions are insufficient yet. It is necessary to investigate the suitable grid configuration according to the weather condition in different climate zone.

In this paper, analysis will focus on the interaction between climate conditions and optimal constant SHGC; then their impact on building energy performance should be evaluated. To expand the climate range and investigate the general shading performance change trend with the climate zone is more helpful for window design and application guide. The energy performance of windows with different constant SHGCs is compared in different climate zones; the relationship between constant SHGC and climate zones will be displayed. Besides, other factors influencing shading and energy performance of windows are also taken into account.

We aim to study the dynamic shading performance characteristic of grid shading as well as their consequential energy performance change trend in different climate zone in this paper. Moreover the optimization of the shading configuration in different climate zones is discussed for achieving deeply energy saving.

2. The window performance with constant SHGC in different climate zone

2.1. Building structure

In order to evaluate the impact of window on the building energy performance, a residential building structure is used as shown in Fig. 1. The building has a floor plan area of 7.2 m × 10 m, with a height of 3 m, and is consisting of two bedrooms, one bathroom, one kitchen, one dining room and one living room. The building is assumed to be one floor single unit and without shading of adjacent buildings or other objects. The unit has two windows on the southern and northern facings. There is no window on the eastern/western facing. Parameters of each window are: width 2 m, height 1.62 m, generic double glazed (3 mm) with air gap, so the window to wall ratio (WWR) is 0.3. External wall is defined as an insulated wall of 170 mm thickness with a U-value of 0.511 W/m^2 K.

For the purpose of maintaining comfort level of indoor environment, the heating temperature was set as 20 °C; Cooling temperature was set as 26 °C, fresh air flow rate was set as 0.4 1/h air change rate while the Infiltration was 0.15 1/h air change rate. Internal occupants' load of 3 peoples and inner heat gain from