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An investigation into the impact of movable solar shades on energy, indoor thermal and visual comfort improvements

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ABSTRACT

Buildings are huge energy consumers and are responsible for a large part of greenhouse gas emissions in the world. Among building energy efficiency measures, solar shading plays a significant role in reducing building energy consumption, especially in hot summer and cold winter zone of China. This paper carried out a field measurement of shading performance of movable shades installed on the south-facing facade of a residential building in Ningbo city of China. The field tests show that external movable solar shades have a good shading performance that can reduce solar transmittance to about 8% and keep indoor illuminance at about 1000 lux with little fluctuations, indicating a suitable level for indoor environments. A building simulation study on energy, indoor thermal and visual performance of movable solar shades was further carried out. Several important indexes were adopted to give an in-depth analysis, including energy performance, room base temperature, transmitted solar radiation, PMV-PPD and its distribution as well as Discomfort Glare Index (DGI). Results show that movable solar shades used for south-facing windows not only reduce building energy demand by 30.87%, but also improve indoor thermal comfort by 21% in summer as well as reduce dramatically extremely uncomfortable risks by 80.4%, and meanwhile the visual comfort condition is also improved by 19.9%.

1. Introduction

With the increasing of population and the improvement of living standards, the percentage of buildings with air conditioners in China have been increased dramatically, leading to a high consumption of energy and environmental- and health-related negative effects. For example, urban areas in China contribute 84% of total commercial energy consumption and are responsible for about 85% of energy related CO_2 emissions [1]. Saving building energy is thus very important for reducing fossil fuels consumption and mitigating climate change. To address this demand, a lot of measures can be used such as better design [2], using high efficient HVAC equipment [3,4] and improving the performance of the building envelope [5]. Among them, solar shading is an effective measure in hot summer and cold winter zone since windows are generally the lowest performing part of the building in controlling energy loss and excessive solar heat gains [6].

Solar shading devices may be fixed or movable. Fixed shading devices are usually used in the building envelope to block solar radiation in the summer. However, they also block a significant amount of solar radiation in winter which is wanted by occupants to reduce heating energy consumption. Although many studies suggested that there might an optimal overhang depth which blocks solar beam radiation from the high summer sun but still allows the low winter sun to shine in and provide welcome solar heating due to solar altitude angle difference in these two seasons [7] (see Fig. 1), overhang is not effective in controlling sky diffuse radiation which is a significant part contributing to increased cooling energy in summer.

On the other hand, movable shading devices can be adjusted to changing outdoor conditions and they are more effective in controlling sky diffuse radiation, thus they generally have a higher energy performance than fixed ones. For movable solar shading devices, external shading has a better performance at reducing heat gain than internal window coverings since solar radiation absorbed by internal ones will finally increase indoor heat gains. Regardless of its high performance, external movable solar devices are rarely designed or used by building development firms in hot summer and cold winter zone due to relatively high initial costs. As a substitute, internal roller shades or coverings are widely used by occupants in order to control solar heat gains. Therefore, movable solar shading especially for external one receives less research focus than other building envelope elements such as external walls and roof. Only few studies on movable solar shading conducted in

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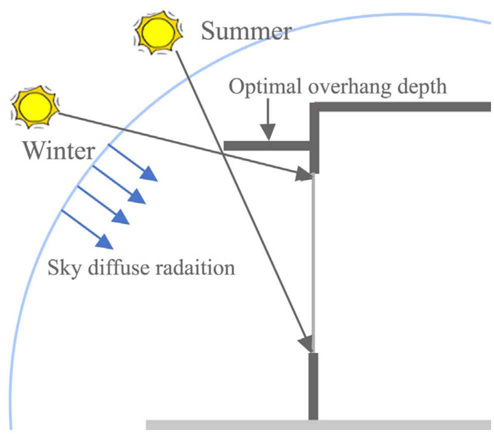

Fig. 1. An optimal overhang depth.

this area. For example, Tian et al. simulated the building energy performance of movable solar shades using DOE-2 [8]. Their research showed that the energy saving potential was significant, ranging from 17.29% to 22.68% for residential buildings in different cities in hot summer and cold winter zone. Using computational fluid dynamic (CFD) simulation, Zhang et al. analyzed the influence of external movable blinds on indoor thermal conditions in Nanjing city [9]. They reported that venetian blinds and roller blinds effectively improved indoor thermal performance in summer. However, there is a negative impact on natural ventilation for roller blinds in transition seasons while venetian blinds do not influence natural ventilation.

Due to a higher recognition of the importance of movable solar shading in Europe and other countries, a lot of literatures, however, have reported the performance of movable solar shading. Littlefair et al. [10] carried out a simulation study of solar shading control on UK office energy use. They compared the energy performance of manually controlled internal blinds, a fixed external overhang, and internal or external blinds under automatic control and manual override.

Nielsen et al. [11] compared the energy and daylight performance of a Denmark office building between three different solar shading types: (1) without solar shading; (2) fixed horizontal Venetian blinds and (3) dynamic solar shading (horizontal Venetian blinds) with slat angle adjustable according to outdoor conditions. Their simulation study showed that dynamic solar shading has the best performance with respect to total energy demand and can dramatically improve the amount of daylight available compared to fixed solar shading.

Palmero et al. [12] investigated the building energy performance and indoor temperature improvements for louver shading devices under climatic conditions of Mexico (Mexico), Cairo (Egypt), Lisbon (Portugal), Madrid (Spain) and London (UK) by using TRNSYS simulation. They concluded that application of louver shading devices may lead to comfortable indoor thermal conditions and significant energy savings. Hammad et al. [13] explored the influence of external dynamic louvers on the energy consumption of an office building located in Abu Dhabi-UAE using the IES-VR software. The so-called dynamic louvers mean that the louvers' slat angle can be automatically adjusted to a given angle at a specific time to keep the overall lighting and HVAC energy consumption at the minimum level. Their findings show that the dynamic louvers system with light dimming strategy achieved energy savings of 28.57%–34.02% depending on window orientation. Besides, Tzempelikos [14,15], Silva [16], Moeseke [17] etc all reported similar results and these literatures focused mainly on the energy performance.

The environmental performance of movable solar shading including thermal and visual conditions has also been widely reported. Kim et al. [18] evaluated the environmental performance of the automated venetian blind by through thermal (room temperature) and visual (indoor illuminance) experiments in a real-scale test room. They found that the overall environmental performance of the automated blinds is better than that of manual blinds which is fully closed if the additional lighting energy consumption is considered. Koo et al. [19] developed a new control method for automated venetian blinds to maximize occupant comfort. This new method can not only protect occupants from direct solar glare but also maximize daylight penetration into buildings based on occupants' preferences on daylight. Its potential benefits may be higher than the previous method. Chaiwiwatworakul et al. [20] studied the application of automated blind for daylighting in tropical region. The automated blind can adjust the angle of slats of the blind by a computer controller based on sunlight or glare conditions. They concluded that this automated system can maintain sufficient interior illuminance with a good visual condition throughout the day. Beside room temperature and indoor illuminance, the influence of movable solar shading on indoor mean radiant temperature [21], bright and glare sensation [22] have also been discussed.

Another kind of movable solar shading is deciduous plant that excludes solar radiation in summer by the plant foliage and let solar radiation to enter indoor in winter when the leaves have fallen. An experimental investigation was carried out by Papadakis and Tsamis [23] to analyze the effect of using trees for solar control of buildings by shading. They found that the radiative and thermal loads in the shaded area proved to be considerably lower relative to the unshaded one and the evaporative cooling effect leaded to lower air temperature around the shaded wall. The use of vegetation as a shading to improve indoor thermal performance in Greek region was reported by Eumorfopoulou and Kontoleon [24]. Their research showed that surface temperatures of plant-covered wall sections were considerably lower than those of the bare wall sections and significantly reduced heat flow losses. For the plant-covered wall, the mean daytime indoor temperature value fulfills the thermal comfort requirements.

Privacy and view toward outside have also been a research focus. Kim et al. [25] investigated the balance between daylighting performance, privacy and view. They presented an experimental configuration of external shading devices. The results demonstrated that external shading devices was capable of improving daylighting and view performance compared with conventional venetian blinds. Other environmental performance improvements result from solar shading such as carbon dioxide emission reductions [26] have also been reported by researchers.

However, these studies focused only on one or two aspects of the energy, indoor thermal and visual performance for moveable solar shading rather than all these three aspects. Furthermore, the performance of movable solar shading differs largely at different locations under various climate conditions. By now, there is still a lack of studies on movable solar shading taking into account the energy, indoor thermal and visual performance with field measurements and simulation combined analysis in hot summer and cold winter zone of China, and this leads to the current study.

The south-facing facade of a residential building was considered in this paper to carry out a comprehensive investigation into the effect of movable solar shading on the energy, indoor thermal and visual performance by field measurements and simulation analysis. To give an in-depth analysis, not only solar transmittance, cooling and heating energy demand will be compared, but also PMV-PPD index and Discomfort Glare Index (DGI) will be calculated and discussed.