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Experimental study on the effectiveness of internal shading devices

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ABSTRACT

These days, many studies are about the performance of some shading devices. Many engineers think the performance of internal shading systems is inferior to external systems. Because when using internal shades, the solar heat has already entered the internal spaces and has become trapped. However, in real applications, external shading is difficult to use, easily damaged and prone to dirt buildup. Internal shading is more flexible, cheaper and easier to repair. Some engineers doubt the validity of this traditional thinking and believe internal shading may be effective and useful to some extent because many occupants use internal blinds to minimize air conditioning costs. In this paper, the possibility of substituting the external shades with an internal ones using high reflectivity materials was studied through experimental tests and simulation validations. The results indicate that an internal shading system may be as effective as an external system if proper materials are used. Such substitution can reduce the overall cost of a shading system and can provide flexibility to the design of building facades. A grey relational analysis of the internal shade optimization is further presented so that the significant factors influencing the internal shading device performance are better understood. These factors should be taken into consideration during the design.

1. Introduction

Energy efficient and good daylighting design is receiving increasing attention as environmentally friendly buildings are becoming more popular. Using suitable shading devices can reduce the energy consumption, and meanwhile, daylighting requirements that illumination levels in buildings be kept within an acceptable range with no or little glare. Therefore, shading devices are well suited to provide protection against excessive solar radiation and decrease a building's cooling load during summer.

In traditional view, the energy-saving effect of internal shading device is far lower than that of external one [1]. But if internal shading devices can get the similar energy-saving effect to external ones, and be used instead of external ones, the designers can be free to design the appearance of buildings, can be more convenient to change the devices, and can reduce the expense of construction. Many studies have compared the influence of different types of shading devices on the energy needs and cooling or heating demands in buildings [2,3]. The effect of external vertical and horizontal shading devices was examined by Alzoubi and Al-zoubi [4], who addressed the quality of daylight in buildings and the associated energy savings for three common positionings. Kim [5] developed a series of simulations and measurements to verify the energy savings provided by external shading devices. The effect of different shading devices and shading control strategies for visual and thermal comfort combined with energy use has been analysed in several studies [6–9]. Frontini and Kuhn [10] investigated the effect of coatings with various internal blinds on the operative room temperature in an office space. Some simulation studies have concluded that the amount of energy that can be saved using internal shading devices is lower than using external ones by just moving the blinds from the outside to the inside. Thus, they advised using only external shading systems. However, this can be incorrect and is expanded upon in the latter part of this paper. At the same time, some researchers have focused on the assessment methods used to determine shading device performance. Gugliermetti and Bisegna [11] proposed simplified algorithms to assess the indoor natural illumination at a prefixed point with external fixed shading devices. A ray-tracing method was developed to describe the global solar transmittance of louver shading devices by Saelens et al. [12], who integrated using TRNSYS to assess the cooling demands and required cooling power in an individual office facing south. The results showed that both the cooling demand and peak cooling power can be estimated within an accuracy of 3%. These studies demonstrated that detailed simulations can capture the performance of both external and internal shades correctly. However, few studies have been done to compare the energy efficiency between internal and external shading devices. Even if the

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comparison has been done, there are still some shortages in these studies. EnergyPlus has been used by Atzeri et al. [13] to compare the performance of outdoor and indoor shading devices, and to examine the thermal and visual comfort and the overall primary energy use. PMV used in their study is a way to evaluate the effect by testers. Due to the subjective evaluations instead of objective judgements, some errors may occur. Thus, more exact ways need to be taken to eliminate the influence from the testers.

In this paper, air-conditioning cooling loads are analysed through experiments and simulations to compare the energy performance of external and internal shading devices. The comparative experiments were performed in Shanghai (China) for two rooms of the same size, orientation and cooling equipment. Hourly cooling loads were recorded to compare the energy performance of the two enclosed spaces installed with external and internal shading systems, respectively. The errors due to feeling deviation of testers usually occur in some experiments of subjective evaluations. Because the experiments and simulations in this paper are all objective, the errors have been ruled out. Thus, the results from the experiments and simulations can eliminate errors due to feeling deviation of testers, and can judge whether internal shading devices can get the same energy-saving effect to external ones when some parameters of internal shading devices are optimized. Because internal shading devices are more convenient and cheaper than external ones, and can provide more freedom to building designers, internal shading devices can replace external ones if these two kinds of devices can save the similar quantity of energy.

Moreover, the energy performance of shading systems depends on multi-factor and multi-variable inputs. Thus, a shading device can be regarded as a grey system, which is a system with many parameters—these parameters can affect the performance of the system, but the correlated degree between these parameters and the performance is unknown. The grey relational analysis can be applied to assess the factors influencing the energy-saving effect. Grey relational analysis (GRA), proposed by Deng [14] in 1982, is an important component of grey system theory (GST) [15]. GRA is a mathematical method suitable for solving problems with complicated interrelationships between multiple factors and is used for capturing their dynamic characteristics. GRA has been successfully applied in many fields, such as solving many multiple attribute decision making problems [16–19], assessing and optimizing boilers [20], flat-plate collectors [21], predicting software project efforts [22,23], forecasting the performance of ejector refrigeration systems [24], etc. Lee and Lin [25] proposed a perspective of multiple objective outputs to evaluate the energy performance of buildings and then used the GRA to rank the evaluated buildings. The grey correlation coefficients between ECEI (Elasticity Coefficient of Environmental Investment), ECEC (Elasticity Coefficient of Energy Consumption) and EEF (Energy Ecological Footprint) in Shanghai (China) were calculated by Liu [26] to demonstrate the interaction between an ecosystem and a behaviour system.

In this paper, we used a grey relational analysis (GRA) to study the main factors affecting an internal shading device. EnergyPlus [27] enabled the simulations of both external and internal shadings to compare the shading effect for various input matrices. The results of the factor analysis are helpful for designers and engineers to choose the right materials and specify installation methods if an internal shading system is to be built.

2. Theoretical analysis and methodology

2.1. Energy performance of internal and external shadings

The distribution of solar heat radiation through a window without any shading is shown in Fig. 1. The sunlight hits the glass, which absorbs some heat and then delivers it to both the indoor and outdoor environments via convection and radiation. Due to the limited heat capacity of ordinary clear glass, heat can only be stored for a short time in the glass before being transferred directly to both sides. Because the outdoor air temperature is higher and the direction of radiation is from outdoor to indoor, the overall trend is a continuous flow of heat from the outside to the inside, which could increase the indoor air temperature. In addition, a portion of the daylight penetrates the glass and heats indoor objects directly, which then heats the indoor air via convection and radiation.

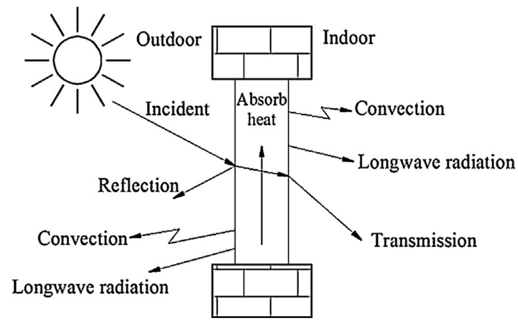

Fig. 1. Distribution of solar heat radiation through a window.

Fig. 2b shows that an external shading system will prevent most of the outside heat from entering a room, whereas an internal shading system (Fig. 2a) redistributes heat that has already entered the room. Therefore, the performance of internal shadings is generally inferior to external shadings.

From the comparison shown in Fig. 2, indoor heat gains are mainly obtained through radiation and convection, presented as:

$$q_{\text{total}} = q_{\text{rad}} + q_{\text{conv}} \tag{1}$$

The terms on the right side of Eq. (1) are difficult to calculate, but it is not necessary to determine q_{total} in part for this study. It is important to know the differences associated with external and internal shading devices, which can be expressed as follows:

$$\Delta q_{\text{total}} = q_{\text{total,int}} - q_{\text{total,ext}} = q_{\text{abs}} + q_{\text{ref}} \times a \tag{2}$$

where $q_{\text{toatal,int}}$ is all the heat components associated with internal shading, $q_{\text{toatal,ext}}$ is all the heat components associated with external shading, q_{abd} represents the heat absorbed by the internal shading device, q_{ref} represents the heat reflected by the internal shading device, and a is the radiation heat reflected by the internal shades, but blocked by the window glass. The radiation parameters are defined as:

$$\alpha + \beta + \tau = 1 \tag{3}$$

where α is the absorptivity of the internal shading device, β is the reflectivity of the internal shading device, and τ is the transmissivity of the internal shading device.

Based on Eq. (3), when β is large, α and τ are correspondingly small. According to Eq. (2), if α is lower and β is higher, q_{abs} will be lower and q_{ref} will be higher. The variation of q_{abs} will be higher than that of $q_{\text{abs}} \times a$. Therefore, the total heat can be small if a highly reflective material is used for the internal shading.

In addition, convection occurs between the shading device and glass inside the room if internal shadings are used, whereas convection occurs outside the room if external ones are used. With an internal shading system, a portion of the radiative heat is reflected outside. However, some portion of this heat is reflected back from glass, increasing the indoor load. Other radiative heat is transferred into the room through gaps and another portion will heat the shading device, which will deliver heat to both sides through radiation and convection. However, if an internal blind is positioned