

EFFECT OF A NOVEL INTERNAL ROLLER SHADING SYSTEM ON ENERGY PERFORMANCE

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ABSTRACT

The purpose of this research is to investigate the impact of movable solar shading on energy performance in subtropical regions of China. An office building retrofitted with a novel internal roller shading system consisting of two shading layers was selected to carry out field measurements and numerous computer simulations were conducted in order to quantify the energy saving performance of this solar shading system, which was further compared with commonly used Low-E windows and regular fabric roller shades. The results show that the solar transmittance ratio is only 1.3% to 7% depending on used solar shading layers in summer and there is almost no negative impact on heating season in winter. The room base temperature reduction ranges from 4–14°C in summer, indicating a significant indoor thermal performance improvement. Meanwhile, the total energy saving for this shading system is 26.06%, 24.42% and over 50%, respectively, compared to Low-E windows, fabric roller shades and the bare window case. Thus, this novel solar shading system is a high energy saving measure and can be widely used in a subtropical zone.

KEYWORDS

building energy, solar shading, roller shades, indoor thermal comfort

1 INTRODUCTION

It has been recognized that buildings offer the largest share of cost-effective opportunities for greenhouse gas (GHG) emissions mitigation and that achieving a lower carbon future will require very significant efforts to enhance measures for energy efficiency in buildings. Methods used to reduce GHG emissions from buildings include passive and active measures. Passive energy efficiency measures consist of window placement and glazing type, thermal insulation, thermal mass and solar shading etc. Solar shading, especially movable shading, is most suitable for climate regions with demands for solar radiation rejection in summer but admission in winter. The climate in subtropical regions of China require movable solar shading utilization in buildings when designing energy efficiency buildings. Literatures regarding energy efficiency measures such as wall insulation [1], advanced windows [2], wall coating [3], low-E windows [4] and green roof [5] have been reported by researchers in subtropical region cities.

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For solar shading, fixed shades such as overhang, vertical fins due to their simple design and construction are widely used in this area and have been investigated by many studies [6-12]. These studies show that fixed shades are not suitable for east- and west-facing windows since the solar angle is too low to be shaded in summer. The south-facing facade requires an optimal depth for fixed overhang shades because the unwanted solar gain should be blocked by shades in summer, while solar radiation is needed in winter to warm indoor spaces. Though Cao et al [7] gave some suggestions on an optimal overhang depth for different cities, their analysis was based on simple calculations without considering building energy performance through hour-by-hour building simulation with typical meteorological year (TMY) climatic data. Moreover, they presented a range such as 0.2-0.4m rather than a value. This range for fixed shades is a function of the ever changing solar angle throughout the year. Thus, this may confuse designers since there are a lot of values within this range, and they do not know which value is optimal. Therefore, the energy performance might not be optimal with these suggested dimensions.

Movable solar shading, however, has an advantage over fixed shading since they can be adjusted to block solar radiation in summer and be kept at a position without a negative impact in winter. A number of literature sources reported energy performance in different climates in the US, Europe, and other countries by different researchers [13-20]. Nevertheless, the impact of movable solar shading on energy performance in subtropical regions of China has been rarely reported. Therefore, this research tries to carry out a field measurement and simulation based study on a novel kind of movable solar shading on a retrofitted office building, in order to quantify the energy saving performance of this shading and to further give a comparison with commonly used Low-E windows and regular fabric roller shades.

2 METHODS

2.1 The research building (Yinzhou Bank)

The investigated building in this research is a 22-storey office building (37080m^2), named Yinzhou Bank, with a glazing-curtain wall in Ningbo City as shown in Fig.1, which was retrofitted with internal movable solar shades in 2013. This building was constructed without any energy efficiency measures. A novel internal roller shading system developed by Ningbo Xianfeng New Material CO., LTD was used in this building, with two layers adjustable by occupants. The heat transfer coefficient of this system combined with a clear-pane window is $2.2\text{W}/\text{m}^2\text{K}$, but its solar shading performance has not been tested. Figure 2 shows the picture of the solar shade used in an office room of this building. The external layer (see Fig.2a) with aluminum coating was used to block solar radiation and the internal layer was used to control daylight. These two layers are both made of polyvinyl chloride polymer (PVC) and polyester fiber. When the two layers are both in use (see Fig.2b) there will be a combination effect on solar and daylight control.

FIGURE 1. The investigated building.



FIGURE 2. Solar shading in use with (a) one layer shade and (b) two layer shade.



2.2 EXPERIMENT SETTING

The location of the test building is in a subtropical region with the outdoor design temperature of -2.7°C and 32.3°C for heating and cooling [21], respectively. And the heating degree-days is 1647, while the cooling degree-days is 196 [22]. The author selected this building for measurement since only this office building has been retrofitted with this kind of movable solar shades. For this building, there is no high-rise building nearby, and thus the test of solar transmittance will not be influenced by surrounding structures. Field measurements were carried out to evaluate the solar shading performance on July 20, 2013, a typical summer day (a clear sunny day with almost no cloud cover) with the outdoor temperature reaching about 37°C . A PC-2 solar radiation measuring recorder [23] (accuracy: $\pm 0.5\%$) and a TB-2 solarimeter (accuracy: $\pm 2\%$) were used to measure the solar shading performance. And two TES-1361 automatic thermohygrographs [24] (accuracy: $\pm 0.8^{\circ}\text{C}$) were used to test the indoor temperature. Two identical southeast-facing office rooms on 18th floor, one with solar shading in use and another without, were selected for comparison. Only two southeast rooms were selected because access to other rooms was not allowed due to security reasons. When testing solar radiation and indoor temperature, two shading layers were both deployed to shade 67% of window area to control solar radiation and maintain daylight illuminance. In this research, it is assumed that the occupant sits (1.2m high) toward the outside with a distance of 0.5m from the window. Thus, the indoor temperature was measured at the occupant's position. Pyranometers and solarimeters were set up perpendicular to the window with a distance of 0.1m from the window at a height of 1.2m above floor. Since sun position was constantly changing, the average value of solar transmittance was used for further simulation analysis.

2.3 SIMULATION MODEL

An office room (see Fig.3) was modeled in the building simulation software Energyplus, which is developed and supported by the US government [25]. The dimension and setting of the building envelope and HVAC etc. comply with the real building and is listed in Table 1, and the typical meteorological year data for Ningbo City in China was used in 8760 hours of simulation. This room model has only one external glazing surface, other surfaces (three internal walls, roof and floor) are assumed to be adiabatic. To account different window orientations

(here east, south and west orientations were considered), the room model was rotated to suitable directions. Through simulation, annual cooling, heating, lighting and total energy performance will be discussed.

FIGURE 3. Building model

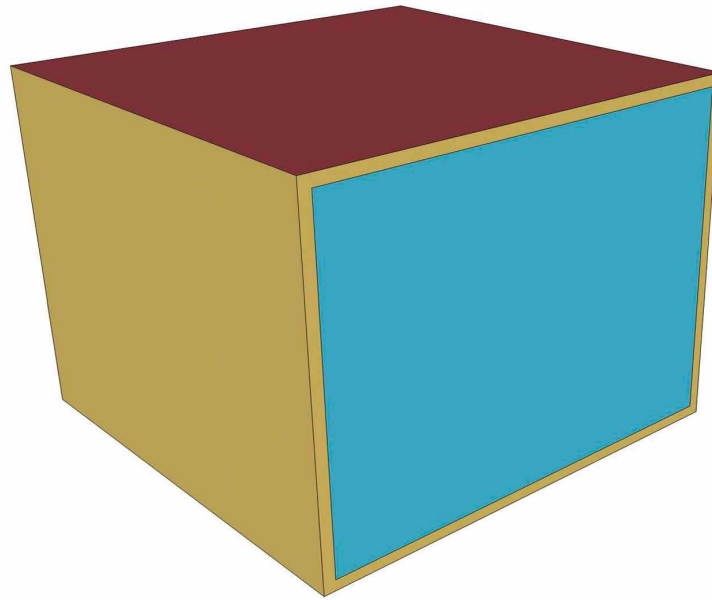


TABLE 1. The dimension and setting of building envelope and HVAC etc.

Parameter	Value
Dimension	Room: 4×4×3m (length×width×height), window: 3.99×2.99 m (width×height), glazing-curtain wall, locates at the center of the wall
Building envelope	No external wall, and adiabatic for internal walls, roof and floor; clear single-pane window, U-value: 6.4W/m ² K, SC:1
HVAC	Temperature: 20-26 oC, running time: 8:00-17:00 (other time: powered off)
Interior heat generation	Light density: 11W/m ² ; equipment: 20W/m ²
Fresh air	30m ³ /(hour.person)

The solar shading control strategy in the building simulation was set to comply with the regular adjustment behavior of occupants on solar shades as shown in Table 2. In summer, 67% of the window area was shaded to block solar radiation and try to maintain daylight illuminance throughout the work time (8:00-18:00), but adjusting to fully opened when the office is not in use (18:00-7:00). In winter, the shades were also fully opened to absorb solar radiation to reduce heating energy, while closed to reduce room heat loss through windows in nighttime (18:00-7:00).

TABLE 2. Solar shading control strategy.

Season	Time	Shaded Sate
Summer	Work time	Shaded 67% of window area
	Nighttime	Fully open
Winter	Work time	Fully open
	Nighttime	Fully closed

NOTE: The season Summer means days from 6. 1-9.30 and Winter means days from 10. 1-5.31.

3 RESULTS AND DISCUSSION

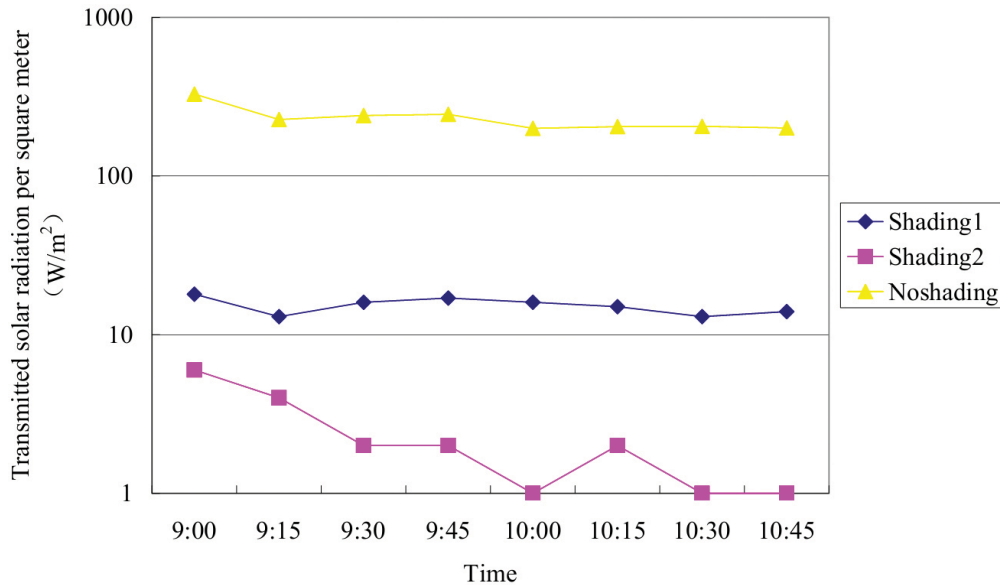
This section is divided into two parts. The first part presents the experimental results, including transmitted solar radiation and room temperature, while the second one gives the simulation analysis on transmitted solar radiation, room base temperature, and energy performance.

3.1 Experimental result

The measurement of solar transmittance of the novel roller shading system is presented and discussed here as well as room temperature, which represents indoor thermal condition.

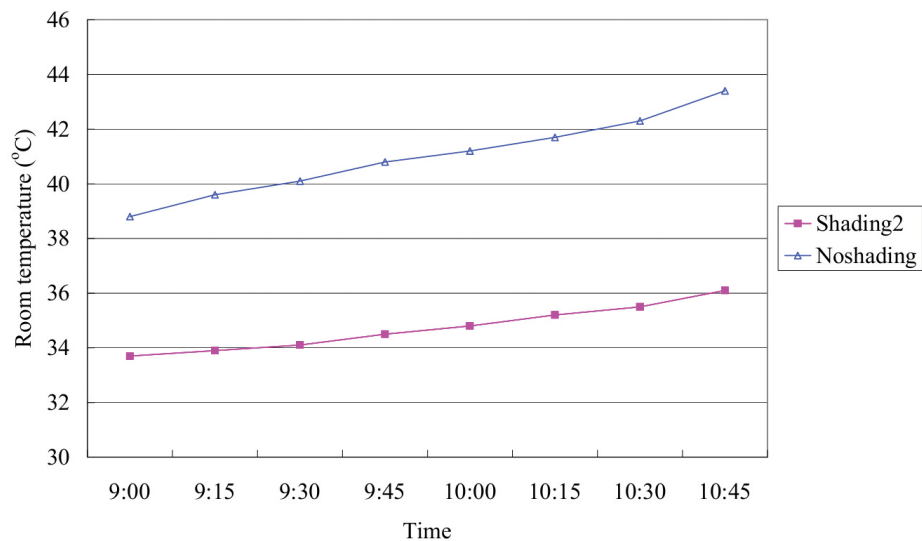
3.1.1 Transmitted solar radiation

Fig.4 presents the comparison of transmitted solar radiation per square meter through windows before and after solar shading. There are two shading types including Shading1 and Shading2. Shading1 means that only the external roller layer (solar shading layer) is used while Shading2 indicates that both external and internal roller layers are in use. According to this chart, the transmitted solar radiation reduced from about 220W/m² for without shading to about 16W/m² for Shading1, which means only about 7% of solar radiation is transmitted. For Shading2, this solar protection effect is more obvious, the transmitted solar radiation reduced to only about 3W/m², indicating only about 1.3% of solar radiation can enter into the room. Thus, this novel roller shading has a potential solar transmittance ratio of 1.3% to 7% depending on used solar shading layers.

FIGURE 4. Comparison of transmitted solar radiation before and after solar shading.

3.1.2 Room temperature

Fig.5 gives room temperature comparisons before and after solar shading. Here only Shading2 is compared with no shading at indoor free running temperature conditions. Without solar shading (no shading), the room temperature increased from about 39°C at 9:00 to over 43°C at 10:45. This means that the indoor thermal conditions become more and more uncomfortable. However, the indoor temperature keeps between 33.8-36.1°C after using solar shading (Shading2) though there is a 2.3°C increase after 1 hour and 45 minutes. The average room temperature reduction is 7.5°C, indicating a significant indoor thermal improvement.

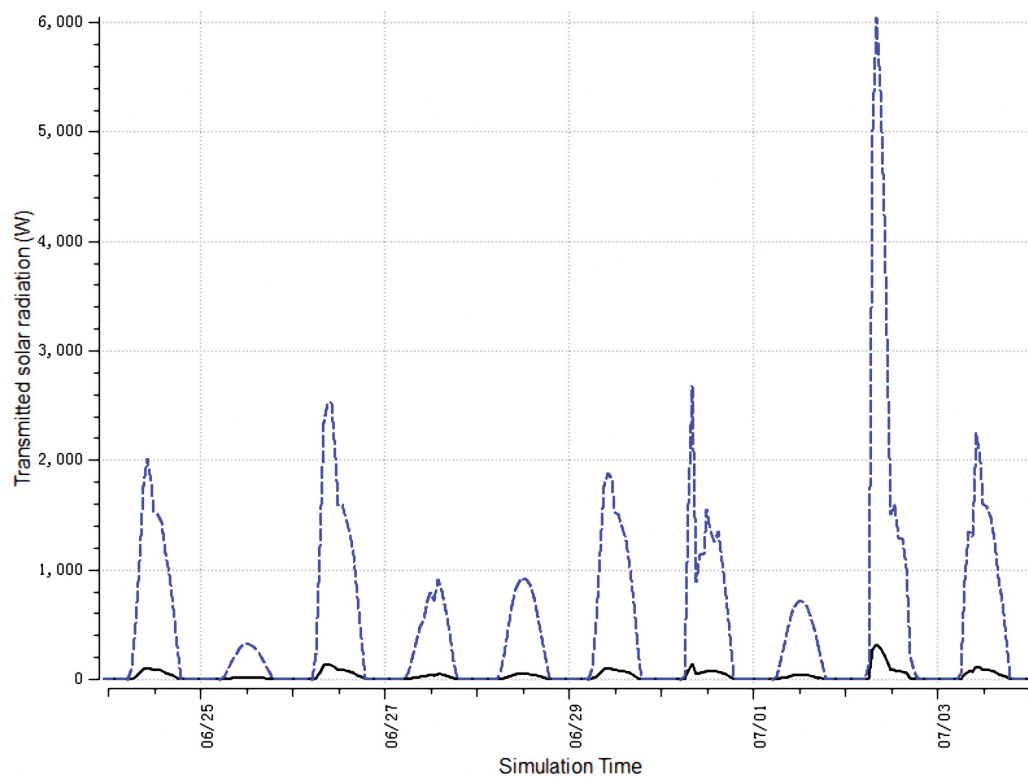
FIGURE 5. Room temperature comparison before and after solar shading.

3.2 SIMULATION ANALYSIS

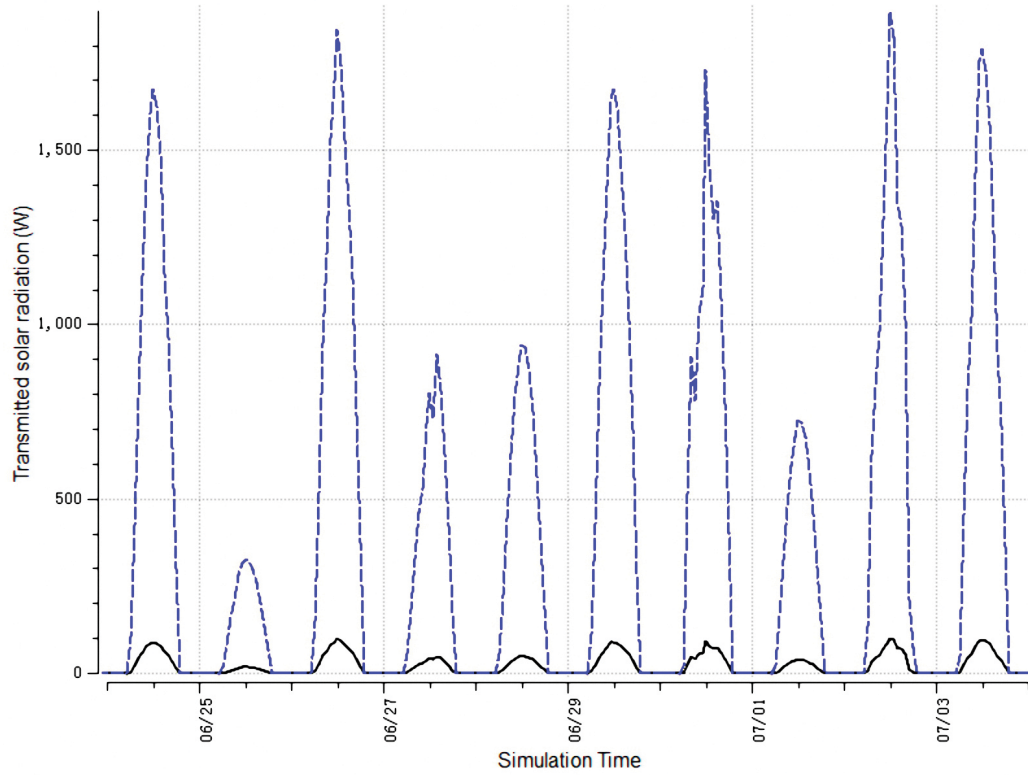
3.2.1 Transmitted solar radiation

Fig. 6 gives the hourly transmitted solar radiation through the whole window area (not per square meter, but it is easy to convert to W/m^2 by dividing the window area) for different orientations during typical summer days. The blue line (dot line) is transmitted solar radiation without solar shading and the black line is after using solar shading. It is clear that this kind of solar shading has a significant performance in decreasing transmitted solar radiation in summer with a maximum value of only about 200W, which is much less than the bare window case having an excessive transmitted solar radiation by up to about 1800W to 6000W depending on window orientation.

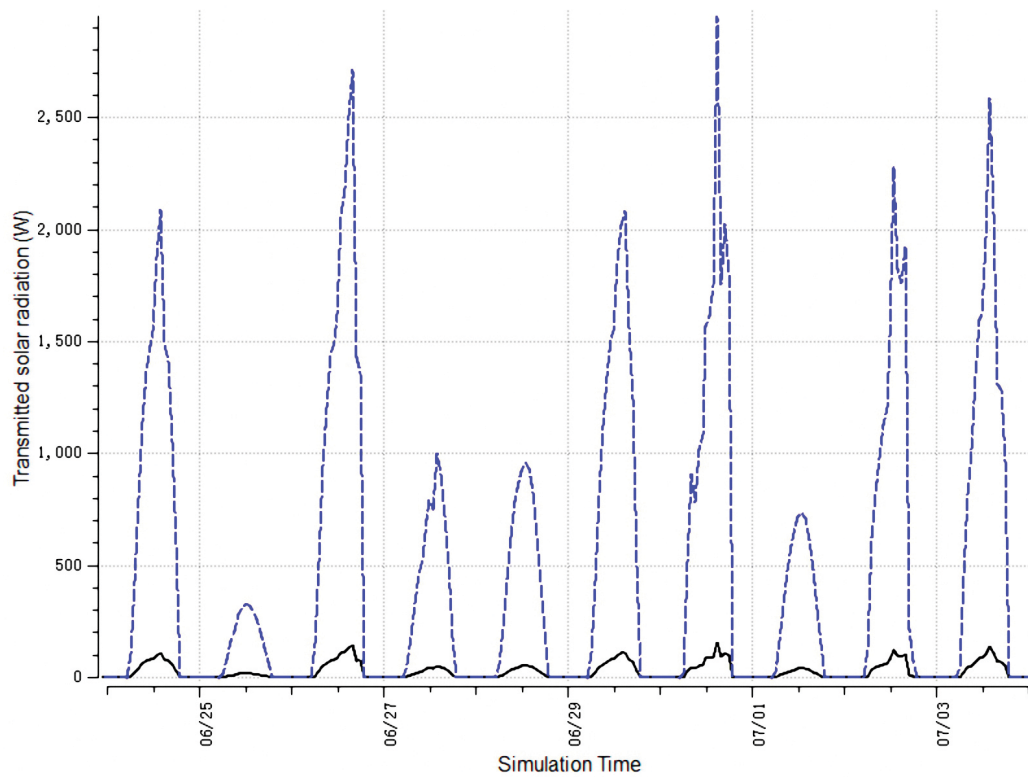
FIGURE 6. Hourly transmitted solar radiation during typical summer days for no shading (blue and dot line) and shading (black line) for (a) east, (b) south and (c) west rooms.



(a)



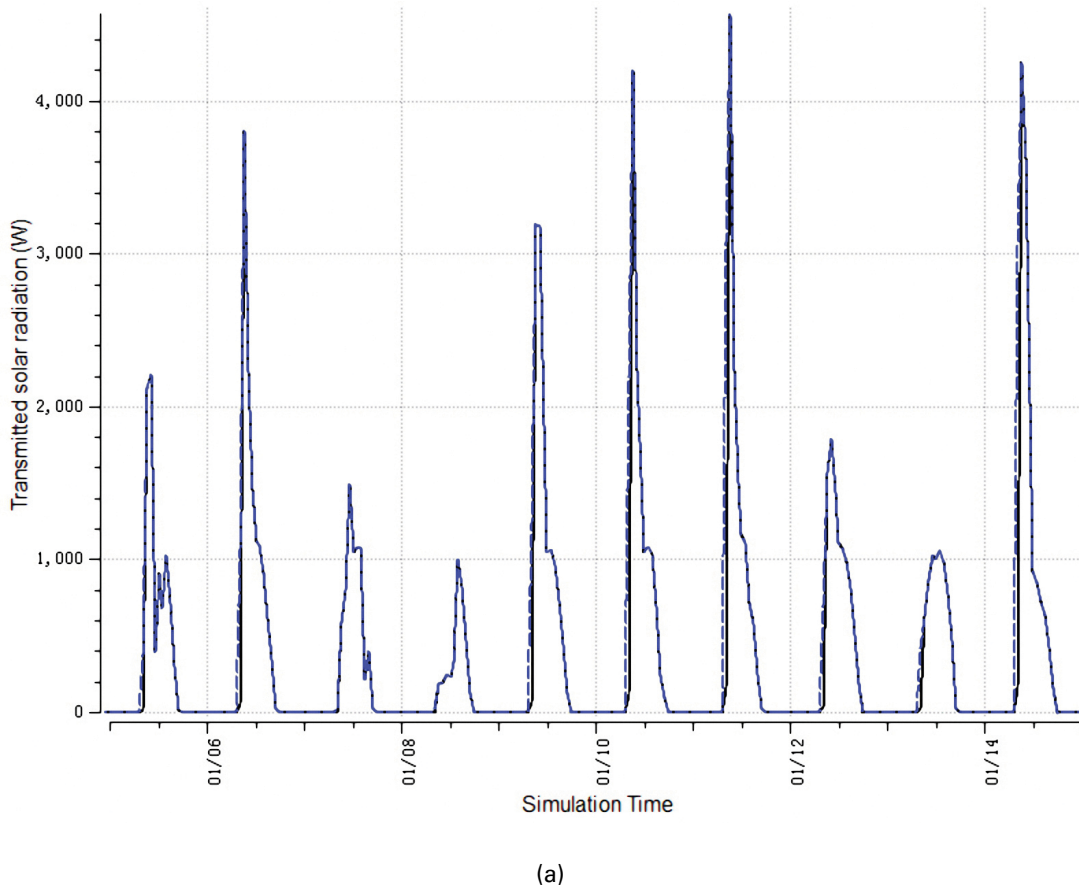
(b)

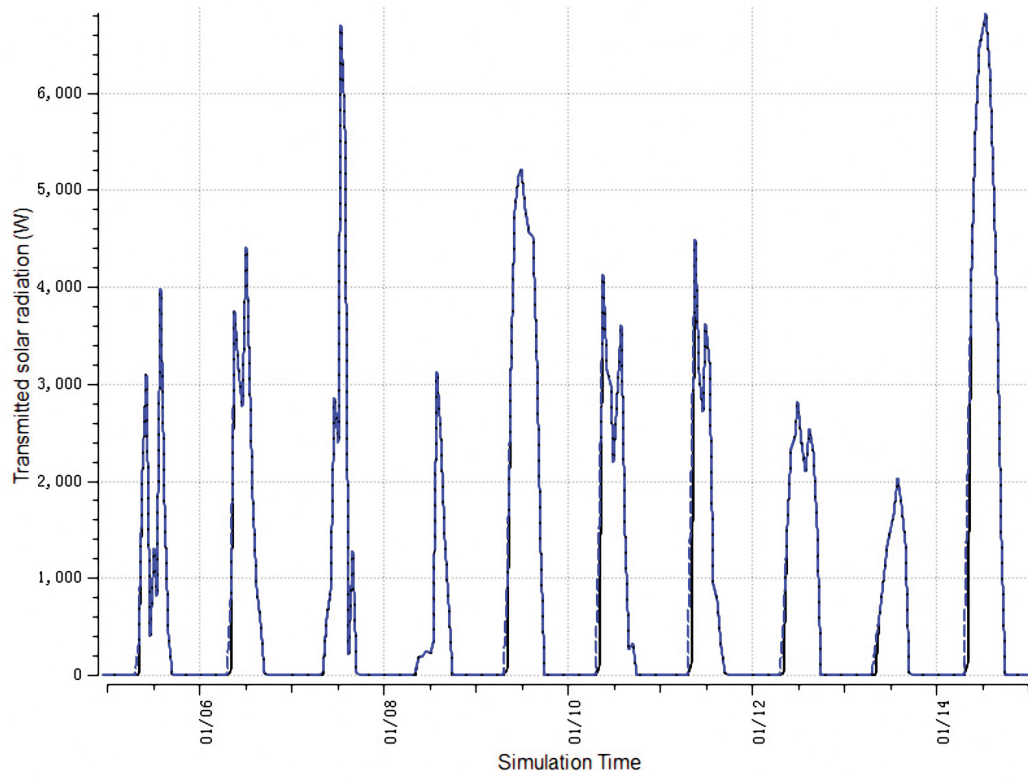


(c)

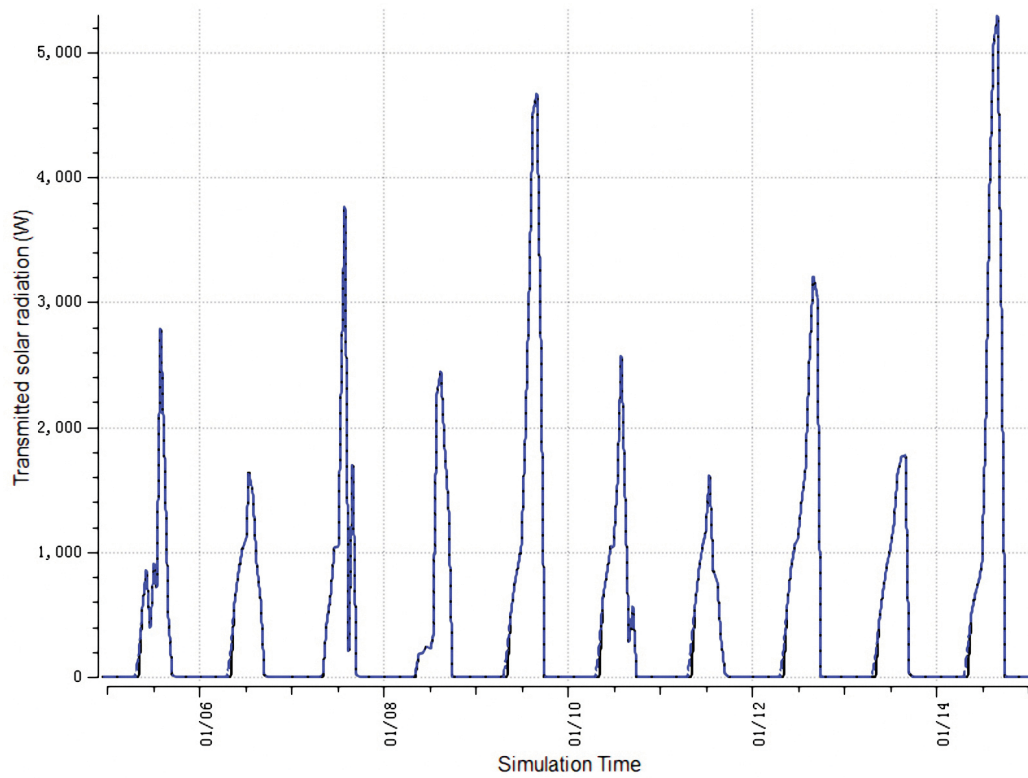
Fig.7 shows hourly transmitted solar radiation through the whole window area during typical winter days. It can be seen that the blue line (dot line) and the black line almost coincide, indicating that there might be a negligible impact on solar reduction by solar shading. This is because the solar shades are fully retracted during work time. Therefore, the heating energy may not be increased considerably.

FIGURE 7. Hourly transmitted solar radiation during typical winter days for no shading (blue and dot line) and shading (black line) for (a) east, (b) south and (c) west rooms.





(b)

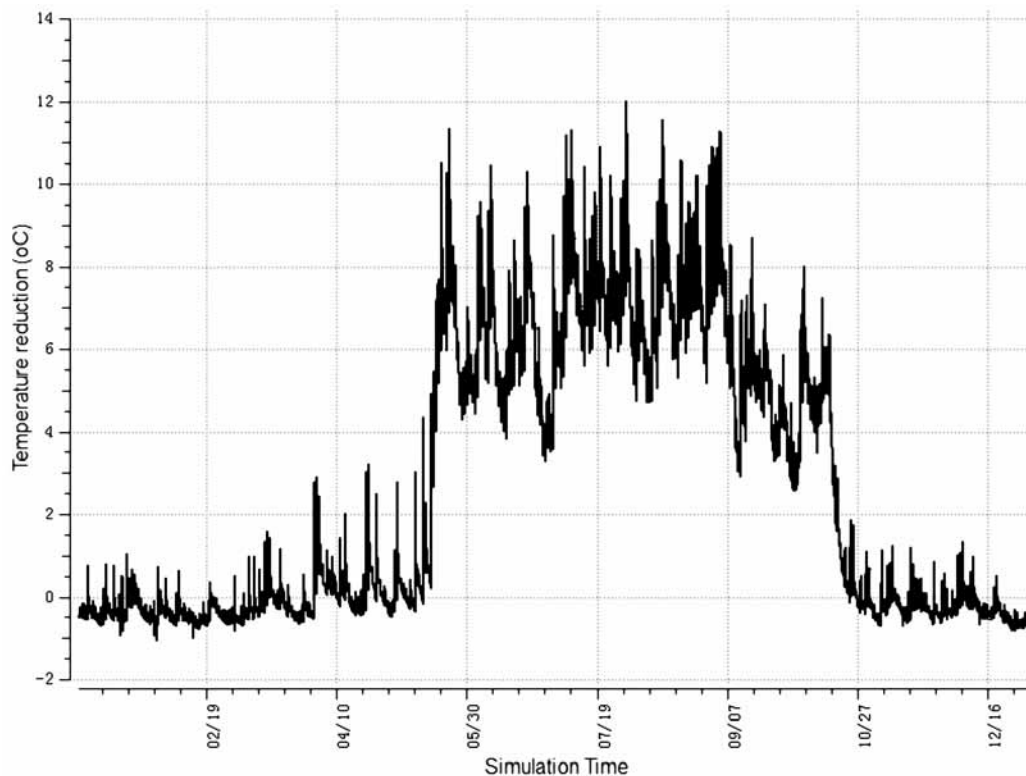


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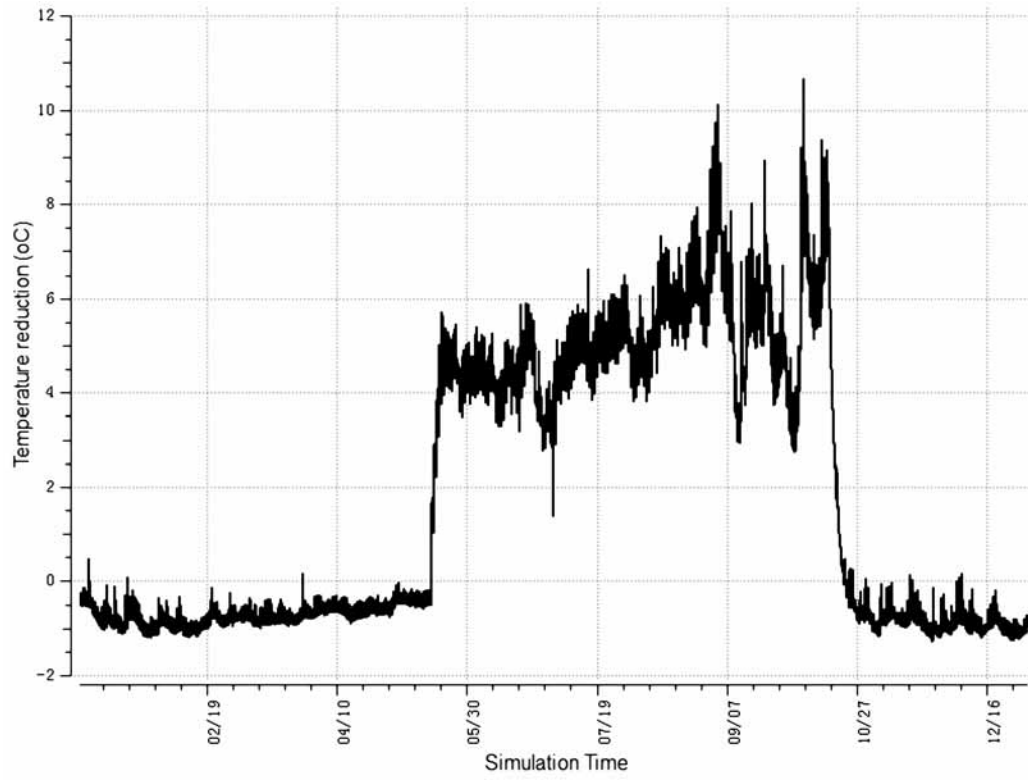
3.2.2 Room base temperature

Room base temperature, which represents hourly indoor air temperature without the air-conditioner running, is a key factor to calculate the indoor thermal environment [26]. When simulating room base temperature, air conditioning was set to be off during the whole year. This means all HVAC systems used to control indoor temperature are kept powered off and the indoor temperature is only influenced by the thermal performance of the building envelope. Room base temperature can also be used to reflect the energy saving performance of energy-saving measures. A higher room base temperature means a greater energy demand for cooling in summer. The annual room base temperature reductions after using solar shading for the three orientations are illustrated in Fig.8. It is clear that the temperature reduction in summer is higher than 0, with most values ranging from 4 to 12 °C for the east orientation. For the south-facing windows, the peak reduction of about 10 °C is a little lower than the east situation. The west-facing windows with solar shading contribute to the greatest reduction of about 14 °C. This means the west orientation has the most potential in reducing cooling energy demand in summer.

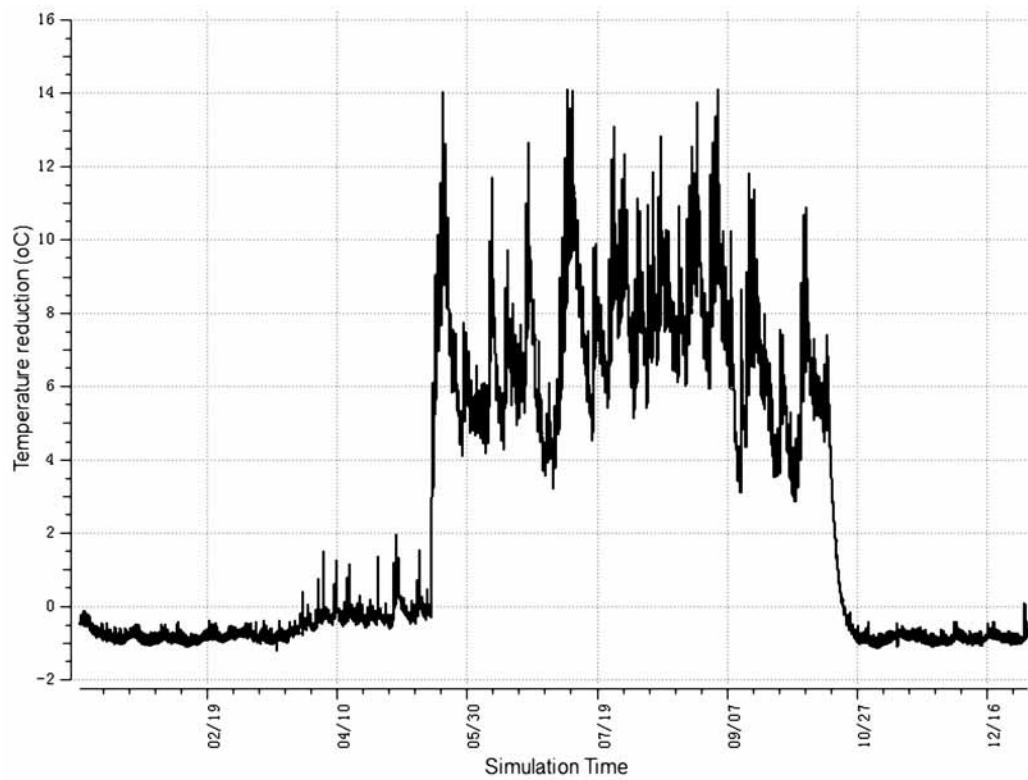
FIGURE 8. Hourly room base temperature reduction in the whole year after using solar shading for (a) east, (b) south and (c) west rooms.



(a)



(b)



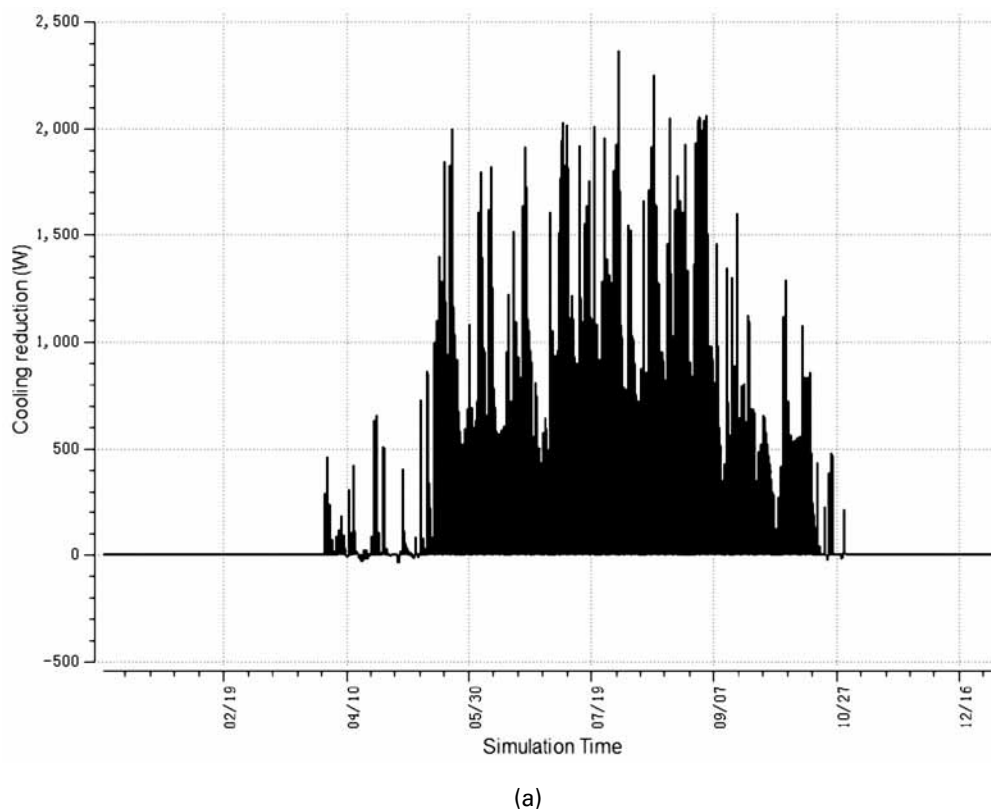
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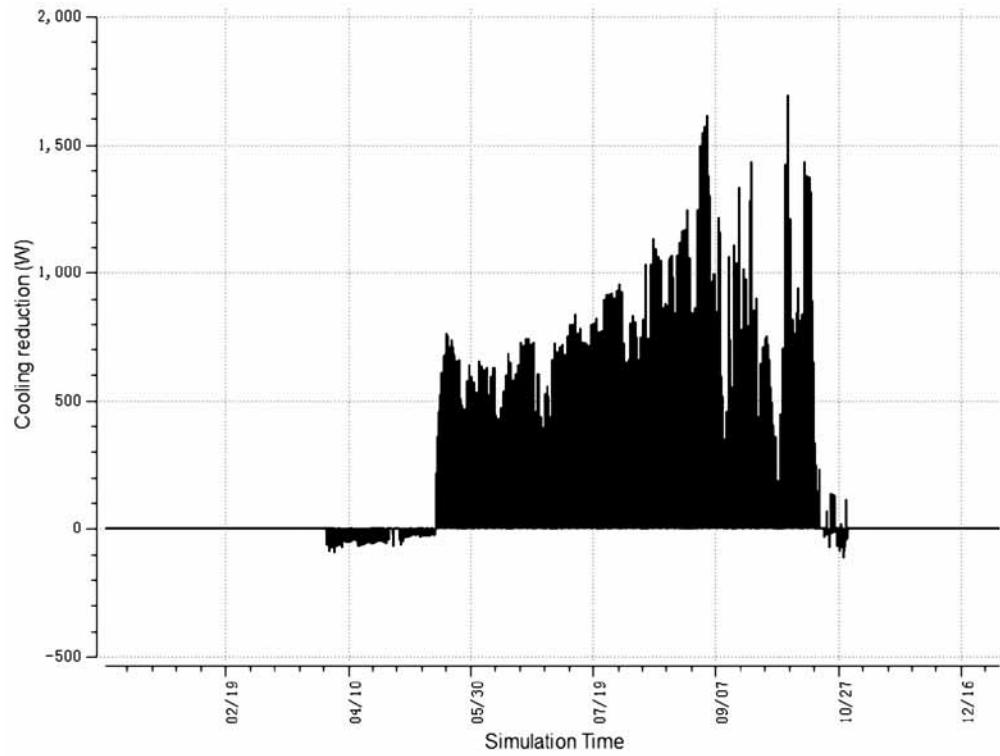
On the other hand, the room base temperature reduction in winter is a little less than 0, indicating that indoor base temperature was increased after using solar shading (warm indoor space), and thus it has a positive impact on improving heating performance. The reason for these negative reductions is that the solar shading was pulled down in winter nighttime to reduce heat loss. Therefore, this will help decrease heating energy demand in winter. To further verify and quantify the energy saving performance in winter and summer, the following section will give a detailed discussion.

3.2.3 Energy performance

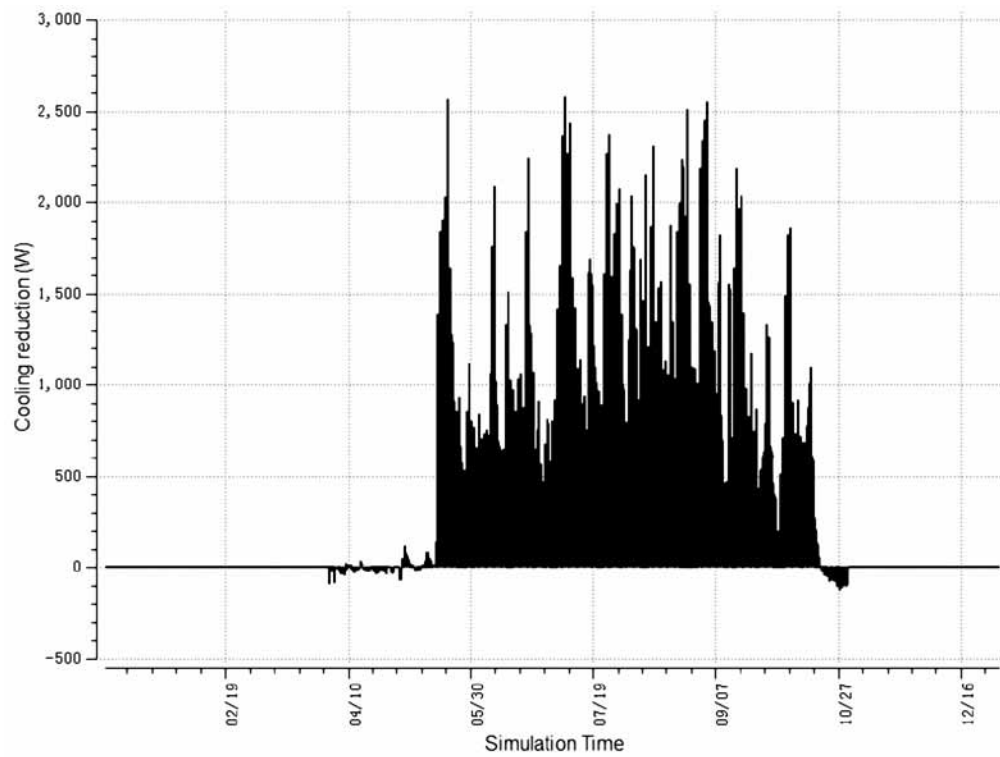
The hourly cooling energy reduction in the whole year is depicted in Fig.9. The peak cooling load can be reduced by about 2400W, 1700W, and 2600W, respectively, for east, south and west orientation. This means that the west-facing windows have the biggest peak load reduction in summer, followed by east- and south-facing windows. This is due to a relatively low solar altitude angle in summer and a higher outdoor temperature for the west room. The minor negative values in April and October may due to the increased insulation performance in nighttime and thus increasing room temperature to higher than the bare window case. The substantial peak cooling reduction means that the HVAC equipment capacity can be lowered after using solar shading and thus this will lead to a reduction of initial costs on HVAC equipment.

FIGURE 9. Hourly cooling energy reduction in the whole year after using solar shading for (a) east, (b) south and (c) west rooms





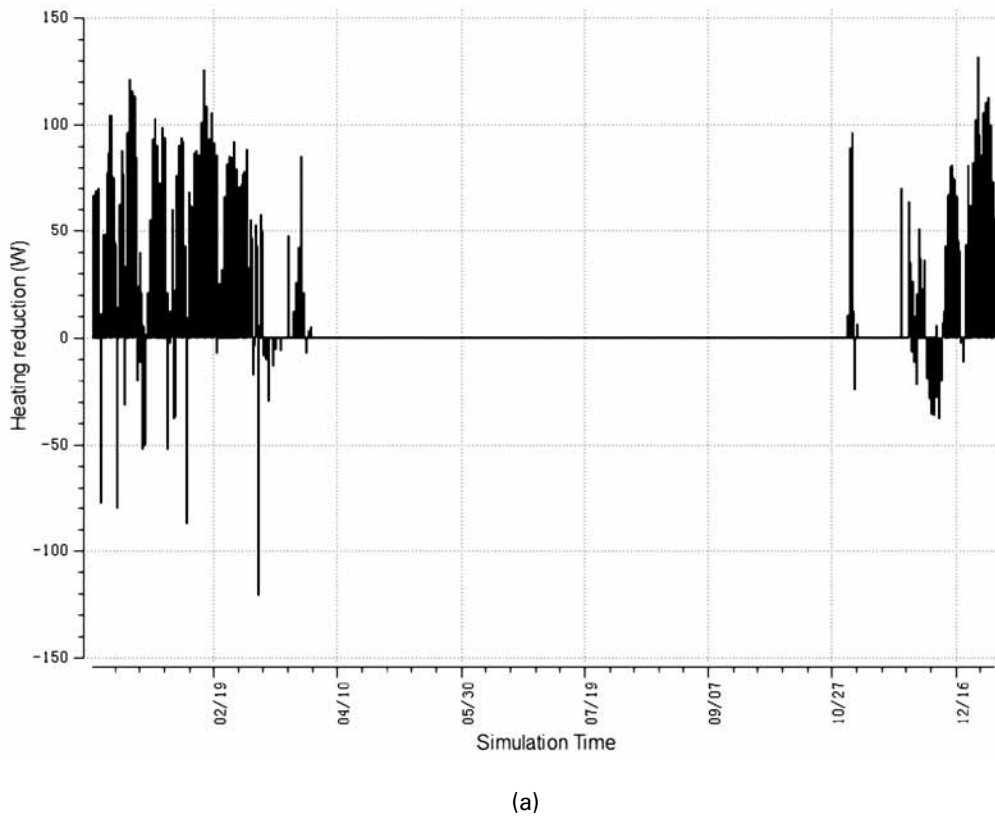
(b)

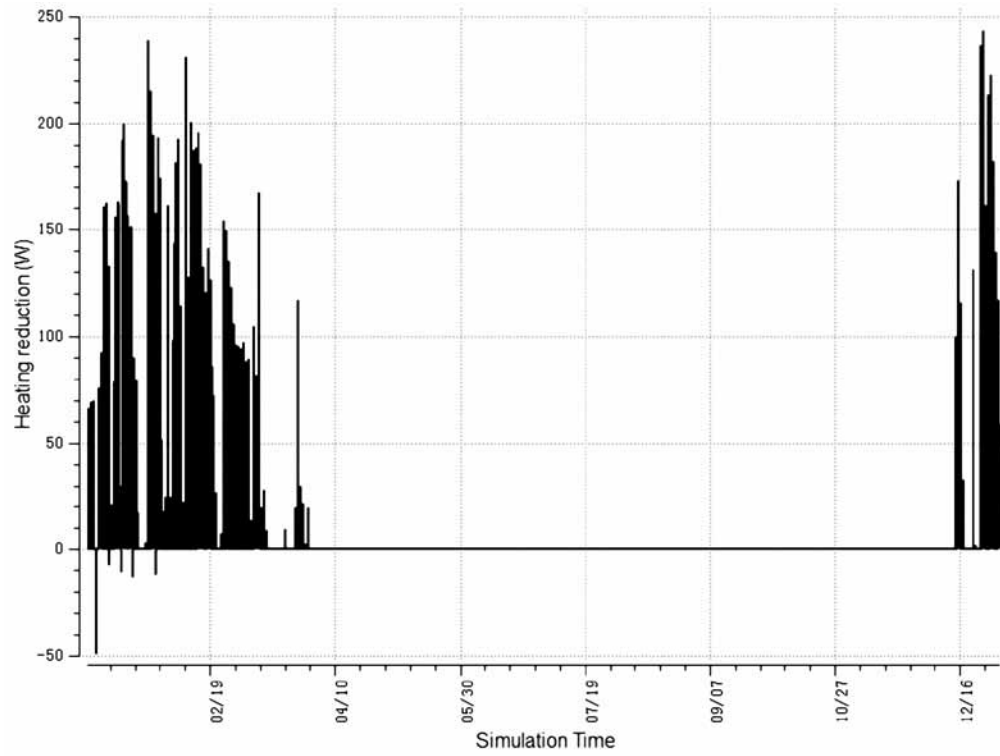


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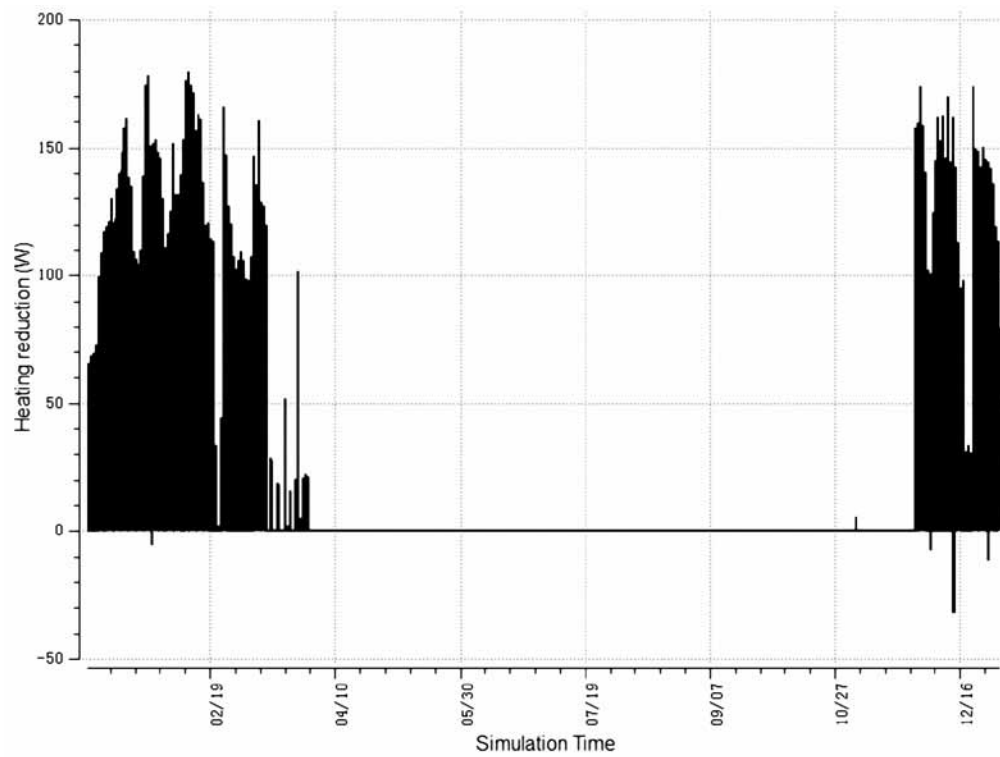
On the other hand, the hourly heating energy reduction in winter, as shown in Fig.10, is similar to the situation in summer. The reduction values are higher than 0 in winter, indicating an increased room temperature and thus a reduction in heating energy demand. The peak heating load reduction is up to about 240W for the south orientation which is, however, higher than that for the east and west rooms that are only 140W and 170W, respectively.

FIGURE10. Hourly heating energy reduction during the whole year after using solar shading for (a) east, (b) south and (c) west rooms





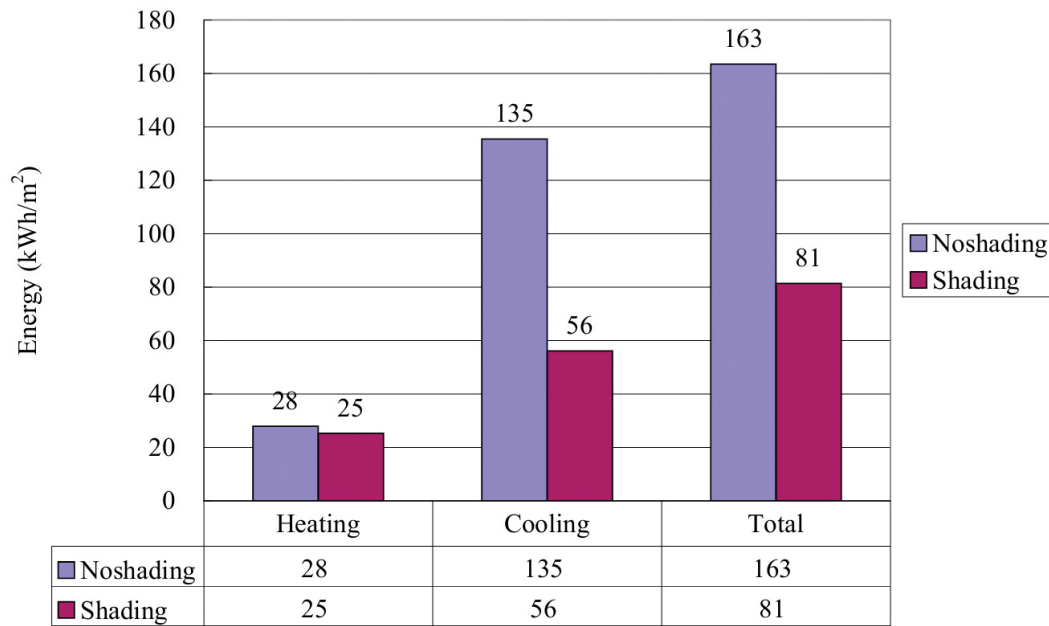
(b)



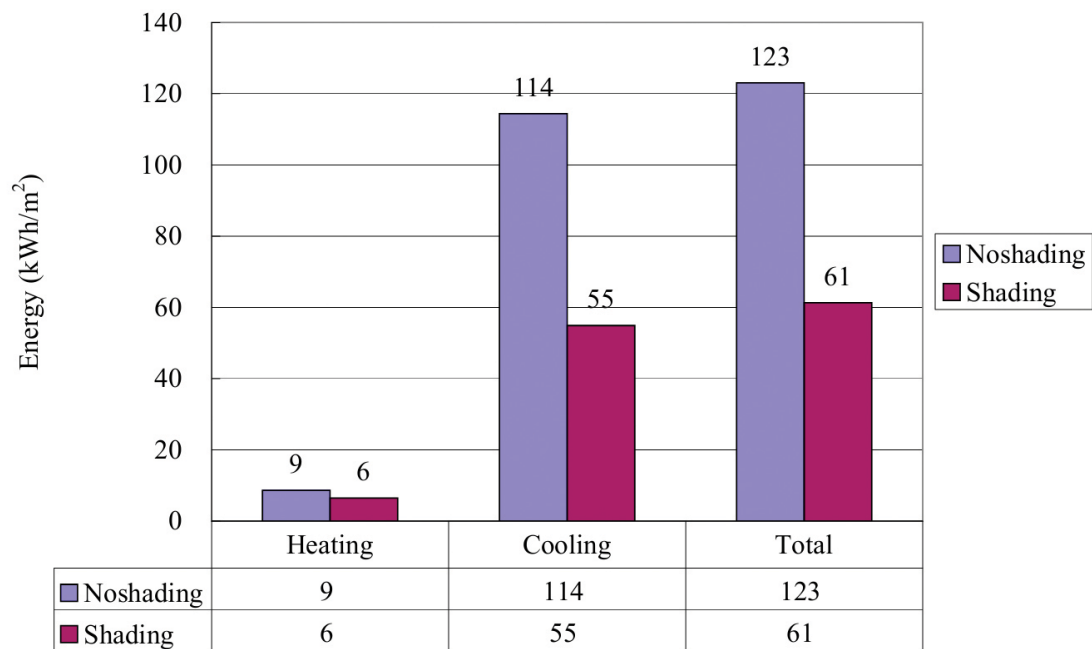
(c)

The above two paragraphs discussed the hourly reduction in cooling and heating energy demands. Fig.11 gives the annual cooling, heating, and total energy performance comparison before and after using solar shading. Here lighting energy is not included since the daylight illuminance for most work time is higher than 300 lux due to a large window-to-wall ratio. Thus, the lighting energy can be neglected compared to heating and cooling energy. For the heating energy demand, the south room achieves the biggest saving of 25.87%, followed by the west room (18.95%), and the east room has the least saving of 9.46%. By comparison, the east room contributes to the largest cooling energy saving of 58.6%, followed by the west room (55.05%) and the south room (52.02%). For the total energy demand (heating and cooling), the west room performs a little better than the other two, which are between 50.18% and 50.52%. This energy saving is equivalent to the saving potential of a combination of adding wall insulation, roof insulation, and replacing single-pane glazing by double-pane glazing for windows. This is because the energy saving potential for the combination of these measures in China in this climate area are close to 50%, according to experience from a large number of simulations by most building designers [27].

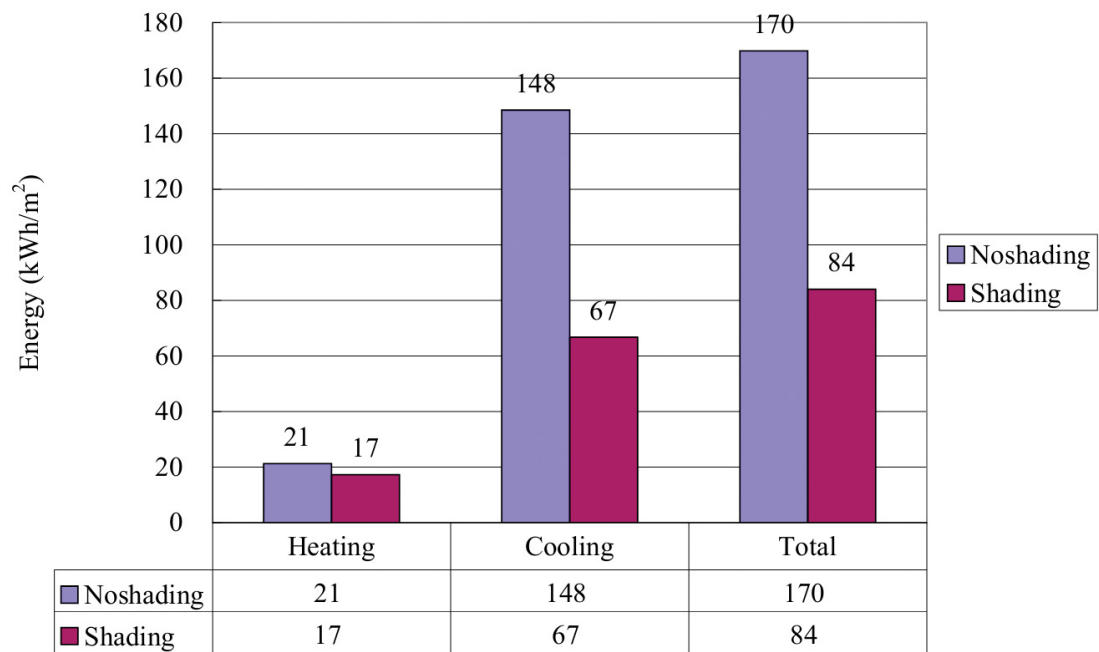
FIGURE11. Annual energy demand before and after using solar shading for (a) east, (b) south and (c) west rooms.



(a)



(b)

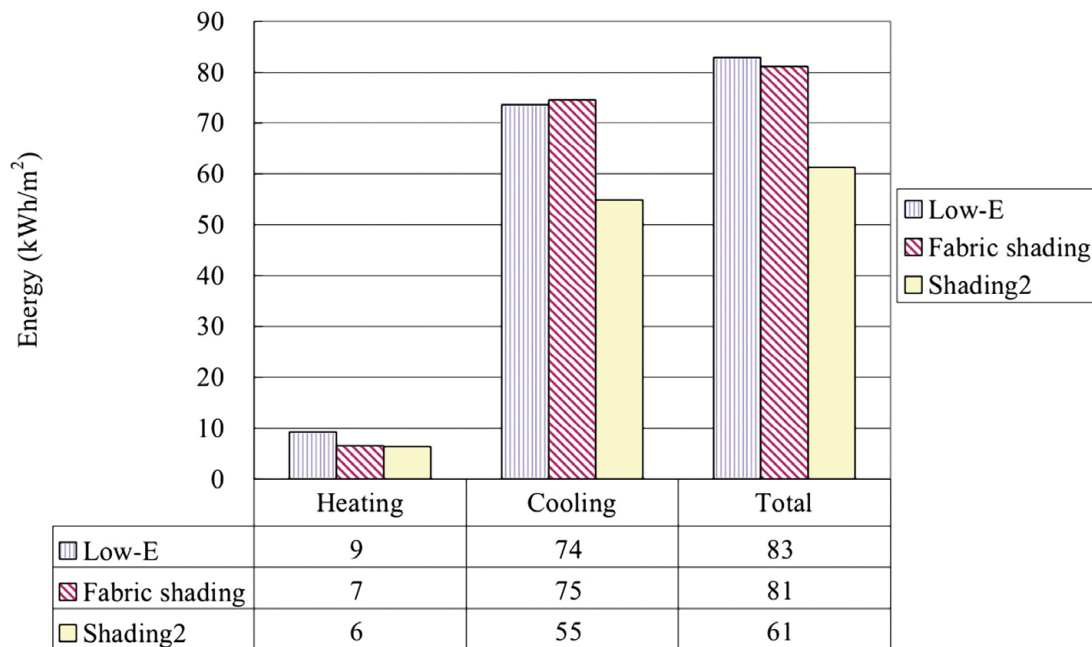


(c)

4. COMPARISON WITH REGULAR MEASURES

Currently, Low-E windows and regular fabric roller shades are widely used in energy efficient buildings to address the overheating and high cooling energy costs. The energy performance of this novel kind of movable solar shading compared to these two measures are discussed below. A Low-E window with U-value of $3.6\text{W/m}^2\text{K}$ and solar shading coefficient (SC) of 0.5 and a fabric roller shade with a SC value of 0.35 were simulated, respectively. The control strategy for fabric shading is the same as the above setting in section 2.3. The energy performance for Low-E was determined by simulation with Energyplus using the same model setting in Table 1 except the window, which was replaced with the Low-E window. The simulation for fabric shading is similar. Fig.12 illustrated the annual energy demand comparisons with Low-E and fabric shading. It can be seen that Shading2 has a significant advantage over the other two measures. The total energy saving for Shading2 is 26.06% and 24.42%, respectively, compared to Low-E windows and fabric roller shades. Therefore, this kind of novel roller shades is a high energy saving measure and can be considered as a priority for solar shading utilization in subtropical zones.

FIGURE12. Annual energy demand comparisons with Low-E and fabric shading.



5 CONCLUSIONS

In this research, the impact of movable solar shading on energy performance in subtropical regions of China was investigated. A field measurement and numerous computer simulations were conducted to quantify the energy saving performance of a novel kind of solar shading with two roller layers and compared with commonly used Low-E windows and regular fabric

roller shades. The results show that the solar transmittance ratio would be as low as 1.3-7%, if occupants use the external roller layer for solar control, depending on the internal roller layer's position in summer (whether and to what extent occupants want to control daylight conditions). Moreover, there is almost no negative impact on the heating season in winter. The room base temperature reduction is also significant and ranges from 4-14°C in summer, indicating a significant indoor thermal performance improvement. Compared to Low-E windows, fabric roller shades and the bare window case, the total energy saving for this shading system is 26.06%, 24.42%, and over 50%, respectively. In conclusion, this novel solar shading system not only provides flexible control over solar gains and daylight availability, but also has an excellent performance in maintaining a comfortable indoor thermal condition, as well as a higher energy saving compared to Low-E windows and regular fabric roller shades. Thus, this novel system can be widely used in subtropical regions.

6. ACKNOWLEDGEMENT

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