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# A Comparison of Smart Shading Control Strategies for Better Building Energy Performance

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***Abstract***

*The objective of this research is to investigate the energy performance of different smart solar shading control strategies on typical residential buildings in hot summer and cold winter zone of China. Four typical sensor based automatic shading control strategies were analyzed using building simulation tools to optimize indoor thermal and energy performance. It was found that solar radiation based sensor control has a better energy performance than temperature based sensor control with an energy reduction (both cooling and heating) of about 5-10% depending on the type of control strategy. The results indicate that solar based sensor control on solar shades can be widely used in residential and commercial buildings for an improved energy performance.*

***Keywords****: Building energy, sensor, smart control, solar shading*

## 1. Introduction

Buildings in China consume approximately 27.5% [1] of national total energy. To reduce building energy consumption, a variety of energy efficiency measures can be adopted such as adding wall insulation materials [2, 3], using energy efficient windows [4], incorporating renewable energy technologies and solar shading devices [5, 6]. Among them, solar shading devices play a critical role in reducing building energy demands and creating a comfortable indoor thermal environment by blocking excessive solar heat gain in summer conditions. Compared to fixed shading devices such as overhang and side fin, movable solar shades are more popular in hot summer and cold winter zone of China since they can fulfill two conflicting aims: maximize winter solar gain, which is desirable as it reduces heating energy demand and, equally, prevent excessive summer solar gain as it is one of the responsible of overheating conditions and cooling energy demand. For movable solar shades, automatic devices are more efficient and contribute to less building energy demands compared to manually controlled ones since they can smart control shades according to the environmental conditions to maintain a comfortable indoor condition by keeping solar shades at a suitable position or angle [7-9].

The emerging technologies improve the performance of automatic solar shades and they can be controlled by the environmental factors such as solar radiation, indoor or outdoor temperature using sensors. To evaluate the energy performance of different smart shading control strategies, a simulation based analysis will be conducted in this paper and four typical sensor based automatic shading control strategies were analyzed using building simulation tools to optimize indoor thermal and energy performance. Finally, the suitable control strategy for building rooms facing different orientations will be commented.

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## 2. Methodology

### 2.1. Typical Residential Building

A typical residential building in hot summer and cold winter zone of China was considered in this research and was simulated by the software EnergyPlus, a whole-building energy simulation program developed by the U.S. Department of Energy (DOE) [10]. The building is a three-unit, six-story residential building in Ningbo city with 6 housing units (about 85m2 for each unit which has one reading room, one living room and two bedrooms) as shown in Fig.1. The total area of the building is 3168.9 m2 and the height of each floor is 2.8 m. Fig. 2 shows the architectural plan of the west housing unit. The window-to-wall ratios are 0.06 for east and west facades, 0.41 for south façade and 0.28 for north façade.

To reflect the impact of control strategies on different orientations, the west bedroom, west living room and west reading room as shown in Fig.2 are considered since only the west housing unit has west-facing windows and the whole housing unit was also simulated to identify which strategy is much better.

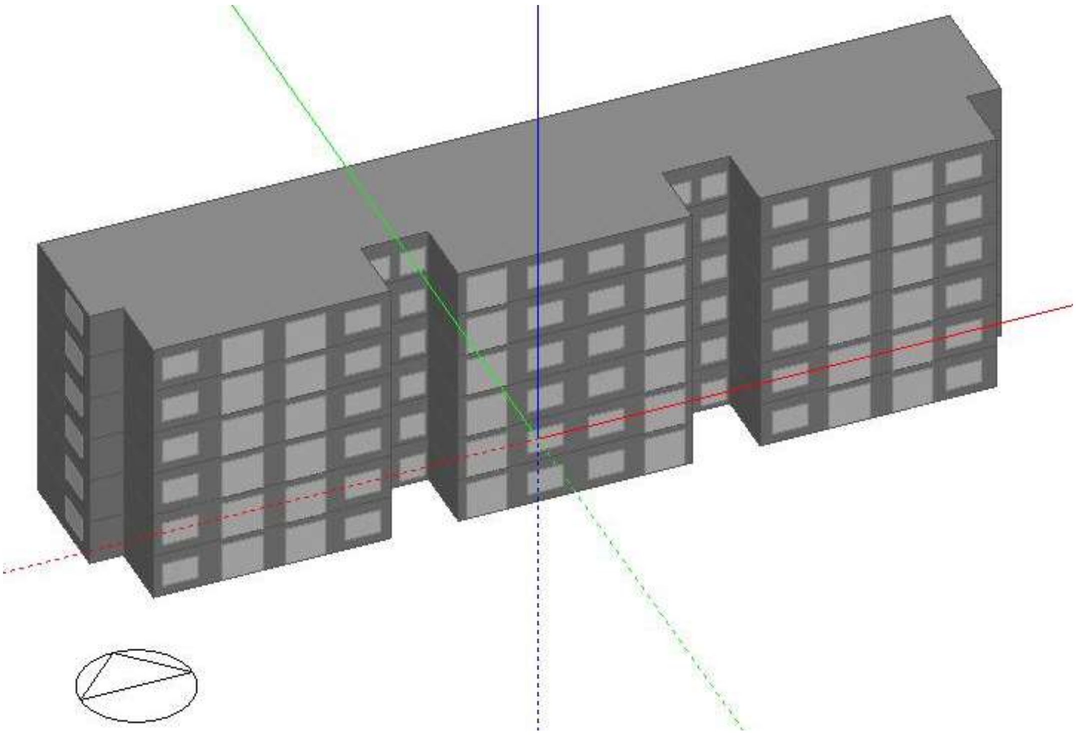

**Figure 1. Typical Residential Building Model**

### 2.2. Simulation Setting

The simulation settings complied with the design standard in this climate region [11] and the typical meteorological year data was used in 8760 hours simulation. The external wall of the building was a 240mm-brick wall with 30mm insulation materials and the windows for this building are double-pane glazing (6+9+6 mm). The room temperatures were set between 18-26 oC for the whole year. The total power density of miscellaneous loads (including lighting systems and occupants) was 4.3 W/m2 and the air change rate was 0.5 per hour. The detailed values of these settings are listed in table 1.

 

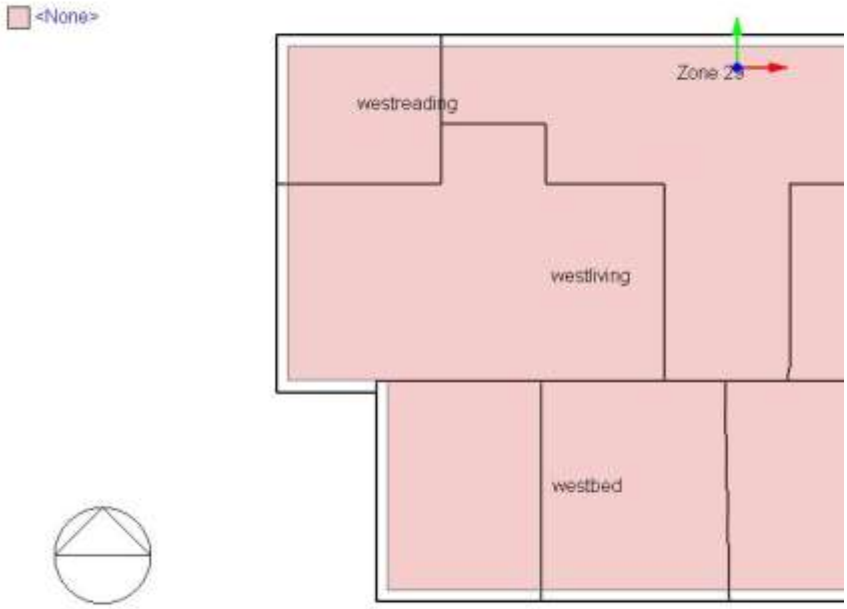


**Figure 2. The Architectural Plan of the West Housing Unit**

**Table 1. The Setting of Building Envelope and Air-conditioner etc.**

| Parameter | Value |
|---|---|
| Building envelope | External wall: U-value= 1.5 $W/m^2K$, Orientation: south;<br>Roof: U-value=1.0 $W/m^2K$;<br>Window: U-value=3.6$W/m^2K$, Solar shading coefficient (SC)=0.84; |
| Air-conditioner | Temperature: 18-26 $^{o}C$ for the whole year |
| Miscellaneous loads | 4.3$W/m^2$ |
| Air change rate | 0.5 per hour |

### 2.3. Smart Shading Strategies

Temperature based or light based sensors for building applications as shown in Fig. 3 are popular and they can be used to control the adjustment of movable solar shades automatically. Thus these sensors based smart solar shading control strategies are considered in this paper. To have a comprehensive comparison, four typical strategies available in local market are considered as shown in table 2. The solar radiation is set to 120W/m2 which is roughly the threshold of direct solar radiation according to our field test, and the outdoor or indoor temperature is set to 26oC since above this value space cooling is required in summer conditions.

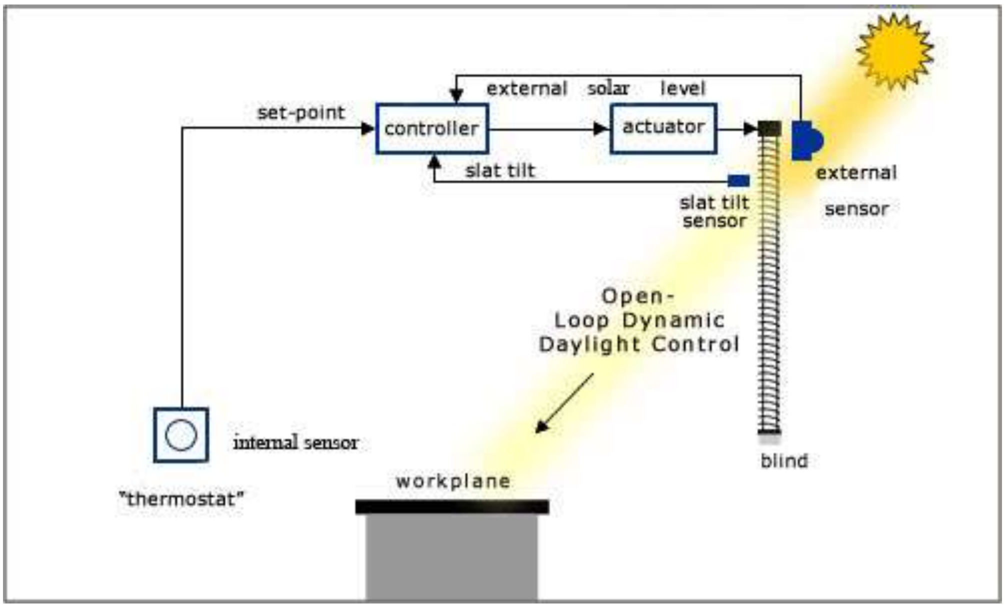


**Figure 3. An Illustration of Temperature based and Light (solar radiation) based Sensors for Applications in Solar Shades Control**

**Table 2. Smart Solar Shading Control Strategies**

| Sensor type | Control method |
|---|---|
| Solar radiation (SOLAR) | Close solar shades when solar radiation arrived on the window surface is higher than 120W/m$^2$ |
| Outdoor temperature (OA) | Close solar shades when outdoor air temperature is higher than 26$^o$C |
| Indoor temperature (IA) | Close solar shades when indoor air temperature is higher than 26$^o$C |
| Solar radiation + indoor temperature (IA + SOLAR) | Close solar shades when both solar radiation arrived on the window surface is higher than 120W/m$^2$ and indoor air temperature is higher than 26$^o$C |

## 3. Results and Discussion

### 3.1. West Bedroom

Figure 4 shows comparison of solar gains through exterior windows for different control strategies. For the west bedroom, it has the highest window-to-wall ratio on the southern façade and thus has a high solar heat gain throughout the whole year ranging from about 50000 to over 130000Wh/m$^2$. According to Fig.4, solar sensor based shading control strategy has the lowest solar penetration which is less than half of the other three strategies. The poorest strategy is OA control with the largest solar penetration.

In terms of energy performance, Fig.5 gives a comparison of these strategies. It can be seen that SOLAR does not has a significant improvement compared to other strategies as shown in Fig.5. It performs similar to IA and IA+SOLAR with a minor cooling reduction compared to IA+SOLAR and a minor heating increase. This is because SOLAR strategy may also block solar radiation that is needed in winter conditions. Thus any strategy (SOLAR, IA, IA+SOLAR) can be adopted in the south-facing bedroom.

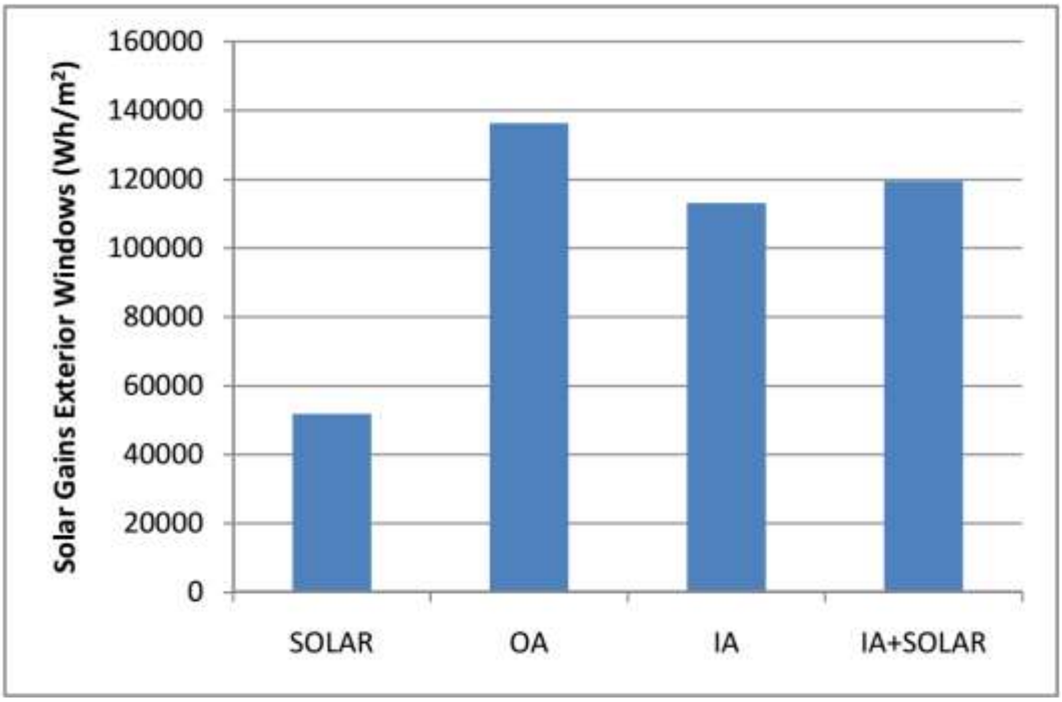


**Figure 4. Comparison of Solar Gains through Exterior Windows for the West Bedroom**

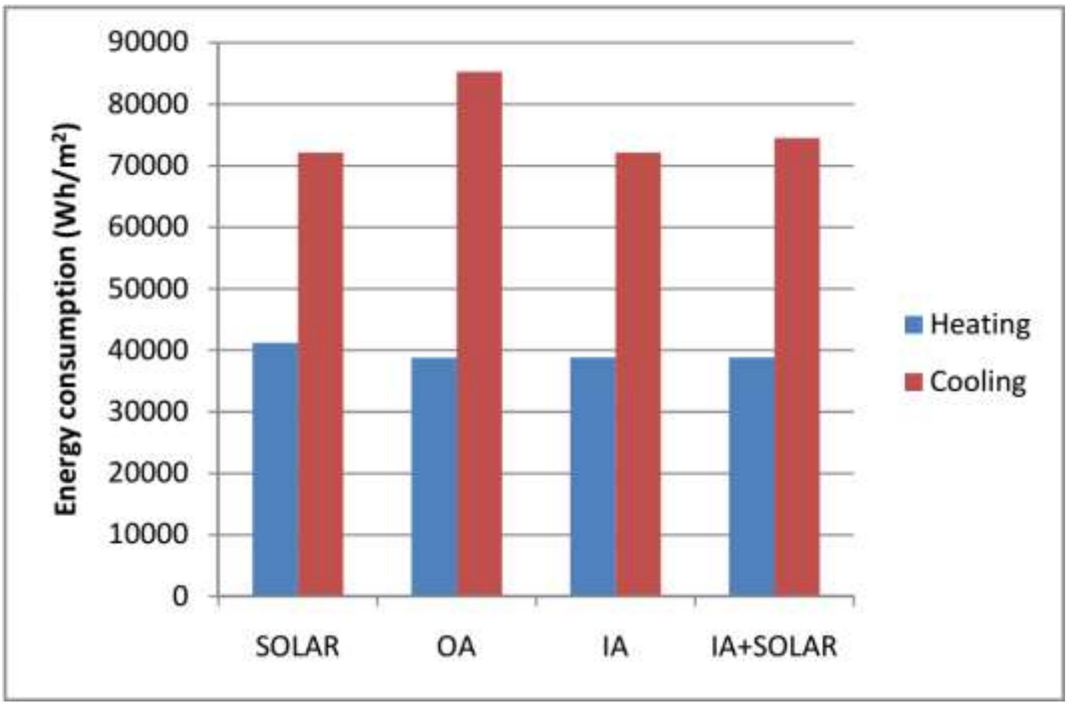


**Figure 5. Comparison of Energy Consumption for the West Living Room**

### 3.2. West Living Room

For the west living room, the solar heat gain throughout the whole year is relatively low compared to the bedroom ranging from about 17000 to over 34000Wh/m$^2$ as shown in Fig.6. It can be seen that solar sensor based shading control strategy also has the lowest solar penetration which is about half of the other three strategies. The poorest strategy is also OA control with the largest solar penetration. This is similar to the west bedroom. The energy performance of different strategies for the west living room is shown in Fig.7. It can be seen that SOLAR not only has a relatively low cooling demand, but it also contributes to the least heating energy demand. Therefore, the best strategy for this room is SOLAR, followed by IA and IA+SOLAR.

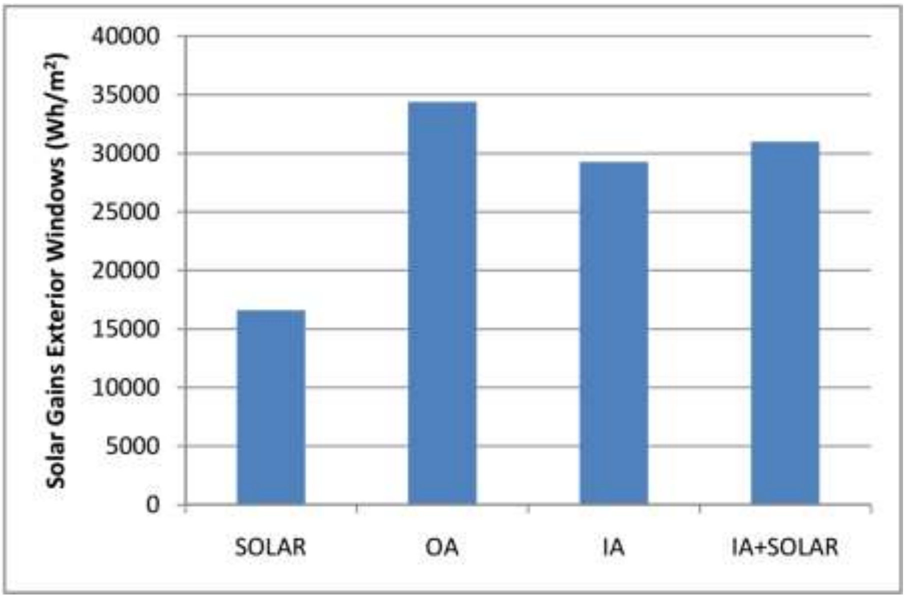


**Figure 6. Comparison of Solar Gains through Exterior Windows for the West Living Room**

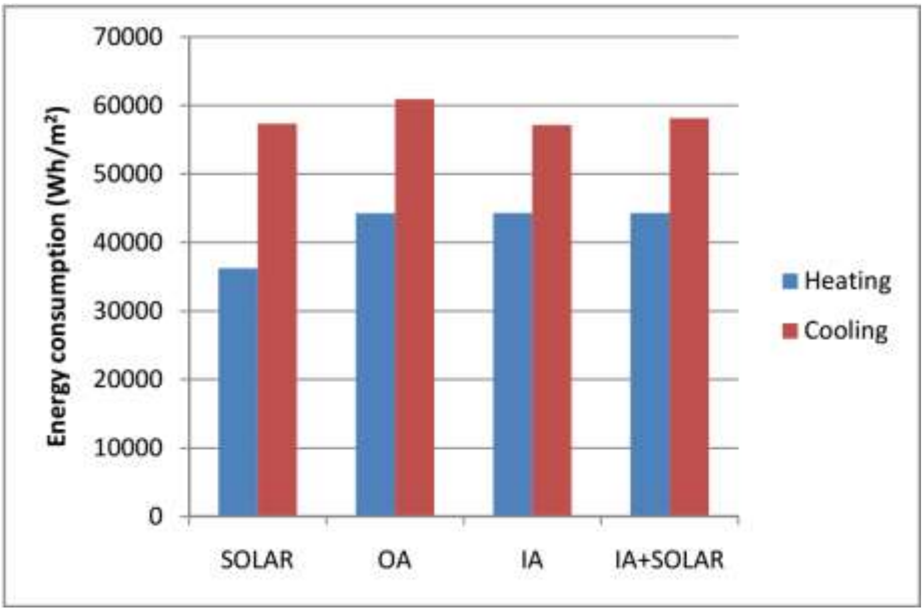


**Figure 7. Comparison of Energy Consumption for the West Living Room**

 

### 3.3. West Reading Room

Figure 8 compares solar gains through exterior windows for the west reading room. It can be seen that the solar heat gain throughout the whole year is higher than the west living room but lower than the west bedroom. It ranges from about 47000 to over 71000Wh/m$^2$. The cooling energy demand for the four strategies is similar while the heating demand differs largely as shown in Fig.9. SOLAR also has the least heating demand compared to the other three strategies. Meanwhile, it can be found that heating demand is higher than cooling demand and this situation is totally different from the other two rooms. This is due to the location of the reading room and the north-facing window receiving less solar radiation relative to the west bedroom and living room. Therefore, the best strategy for this room is also SOLAR.

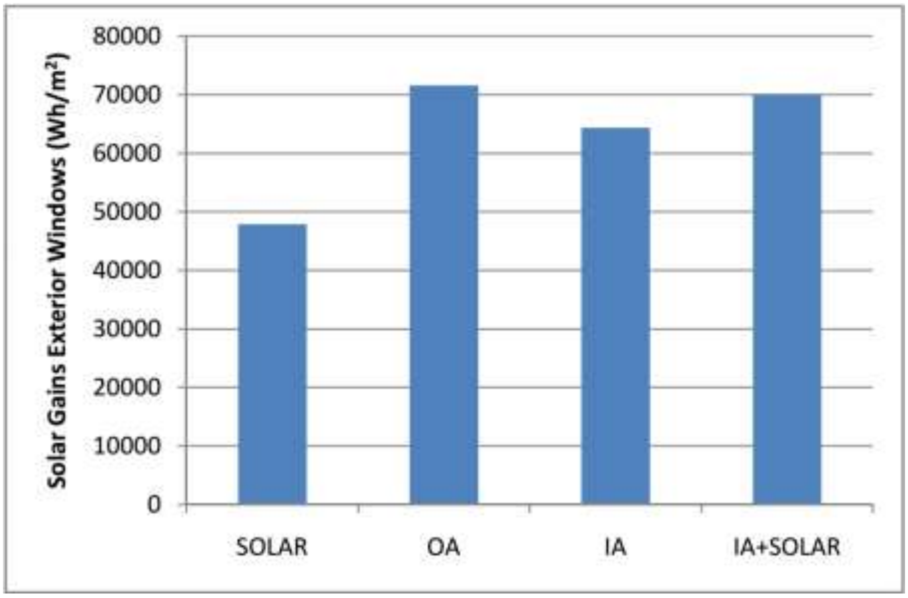


**Figure 8. Comparison of Solar Gains through Exterior Windows for the West Reading Room**

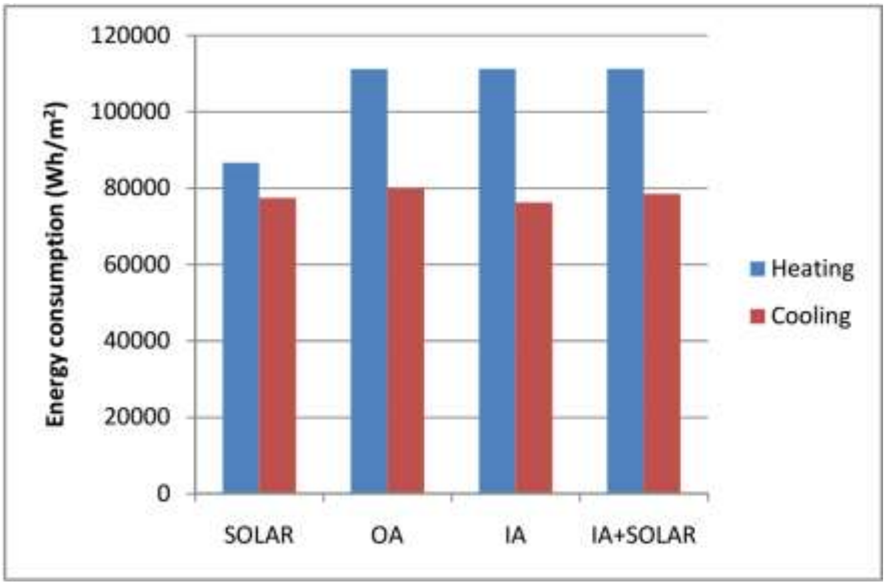


**Figure 9. Comparison of Energy Consumption for the West Living Room**

### 3.4. Total Energy Consumption

Figure 10 presents the comparison of energy consumption for the west housing unit. It can be seen that SOLAR has the least total (heating and cooling) energy demand, followed by IA, IA+SOLAR and OA. The energy reductions of SOLAR are 4.8%, 6.2% and 10.6%, respectively, compared to IA, IA+SOLAR and OA. Therefore, it is better to use SOLAR as the control strategy for the whole building. If this strategy is not available, IA would be considered as an alternative.

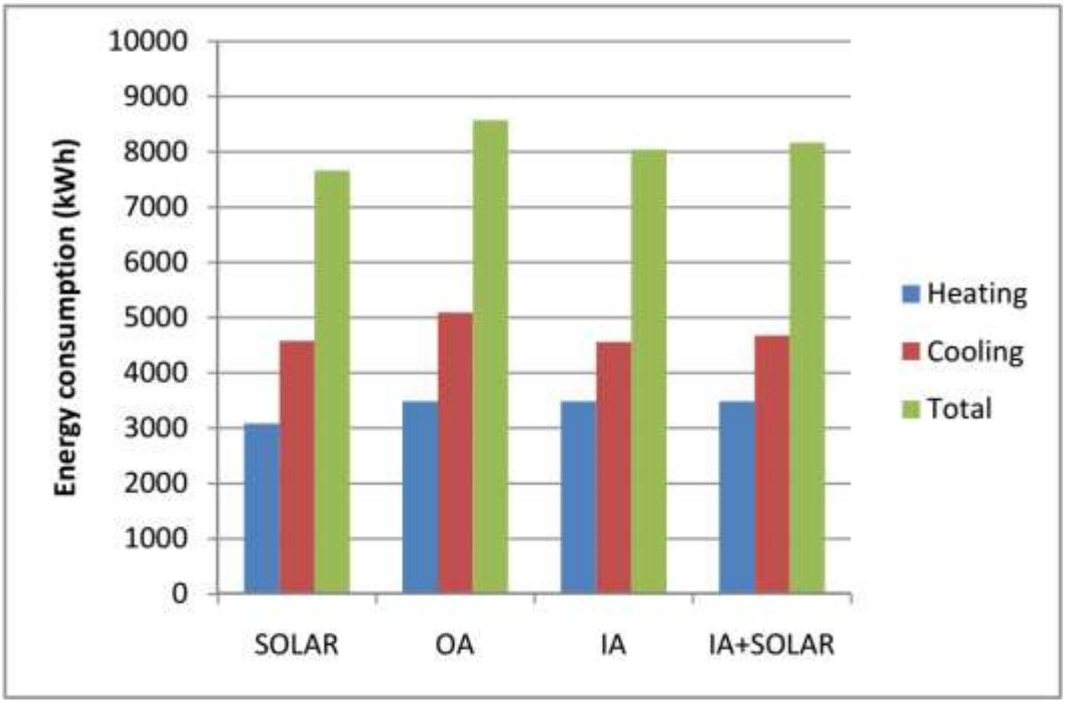


**Figure 10. Comparison of Energy Consumption for the West Housing Unit**

## 4. Conclusion

This paper investigates the energy performance of different smart solar shading control strategies. Four typical sensor based automatic shading control were analyzed using building simulation tools. It was found that solar radiation based sensor control has a better performance than the temperature based sensor control and this control strategy can be widely used in residential or commercial buildings since its cost (it requires only one sensor for each facade) is lower than temperature sensor based control strategies (they require one sensor for each room).

## Acknowledgments

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