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Research Paper

The effect of shading devices on the cooling load of residential buildings in Seoul, South Korea

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ABSTRACT

Installing solar shading over the glazing surfaces of a building is essential in reducing solar heat gains, visual glare complaints and provides an overall better indoor daylight distribution. Many types of shading devices exist on the market presently. These devices differ in performance based on climate, position of installation and size etc. In Korea, the most common type of shading devices are indoor Venetian blinds. This is partly because Venetian blinds are relatively cheap, easy to install and easily adjusted to fit a preferred indoor environment. However, other types of shading devices are likely to offer more energy saving benefits than Venetian blinds, particularly in regards to cooling energy. In this paper, we compared the energy-saving potential of five various types of shading devices for a residential apartment unit. We used a dynamic building simulation software and Integrated Environmental Solutions -Virtual Environment (IES-VE) in our analyses. Our results show that the use of an egg craft shading system leads to 2.26 MWh less annual energy consumption as compared to Venetian blinds. In addition, our results indicate that simple design considerations such as slat widths and angles for Venetian blinds and projection lengths for light shelves offer significant energy benefits when chosen correctly.

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INTRODUCTION

The primary challenge in the building sector is energy efficiency. It is reported that 40% of global energy is consumed by buildings alone (Yang et al., 2014). This coupled with the increasing effects of climate change further highlight the importance and urgency of energy-efficient buildings (Hooyberghs et al., 2017). One way of reducing the energy consumed by buildings is through the use of solar shading devices. The primary role of shading devices is to prevent direct sunlight from reaching indoor spaces during cooling periods (Kirimtat et al., 2016). This, in turn, has several advantages in terms of reduced energy consumption for cooling, reduced chances of visual glare, improved daylight performance and improved occupant thermal comfort (Evola et al., 2017).

Over the years, various types of shading devices have been developed and employed in practice (Kirimtat et al., 2016). Many of these devices differ in many ways including shape, size and position within a building, etc. Different shading devices are therefore likely to benefit a given building in different ways. For example, Dubois (2011) compared the energy-saving potential of seasonal and fixed awnings installed on a south-facing window of an office building. He found that, with seasonal awnings, 12 kWh/m^2/year could be saved. With fixed awnings, however, only 11 kWh/m^2/year could be saved. Dubois (2001) reasoned that fixed awnings block the much -needed sunlight during the heating period, which in turn increases heating energy consumption.

Other studies focused on the performance of single shading devices for specific climates, mostly through dynamic building simulation software (Kirimtat et al., 2016). A recent study by Berardi and Anaraki (2018) demonstrated the daylighting benefits of light shelves in Canada considering different glazing areas and façade configurations. While this study of Berardi and Anaraki (2018) and Littlefair (1995) focused primarily on daylighting performance of light shelves, Palmero-Marrero and Oliveira (2010) demonstrated the effectiveness of louver shading on building thermal performance under diverse climatic conditions. They reported significant energy savings and overall improved indoor thermal conditions when louvers were present as compared to when louvers were absent. Similarly, Shahid and Naylor (2005) showed the energy-saving benefits of horizontal Venetian blinds. Tzempelikos (2008) further demonstrated the usefulness of Venetian blinds considering the shape, thickness and tilt angle of the Venetian blind slats.

Given the many types of shading devices that exist on the construction market, another set of studies has revolved around evaluating and comparing the performance of different shading devices in regards to energy – saving potentials, daylighting performance and thermal performance etc. For example, Kim et al. (2012) compared the potential advantages of external shading devices over interior shading devices. He compared conventional exterior shading devices, that is, overhangs to interior Venetian blinds and how they influenced building energy consumption. He reported that external shading devices are likely to reduce the overall building energy consumption more than interior shading devices. This is because external shading devices are able to block direct sunlight before it reaches the inner spaces and thus reduce cooling loads. On the other hand, interior shading devices are likely to increase cooling load due to the far infra-red radiation re-radiated into the inner space. This conclusion was reiterated by Atzeri et al. (2014) who reported that interior shading devices seemed to increase cooling load in an office building located in Italy.

On the other hand, Ye et al. (2016) argued that internal shading devices are capable of outperforming external shading devices if minor modifications such as increasing reflectivity of the material used are considered. Moreover, the long-term expenses would be cheaper since external shading devices are more prone to damage and thus may require regular replacements or maintenance (Ye et al., 2016). Furthermore, Bessoudo et al. (2010) studied the impact of various interior shading devices including roller shades and blinds with rotated angles on indoor radiant temperature in cold climates. Bessoudo et al. (2010) found that interior shading devices may offer significant benefits during the cold season. These findings are supported by studies conducted by Tzempelikos et al. (2010). As such, the proof regarding external and internal shading devices, and which provides better performance is rather inconsistent throughout the literature. This is perhaps because of the many factors that are likely to influence the performance of a given device (Kirimtat et al., 2016).

In Korea, internal shading devices, particularly Venetian blinds are the most common. This is partly because shading devices in Korea are often chosen by house owners. They thus decide based on semantic factors such as aesthetics, price, and ease of installation rather than performance. In this study, therefore, we compared the performance of five types of shading devices and their effectiveness in reducing building cooling load.

Target shading devices

In daylighting design, it is essential that direct sunlight is diffused and scattered in indoor spaces. This prevents visual glare and the accumulation of cooling load due to solar insolation (Ochoa and Capeluto, 2006). As earlier discussed in the introduction, several types of shading devices have been developed and used to achieve a realistic balance between a good daylighting performance and reduced accumulation of solar insolation (Valladares-Rendón et al., 2017). Here, we considered five shading systems and their effectiveness in reducing building cooling load.

Horizontal blind system

Blinds have for long been used to shade off direct sunlight (Kirimtat et al., 2016). Previous studies have shown that the effectiveness of the blind system is influenced by the slat angle and slat width (Tzempelikos, 2008; Kim et al., 2012). Building occupants can adjust slat width and angles to attain maximum daylighting performance. As such, we considered the overall performance of horizontal blinds based on slat angles and slat width. Figure 1 shows a conceptual diagram of a horizontal blind system considered in this study.

Horizontal louver system

Horizontal louvers are also very common in practice. Most times, the design process of horizontal louvers follows a similar process to that of a conventional overhang system (Kim et al., 2012). In this study, therefore, we present a horizontal louver design based on the movement of the sun; the outward projection is long enough to prevent direct sunlight from the high angled sun experienced during the summer time but also short enough to allow the low angled sun experienced during the winter season. Figure 2 shows a conceptual design scheme of the horizontal louver discussed here.

Light shelf system

Light shelves are lighting systems that are able to enhance

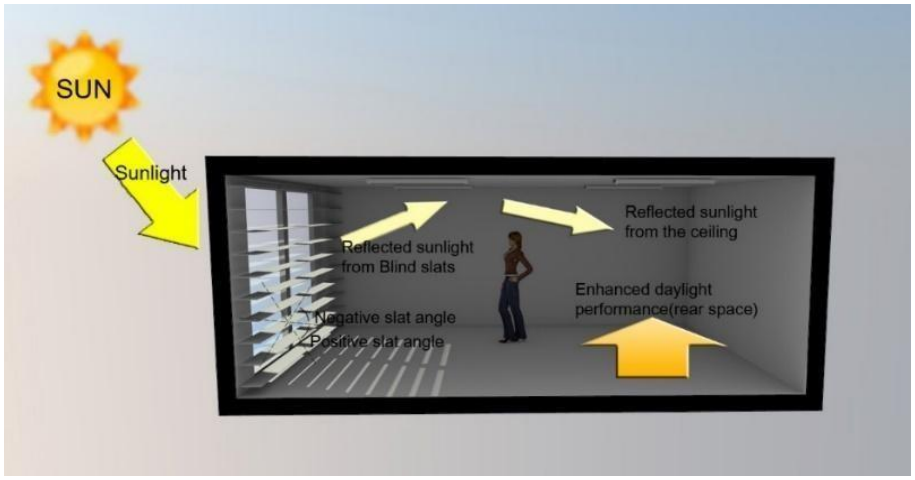

Figure 1: Horizontal blind conceptual diagram.

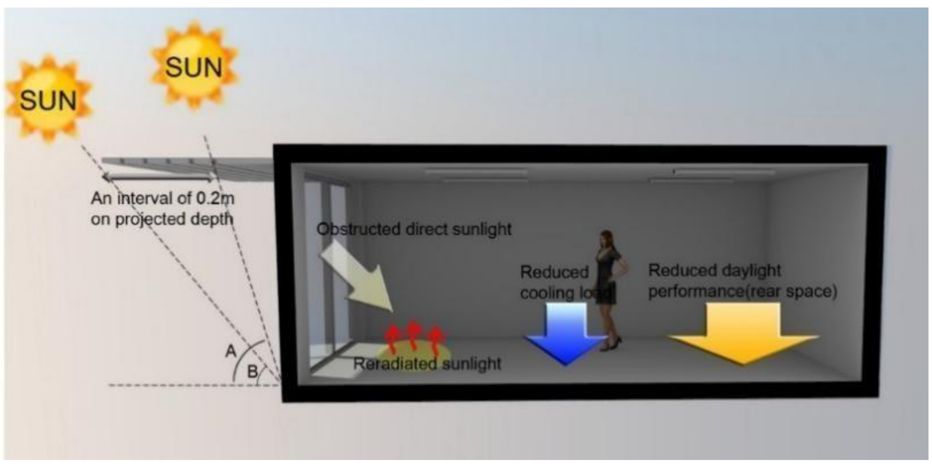

Figure 2: Horizontal louver conceptual diagram.

the visual quality of indoor spaces by providing deep daylighting and save energy by blocking direct sunlight (Berardi and Anaraki, 2018). The light shelf system has been largely discussed in the previous literature (Kontadakis et al., 2017). In this study, we considered two types of light shelf systems, Type-A and Type-B. Type-A is a conventional light shelf system where the light shelf is positioned between the view and daylight window. The external section for the Type-A light shelf is fixed, while Type-B differs slightly from Type-A in that the external element of the light shelf can be adjusted and set to a particular angle based on the movement of the sun. In addition, given that the external element of Type-B can be adjusted, it offers a chance for a better exterior view.

Figure 3 shows the conceptual diagram of the Type-A, while Figure 4 shows the conceptual diagram of the Type-B light shelves considered in this study. To calculate the dimensions of the Type-A light shelf, we used a method developed by the British Research Establishment (BRE). The method involves sectioning the window into two parts with the area from the bottom of the window to the height of the light shelf and the area from the light shelf to the top of the window denoted as parts A and B, respectively (Rennie, 1998).

Egg craft system

The egg craft system is a combination of both the vertical and horizontal louvers. This type of shading is used to achieve control of both the horizontal and vertical sunlight (Kirimtat et al., 2016). For such kinds of devices, the amount of sunlight reaching the interior space depends largely on the length and size of the vertical and horizontal shading devices. As such, we varied the length of the vertical slat length between 0.2 and 0.5 m, respectively. The length between the vertical and horizontal louvers was kept at a constant of 0.5 m. In addition, we considered different slat

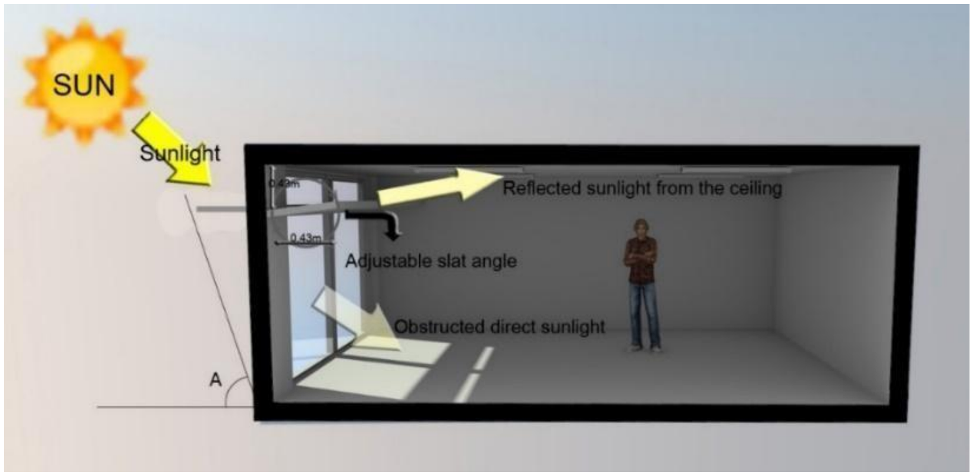

Figure 3: Type-A light shelf conceptual diagram.

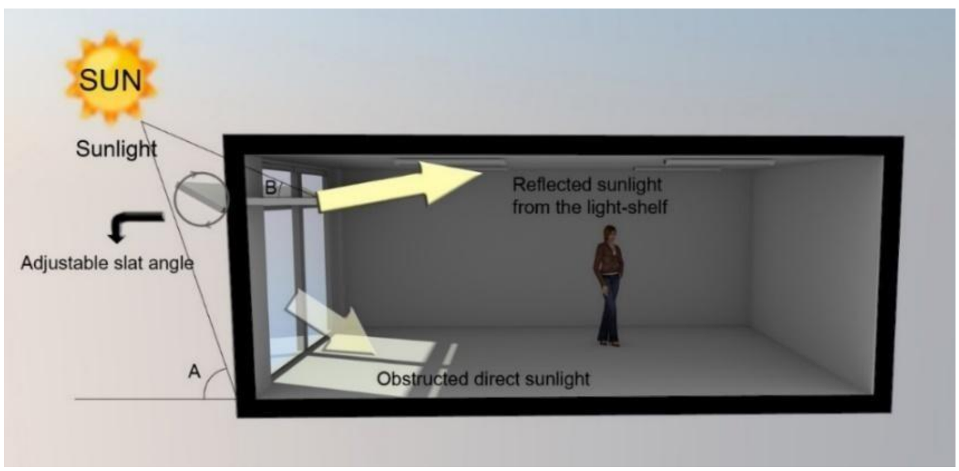

Figure 4: Type-B light shelf conceptual diagram.

angles to see the effect of angular projections of the egg craft on cooling load. Figure 5 shows a conceptual design diagram of an egg craft shading system, while Figure 6 shows the shading hours provided by the egg craft system based on the azimuth of the sun and the angle at which the slats are projected.

MATERIALS AND METHODS

Building model

In order to study the comparative advantages of the aforementioned solar shading devices on the annual cooling load of buildings, we considered a typical residential Korean apartment unit as our building case model. The total area of the unit space is 145 m^2 and the floor to ceiling height is 2.3 m. The bedrooms and the living room are oriented towards the south. The Window–to–Wall Ratio (WWR) of the southern wall is 90% which leads to a large amount of solar radiation getting into the building. The unit also consists of a balcony in front of the main room which serves as a service area. Table 1 shows the material characteristics of the space considered.

Simulation modeling

We employed a building simulation software, IES-VE, to calculate the annual building cooling load. IES-VE has been extensively validated through numerous validation studies and was found to be accurate and reliable (Nikpour et al., 2013; Loonen et al., 2017). The software program is capable of modeling diverse aspects of building physics (IES).

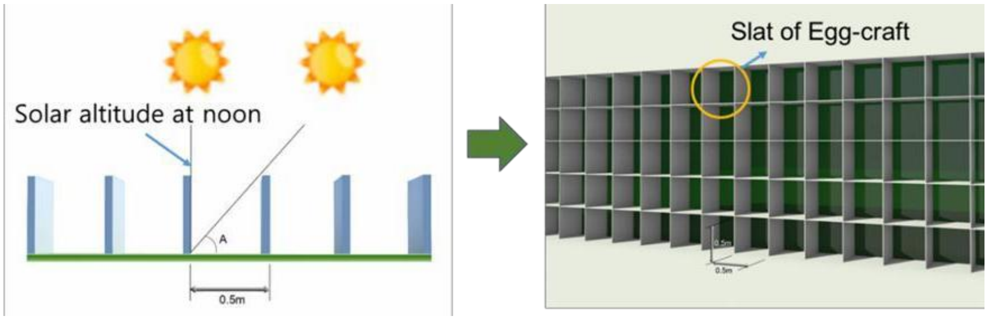

Figure 5: Egg craft conceptual diagram.

The beginning of obstructed direct sunlight(time)					
	A degrees	Azimuth of the sun	March	June	December
A 5	A: 45°	135°, 225°	~ AM 10, PM 3~	~ AM 11, PM 1~	~ AM 10, PM 3~
A 4	A: 39°	129°, 231°	~ AM 10, PM 3~	~ AM 11, PM 2~	~ AM 10, PM 3~
A 3	A: 31°	121°, 239°	~ AM 10, PM 3~	~ AM 11, PM 2~	~ AM 10, PM 3~
A 2	A: 22°	112°, 248°	~ AM 9, PM 4~	~ AM 10, PM 3~	~ AM 10, PM 5~

Figure 6: Shading hours based on azimuth angle and the projection angles of vertical slats.

Table 1: Characteristics of building elements.

Element	Construction	U-value (w/m^2K)
Wall	Dense concrete + insulation brick	0.3970
Internal partition	Concrete (200 mm)	2.4823
Glass (including flame)	(6 mm + 6 mm) × 2 layers	1.4600
Slab	Sandy soil + Polystyrene + Concrete	0.4121
Ceiling	Sandy soil + Polystyrene + Concrete	0.9565

Key modeling processes in our case involved modeling five different types of solar shading devices and calculating annual cooling loads for each shading device. This allowed us to conduct a comparative analysis of the five solar shading devices.

Since the building considered here is a residential apartment unit, the usage pattern of the space is rather inconsistent. This is because different family members may have different schedules at different times of the day. We thus considered the building to be in the "usage state" throughout the day. Table 2 shows the assumptions made regarding the general usage of the space studied.

RESULTS AND DISCUSSION

Horizontal blind system and cooling load

For the blind system earlier described, we considered different slat angles on the effect of annual cooling load. We

Table 2: Building operation assumptions.

Variable	Values
Design temperature	26°C (Cooling set point) and 20°C (heating set point)
Humidity	30 – 70%
People	4 people (sensible heat gain: 90 W/person)
Use schedule	All day used
Infiltration	0.59 l/sm^2
Weather data	Seoul, South Korea (latitude: 37°C, Longitude: 27°C)

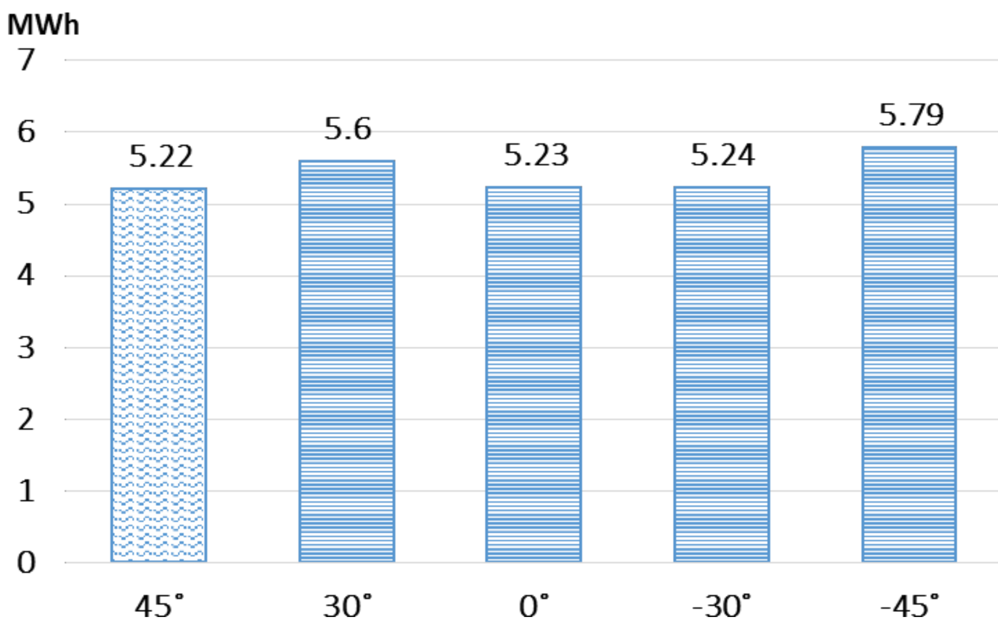

Figure 7: Annual cooling load based on slat angles of a horizontal blind system.

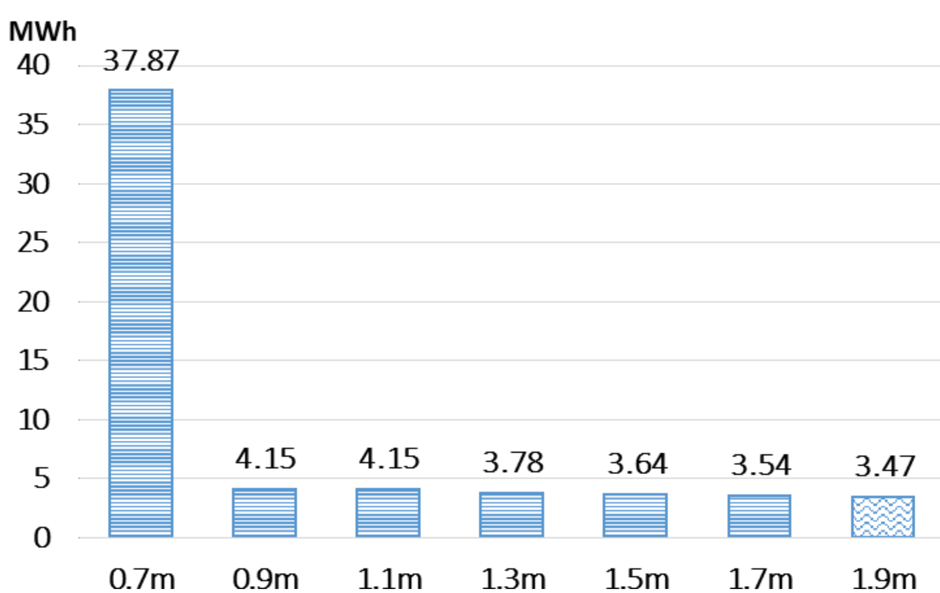

Figure 8: Annual cooling load based on the projection-length of the horizontal louver.

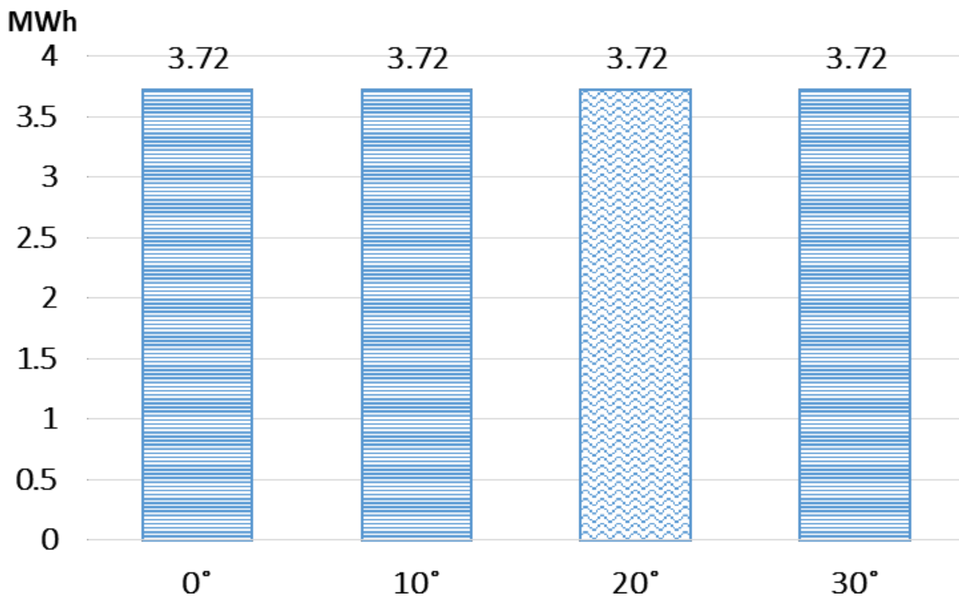

Figure 9: Annual cooling load performance of the light-shelf Type-A based on slat angles.

considered slat angles at 0° (slat fixed in a horizontal position), 30° and 40° in the upward direction. We also considered 30° and 40° in the opposite downward direction. Figure 7 shows the performance of this type of system based on slat angles.

Figure 7 shows a blind system with slats tilted at 45° angle to be the optimum energy-saving option. Its performance, however, is only slightly higher than the systems with 0 and 30° slat angles, respectively. This is because, with a 45° angle, direct sunlight rays bounce off the slat and are reflected to the outside. With the other slat angles, however, reflected rays of sunlight are most likely to fall in the inner space. This reduces the intensity of the incoming solar rays, which is imperative in preventing issues related to visual glare, but the overall heat gain is most likely to be the same.

Horizontal louver and cooling load

In this study, louver systems with different protruding lengths were compared. We varied the length of the horizontal louver from 0.7 to 1.9 m, with increments of 0.2 m, respectively. Figure 8 shows the performance of this kind of system based on the protruding length of the louver.

Our results indicate that increasing the projection-length of the louver system tends to reduce the annual cooling load. The louver system with the shortest projection-length (0.7 m) indicated an annual cooling load that was 90% higher than that of the louver system with the longest projection-length (1.9 m). This is an expected outcome because for a 0.7 m horizontal louver, high angled direct sunlight can easily reach the glazing area. As such, sunlight is most likely to penetrate the building envelope to the inner space, which in turn increases the need for cooling. The opposite is true for the louver system with a projection length of 1.9 m. For this reason, the longer the projection length of a louver system, the less energy needed for cooling. However, very long louver systems may not be preferable in regards to building aesthetics. In that case, in Korea or in a similar climate, louver lengths between 1.1 and 1.5 m, respectively may present the best alternatives.

Light shelf system and cooling load

As earlier discussed, the performance of two types of light shelves; Type-A and Type-B was studied. For Type-A, the external shelf is fixed whereas the indoor shelf is adjustable between 0° and 30°. Figure 9 shows the performance of this type of system based on adjustable angles.

No variation was observed in annual cooling load as we varied slat angles. This is an expected outcome because most of the high-intensity solar rays are blocked by the external shelf before they reach the inner space. The role of the inner shelf is mainly to distribute the incoming light to the rear sections of the space. Its role, therefore, has more to deal with daylighting of a space than blocking out solar insolation. As such, changing slat angles of the inner shelf has no effect on the cooling needs of a space.

With regards to light shelf Type-B, the length of the outdoor shelf is shorter than the inner shelf. In addition, the projection angle of the outdoor shelf can be adjusted; this is important because the sun's movements change according to the time of the day and season of the year. With this type of shading device, therefore, the angle of the external shelf can be adjusted based on the position of the sun during the day and season of the year. In this study, we varied the

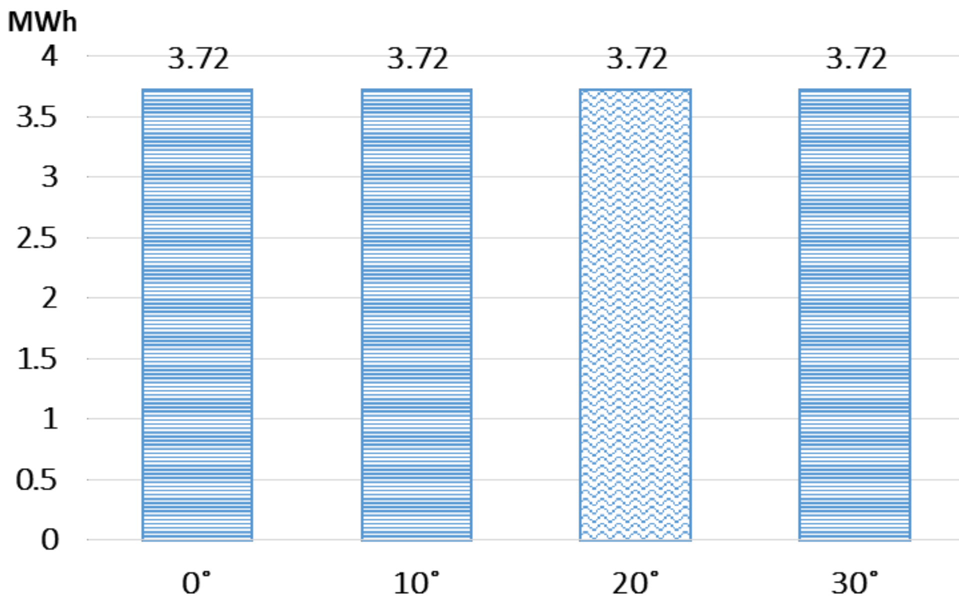

Figure 9: Annual cooling load performance of the light-shelf Type-A based on slat angles.

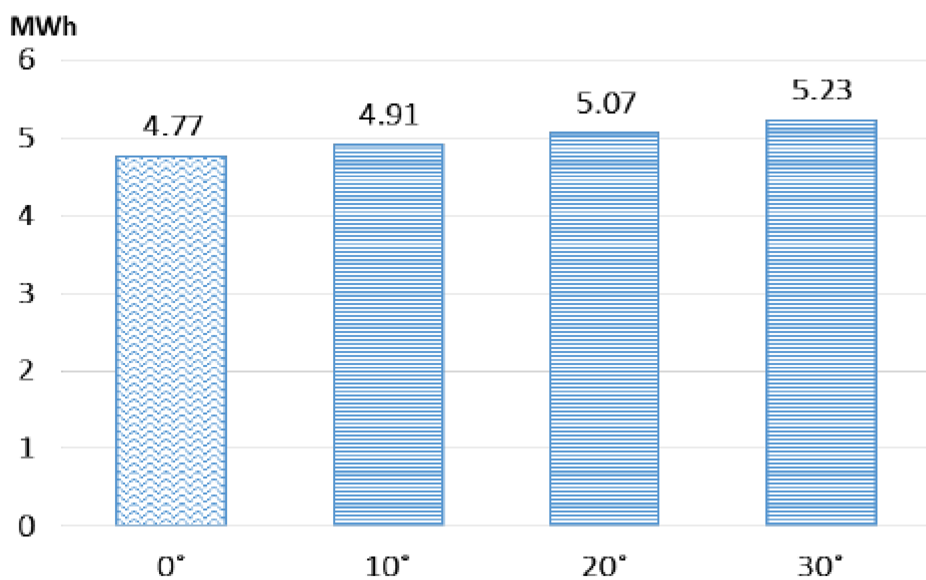

Figure 10: Annual cooling load performance of the light-shelf Type-B based on slat angles.

angle of the external shelf from 0° to 30° through increments of 10°. Figure 10 shows the performance of the light shelf Type-B.

As indicated in Figure 10, our results show that the external shelf at 0° provides the optimum performance in terms of cooling energy. For every 10° angular increment, from 0° to 30°, annual cooling load increased by 0.2 MWh. This is most likely due to reflected light. For a 0° angle, light is reflected upward and away from the glazing area of the space which reduces the amount of heat penetrating into the inner space through windows. For the other angle projections, light is reflected downward and onto the glazing area. This allows the reflected light to enter the building through windows and may be the cause of the increased cooling load observed.

We also compared the performance of light shelf Type-A and Type-B. In general, the building model equipped with light shelf Type-A indicated a lower annual cooling load as compared to that with light shelf Type- B; the annual cooling load for the Type-A light shelf was 1.5 times lower than that for the Type-B. The reason for this is primarily because the external shelf for the Type-A light shelf was longer than the Type-B light shelf. As such, the Type-A light shelf is most likely to block more light from reaching the

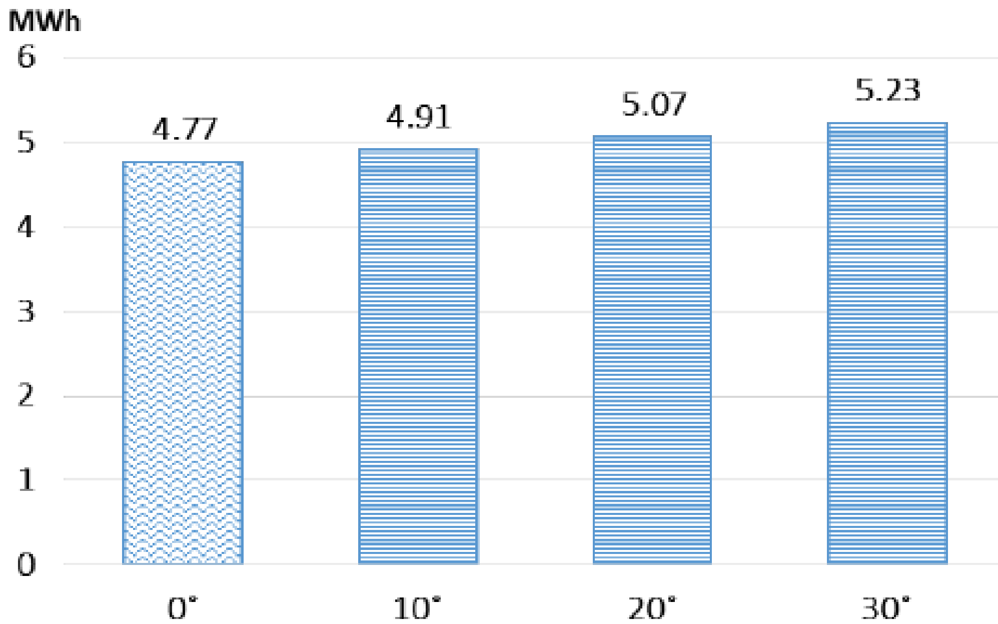

Figure 11: Annual cooling load performance of the egg craft system based on projection length.

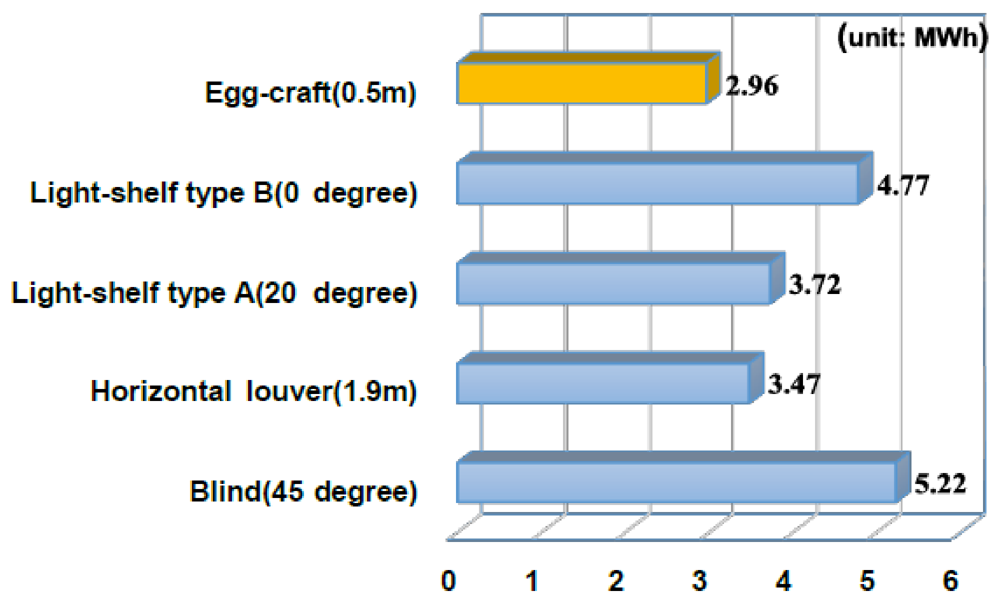

Figure 12: Comparative analysis of various shading devices based on annual cooling load.

inner spaces, especially when the sun's position is at higher altitudes than the Type-B light shelf. This outcome reiterates the conclusions by Kim et al. (2012) regarding the importance of the external shelf in Korean apartment units.

Egg craft and cooling load

The performance of an egg craft system with various projection lengths was studied. As earlier discussed, an egg craft system consists of both horizontal and vertical louvers joined together to form a sort of solar shading "box" that surrounds a glazing area. This provides shading for the glazing area from both vertical and horizontal solar radiation. In this study, we varied the projection lengths of the vertical louver from 0.2 to 0.5 m through 0.1 m intervals, respectively. We then studied the influence of varying lengths on annual cooling load. Figure 11 shows the performance of the egg craft system.

Our results show that increasing the projection length of the egg craft system reduces building cooling load. Specifically, there was a 0.72 MWh difference in annual cooling load between the shortest vertical projection length (0.2 m) and the longest (0.5 m). This is because, as seen with other types of shading devices, longer projection lengths are able to block more sunlight, especially during the summer time when the solar altitude is high.

Comparative analysis of shading devices based on annual cooling load

The performances for all five shading systems presented in this study were compared. We chose the optimum performing status of each shading device based on slat angles and projection lengths and compared the final outcome based on annual cooling load.

Figure 12 shows the comparative analysis among the studied shading devices based on annual cooling load. Our results indicate that for a Korean climate or similar climates, the egg craft system provides optimum cooling energy reductions. This is expected because the egg craft system provides shading for the glazing area from both the vertical and horizontal sunlight. In addition, it provides shading from secondary reflected light including light reflected off the ground or adjacent built structures. We also found the horizontal blind system to be associated with the highest annual cooling load among the shading systems studied. This is also expected because, for the other devices, direct sunlight is blocked before it reaches the interior of the space. For the horizontal blind system, however, incoming sunlight is blocked after it has reached the inner space. Because of this, blocked sunlight is re-radiated into the inner space in form of heat. Our results support findings reported from previous studies (Kim et al., 2012; Atzeri et al., 2014).

In Korea however, the horizontal blind system is the most common type of solar shading. The reasons for this are two-fold. First, they are affordable and therefore have an economic advantage over the other types of shading systems. Secondly, since they are installed inside the building, it becomes easier for the occupants to adjust the blinds to suit their respective lighting needs. That being said, it is important to note that in regards to cooling load, and the potential of shading devices to reduce it, blinds indicate the poorest performance amongst the five types of shading devices discussed.

Conclusions

In this study, the influence of various types of solar shading devices on the annual cooling load of a Korean apartment unit using a dynamic building simulation software, IES-VE was studied. Our results show that the egg craft system and the horizontal blind system present the optimum performance and the worst performance respectively. In the Korean construction industry, however, the horizontal blind system is the most commonly used type of solar shading device.

However, based on our results, we suggest that designers and building owners consider using the egg craft system instead of the horizontal blind system. The use of the egg craft system would provide significant long-term economic savings considering the amount of money spent on utility bills as a result of cooling.

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