Topic: Building Physics, Building Envelope and Materials

Study of Energy Saving Potential of Solar Shading Devices in Various Climates

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Keywords: Shading device, Energy saving, Building simulation, Comparative analysis

SUMMARY

Research studies previously performed using a singular climate had shown that certain solar shading devices have the potential for energy savings for buildings. In this paper, a commercial building was studied using the DesignBuilder programme to identify the solar performance of the building. The model represented a typical commercial building with standard properties. This study allowed for comparison for horizontal louvre, overhang and vertical shading types in various climates (Florida, Cairo, Leeds and Reykjavik) for a year presented in terms of monthly energy demand. Comparative analysis identified that the horizontal louvre type, which consisted of 5-louvre with 400 mm spacing between the adjacent louvres, performed best to reduce the annual energy usage for Florida (4191 kWh), Cairo (5194 kWh), Leeds (1882 kWh) and Reykjavik (957 kWh). In general, all environments showed increases through heating and lighting, but proportionally cooling reduction was higher annually.

INTRODUCTION

Modern sustainable buildings seek to reduce energy usage in which solar radiation has a large impact. Direct solar radiation has a large impact on increasing solar gains, heat exchange and daylight through the building fabric to have a positive or negative effect on energy usage through cooling, heating and lighting [1]. Reducing energy usage is of high importance for world climate change as buildings account for an estimated 30% of global energy consumption [2]. Various methodologies can be used throughout the construction industry to decrease energy consumption in buildings. Studies suggest that a more energy-efficient building envelope could potentially save energy usage by 35% [3]. Such methods include adopting suitable U-values for building components and using solar shading devices. Solar shading devices are a low cost and available solution to reduce solar gain.

Within the usage of solar shading positive and negative effects can be seen. The potential negative impact is that in cooler climates solar shading has the ability, to reduce solar gains which in turn means that more energy must be used through heating in the winter months [4]. If the solar shading device results in reduced daylight access, then dynamic lighting systems may use more energy [5]. On the other hand, the positive effects of shading devices are potential energy reduction through reduction of solar gains and increased visual comfort through the reduction of intense daylight [6], [7], [8]. Dynamic solar shading can be used to adapt shading to mitigate these issues [9], however these systems are often not available and cost effective in developing countries [10]. A paper by Shahdan et al. [6] argues that the negative effects of shading devices occur as designers focus on the aesthetic properties of shading devices rather than the energy-saving potential. Current research has identified the shading effects in individual climates but no research identifies how standardised shading devices compare against different climates [6], [7], [8]. Identifying the affect of different shading devices in different climates is important in the context of global energy usage as it would provide a basis for fixed shading selection. Based on the above contexts, this study investigated the cooling, heating and lighting energy consumption of a commercial building configured with different shading types under a range of climate conditions from sub-tropics to temperate. Allowing the energy-saving performance of each shading solution to be evaluated and compared.

METHODS

The focus of the study was on the comparison of simulations for six shading devices (mainly in horizontal, overhang and vertical louvres) in four distinct climate zones (Florida, Cairo, Leeds and Reykjavik). Data were gathered through systematic simulated analysis of the energy performance of a building zone using solar shading technologies in varying climates. This study was conducted through a series of simulations developed using DesignBuilder (DB). Initially, to gain an understanding of the potential changes in energy usage, a baseline with no shading devices was simulated for each climate as the initial simulation. Then each shading device was simulated for each type of climate to find the variation of energy consumption for cooling, heating and lighting systems as a result of the change in daylight annually. In terms of model validation, this study focused on the comparison for different cases but in the same context, which aimed to predict a single case using the DB model thus, the results were used to simply identify the discrepancy amongst the cases. This type of modelling has been calibrated and validated within various similar studies [11], [12], [13], which, therefore, is appliable and valid for this study. The Köppen–Geiger climate classification model was used to identify a variety of climatic conditions. It should be noted that the Type E-H were not used as they are polar climates and usually lack modern commercial buildings. Using this classification technique ensures that the climates and locations selected present a range of climate conditions for this study (see Table 1).

Table 1. Simulated climates and locations.

Location	Coordinates	Köppen–Geiger	Elevation at floor level
Florida PMP Airport	26.25 ºN, 80.11 ºW	Aw	19.2 m
Cairo Airport	30.10 ºN, 31.18 ºE	BSh	87.2 m
Leeds Bradford Airport	53.87 ºN, 1.65 ºW	Cfb	221.2 m
Reykjavik	64.13 ºN, -21.9 ºW	Dfc	74.2 m

The developed simulated scenario represents a typical office building room (see Figure 1). The envelop thermal properties are presented in Table 2, while the floor was considered adiabatic. The proposed building zone was present on the 4th floor at 13.2 m above ground level with the glazing facing south. The simulation used the DB “Office_OpenOff_Occ” schedule with operating hours of 7 am to 7 pm. It was assumed that 8 people occupy the zone with a metabolic rate of 0.9, winter clo of 1.00 and summer clo of 0.5. The air temperature setpoints were 22ºC and 24ºC for heating and cooling respectively, controlled via the predictive mean vote model to provide thermal comfort. Ventilation rate was set at 10 l/s per person. The zone utilised a single ducted fan coil unit supplied by a gas boiler for heating (CoP of 0.8) and electricity for cooling (CoP of 2.7). An adaptive lighting system was used vary light output depending on daylight to achieve the setpoint of 400 lux. This system was considered to identify the impact of daylight reduction on energy usage.

Table 2. Building envelope thermal properties [7].

Component	U-value (W/m^2K)	Thickness (mm)	Surface area (m^2)	Solar gain coefficient
Internal wall	\	138.5	59.3	\
External wall	0.35	200	37.53	\
Flat roof	0.25	\	\	\
Door	3.5	51	1.95	\
Glazing	2.7	24	23.892	0.9

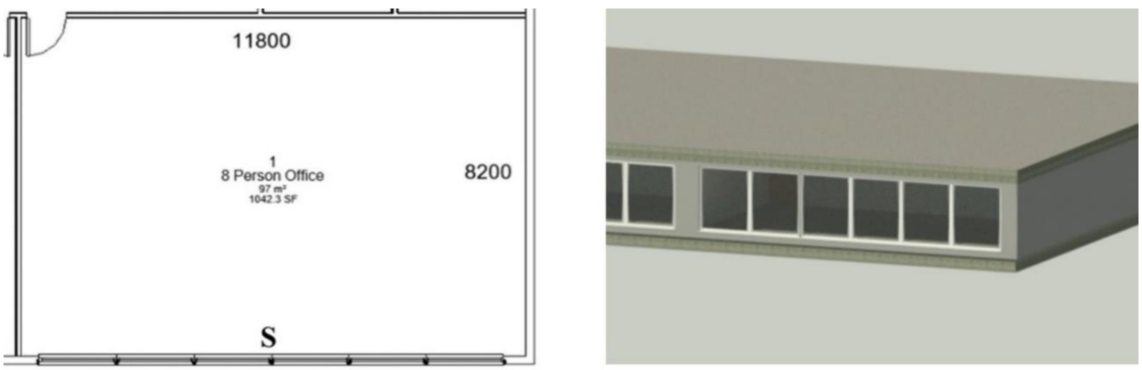

Figure 1. Plan (Left) and 3D (Right) view of office room experimental scenario.

Table 3 and Figure 2 details the 6 shading devices simulated within this study. These shading are common on commercial buildings [6], [7], [8], [14], [15]. Each shading type had two variants to identify the effect of factors such as projection and louvre spacing.

Table 3. Shading device specification [4], [7].

Shading type	Standard geometry	Type dependent geometry
Type X: Horizontal louvres	Distance from the window: 200mm Thickness: 70mm Projection: 350mm	X1 Louvre spacing: 400mm X1 No of louvre: 5 X2 Louvre spacing: 600mm X2 No of louvre: 4
Type Y: Overhang louvre	Vertical offset: 0 mm Thickness: 100mm Horizontal window overlap: 400mm	Y1 Projection: 600mm Y2 Projection: 900mm
Type Z: Vertical louvres	Distance from the window: 100mm Thickness: 70mm Louvre spacing: 1810 mm	Z1 Louvre projection: 400mm Z2 Louvre projection: 800mm

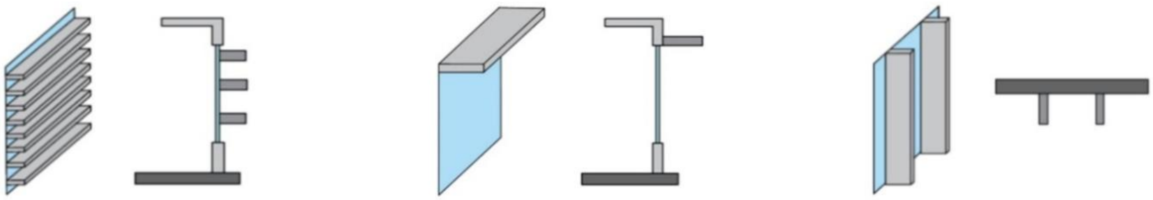

Figure 2. Schematics of horizontal (Left), overhang (Middle) and vertical louvres (Right).

RESULTS

Each specified shading device was simulated with each climate for the boundary conditions previously discussed. Results are presented in terms of energy usage per shading device. Monthly energy usage in Florida is shown in Figure 3. In the winter months, all shading devices reduced energy consumption. X1 was the highest performing with a peak reduction of 597 kWh in February (45% Decrease). In the summer months, Y2 proved to be the highest performing with a peak decrease of 282 kWh in September (20% Decrease). In terms of annual energy reduction, the highest performing shading device was X1. Compared to baseline, X1 showed a reduction of 4330.19 kWh for cooling consumption and saw increases of 118.85 kWh and 19.45 kWh for lighting and heating, respectively. The reduction from cooling outweighed the increase from lighting and heating and therefore X1 had a larger energy decrease. All tested solar shading devices increased the annual energy usage of lighting and heating services, this indicates that in months of lower temperatures, the building does not gain the benefit of passive solar heating and daylighting.

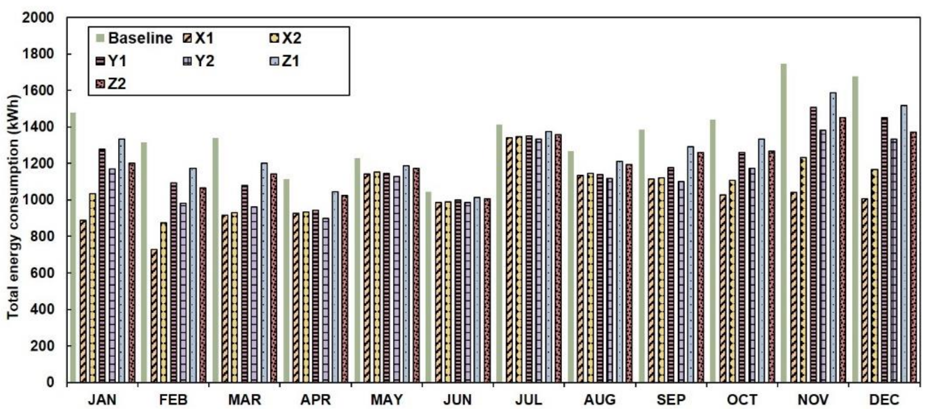

Figure 3. Variation of monthly energy usage among different shading devices in Florida.

Monthly energy usage in Cairo posed a variation of results as seen in Figure 4. In winter months all shading devices reduced the energy consumption, and the highest performing X1 with a peak decrease of 660.9 kWh in February (52% Decrease). In the summer months, Y2 proved to be the highest performing with a peak decrease of 390 kWh in April (31% decrease). In terms of annual usage, the highest performing shading device was X1, which had a reduction of 5320.13 kWh for cooling consumption and saw increases of 71 kWh and 54.69 kWh for lighting and heating, respectively. For baseline energy usage, cooling (15864.93 kWh) and lighting (1304.17 kWh) energy primarily contributed to total energy usage with a small heating energy (3.02 kWh), therefore the most suitable shading device should aim to reduce cooling energy. Thus, X1 performed the best as cooling outweighed the increase from lighting and heating.

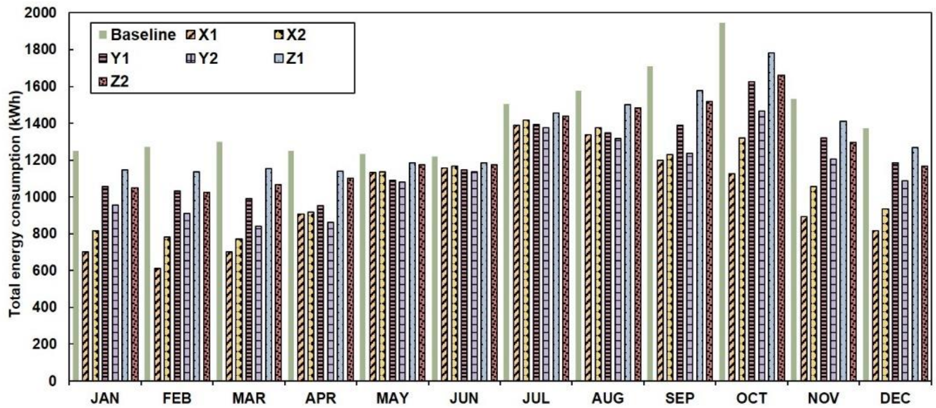

Figure 4. Variation of monthly energy usage among different shading devices in Cairo.

Monthly energy usage in Leeds can be seen in Figure 5. In winter months all shading devices showed increases in energy consumption with the highest performing X1, which had a peak reduction of 79 kWh in March (12% Decrease). The decrease for X1 was minimal as cooling energy decreased (157 kWh), while heating (65 kWh) and lighting (13 kWh) increased balancing the reduction out. Throughout winter months all shading devices presented similar results to baseline, this was due to low sunlight thus, solar shading had minimal effect on energy usage. In the summer months, X1 proved to be the highest performing with a peak decrease of 432 kWh in August (39% Decrease). In terms of annual energy usage, the highest performing shading device was X1, which saw an annual reduction of 2422.86 kWh for cooling consumption and increases of 159.43 kWh and 380.58 kWh for lighting and heating, respectively. The baseline energy usage results identified cooling (5787.75 kWh) primarily contributed to total annual energy usage with a smaller contribution from lighting (1747.16 kWh) and heating (1547.5 kWh). Therefore, the most suitable shading device should aim to reduce cooling energy. As the reduction in cooling by X1 outweighed the increase from lighting and heating, X1 had the largest energy decrease.

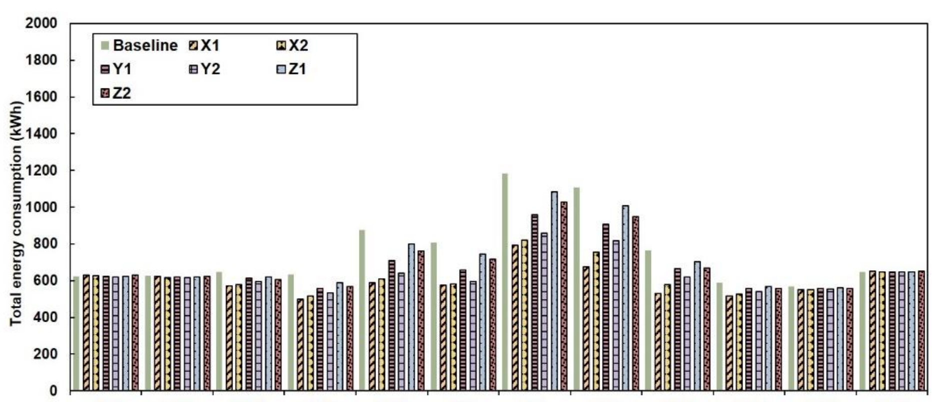

Figure 5. Variation of monthly energy usage among different shading devices in Leeds.

Figure 6 shows energy usage in Reykjavik. In winter months shading devices saw some increases and decreases in energy consumption with the highest performing X2 with a peak reduction of 25 kWh in October (4% Decrease). In the summer months, X1 proved to be the highest performing with a decrease of 240 kWh in July (32% Decrease). Overall, the highest performing shading device was X1. The geometry of X1 ensured that a large percentage of the glazing area was covered during direct sunlight hours but enabled some heat gain to ensure natural heating in winter. For baseline energy usage, cooling (3188.27 kWh) and heating (3155.65 kWh) primarily contributed with a smaller quantity from lighting (2384 kWh). Therefore, the most suitable shading device must aim to reduce cooling energy and have a small increase in lighting and heating. It is seen that X1 had a reduction of 1788.32 kWh for cooling consumption and increases of 143.52 kWh and 697.32 kWh for lighting and heating, respectively. The reduction from cooling outweighed the increase from lighting and heating, and therefore X1 saw a large energy decrease.

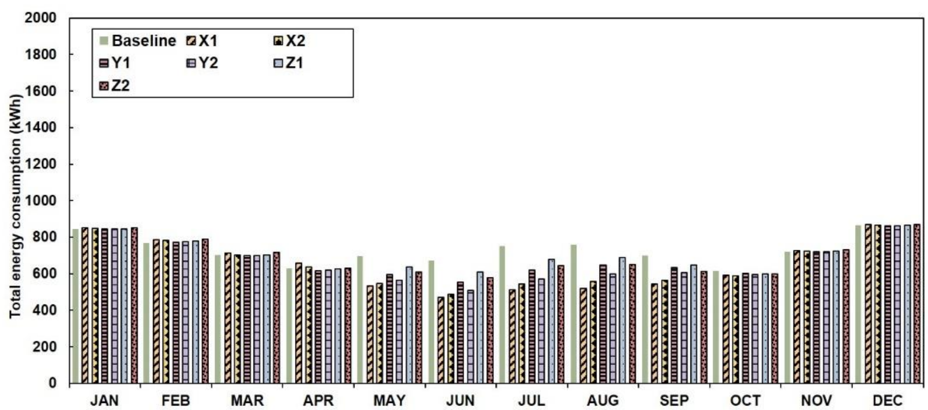

Figure 6. Variation of monthly energy usage among different shading devices in Reykjavik.

DISCUSSION

For Florida and Cairo (Type A and B climates), Y2 resulted a larger overall energy reduction in the summer months compared to the other shading devices. It was suggested that this occurred due to the larger projection of Y2. In the summer months, the altitude angle of the sun is closer to 90º in these climates than in winter thus the larger projection provides a low area exposed to direct sunlight (A_{WS}) given the higher vertical fraction of solar irradiation present. The altitude angle was also the cause of the lower performance for Y2 in the winter months compared to the other shading devices. As the altitude angle was primarily lower than 45º, the horizontal fraction of solar radiation was increased thus the larger projection of Y2 had less effect on solar radiation. Therefore, it could be concluded that climates that experience altitude angles of close to 90º will benefit highly from shading with larger projections. Overall for the A and B climates, X1 was the highest performing annually, as X1 presented 5 louvres which shaded both the vertical and horizontal fraction of radiation to ensure a reduced A_{WS} throughout all solar positions. Thus, it resulted in higher energy savings for cooling through the winter and summer months. This study therefore concludes that when utilising south-facing facade systems for A and B type of regions, a type X1 shading type was most effective.

For the cooler climates of Leeds and Reykjavik (Type C and D), Overall X1 presents a higher reduction of cooling usage and a low increase of heating which enabled large energy savings to be seen throughout the year. It is clear from the monthly and annual analysis that when large surface area devices such as X1 provided increases in heating and lighting, it was compensated by decreases in cooling. X1 provided low A_{WS} therefore in summer at peak energy consumption large reductions were seen. When X1 is compared to X2, it is clear to see that for this climate when a smaller spacing was used, more energy was saved due to a smaller A_{WS}. To conclude, X1 type shading was the most effective for Type C and D climates. Overall the analysis of Type A, B, C and D climates identified that X1 was the most effective shading device for reducing energy usage. However, as X1 provided a large shading coverage it could significantly reduce the daylight thus reducing visual comfort. Thus this study suggests if more daylight is needed for visual comfort, X2 type shading should be used. X2 type shading showed a smaller increase in lighting demand (3.42% - 5.8%) than X1 (5.47% - 10.56%) whilst still providing large cooling energy reduction.

The Z type shading performed low throughout all climate simulations. This was due to Z shading providing minimal shading during azimuth angles close to 180º when the sun was perpendicular to the glazing. When the sun is close to azimuth angles of 180º there is a negligible shading effect thus the A_{WS} is larger given the solar radiation incident on its surface. Thus for south-facing buildings, Z type shading was ineffective. However, Z type shading devices also confirmed the projection effect as seen by the Y shading devices, while Z2 saw larger reductions in energy usage when compared to Z1.

CONCLUSIONS

This study presents research into the energy-saving potential of horizontal, overhang and vertical shading devices for a potential commercial building in the climates of Florida, Cairo, Leeds and Reykjavik. It was found that shading devices decreased cooling energy usage but also increased heating and lighting energy usages. It was also demonstrated for all climates that all the shading devices provided an overall decrease in net energy usage. Therefore, this research has provided useful insight into the effectiveness and suitability of shading devices for the different environments. Comparative analysis identified that the X1 horizontal louvre type could significantly reduce the annual energy usage for all the climate zones – Florida (4191 kWh), Cairo (5194 kWh), Leeds (1882 kWh) and Reykjavik (957 kWh). In terms of climate conditions, shading was significantly more effective at reducing energy usage in hotter Type A and B climates whilst C and D climates saw smaller reductions. All climates are suggested to use the Type X1 shading for maximum energy reduction or X2 louvres depending on daylight needs. Further studies should include the effectiveness under various orientations other than south-facing analysis.

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