The Impact of External Window Shading on Energy Requirements of Office Buildings

Samah K. Alghoul
Dept. of Mechanical and Industrial Engineering
University of Tripoli
Tripoli-Libya.
s.alghoul@uot.edu.ly

Hassan G. Alrijabo
Dept. of Mechanical and Industrial Engineering
University of Tripoli
Tripoli-Libya.
h.alrijabo@uot.edu.ly

***Abstract*— Residential and commercial building sector consumes a significant amount of nationally produced energy. Therefore, reducing buildings energy requirements is a key factor to achieve green buildings and sustainability. In this paper, the influence of adding overhang shading to a window on building energy consumption was investigated. An office room with one window was selected as a case study. The room is located in the city of Tripoli, Libya. The window and therefore the overhang shading face cardinals and intercardinals orientations by rotating the model room 45 degrees. The model was created using OpenStudio and EnergyPlus software to simulate the office room and estimate the energy requirements due to thermal and electrical loads. The projection factor of the shading changes between 0 and 1 for all orientations. The results presented here show that adding overhang shade to the South, Southeast, and Southwest orientations results in a significant energy saving. This amount could reach 20% of energy consumed when a projection factor of 1 is used. On the other hand, North facing window with an overhang shading provided a negligible energy saving for the range of the projection factors selected in this study. Recommended projection factors for all orientations were obtained and presented in this work for different levels of energy conservation.**

Keywords*— *overhang shading, projection factor, energy consumption, energy simulation, EnergyPlus

I. Introduction

One of the most common reasons of overheating that occurs in buildings is excessive solar gains through windows. That makes controlling solar gains a key consideration in maintaining indoor comfort and implementing low energy building design. Solar gains can be limited with effective shading design which can reduce overheating, regulate swings in temperature and reduce building's cooling loads. In comparison to mechanical cooling, shading is energy efficient and more cost effective way to control overheating [1]. Effective shading is an essential part of a sustainable building and should be considered from early design stages of new buildings and also for retrofit of existing buildings [2].

Direct radiation falling on transparent surfaces of buildings contributes significant amount of energy to the building's energy use. Clear glass transmits more than 80% of incident solar radiation and more than 75% of the visible light [3]. The penetration of solar radiation to indoors can be favorable and healthy in some circumstances, however, it can be extremely unfavorable, depending on climate, season, building function, and activities of occupants.

It is known that, from the total incident solar radiation on fenestration systems, a portion is absorbed, other reflected and the remaining is transmitted through the glass directly to the indoor environment. The amount related to the energy absorbed, reflected, and transmitted vary according to the angle of incidence of the radiation, radiation wavelength, glass thickness & color, and the refraction index of the glass [4]. Overall, solar radiation absorbed by a glazing system and transmitted to a building space controls the level of solar gains in that building.

It is proved that external shading is more effective than internal shading in reducing overheating in buildings. That is because most of the heat due to solar radiation is prevented from reaching a building surface. From previous research, external shading can lead to a reduction of solar heat gain by 80% to 90% [5]. Proper design of fixed shading devices is vital to ensure that a building does not get overheated and enough daylighting allowed to the building [6].

In this study, the influence of overhang shading on annual heating and cooling energy consumption is investigated. A simple double-glazed (air filled) window is considered for an office room located in the city of Tripoli. EnergyPlus software is used to calculate heating, cooling and total energy consumption for projection factors ranging between 0 and 1.0, and for all eight cardinal and intercardinal orientations.

II. Methodology

A model office space with one window placed on an external wall was chosen in this work. For the analysis, all opaque office components of the reference room were modeled as adiabatic walls, except the wall that includes the window under study. The window to wall ratio (WWR) was kept constant throughout this study and set equal to 20% which is considered most efficient window size [7]. Different overhang shading with projection factors (PF) ranging between 0 and 1.0 were added to the window one a time, and the office was rotated by steps of 45 degrees every time to make the wall face all eight cardinal and intercardinal directions.

Fig. 1 illustrates the methodology of this study in four steps. In the first step, a base model was created with a window but without shading, i.e. the projection factor (PF) is equal to zero. Then the base model was altered in the second step to account for projection factors between 0 and 1 for eight orientations. In step three, total and hourly energy requirement of the space were extracted from the simulation in order to study the effect of overhang shading. Finally, the effect of overhang shading on energy saving was categorized according to its feasibility for the purpose of recommending proper projection factors for different orientations.

SketchUp software was used to draw and create the model geometry. Then OpenStudio is used to modify the model properties that includes: construction, materials, occupancy, internal loads and schedules [8]. EnergyPlus is used to perform an annual energy simulation [9,10] for the case study with different parameters illustrated in Fig1. Eventually, the obtained results are presented in OpenStudio and prepared in proper format.

III. External Shading Devices

External shading devices are more effective than internal devices in reducing solar heat gain because they block radiation from reaching a building's outer surface before it passes through a window. In general, light-colored shades are preferable to dark shades, because they reflect more and absorb less radiation.

Fig. 2 shows solar radiation incident on a glazed window. That radiation can be reduced considerably by using external shadings. It reduces the area of the window that is exposed to direct sunlight, and therefore reduces overheating in the building. A common way of providing external shading, known for thousands of years is the use of overhangs. Fixed overhangs are considered one of the simplest methods used to reduce direct solar into buildings. However, it is still an efficient method that is widely used nowadays all over the world. Good design of overhangs may lead to reducing the solar radiation during summer and prevent overheating while allowing solar radiation into the building during winter leads to reducing required heating loads.

The height of the shading (h) provided by an overhang, shown in Fig. 2, can be estimated by using the following formula:

$$h=\frac{A\times\tan(\text{solar altitude})}{\cos(\text{solar azimuth-window azimuth})} \quad (1)$$

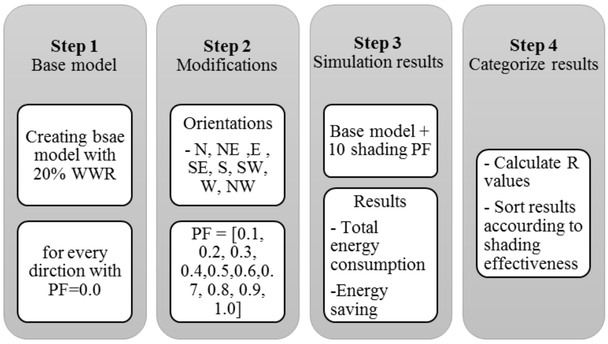

Fig. 1. Steps of the methodology used in this work.

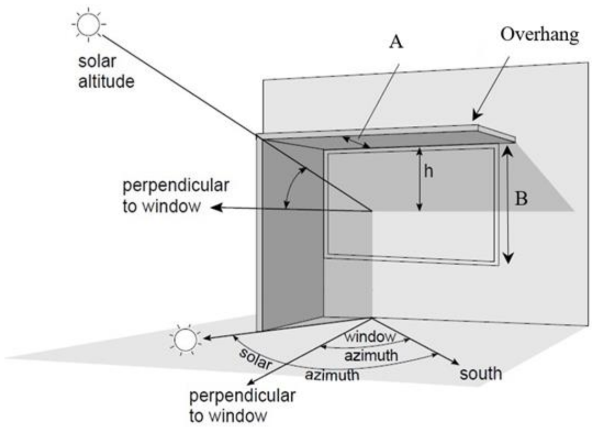

Fig. 2. Solar radiation on window with overhang shade [1]

The projection factor (PF) is calculated by measuring the depth (A) of the overhang and dividing it by the distance from the bottom of the window to the lowest point of the overhang (B) as shown in Fig. 2 and it can be defined as:

$$PF=A/B \quad (2)$$

One way to examine the effectiveness of the overhang shading is the annual ratio of energy efficiency. It is defined by the ratio of annual energy conservation (no shading is used) to the original annual energy consumption. The annual ratio of energy efficiency (R), and the corresponding conservation effects that could be achieved are defined in the following equation [2];

$$R=\frac{C_b - C_a}{C_b}\times 100 \begin{cases} R<1 & \rightarrow \text{No effect} \\ 1\le R<5 & \rightarrow \text{Fair effect} \\ 5\le R<10 & \rightarrow \text{Good effect} \\ R\ge 10 & \rightarrow \text{Strong effect} \end{cases} \quad (3)$$

Where C_b is the total annual energy consumption for the original case in kWh/m^2, and C_a is the total annual energy consumption after improving energy conservation in kWh/m^2.

IV. Materials

An office room has been chosen for the simulation in Tripoli climatic region (32.7° N latitude; 13.08° E longitude). The room area is 16.0 m^2 (4.0×4.0×4.0 m, l×w ×h) and has one window with window to wall ratio (WWR) of 20%. The weather data used in the simulation is obtained from EnergyPlus website for the city of Tripoli, Libya [3].

The specifications of the construction materials were chosen to comply with the most common materials regularly available in Libyan market. External walls composite of 20 cm concrete blocks with 2 cm cement plaster on internal and external sides. A double glazed, air-filled, clear window was chosen in this study. The thickness of the glazing layers is 6 mm each, and the thickness of the air layer is 13 mm. The overall heat transfer coefficient of the walls is 2.4W/m^2. K whereas for the window is equal to 2.72 W/m^2. K.

V. SIMULATION SETUP

Internal gains due to people, lighting, and electric appliances are estimated according to ASHRAE [4]. The “Ideal Loads Air System” is used in order to study the performance of the office room without modeling a full HVAC system. The main adopted design parameters and operating conditions are listed below:

- Occupancy density: one person
- Heating set-point: 21°C (07:00 – 19:00) & 15.6°C (rest of the day)
- Cooling set-point: 24°C (07:00 – 19:00) & 26.7°C (rest of the day)
- Artificial lighting system: 10.7 W/m^2
- Plug and process: 6.9 W/m^2

VI. RESULTS AND DISCUSSION

The results presented below show the influence of using overhang shading on energy consumption for a clear double-glazed window of an office space located in Tripoli city, Libya. The window to wall ratio WWR is set to be fixed and equal to 20% while eight orientations were selected in this study.

The transmitted solar radiation energy shown in Fig. 3 (a & b) is the sum of the window transmitted beam solar radiation energy and window transmitted diffuse solar radiation energy. The figure represents eight curves for different window directions and for sunlight duration of a chosen day, i.e. between 7 and 22 hours on July 21. The highest transmitted solar energy occurs early morning for East, Northeast, and Southeast. For South, it occurs two hours after noon while for other directions it occurs later between 17 and 19 hours. The value of maximum transmitted solar radiation energy during the whole year is 1.8 kWh which occurs at the South and Southwest orientations.

Fig. 4 shows transmitted solar radiation through Southwest facing window for different projection factors on two days: January 21 and July 21. On July, the radiation energy when no external shading is used reaches a value of 0.5kWh and decreases with the shading to 0.3 kWh while on January, the maximum radiation energy is about 1.2 kWh and decreases to 0.6 kWh.

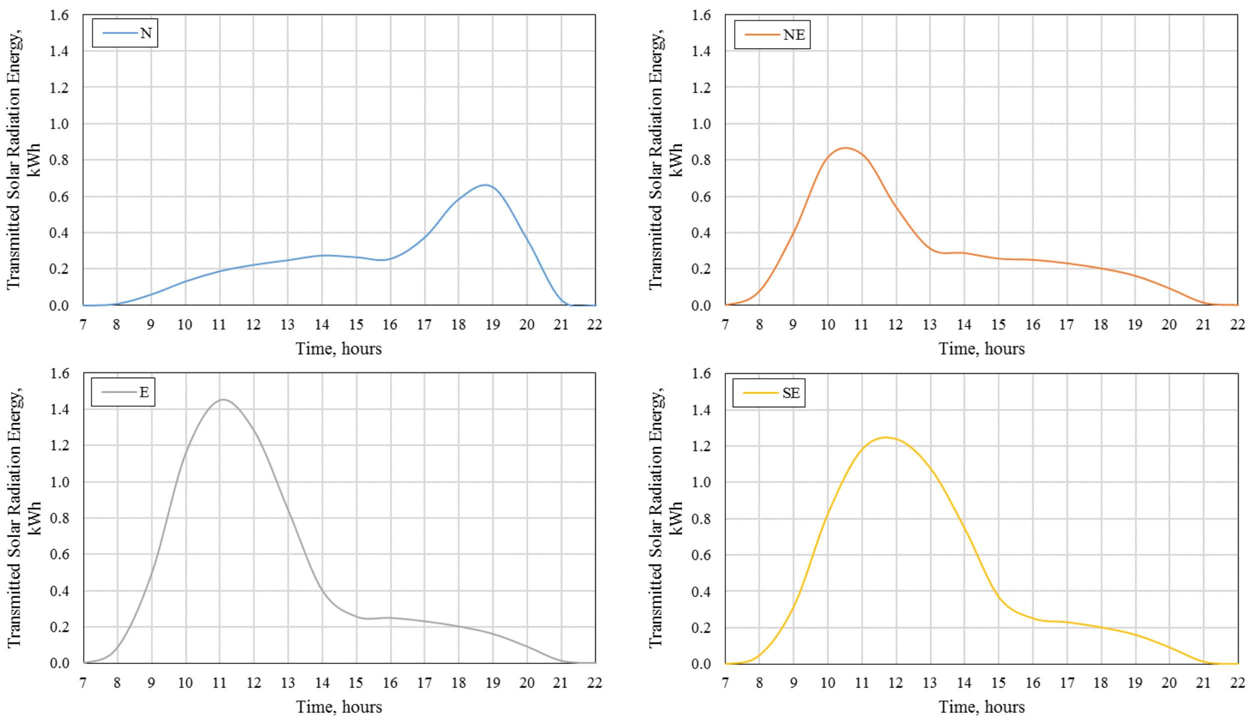

Fig. 3. (a) Transmitted solar radiation through the window without shading for different orientations on July 21

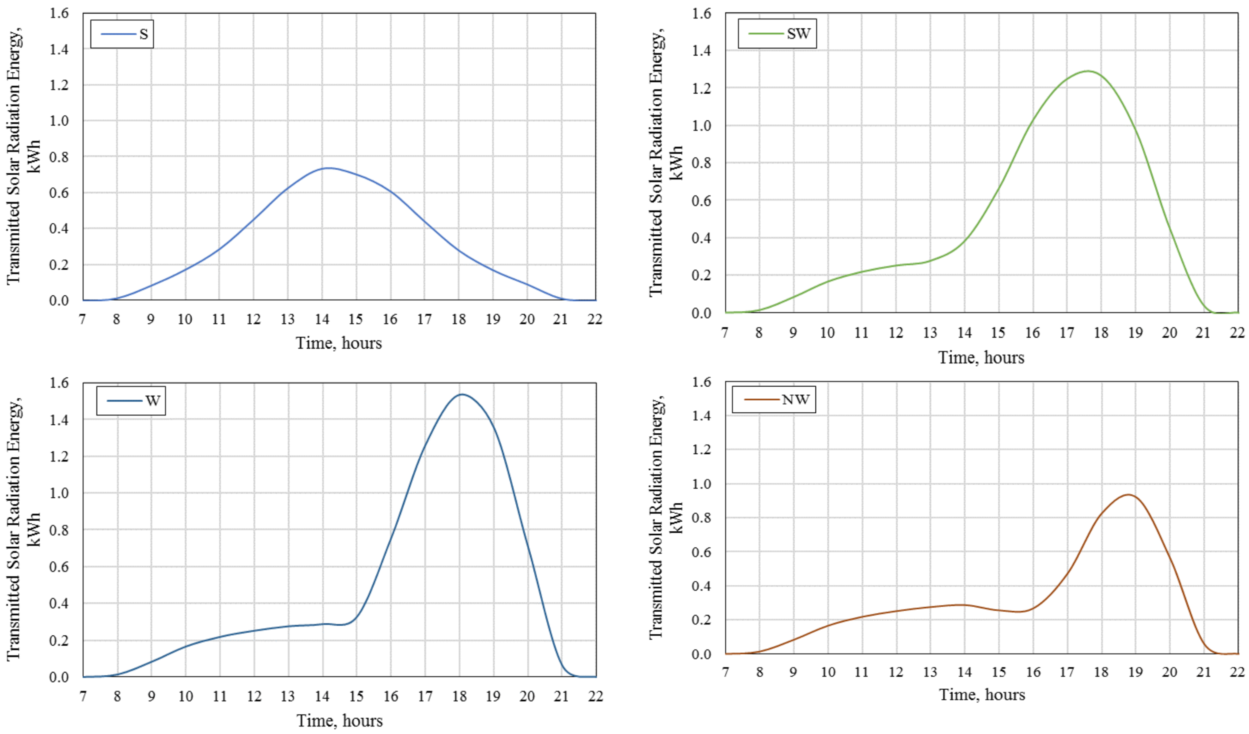

Fig. 3. (b) Transmitted solar radiation through the window without shading for different orientations on July 21 (continue)

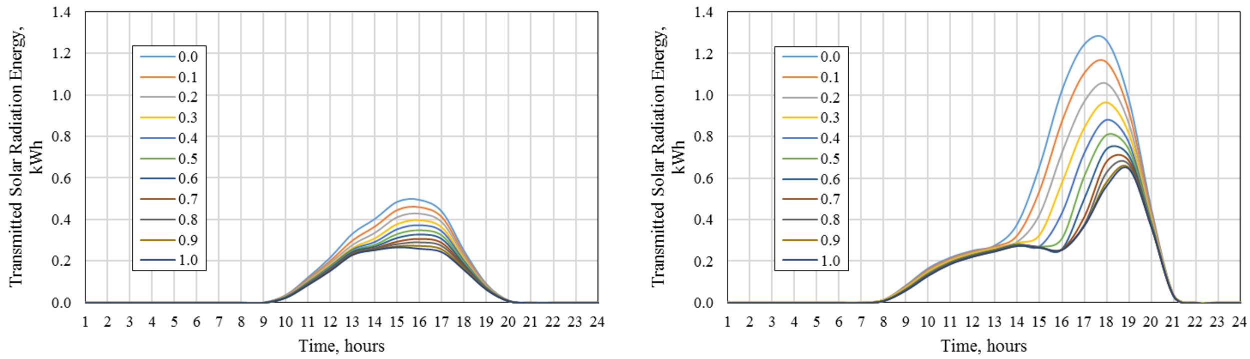

Fig. 4. Transmitted solar radiation through southwest facing window for different projection factors on January 21 (left) and July 21 (right)

Fig. 5 shows the annual energy consumption of the office space for all orientations and for projection factors ranging between 0 and 1. The annual energy consumption with the window without external shading (PF equal to zero) has maximum values for all orientations as shown in the figure. Adding shading to the window results in a reduction of the annual energy consumption. The trend of energy consumption is close to symmetry around the South orientation.

Increasing the projection factor leads to a decrease in annual energy use as also shown in Fig. 6. The minimum reduction occurs at North, Northeast and Northwest orientations while South, Southeast, and Southwest have the maximum reduction. The reduction is sharp for projection factors less than 0.5 for all orientations.

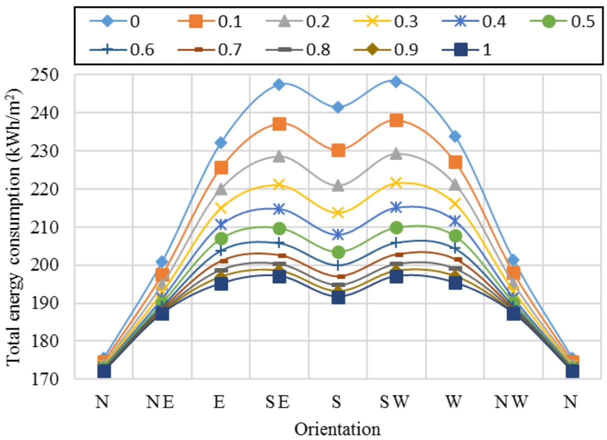

Fig. 5. Total annual energy consumption for different projection factors

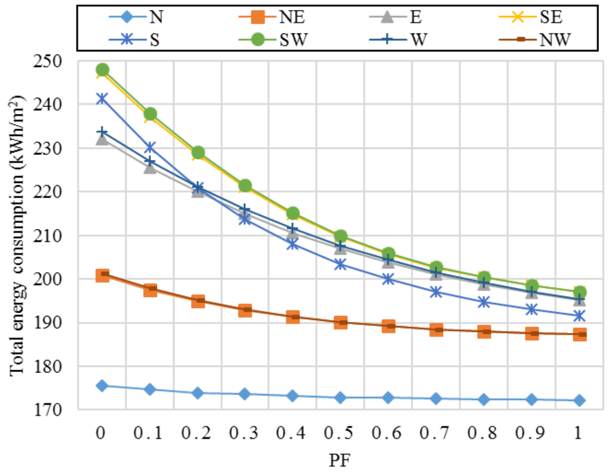

Fig. 6. Change in annual energy consumption with projection factor

Fig. 7 shows the difference between the annual energy consumption without using overhang shading and with overhang shading. The amount of energy saving for the North direction is slight, with values between 1 and 3 kWh/m^2, for projection factors between 0 and 1.0. The saving for all other orientations increases with increasing the projection factor. For South, Southeast and Southwest directions, the saving reaches a high value of 39kWh/m^2 for projection factor equal to 0.5 and about 50 kWh/m^2 for projection factor equal to 1. The percentage of the saving in energy consumption per unit area could reach an important amount of 20% as presented in Fig. 8.

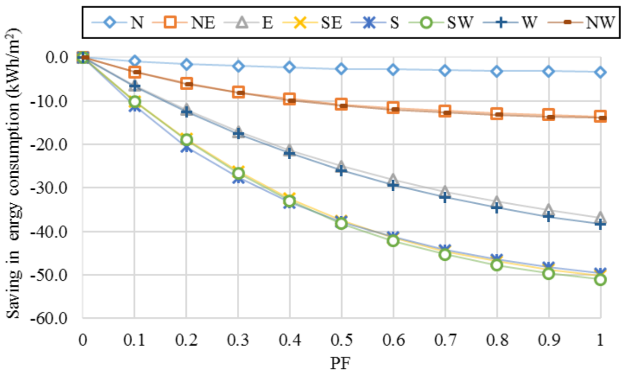

Fig. 7. Energy saving due to overhang shading

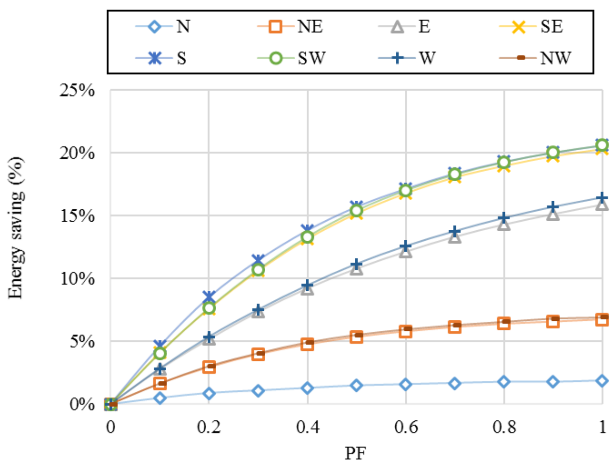

Fig. 8. Percentage of energy saving

The evaluation of the annual energy saving for overhang shading for different projection factor (PF) is shown in table 1. For North direction, the effect of the overhang shading is not valuable as there is no good energy saving effect for all projection factors. For Northeast and Northwest, a projection factor of 0.5 is useful to get a good energy saving effect. A projection factor of 0.2 gives a good energy saving effect for East and West orientation and when projection factors of 0.5 and more is used a strong energy saving is achieved. Overhang used in Southeast, South, and Southwest orientation provide a strong energy saving when using a projection factor of 0.3.

TABLE 1: THE EVALUATION OF ANNUAL ENERGY SAVING ACCORDING TO THE ANNUAL RATIO ENERGY EFFICIENCY, R (%)

PF	N	NE	E	SE	S	SW	W	NW
0.1	0.5	1.6	2.8	4.1	4.6	4.1	2.8	1.6
0.2	0.9	2.9	5.2	7.6	8.5	7.6	5.4	3.0
0.3	1.1	4.0	7.3	10.6	11.4	10.7	7.5	4.1
0.4	1.3	4.8	9.2	13.1	13.8	13.3	9.4	4.9
0.5	1.5	5.4	10.8	15.2	15.7	15.4	11.1	5.5
0.6	1.6	5.8	12.1	16.8	17.1	17.0	12.6	6.0
0.7	1.7	6.1	13.3	18.0	18.3	18.3	13.7	6.3
0.8	1.8	6.4	14.3	19.0	19.3	19.2	14.8	6.6
0.9	1.8	6.6	15.1	19.7	20.0	20.0	15.7	6.8
1.0	1.9	6.7	15.9	20.3	20.6	20.6	16.4	6.9

* Definition of colors
no effect
fair effect
good effect
strong effect

VII. CONCLUSION

External shading device is one of the most effective methods for preventing solar radiation from entering buildings and therefore reduces energy requirements of buildings. This paper studies the effect of using overhang shading device with different projection factors in various orientations on annual energy consumption. An office room in the city of Tripoli, Libya was chosen as a case study. The room has one window with WWR of 20%. OpenStudio and EnergyPlus software were used to estimate annual energy use of the office space. The final results have been evaluated to allow the selection of the best overhangs projection factors (PF) based on efficient energy saving. The study has provided some conclusions. (1) for the best scenario, using overhang can reduce the annual energy consumption by 20%. (2) overhang shading for North orientation is not efficient for energy saving while it provides good energy savings for Northeast and Northwest orientation. (3) strong saving in energy consumption was achieved when using overhang shading for East, Southeast, South, Southwest and West orientations but with different projection factors.

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