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Integration of Photovoltaic Cells in Building Shading Devices: Enhancing Energy Efficiency and Indoor Environment in Administrative Building

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ABSTRACT

This study focuses on the thermal performance simulation of the CSERS administrative building. It proposed the integration of shading elements on the south façade of the building to enhance thermal comfort for office occupants. These shading elements incorporate photovoltaic cells, displaying the potential of utilizing photovoltaic in external shading devices. The main objective of this approach is effectively address issues related to high internal temperatures and excessive solar radiation exposure. Furthermore, it ensures the preservation of key functions of the building envelope, such as thermal insulation, provision of natural lighting, and prevention of internal thermal glare.

Comparative analysis is conducted between the building equipped with shading devices and the one without, with a focus on measuring the total electrical energy generated by the photovoltaic panels. Simulation programs such as SketchUp and EnergyPlus are utilized for this purpose. The results of the simulations reveal that strategically designed shading on south-facing windows leads to 17.15% reduction in annual heat gains transmitted to the building. In addition, the integration of photovoltaic shading devices demonstrates outstanding performance characteristics, contributing a productive capacity of around 5916.388 MW/h to the building. This integration effectively harnesses solar energy to improve the indoor environment of the building.

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دمج الخلايا الكهروضوئية في أجهزة تظليل المباني: تعزيز كفاءة الطاقة والبيئة الداخلية في المباني الإدارية.

نسرين عياد محمد عبود.

ملخص: تركز هذه الدراسة على محاكاة الأداء الحراري للمبنى الإداريCSERS . واقترح دمج عناصر التظليل على الواجهة الجنوبية للمبنى لتعزيز الراحة الحرارية لشاغلي المكاتب. تتضمن عناصر التظليل هذه خلايا كهروضوئية، مما يوضح إمكانية استخدام الخلايا الكهروضوئية في أجهزة التظليل الخارجية. الهدف الرئيسي من هذا النهج هو المعالجة الفعالة للقضايا المتعلقة بارتفاع درجات الحرارة الداخلية والتعرض المفرط للإشعاع الشمسي. علاوة على ذلك، فإنه يضمن الحفاظ على الوظائف الرئيسية لغلاف المبنى، مثل العزل الحراري، وتوفير الإضاءة الطبيعية، ومنع الوهج الحراري الداخلي. يتم إجراء تحليل مقارن بين المبنى المجهز بأجهزة التظليل والمبنى الذي لا يحتوي عليه، مع التركيز على قياس إجمالي الطاقة الكهربائية المولدة من الألواح الكهروضوئية. ويتم استخدام برامج المحاكاة مثل SketchUp وEnergyPlus لهذا الغرض. تكشف نتائج عمليات المحاكاة أن التظليل المصمم بشكل استراتيجي على النوافذ المواجهة للجنوب يؤدي إلى انخفاض بنسبة 17.15% في مكاسب الحرارة السنوية المنقولة إلى المبنى. بالإضافة إلى ذلك، يُظهر دمج أجهزة التظليل الكهروضوئية خصائص أداء متميزة، مما يساهم في قدرة إنتاجية تبلغ حوالي 5916.388 ميجاوات/ساعة للمبنى. يعمل هذا التكامل على تسخير الطاقة الشمسية بشكل فعال لتحسين البيئة الداخلية للمبنى.

الكلمات المفتاحية – الخلايا الكهروضوئية، أجهزة التظليل، البيئة الداخلية، سكيتش أب، إنيرجي بلس، العزل الحراري.

1. INTRODUCTION

Providing safe and comfortable thermal conditions for occupants inside a building is a fundamental goal of sustainable architectural design. This can be achieved through appropriate climate-responsive design of residential, commercial, and other types of buildings. Despite architects' understanding of the importance of climatic aspects in design and the academic interest in this field, as evidenced by numerous valuable scientific and academic studies, most Libyan buildings are not climate-designed, and desirable climatic conditions are lacking (Aboud, 2021;Abdunnabi, et al., 2020). Several studies have been conducted on the applications of solar thermal energy in heating and cooling systems in buildings. One of the key findings in most of the conducted research is that solar energy control devices contributed to reducing the average annual solar radiation by 86% during peak hours while maintaining high levels of diffuse radiation (De Carvalho, et al., 2019). The problem addressed in this study is the absence of climate design in practical applications, leading to a lack of thermal comfort and suitable climatic conditions inside buildings. The study focuses on the problems facing internal thermal comfort during occupancy peak hours, which include exposure to daylight and intense sunlight in our desert climate, despite the presence of insulating materials in the building envelope. Most of these problems have been encountered in buildings worldwide, but with the implementation of passive design strategies in modern and existing buildings, thermal comfort for building occupants has been achieved. There has been a significant global shift in climate design with the emergence of computer programs capable of digitally representing the climatic behavior of buildings, predicting internal climatic conditions, and evaluating these conditions. Simulation has become an important part of scientific research in the field of climate design. This study presents how an existing administrative building can be retrofitted using passive shading strategies in buildings, using simulation tools such as EnergyPlus, SketchUp, and OpenStudio to provide thermal comfort for its occupants. The residential sector is responsible for over 40% of the world's total primary energy consumption and 30% of greenhouse gas emissions (World Energy Outlook, 2015). Most of the final energy consumed in buildings is attributed to space heating, cooling, and domestic hot water.(Tawil, et al.,2018). This thermal energy can easily be obtained from solar energy. The global market for solar thermal energy reached 472 gigawatts in 2017, equivalent to 388 terawatthours. In recent years, solar-supported district heating systems and solar heating/cooling applications in commercial and industrial sectors have gained increasing attention worldwide. In 2022, the flat-plate solar collector market demonstrated an investment value of approximately $25.84 billion. It is projected that this market will experience substantial growth, reaching an estimated value of $44.73 billion by 2030, exhibiting an annual growth rate of 8.15%. Notably, the market experienced a significant 36% growth in 2020 when compared to the figures from 2015. At present, the global cumulative thermal capacities of thermal solar collectors have reached approximately 6,479 MW. Key players in this industry include China, Germany, and Denmark, which are among the foremost investors in this sector (www.waujpas.com). Hyunmin Lee and Heaugwoo Lee conducted a comprehensive test on the integration of photovoltaic (PV) modules into lightweight shelves. In this study, PV modules were applied to curved lighting shelves to enhance daylight performance and efficiency of focusing. The effectiveness of this approach was observed after a wide-ranging test. The results showed that the daylight performance of curved lighting shelves outperformed flat lighting shelves. However, the high angles of curvature can reduce the daylight performance. Additionally, installing PV modules on flat lighting shelves provides energy savings through light concentration, but this approach leads to a reduction in the reflector area and its impact on daylight performance. It was observed that installing PV modules in the lower part of curved lighting shelves provides energy savings ranging from 6.1% to 25.3% compared to traditional lighting shelves and creates a comfortable lighting environment. A study by Sohani et al. indicates that the types of analysis used in studies related to BIPV/T systems in the Middle East and North Africa region include energy, thermal, economic, environmental, visual, external energy, and economic analysis, as well as external environmental analysis. In addition, they evaluate the prediction error of artificial intelligence models and machine learning. Energy analysis refers to calculating the generated energy and recovered heat by the system, and the results are compared with other countries, indicating that the typical analysis is the most common approach. Energy analysis is used more than any other type of analysis, and batteries and phase change materials are preferred for storing electrical and thermal energy, respectively. The researchers recommend conducting more detailed,economic, and environmental assessments as part of future studies. The study also highlights the importance of evaluating the prediction error of artificial intelligence models and machine learning to ensure the accuracy of the results. Although these studies indicate the benefits of integrating solar modules into lightweight shelves, several factors need to be considered before widely implementing this technology. Among these factors are cost, efficiency, design, reliability, system maintenance, and environmental impact (Sohani, et al.,2023). Overall, the use of solar modules in lightweight shelves can be an innovative and efficient idea in terms of harnessing solar energy and saving energy. However, more detailed studies and comprehensive evaluations are needed to determine the feasibility and effectiveness of this technology in specific conditions and different contexts. Encouraging results have been achieved in this study and previous studies regarding the application of photovoltaic cells in their integration with building structures. This approach allows for the direct integration of photovoltaic cells into shading devices on the exterior facade of the building, contributing to improving energy efficiency and indoor environmental quality in various buildings. By directing these devices to effectively expose the photovoltaic panels to sunlight, solar energy is efficiently utilized, resulting in increased photovoltaic energy production (Chen, et al.,2022). Additionally, this integration provides strong support for generating electricity from solar energy on the building's facade, with effective management of solar energy absorption and reduction of risks associated with high internal temperatures and excessive solar radiation exposure. The shading device was designed for application at the Libyan Center for Solar Energy Research and Studies (CSERS) in Tajura, Libya. The center covers an area of 8 hectares and includes 10 main buildings, including the administrative building, laboratories, and conference building. The average annual electricity consumption of the center is approximately 263 megawatt-hours, based on the recorded averages in 2012 and 2013. According to data recorded on March 6, 2018 shown in Figure 1, the estimated consumption for the administrative building is 155 megawatt-hours. The building envelope is characterized by thermal insulation and double-glazed windows.(Abdunnabi, et al., 2020).

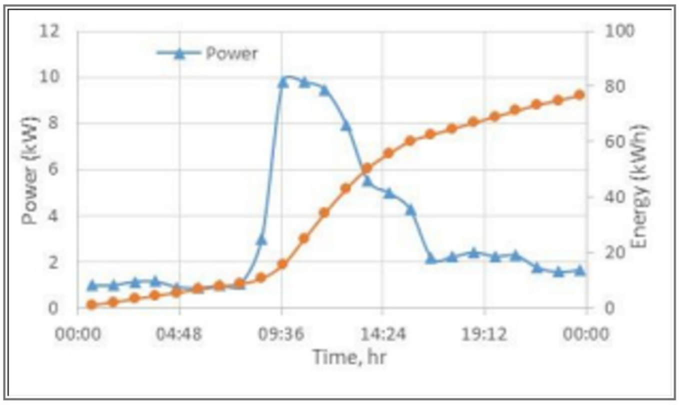


Figure 1. Power and accumulated energy of the administrative building (date:March 6, 2018).

2. SITE DESCRIPTION

2.1. Location of Tajoura

Tajoura is a coastal city located in northwestern Libya. It is positioned approximately 11 km east of the Libyan capital, Tripoli, making it the eastern gateway to the city.Tajoura benefits from a pleasant Mediterranean climate, with its geographical coordinates at latitude of 32.88167 ° N and a longitude of 13.35056 ° E. The city is situated at an elevation of 6 meters above sea level. Tajoura has a population of approximately 180,000 people, making it a vibrant and bustling community. The Mediterranean climate, combined with the city's location and population, contributes to the overall character and liveliness of Tajoura.

2.2. The project Location

The Libyan Center for Solar Energy Research and Studies in Tajoura, a city located 30 km east of Tripoli, Libya.

Figure 2A. The location of the building study in Libyan Center for Solar Energy Research and Studies inTajoura Tripoli – Libya (Libya Location, 2010).

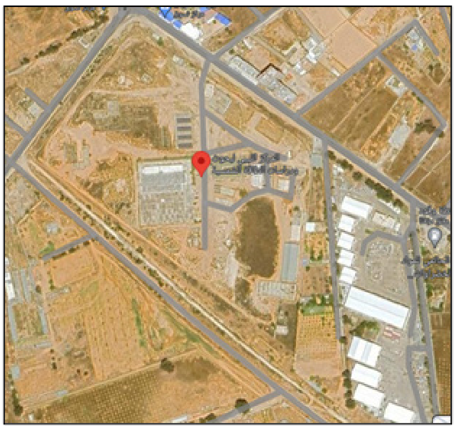


Figure 2B. The location of the Libyan Center for Solar Energy Research and Studies in Tajoura Tripoli – Libya (Libya Location, 2010).

It is specifically located on Factories Road, approximately 17.2 km from the eastern end of the highway. This information provides the precise location of the center, allowing for easy navigation and identification of its whereabouts.see Figure 2A & 2B.

2.3. Description of ENERGY PLUS Program

EnergyPlus Simulation Software.

Program Version and Build	EnergyPlus, Version 22.2.0-aa78da9668,YMD=2023.07.26 09:59

Energy Plus® is a comprehensive building energy simulation program used by engineers, architects, and researchers to model energy consumption in various aspects of buildings, including heating, cooling, ventilation, lighting, plug loads, and water use. It is funded by the U.S. Department of Energy Building Technologies Office.(Asan, 2000).The program operates through a console-based interface, reading input and generating output in text files. However, it also offers user-friendly graphical interfaces like Open Studio® software. Energy Plus stands out with its innovative features, such as sub-hourly time steps and customizable modular HVAC systems that integrate with a heat and mass balance-based zone simulation (Asan and Sancaktar,1998). Open Studio® is a collection of software tools that support whole building energy modeling and is compatible with Windows, Mac, and Linux platforms. It includes the Open Studio Sketch Up Plug-in, which allows users to quickly create building geometry for Energy Plus using Trimble's Sketch Up 3D modeling tool. See Figure 3. The Open Studio Application serves as a comprehensive graphical interface for Open Studio models, covering aspects like building envelope, loads, schedules, and HVAC systems. These tools provide a robust platform for energy modeling and analysis in building design and research (Al-Sanea, & Zedan, 2011).

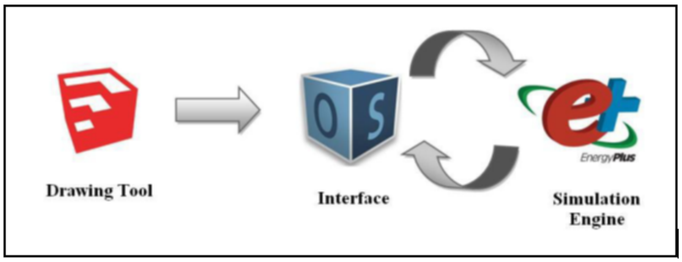


Figure 3. Stages of simulation application.

3. METHODOLOGY

In this paper, the administrative building is a case study. The building is presented below and is located in the city of Tajoura, Libya (latitude 32.814603°N - longitude 13.438828°E). The height above sea level is 6 meters. The hourly, monthly, and yearly building heat load consumption is simulated, compared, displayed and discussed.

The steps considered in this study are schematically shown in Figure 4. First, the simulation of the basic state of the building parameters was carried out with an appropriate set of relevant parameters, including, drawing, and creating the model geometry, construction details, materials, people, interior lights, and air infiltration. Three specific software packages are used to achieve the objectives; Energy Plus simulation software/engine, Sketch Up and Open Studio. A detailed description of the software used in this paper was provided above.

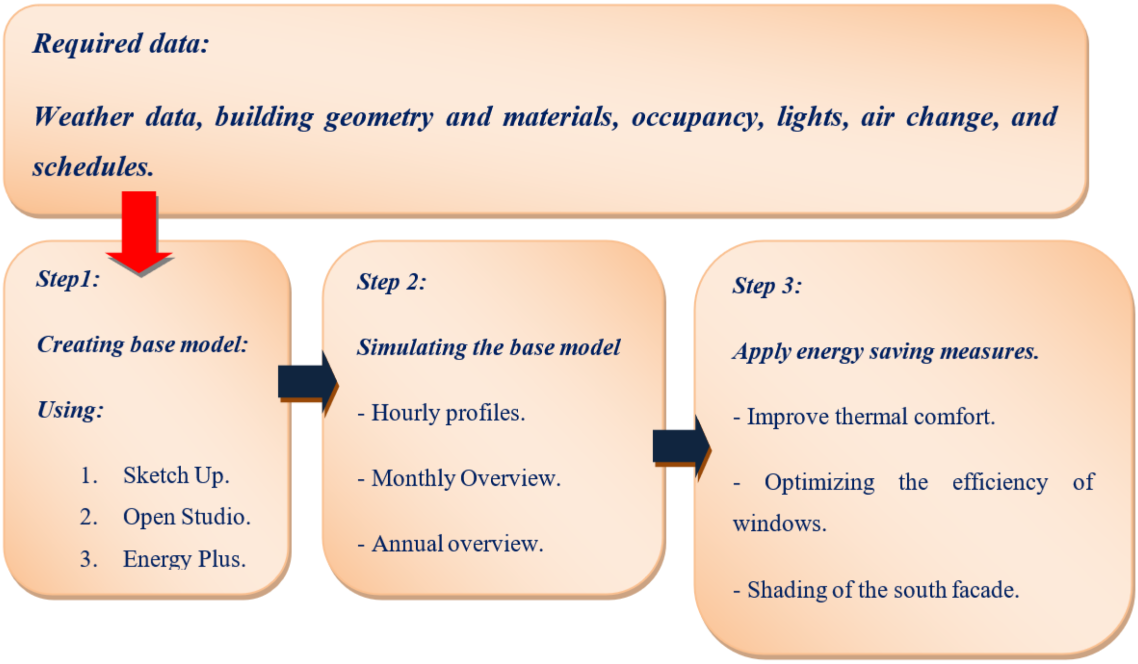


Figure 4. Steps of Methodology used in this work.

3.1. Building description

The building is a one-story office building with a gross floor area of 1081.12 m^2 (net conditioned building area). The building houses various administrative and service offices for employees, a medium-sized store, a public library, a meeting room, a private office for document copying, and an office for photocopiers and printers. Additionally, the building features a kitchen, separate bathrooms for women and men, and three halls, two of which are designated for reception purposes and one for prayer. There are two entrances in the building, as well as an internal courtyard in the middle of the building. Some offices open to the internal courtyard, while others have windows opening in different directions. This description provides an overview of the layout and functions of the administrative building, highlighting its various spaces and amenities. The Figure 5A and 5B. Shows Sketch UP Model and EnergyPlus Model.

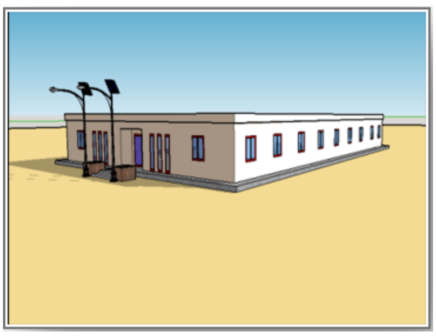


Figure 5A. Sketch UP Model.

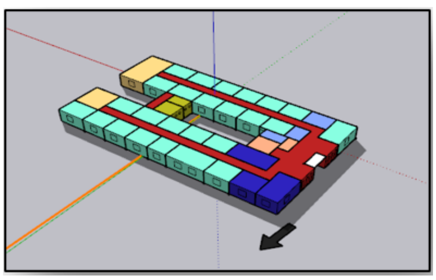


Figure 5B. EnergyPlus Model.

Based on the provided Figure 6, the figure illustrates that the largest portion of the building is allocated to offices, with two different sizes.It is important to note that the figure provides a visual representation of the space distribution, allowing for a clear understanding of the building's layout and allocation of different areas.

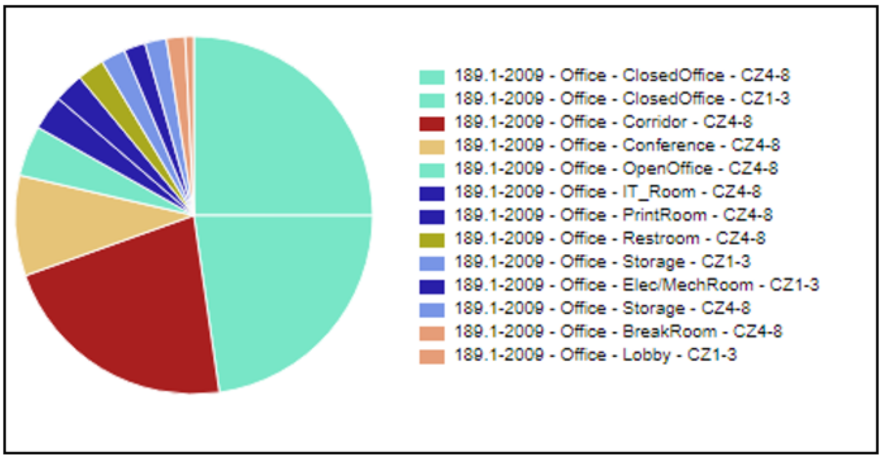


Figure 6. Percentages of space distribution for the building.

The building is with windows on all facades to enhance ventilation and maximize natural lighting. The size of the windows is 1.50×1.50 m^2, except for the WC windows, which have a size of 0.6×0.6 m^2. The window-to-wall ratio (WWR) in all the building facades is as shown in Table 1.

Table 1: The window to wall ratio in the building.

Description	Total (%)	North (%)	East (%)	South (%)	West (%)
Gross Window-Wall Ratio	3.82	3.81	4.08	3.81	3.6

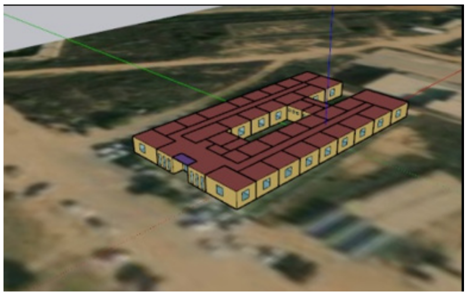
In the simulation, the weather file used is "Tripoli. Intl. AP.TB LBY SRC- TMY WMO#=620100". The elevation of the location is 263ft. The climate zone utilized in the simulation is ASHRAE. Furthermore, the total site energy recorded in the simulation is 437.41 GJ. These details provide important information about the specific weather conditions, location elevation, climate zone, and energy consumption of the simulated building.In the simulation process, the building is first drawn and converted into a three-dimensional structure. It is then assigned to a group of zones, and the types of spaces and thermal zones for the site plan are specified. Windows, doors, and other features are allocated to the building surfaces.During the simulation, the model distinguishes between interior and exterior surfaces by coloring them green and blue, respectively. Surfaces in contact with the ground are represented in a light brown color. These colors are used to ensure accurate and realistic simulation results.All surfaces in the building are interconnected, forming a connected structure.The building structure consists of a system3D Panel Construction, it is has specific heat transfer characteristics, as shown in Table 2.During the simulation, the temperature on both sides of each material layer is calculated. Heat transfer across each material takes into account the temperature difference across the material, as well as the thermal resistance and the material's ability to store heat energy. This comprehensive approach ensures accurate analysis of heat transfer within the building.

3.2. Windows and doors in the building

In the case study building, transparent materials like glass windows and glass doors are used. These materials allow heat transfer through Radiation also has the ability to heat absorption.

They can transmit or reflect solar radiation at each layer. The energy simulation programmers evaluated the building using the ASHRAE criterion. The geometry and design of the building envelope, as presented in Table 2, were determined to simulate how the envelope responds to weather conditions. Internal heat gains, such as lighting, were considered, with fluorescent lamps being used. The window type chosen from the Building Components Library (BSL) matches the specifications of the actual windows in the building, with a specification of “DblClr 3mm - 6mm Air.” This window type is designed to integrate well with OpenStudio tools. The specifications of the added window are “clear 3mm + Air 6mm + Clear 3mm”. see Table 2,And the conductivity was (0.90 w/m.k). These details highlight the use of specific materials and components in the building’s design to accurately simulate its energy performance.

Table 2: The parameters for the base case.

Reference office	office building		
Figure 7. Picture of the building			
Parameter	quantity	unit	note
Number of floors	1		
System used in construction	3D Panel Construction.		
Floor area	1081.12 (m^2)		
Ceiling height	3.7 (m)		
Doors type:			
1- Interior door	1- Wood door (4cm).		
2- external door	2- Double glazed door with metal frame (Dblclr 3mm-6mm air).		
Windows type	Double glazed	Metal frame	
Ventilation type	Fixed for all cases as per ASHREA standard.		

According to Table 3.The provided information, the building material used for insulation is EPS (Expanded Polystyrene) in the form of a 3D panel with thickness (10 cm).This insulation is enhanced by adding an outer layer of galvanized iron mesh and a layer of shotcrete. The R-Value, which measures the thermal resistance of the insulation, is determined to be 15.26 (ft^2*h*R/Btu). This indicates the effectiveness of the insulation in reducing heat transfer through the building envelope. Regarding the floors in the building, different materials were chosen based on the specific functions of each area. The offices are equipped with carpet flooring, which has its own thermal specifications as mentioned in the Table 3. The corridors, foyer, waiting hall, and reception hall feature wooden floors, commonly known as parquet. Additionally, the bathrooms and kitchen have a different type of flooring, specifically ceramic tiles. These choices in flooring materials take into consideration both functionality and aesthetics, providing suitable surfaces for different areas within the building while also considering thermal properties and durability.

Table 3: Material specifications and thermal properties.

Material	Thickness (m)	Conductivity K(w/m.k)	Density P(kg/m^3)	Specific heat (J/kg.k)	Roughness	area a(m^2/s)	Heat capacity
(EPS) Construction wall	0.1000	0.0380	0.1800	1500.0	Medium Rough	14.0×10^{-7}	27.00
Parquet	0.0300	0.170	700.00	880.00	Medium Rough	-	880
Ceramic	0.0200	0.2500	2300.0	750.00	Smooth	-	-
Carpet	-	0.200	630.00	-	-	-	1100

4. OCCUPANT INPUT

In the SketchUp and OpenStudio program, the individuals per space floor area were calculated to be 0.0100, based on the input of the number of occupants relative to the actual area of the building. This calculation takes into account the number of individuals in different areas of the building, considering the specific functions of each space.For example, in regular offices, the number of individuals added ranged from a ratio of 1:3 to the opposite. In some other offices, the maximum ratio was 4:8 persons. Similarly, in areas such as the Break Room, Rest Room, Meeting Room, and other areas in the building. The number of individuals added was determined based on the function and size of the respective area. This approach ensures that the occupancy of each space is appropriately accounted for, taking into consideration the specific requirements and usage patterns of different areas within the building. By considering the function of each space, the program aims to provide a more accurate representation of the number of occupants in the building to calculate thermal comfort.

4.1. Luminance input

Based on the provided information, the luminance in the building was calculated using the "Watts Per Space Floor Area" method. The equation used for this calculation was:

$$Illumination \quad level = \frac{Number\ of\ lamps \times Lu\,min\,ous\ flux}{Room \quad area} \qquad ....(1)$$

This method allowed for the determination of the actual lighting levels in the building, which were then entered into the simulation program. In terms of energy consumption, the estimated electric energy consumption of the administration building is 155 MWh. For the internal lighting loads, the study building's total internal lighting was based on the results obtained from Energy Plus. The actual inputs and calculations used in the building amounted to 27.26 MWh, with a density of 89.04 MJ/m^2. Total Interior Lighting in all the year = 27267.19 kWh in OpenStudio result, Based on the peak time input into the simulation. These values provide insights into the energy consumption and lighting levels within the building, allowing for a better understanding of its overall energy performance and lighting requirements.

5. TYPE OF AP-75 PV MODULE

The AP-75 PV module is selected for its specific characteristics and compatibility with industry standards.

Peak Power *(Wp)	75 Watts
Dimensions	20.7 x 47.2 x 1.4 in. (527.0 x 1201.0 x 35.0 mm)

Standard Test Conditions {defined as: Irradiance = 1000 W/m^2 ; cell temperature = 25°C; solar spectral irradiance per ASTM E892, *rated power tolerance ±10%.

5.1. The efficiency of solar panels was calculated through the equation below

$$\eta_{max} = \frac{P_{max}}{GA_{mod}} \quad \text{........}(2)$$

A_{mod} is a panel module area .(m^2), (in fact $A_{mod} = N_s N_p A_{cell}$), when A_{cell} is a cell area, N_s is a number of cells connected in serious and N_p is a number of cells connected in parallel (Teyabeen & Jwaid, 2023). The actual distances and the efficiency of the solar panels were entered into the simulation program in order to provide us with the real value of the total electrical energy generated by the photovoltaic panels integrated into the shading device.

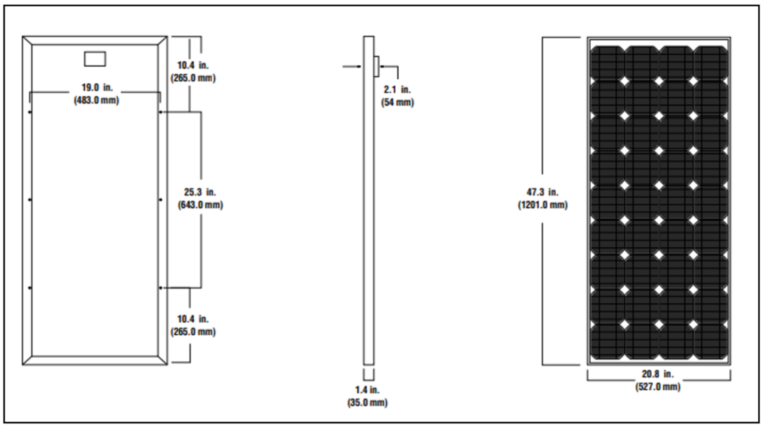


Figure 8. Type of AP-75 PV module. (AP-75 Photovoltaic Module Datasheet, n.d.).

Note: Mounting hole diameter is .26” (6.6 mm).

5.2. The electrical characteristics of AP-75 PV solar panel is as follows

Peak Power *(Wp)	Watts	75
Open Circuit Voltage (Voc)	Volts	21.0
Max. Power Voltage (Vmp)	Volts	17.0
Short Circuit Current (Isc)	Amps	4.8
Max. Power Current (Imp)	Amps	4.4
Short Circuit Temp. Coefficient	mA/°C	+0.2
Open Circuit Voltage Coefficient	V/°C	-0.08
Max. Series Fuse	Amps	10

Module Efficiency: The module efficiency is 15%. (AP-75 Photovoltaic Module Datasheet, n.d.) These electrical characteristics demonstrate the performance of the PV module under Standard Test Conditions (STC), which are defined as a cell temperature of 25 degrees Celsius and an irradiance of 1000 W/m^2.

5.3. The way to calculate the actual power generated from the PV panel

The real power (P_{PV}) of the PV panel under real operation and climatic conditions of global tilted solar radiation and ambient temperature (H_t, T_∞) is (Hafez, et al., 2020):

$$E_{PV} = P_{STC}\left[1+\beta_p(T_{cell}-T_{STC})\right]\frac{H_t}{H_{STC}} \qquad .....(3)$$

Where:

T_{STC} and T_{cell} are the celll's surface temperature at Standard Test Condition.

β_p is the power temperature coefficient (1/°C).

P_{STC},H_{STC} are the rated power (W/m^2) corresponding to solar radiation incident on the PV surface (1000 W/m^2).

5.4. The PV cell's temperature may be estimated by using the following correlation (Nassar & Salem, 2007)

$$T_{cell} = T_\infty + 7.8\times10^{-2} H_t \qquad ....(4)$$

5.5. A Diagram Illustrating a Grid-Connected Photovoltaic System

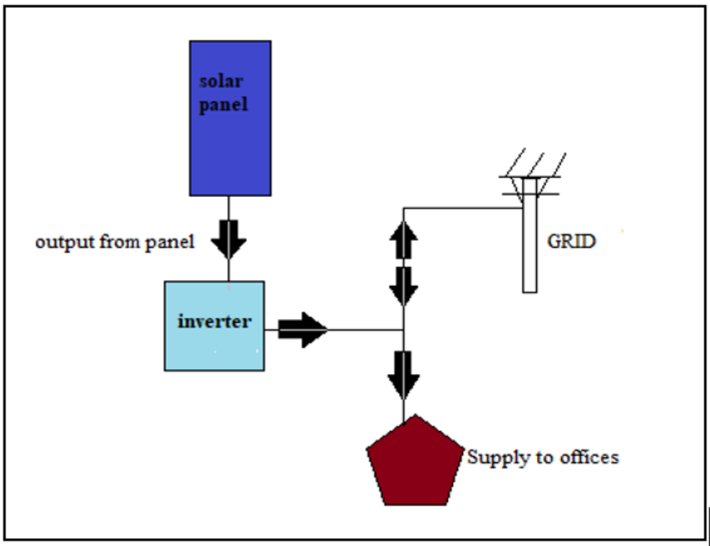


Figure 9. A diagram illustrating a grid-connected photovoltaic system.

In figure 9 a diagram illustrating a grid-connected photovoltaic system with a set of solar panels, a inverter and connection to electrical grid and the offices.

Description of the key elements in this system:

Photovoltaic Units (Solar Panels): The photovoltaic units are installed on the shading devices above the south-facing facade of the building to receive direct sunlight. These units convert sunlight into electrical current.

Inverter: The inverter is a crucial component in the system as it converts the direct current generated by the photovoltaic units into alternating current. The inverter is connected to the electrical grid.

Electrical Grid: The photovoltaic system is connected to the local or public electrical grid. The electricity generated by the photovoltaic system is distributed through the grid for general use.

Bidirectional Electricity Meter: A bidirectional electricity meter is installed to measure the electricity generated by the photovoltaic system and the electricity consumed from the grid. This meter is used to determine the surplus or deficit of electricity based on the exchange between the system and the grid.

5.6. Window Dimensions with Shading Device

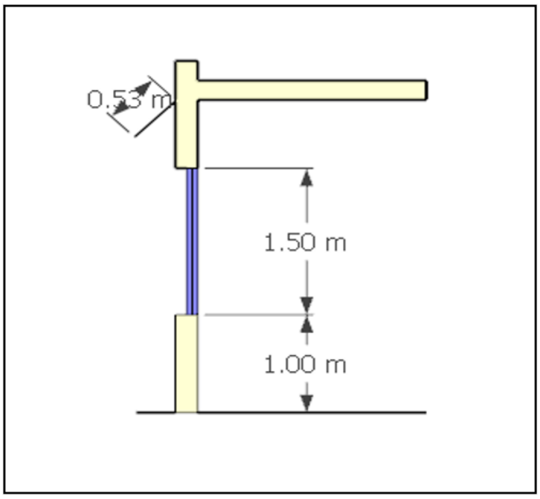


Figure 10. Window dimensions with shading device.

The Figure 10 illustrates the dimensions of the southern facade's external wall, including a glass window and fixed shading devices. The window is positioned above ground level, starting at a height of (1m), and extends to a total height of (1.5m), encompassing both the glass pane and metal frame. The shading device is located above the window, with a vertical distance of (0.71m). In order to maximize the utilization of photovoltaic energy and reduce reliance on the general electricity grid, the solar panels have been oriented horizontally. The selected surface for incorporating the solar panels within the shading devices spans a width of (0.527m) and is inclined at an angle of approximately 45o.Based on the data collected and analyzed, the average outdoor air flow rate during occupancy varied by region. The total ventilation rate for the building was determined to be 0.4585 m^3/s, indicating the amount of fresh air intentionally supplied to the indoor spaces. On the other hand, the total infiltration rate, which represents the unintentional air leakage into the building, was measured to be 0.8596 m^3/s. This information provides insights into the overall air exchange and ventilation performance of the building, highlighting the importance of proper ventilation systems and strategies to maintain indoor air quality.

Table 4. : Genera Simulation Parameters.

Location	East of Tripoli - Libya
Climate	Mediterranean climate (mild in summer, cool and mild in winter)
Building type	Office building
Net area	1081.12 (m^2)
Total People [m^2 per person]	8.41m^2 per person
Total Infiltration rate	0.8596 m^3/s
Target illuminance	300 lx
Lighting power density	89.04 MJ/m^2
Thermal comfort ranges	Maximum temperature of 26 °C and relative humidity between 25 and 55%.
Total Interior Lighting	27.26 MWh
Total ventilation rate	0.4585 m^3/s
Glass U-factor [$W/m^2/k$]	3.122

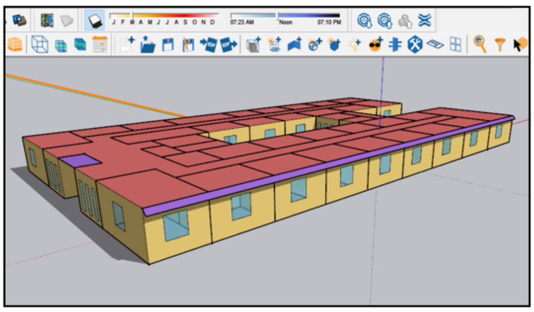
Glass visible transmittance	0.812
Reflectance for construction (Roof and wall)	0.30
For personnel internal load based on EnergyPlus simulation =	0.300 radiant part

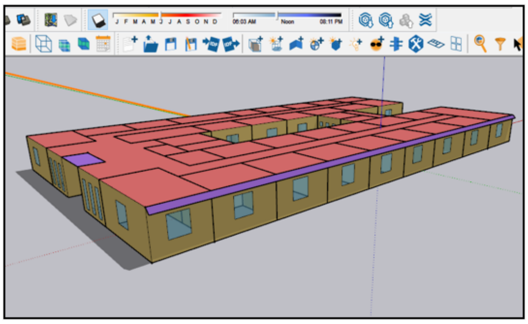
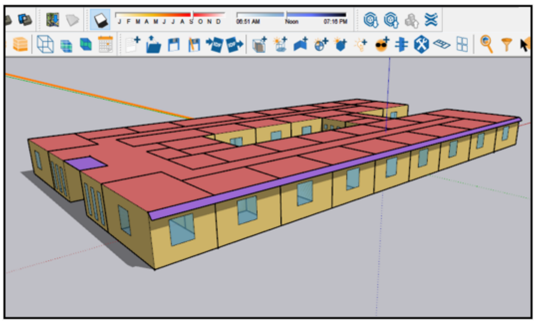
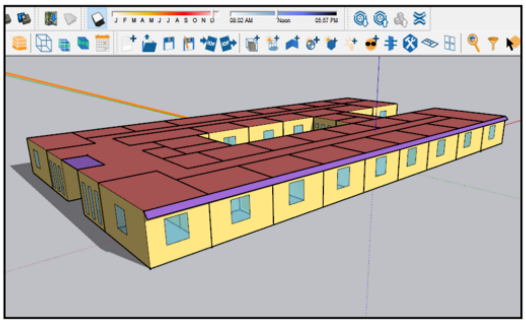
Based on the information provided in the EnergyPlus book, is mentioned that the EnergyPlus simulation program does not provide the ability to use lighting to verify a given lighting design and electrical lighting distribution (Brackney, et al., 2018). Instead, the program calculates the electrical energy used by the lights and their thermal effects. In the case of simulating a case study building, the program calculates the electrical energy used by the lights and their thermal effects based on the available inputs in the simulation software. This means that you can input building-related information regarding the lights, such as the electrical power of the lamps, their quantity, and their distribution within the building, and the program will calculate the consumed energy and the resulting thermal effects.

6. RESULT AND DESICCATION

According to the ASHRAE Standard on page 4, it is stated that at operating temperatures above 22.5°C (72.5°F), the overall thermal equilibrium of the body determines comfort (Standard, A. S. H. R. A. E. ,1992). However, at operating temperatures below 22.5°C, the challenge lies in avoiding local thermal discomfort. When simulated the sun using the SketchUP program and applied the previous calculations mentioned in Figure 10.To draw the shading canopy for the southern facade, I observed that the canopy performed effectively. By manipulating the (Date) icon and its function (changing the date to adjust the shadows) as well as the (Time) icon and its function (changing the time to modify the shadows), I was able to analyze the canopy's performance during peak times in the building. The results indicated that the canopy successfully provided shade during the summer months, while allowing the sun's rays to enter and warm the building during the winter months. Overall, the canopy demonstrated excellent functionality based on the simulation, Table 5 shows this. After incorporating shading devices into the building, there were noticeable improvements in its performance. The shading devices effectively reduced the amount of direct sunlight entering the interior spaces, resulting in a more comfortable and energy-efficient environment. These devices helped to minimize glare, prevent over heating, and reduce the need for excessive artificial lighting or cooling systems. Additionally, the shading devices added an aesthetic appeal to the building's facade, enhancing its overall design. Overall, the addition of shading devices proved to be a beneficial and practical solution for improving the building's functionality and energy efficiency.

6.1. The Building After Adding a Shading Device

Description	Figure number	The Figure
Figure 11A displays the simulation process for the month of March. The date icon and shadows icon in the top bar of the figure indicate the specific time frame. The figure illustrates the penetration of sunlight into the offices.	Figure 11A. The building in March.	

In Figure 11B, the simulation process for the month of June is depicted. The date icon and shadows icon in the top bar of the figure indicate the specific time frame. The figure illustrates the presence of an umbrella that effectively blocks the intense sunlight from reaching the offices, helping to keep them cooler.	Figure 11B. The building in June.	
Figure 11C, represents the simulation process for the month of September. The date icon and shadows icon in the top bar of the figure indicate the specific time frame. The figure demonstrates that only a portion of sunlight enters the offices, ensuring that it does not cause discomfort to the employees.	Figure 11C. The building in September.	
In Figure 11D, the simulation process for the month of December is depicted. The date icon and shadows icon in the top bar of the figure indicate the specific time frame. The figure shows the entry of sunlight into the offices, which helps warm the building during this cycle.	Figure 11D. The building in December.	

The simulation settings are aligned with the actual building, and typical weather data for a full year (8760 hours) were employed in the simulation.

6.2. Zone Conditions: temperature, (values represent hours spent in each temperature range) Before and after adding a passive shading strategy to the building case study

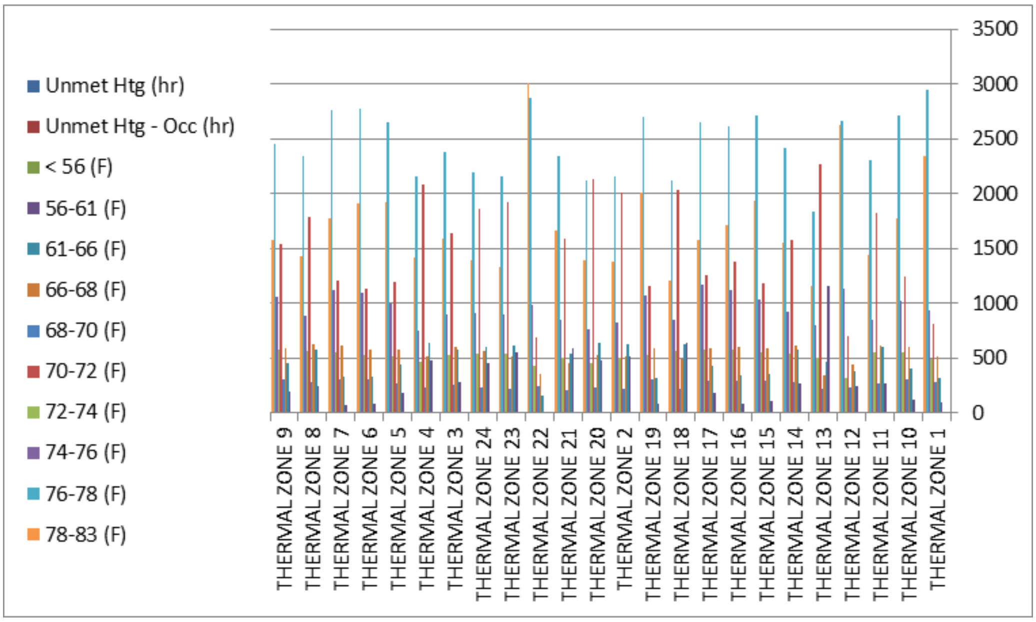


Figure 12A. Zone Conditions: temperature, (values represent hours spent in each temperature range) Before adding a passive shading strategy to the building case study.

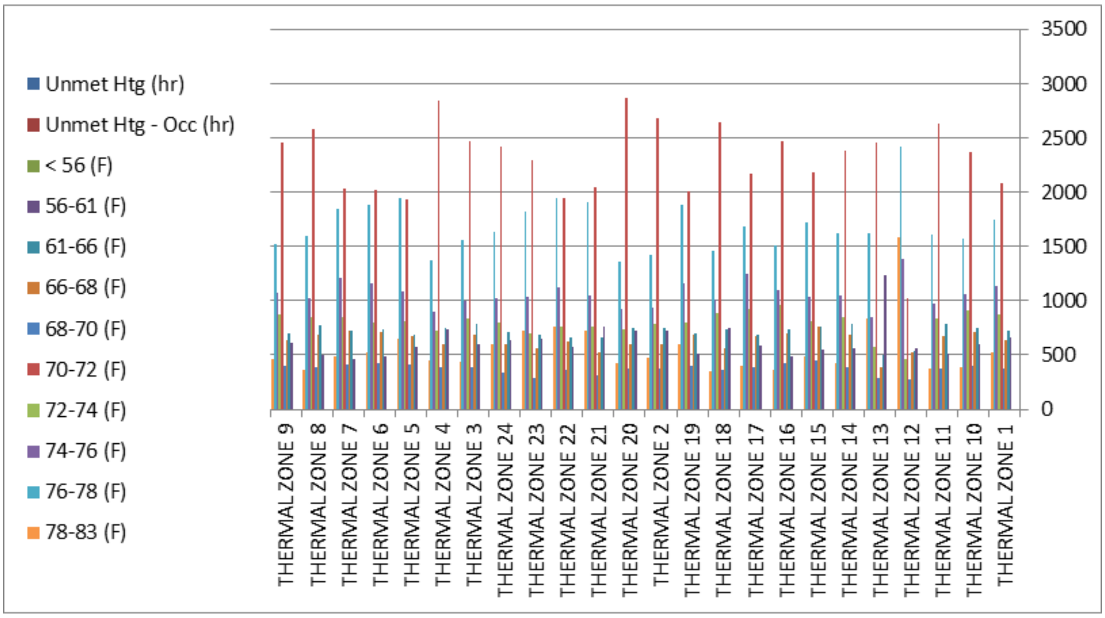


Figure 12B. Zone Conditions: temperature, (values represent hours spent in each temperature range) after adding a passive shading strategy to the building case study.

6.3. The Thermal Performance Of The Building

The results indicate that there is a difference in annual energy consumption when shading devices are installed at the mentioned height in Figure 10, in addition to the annual consumption of the building. The results show that throughout the year, the performance of the horizontal shading devices used with PV (photovoltaic) systems is better on the southern orientation. The annual energy consumption (energy per total building area) based on the inputs to the program was 478.8 MJ/m^2 before the addition of shading devices, and it became 396.75 MJ/m^2 after the addition of shading devices. The significant energy savings resulting from the shading devices on the southern facades can be explained by the fact that the southern facade is exposed to sunlight for a longer duration. These results are obtained for the installation of solar panels in a horizontal manner facing the southern facade to provide shading for the mentioned facade at a tilt angle of 45 degrees. The results of the thermal performance analysis of the building after the addition of shading devices indicate the following, based on the difference in cooling and heating the area. The performance of the shading devices was better on the southern facade, where the highest savings were achieved. This is consistent with existing literature (Hammad & Abu-Hijleh, 2010), and can be explained by the fact that the southern facade has a longer duration of direct sunlight exposure, so any shading device that blocks solar radiation will result in significant savings. This is also supported by the results of the heating and cooling analysis for the entire year of the building, which showed that..It was found that the most effective shading device was the horizontal one. It is worth noting that previous studies conducted in climates similar to Libya used only horizontal shading in the south and vertical openings in the east and west facades (Hammad & Abu-Hijleh ,2010; Palmero-Marrero & Oliveira, 2010). It is important to emphasize here that the shading was at a tilt angle of 45 degrees, which can have a significant impact on the results, and this condition is more suitable in winter. The proposed window configuration is shown in Figure 10. The vertical shading was relatively less effective on the southern, eastern, and western orientations. This is consistent with previous studies conducted in countries with climates similar to Libya (Gutierrez & Labaki, 2007).

Furthermore, the results of the energy consumption showed a significant reduction in winter compared to summer. This is expected because the daylight hours are shorter in winter, resulting in less exposure to sunlight. It may also indicate that shading devices are more effective in blocking solar radiation when the sun is at a lower altitude. Moreover, the difference in cooling and heating loads for the building based on the aforementioned inputs showed that the cooling load before adding the shading was 209.07 GJ and became 177.55 GJ after adding the shading. As for the heating load, it was 141.66 GJ before adding the shading and became 161.70 GJ after adding the shading, indicating an increase in the heating load after shading, which is natural. The difference in cooling load for the area was 8.75 KW/h, and the difference in heating load for the area was 5.56 KW/h. Energy density was used to evaluate the efficiency of energy use in the building for cooling, heating, and electricity consumption. The cooling area energy density was 0.05318 MW/h and became 0.0447 MW/h. The heating area energy density was 0.0354 MW/h and became 0.0407 MW/h. The electricity density represented by the interior lighting of the building was 0.0247 MW/h. In the summary of the annual thermal flexibility in the EnergyPlus program, the safety hours for hot events were the same as the safety hours for cold events, with the highest degree for each building zone being 12775.00 and the average being 306600.00. This indicates that shading has a noticeable effect and thermal comfort for the building. The annual report of the heat emissions showed that for the thermal envelope, the heat load was 3999.66 GJ. The total heat emissions for the thermal envelope and infiltration were 4025.48. Scaling factors: The scaling factor refers to the factors used to calculate the cooling and heating loads. The sizing of systems depends on multiple factors such as room area, insulation type, windows, and local climatic conditions. The design and appropriate sizing of the heating, ventilation, and air conditioning (HVAC) system are crucial in ensuring optimal performance, energy efficiency, and indoor comfort. Additionally, calculating the scaling factor requires knowledge of the room dimensions and features such as window type and insulation. If the rooms are insulated and have south-facing windows without direct sunlight passing through during peak building hours (between 8 AM and 3 PM), the results in EnergyPlus showed that the cooling scaling factor is 1.1500 and the heating scaling factor is 1.2500. Appropriate design and sizing take into account factors such as building orientation, insulation levels, window-to-wall ratio, and local climatic conditions. Improper sizing can lead to inadequate heating or cooling and increased energy consumption. Moreover, proper sizing and design of HVAC systems contribute to improving indoor air quality and ventilation, both of which are essential for occupant health. Studying these factors is vital for achieving energy efficiency, indoor comfort, and environmental sustainability. The humidity results shown in EnergyPlus based on the inputs indicate the humidity levels in the building. Maintaining a comfortable humidity level inside the building is important for indoor air quality and occupant health. The humidity value was approximately 84400.00 J/kg when the type of humidity was latent internal energy. When the type of humidity was dewdrops and wet bulb, the humidity ranged between 22.60, 14.80, and 23.30. The building was exposed to moisture, sometimes dewdrops, and sometimes latent internal energy.

6.4. Adding photovoltaic panels to the building's shading device

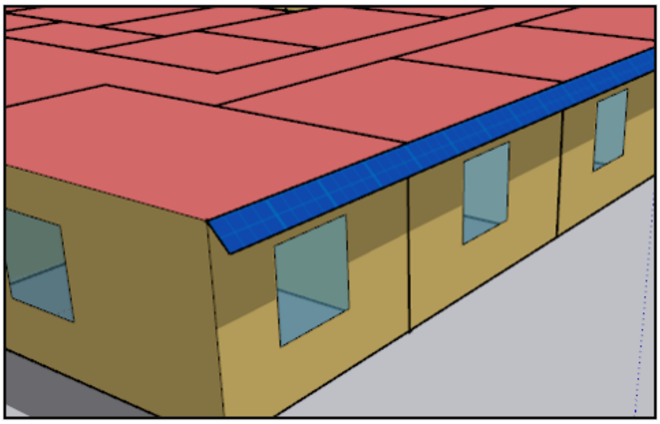


Figure 13. Adding photovoltaic panels to the building's shading device.

The total electrical energy generated from the photovoltaic panels that added to the shading device = 5916.388 kWh. Based on the results discussed above, it has been concluded that horizontalshading devices achieve good performance for the building when working in conjunction with appropriate building envelope characteristics for the environment. The annual energy consumption is reduced to 396.75 MJ/m^2 per hour in the ideal case, compared to 478.8 MJ/m^2 per hour in the base case. The energy savings achieved through this configuration amount to 17.15%. The total annual energy consumption of the solar panels used for shading is estimated to be 5916.388 kWh, which reduces the electrical loads from the general power grid. Therefore, the simulation results are considered good and provide architects and designers with a deep understanding of the benefits of solar shading, as some may not be aware of these advantages.

7. CONCLUSION

In conclusion, this paper highlights the value of thermal comfort calculations and the need for representing the occupants' presence within a space. By utilizing concepts of radiant temperatures and the impact of building envelopes, it is possible to determine the influence that the building envelope can have on the thermal comfort of its occupants. The results presented above indicate that occupancy has much less significance in the summer when the temperature difference between the air and the surface is expected to be smaller compared to the winter, where the difference can be much greater. The results also demonstrate the benefits of a program like EnergyPlus in designing buildings from an energy and thermal comfort perspective for the building occupants. Future research on thermal comfort with EnergyPlus is expected to focus on environmental sustainability and integrating the building with its external environment. Versions of the EnergyPlus program will enable architects and engineers to estimate the impact of the building envelope and negative shading devices on thermal comfort to determine average radiant temperature, solar cell efficiency, and their integration into shading devices to achieve high building efficiency. In this case, orientation becomes more important in terms of wind direction, ventilation, solar radiation patterns, and negative strategies. Additionally, it is concluded that the use of negative shading in buildings increases the average annual productive power index (from 15% to 40%). Therefore, in some cases, there may be limitations in existing buildings that cannot be completely changed. Hence, it is necessary to introduce strategies and modify certain functions in the building to provide a clean, healthy, and comfortable environment for building users, avoiding demolition and destruction.

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Conflicts of Interest: The authors declare that they have no conflict of interest.

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