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ENERGY EFFICIENCY PREDICTION BASED ON THE INTEGRATION OF PHOTOVOLTAIC SOLAR PANELS AS A DOUBLE SKIN FACADE IN EXISTING OFFICE BUILDINGS

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ABSTRACT

The objective of this research is to address issues related to the energy efficiency of administrative buildings. The energy renovation of buildings using photovoltaic systems as a second skin offers several advantages, including: The integration of solar PV systems into the building's exterior envelope appears effective and promising for the future facades of existing administrative buildings, where these systems offer renewable energy production and improving the building's interior comfort. To adjust the energy efficiency of office buildings, this study provides a step-by-step process for predicting the energy efficiency of integrating these PV systems. The main steps of the approach are: (1) studying the environment and thermal potential of buildings using a "Testo 865" thermal camera and a "Testo 830-T2" infrared thermometer; (2) proposing the double-skin facade (DSF) system; (3) calculating the efficiency of these PV systems by applying a calculation formula for PV system production. The results demonstrated that the maximum efficiency of the PV systems, depending on the cases of the studied buildings, can reach up to 32% of the total annual electrical consumption. The PV system can become a second skin for the existing facade, helping to minimize energy consumption while improving the thermal performance and appearance of existing administrative buildings.

KEYWORDS

Energy Efficiency, Office Building, Photovoltaic Panels, Double Skin Façade, Hot Arid Region

CITATION

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1. Introduction

The oil crisis of the 1970s served as a catalyst for much of the research and development efforts focused on improving energy efficiency and promoting renewable energy sources (Gajdzik, 2024). Government initiatives such as the R2000 Standard program and the incentive program for tertiary buildings, particularly administrative ones, which advocate and encourage energy-efficient practices (R-2000 Standard, 2012), have had a positive influence on the planning and construction of new buildings (Osobajo, 2020). In any case, populace development, financial development, and made strides living guidelines have driven to expanded vitality utilization, coming about in higher nursery gas emanations (Xiaodong, 2016). The building division is mindful for around 40% of worldwide vitality utilization and about 50% of power utilize (Xiaodong, 2016). About half of the energy consumed by buildings is used for space heating and cooling, and almost 10% for heating domestic hot water and water (QTR, 2015). The production of renewable energy sources offers an occasion to make considerable progress in decreasing energy consumption of buildings and mitigating global warming (Nezhnikova, 2019).

In hot and arid climates, adopting introverted architectural designs represents a passive and advantageous approach to reducing energy consumption (Kamal, 2018). Previous research has shown that incorporating a courtyard into building designs improves thermal conditions in interior spaces, especially those adjacent to the courtyard, whereas interior spaces with exterior exposure do not benefit from the same advantages (Akhlaghinezhad, 2024). The use of double-skin facade technology has proven effective in addressing the vulnerability of courtyard buildings by protecting the entire building envelope from overheating, thereby improving interior comfort and minimizing energy consumption (Shameri, 2011).

Building envelopes are favored for their conceptual and constructive efficiency, serving multiple purposes (Kumar and Raheja, 2016). The facade is regarded as a dynamic interface that connects the interior and exterior environments (Nady, 2017). Its primary function is to regulate the heat transfer between the inside and outside to maintain user comfort (Bakhshoodeh et al., 2017). This control is crucial not only for maintaining the quality of the indoor environment but also for reducing the energy demand for equipment operation (Vox Giuliano et al., 2022). Currently, the integration of photovoltaic systems into architectural design, particularly at the facade level, remains a significant challenge (Chen et al., 2019).

The development of a photovoltaic (PV) system is promising for advanced second facade applications, as it effectively reduces heat transfer, regulates incoming solar heat, and generates environmentally friendly electricity (Dellicompagni et al., 2022). This PV system can serve a dual purpose by partially supplying the building's energy demand through charging installations and contributing excess energy to the national grid (Come Zebra et al., 2018). Despite significant technological advances in the solar panel industry, their integration into architectural facades has not been entirely convincing (Vijayan et al., 2023). Certain architectural trends, such as the "high-tech" approach, lend themselves well to the integration of this innovative energy production technology, as their elements align with those of the photovoltaic industry (Wilson et al., 2020). While PV panels have primarily been installed on rooftops, the limited roof surface area necessitates the integration of photovoltaics into building facades (Polcovnicu et al., 2021). Once optimal methods for integrating photovoltaic systems are identified and studied, the energy efficiency of a building, encompassing aspects such as lighting, heating, and ventilation, can be significantly improved by leveraging the vast exterior surfaces offered by the building envelope on multiple levels (Parnian, 2023). In this way, photovoltaic systems can be perfectly adapted to the building's form, ensuring optimized energy performance (Khatib, 2013).

Photovoltaic (PV) technology offers significant advantages, particularly its remarkable potential for seamless integration into architectural structures (Zhao et al., 2023). Buildings, with their large surface areas, provide numerous opportunities for capturing energy through the integration of solar PV systems (Wang et al., 2023). These systems can be strategically incorporated into various parts of a building, including the roof and facade (Albatayneh et al., 2022). Moreover, they serve dual purposes by not only generating electricity but also providing protection for different interior environments (Akrouch et al., 2023). The integration of PV systems encompasses both passive and active approaches, involving measures to passively reduce solar heat gain while simultaneously generating electricity (Pereira et al., 2022). PV modules themselves can vary in transparency, ranging from opaque to semi-transparent, and can be single or double glazed (Pereira et al., 2022). The base material of the unit can also be constructed from metal or plastic, offering flexibility in integration options (Machín and Márquez, 2024). This versatility highlights the adaptability of PV technology in harmonizing energy production with architectural aesthetics and functionality (Green and White, 2024).

It is crucial to prevent the undesirable heat accumulation from PV modules within the building, as excessive heat gain can significantly impact occupant comfort (Pandiaraj et al., 2022). To address this concern, incorporating a ventilation cavity like that used in a double-skin facade (DSF) system is essential (Yoon, 2017). Additionally, in regions with extremely hot climates, it may be advantageous to implement supplementary ventilation mechanisms that can be powered by the PV modules themselves (Alktranee and Bencs, 2023). This approach not only ensures the effective dissipation of heat but also highlights the potential for using the energy generated by PV systems to enhance the building's climate control, further promoting sustainability and occupant comfort (Hafez et al., 2023).

The integration of photovoltaic (PV) technology into building design relies on key factors. The total available space for PV installations includes both additional roof surface and building facades exposed to direct sunlight (Sailor et al., 2021). This available surface presents a valuable opportunity to efficiently harness solar energy and optimize the performance of the PV system (Saeedi F. et al., 2015). By strategically utilizing these surfaces, it becomes possible to minimize the peak energy consumption of administrative buildings, thereby contributing to improved energy efficiency and sustainability (Saidur, 2009). Essentially, these available spaces serve as untapped resources that can be leveraged to enhance the efficiency of PV systems and reduce the building's overall energy needs (Behi et al., 2021).

Standard test conditions (STC), which measure panel performance under defined factors such consistent light exposure, panel orientation, and temperature, are used to assess the energy production of solar panels (Kurnik Jurij et al., 2011). For example, a 250-watt panel generates 250 watts at 25°C with 1000 watts of solar radiation per square meter (Parthiban and Ponnambalam, 2022). To preserve transparency and dependability, manufacturers must make sure that solar panels reach or surpass this power output in certain circumstances (Krstic et al., 2024). Current panels' efficiency, which measures how well they can turn sunlight into electricity, usually falls between 15% and 18% (Huld et al., 2010). To determine this efficiency, the incident radiation flux is multiplied by the panel's surface area, then the maximum rated power is divided by this product, and the result is multiplied by 100% (Nehme et al., 2020).

Actual panel performance can deviate from STC values due to temperature variations, often higher than the 25°C of STC. For example, an ambient temperature of 20°C can result in a panel temperature of 40°C, reducing efficiency (Aslam et al., 2022). In hot climates, the PV cell temperature, which strongly influences performance, should not exceed 25°C for optimal efficiency. Each degree beyond 60°C reduces efficiency by 0.5% (Huld et al., 2010). Therefore, it is essential to provide sufficient spacing between PV structures to prevent overheating, with a minimum of 15 cm in hot climates (Parthiban and Ponnambalam, 2022).

2. Methodology of the research

This research adopts a systematic methodology to assess the integration of solar photovoltaic (PV) systems into the exterior envelope of existing administrative buildings as a double-skin facade (DSF), aiming to enhance architectural aesthetics while minimizing annual electrical consumption. The process begins with an in-depth environmental and thermal analysis of the buildings using a "Testo 865" thermal camera and a "Testo 830-T2" infrared thermometer. This step enables the identification of thermal performance issues and potential solar energy gains. A DSF system that incorporates PV modules onto the building's facade for both practical and decorative reasons is suggested after the environmental study. In the last step, the efficiency of these PV systems is determined by using a calculation formula for PV system production that considers variables like the average amount of solar radiation received, the PV panels' efficiency, and the available surface area for installation. By taking this methodical approach, the study hopes to offer a thorough framework for forecasting the energy efficiency results of installing PV systems in administrative buildings, which will ultimately lead to increased sustainability and lower energy expenses.

3. Case Study Presentation

3.1. Biskra location

Biskra, a city in southern Algeria at around 34° 48' north latitude and 5° 44' east longitude, is the site of the study. The elevation of the city is 86 meters above sea level. Biskra is renowned for its hot and dry environment, which is marked by noticeable changes between summer and winter conditions as well as large temperature swings between day and night. Notably, there is a significant thermal variation between the highest and lowest recorded temperatures in each month. Furthermore, the hot season is marked by exceptionally high temperatures, which have a significant impact on both the thermal performance of buildings and the comfort of their occupants (Fig.1).

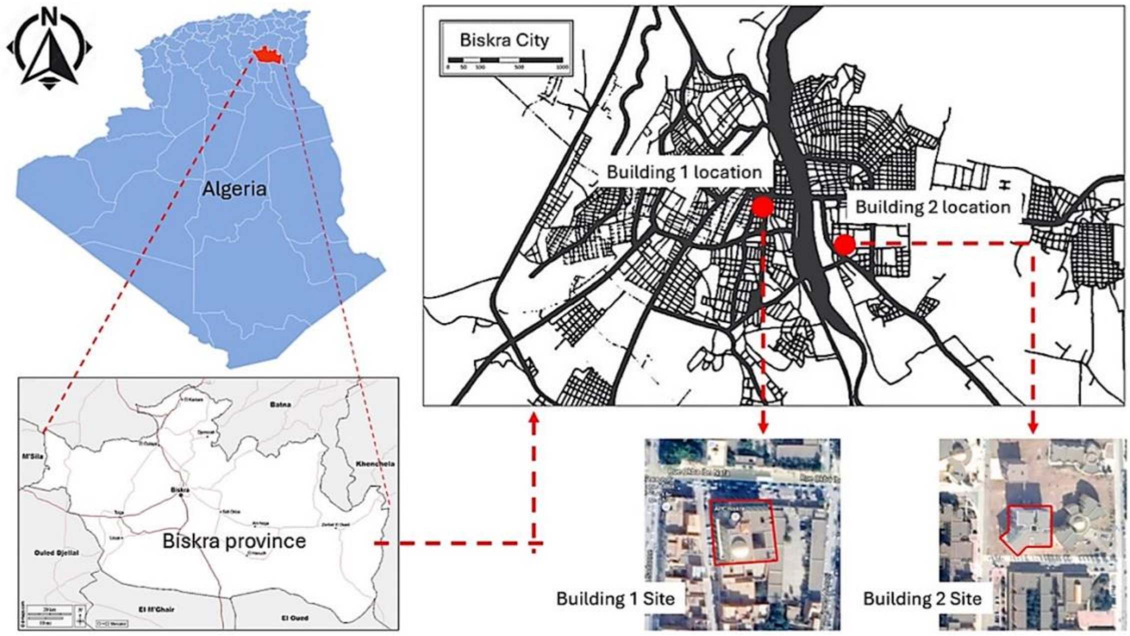
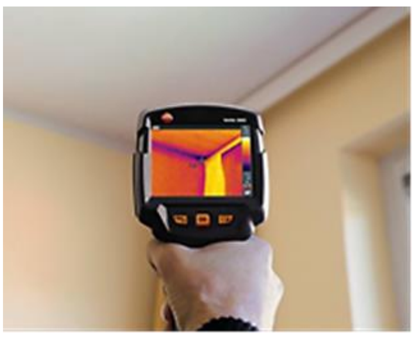


Fig. 1. *Presentation of the case study details (Source: Author).*

3.2. Measuring instruments

The equipment used for data collection included two instruments. The first was a Testo 865 thermal camera, which incorporates essential features for high-quality thermographic measurements. This thermal camera is known for its accuracy, speed, and reliability (Fig. 2). The Testo 865 offers various advantages, including high-quality thermographic capabilities, impressive measurement accuracy of ±2°C, the ability to detect temperature differences as small as 0.12°C, and automatic detection of hot and cold spots. The second monitoring instrument used was the Testo 830-T2 infrared thermometer, equipped with a 2-point laser targeting system and a 12:1 optical ratio, allowing for efficient and non-contact surface temperature measurements. Additionally, it can be connected to a temperature probe (TC type K) for versatile measurements. These measurements were carried out during the summer period of July 2023. The measured parameters included the internal surface temperature (ST_{int}) and the external surface temperature (ST_{ext}).

(a)



(b)

Fig. 2. *The measuring instruments used:*
(a): Thermal camera "Testo 865", (b): Testo 830-T2 - Infrared thermometer (Source: Author).

3.3. Selected buildings

The selected administrative buildings for the experimental study exhibit different architectural characteristics. A detailed overview of the selected cases is provided in Table 1, which presents essential information about the studied forms, their unique exterior surface characteristics, and their orientations. This table serves as a reference for understanding the specific building configurations that formed the basis of our experimentation, offering insights into key morphological factors influencing comfort conditions and energy consumption. Building 1 is an introverted structure featuring a 4-story central courtyard with four façades oriented in different directions (Main: at the angle of the west/east façade, the north façade). The building's overall shape is generally regular. Building 2 is an office and laboratory building at the University of Biskra. This structure has a fragmented introverted shape with a deep central courtyard. It consists of 5 levels and features one façade made of concrete skin and another constructed with latticework.

Table 1. The selected office buildings (Source: Author).

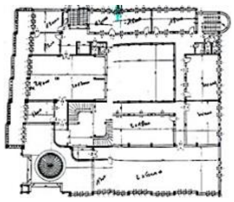
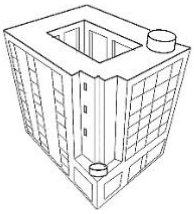
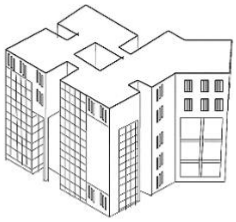
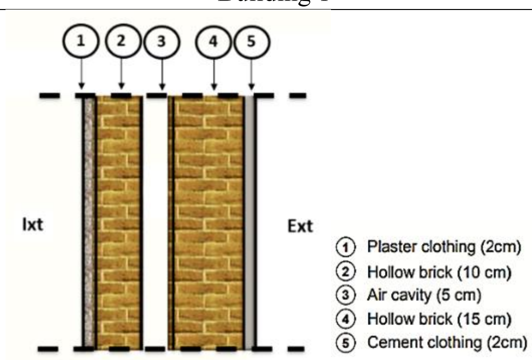
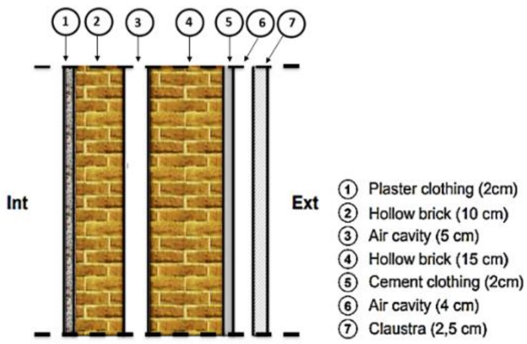
Building1 CPA (Communal Popular Assembly)		Building 2 Building of laboratories (at the University)	
			
Site plan	1st Floor	Site plan	1st Floor
			
Building 3D	Illustration	Building 3D	Illustration
- 4-Story building - 4 facades - Regular shape (with 4 faces/4 orientations: N/E, S/E, S/W and N/W)		- 4-Story courtyard building - 4 facades - Exploded shape (with multiple faces/different orientations)	

Table 2 provides a comprehensive overview of the material composition used in the construction of the studied building samples, show up the specific materials utilized in these various architectural forms. It also offers a detailed description of the construction system employed for the walls and façades of the studied building samples. This table provides a complete insight into the structural elements and materials used in the exterior components of the buildings, thereby enhancing our understanding of the various construction methods and materials utilized in the study.

Table 2. Material composition of the facade walls of the buildings studied (Source: Author).

The composition of the façade's external wall	
Building 1	Building 2
	
- Wall composition 2cm coating cement - 15cm hollow brick- 5cm air gap- 10cm hollow brick- 2cm coating plaster	- Wall composition 1st skin: 2cm coating cement - 15cm hollow brick- 5cm air gap - 10cm hollow brick - 2cm coating plaster 2nd skin: steel - air cavity (10 to 15cm) – concret Claustra of the exterior wall
- Wall thickness (cm) : Double wall with air gap: 34	- Wall thickness (cm) : 1st skin: 34/2nd skin: 15

4. Results and discussion

4.1. Thermal analysis

The recorded measurements conducted in 2023 encompass both the outdoor and indoor air temperatures (AT_{ext} and AT_{int}) and the surface temperature measurements for both studied buildings. Building 1 features a double concrete wall with an air cavity, while Building 2 has a concrete wall and partially incorporates a second skin made of latticework. The graphical representation of these surface temperature measurements is shown in Figure 3. This figure illustrates the average surface temperature data for these different building forms, providing a comparative view of how the interior surface temperatures vary in response to external conditions.

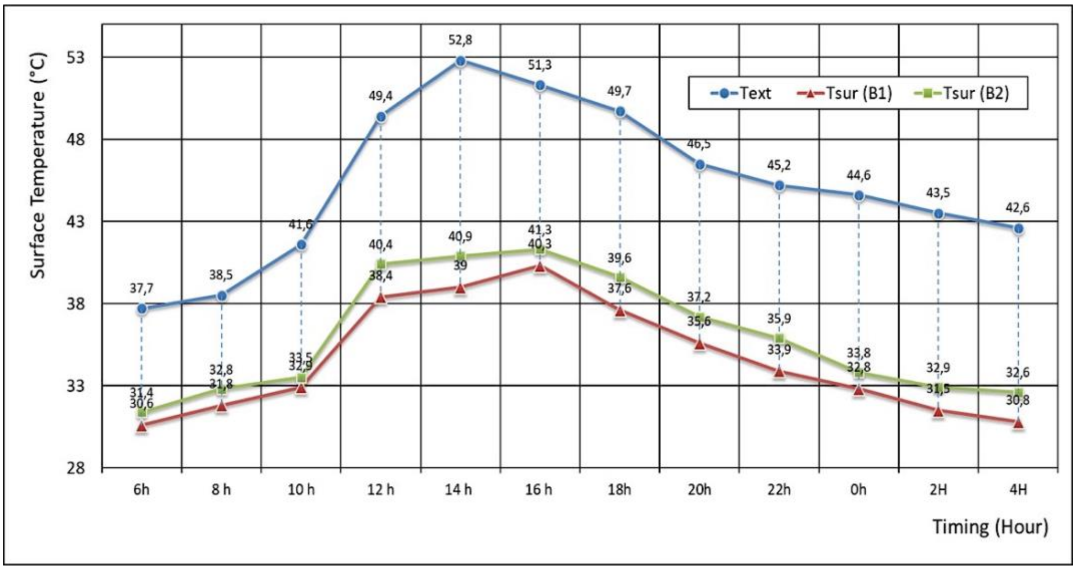


Fig. 3. (a) Average external/internal surface temperatures of exterior walls (Source: Author).

The data showed in figure 3 reveal that the outdoor temperature (ST_{ext}) remains consistently high throughout the day, peaking notably at noon when it exceeds 50°C, reaching a maximum of over 52.8°C at 2 PM. In contrast, the interior surface temperatures of the façade walls (ST_{int}) differ significantly from the outdoor temperature, with a maximum value of 41.3°C. This temperature variation reflects a substantial difference of 11.5°C (equivalent to an increase of 21.8%) compared to the outdoor temperature, attributed to the influence of wall insulation and shading devices used. Furthermore, it becomes evident that Buildings 1 and 2, equipped with deep courtyards, exhibit better indoor thermal conditions during scorching summer days. The presence of these courtyards contributes to enhancing comfort within the buildings by mitigating the effects of extreme outdoor temperatures, particularly in the spaces adjacent to them.

We conducted measurements to determine both the outdoor air temperature, designated as (ST_{ext}), and the indoor air temperature (AT_{int}) in different rooms of the buildings with various orientations, as illustrated in Figure 3. The results underline that the indoor air temperature (AT_{int}) consistently records values lower than the outdoor air temperature. The composition of the walls plays a crucial role in stabilizing indoor temperatures, effectively mitigating significant daily temperature fluctuations. As a result, the indoor air temperature generally ranges from 36.6 °C to 38.7 °C during working hours. However, it is important to note that these temperature levels tend to exceed the ideal range for thermal comfort in hot and arid zones, indicating the necessity to consider additional measures to optimize indoor comfort conditions, such as the use of active HVAC systems.

Figure 4 provides valuable information on the substantial improvements in indoor thermal comfort facilitated by courtyards, particularly in areas adjacent to these open spaces. In the face of extreme outdoor temperatures reaching up to 53 °C, the minimum indoor ambient air temperature can be effectively reduced to as low as 35 °C, primarily due to the presence of courtyards and the strategic use of double-wall insulation with an air cavity. These facades play a crucial role in reducing the impact of outdoor air temperatures on the comfort conditions of indoor spaces. However, it is essential to note that the use of double-wall concrete facades, while providing effective solar protection and a shield against solar radiation, also presents challenges. These facades attend to realize a significant sum of heat, preceding to an obvious increase in surface and ambient temperatures, principally due to convective and radiative processes. As a result, occupants regularly find themselves in uncomfortable thermal conditions, especially during the summer and winter seasons, inducing them to rely on air conditioning and/or heating systems. Unfortunately, this dependence on air conditioning has negative consequences for the building's energy efficiency, emphasizing the need for deeper reflection on the balance between thermal comfort and energy conservation. Therefore, there is a requirement to apply a second skin that provides both improved comfort and renewable energy.

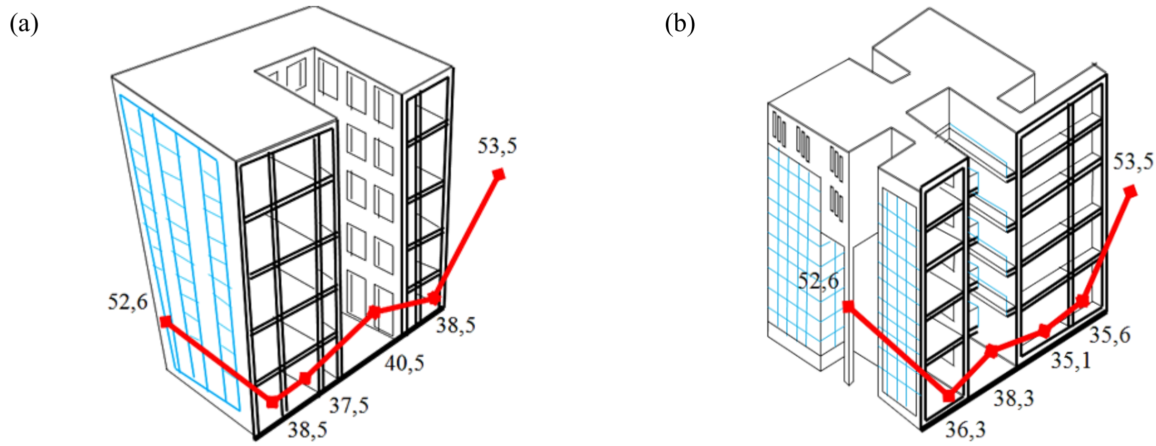


Fig. 4. Impact of courtyard and wall composition on indoor air temperature variations (Source: Author).

Our findings on indoor comfort conditions in courtyard buildings focus on the interconnected nature of morpho-climatic factors. This suggests that even in harsh arid climates, it is possible to exert control over indoor environments to improve comfort. Furthermore, the impact of courtyards on the indoor spaces comfort, especially those in direct contact with the outdoors, can be considerably improved by incorporating a double-skin façade. The façade can also have a dual function by integrating photovoltaic (PV) panels, a choice that has great potential to intersect the building's energy consumption needs. This multidimensional manage emphasizes the importance of reflecting a general design that incorporates both aesthetics and environmental sustainability.

4.2. Annual consumption of electrical energy

To determine the annual electrical energy consumption (AEC), we established, from the four most recent quarterly bills of the year 2023, the annual electricity consumption per month of the buildings studied. These data not only allow to highlight the energy consumption rates, but also contribute to a more complete understanding of the energy consumption trends of the building, as well as the determination of the months of extreme electricity consumption.

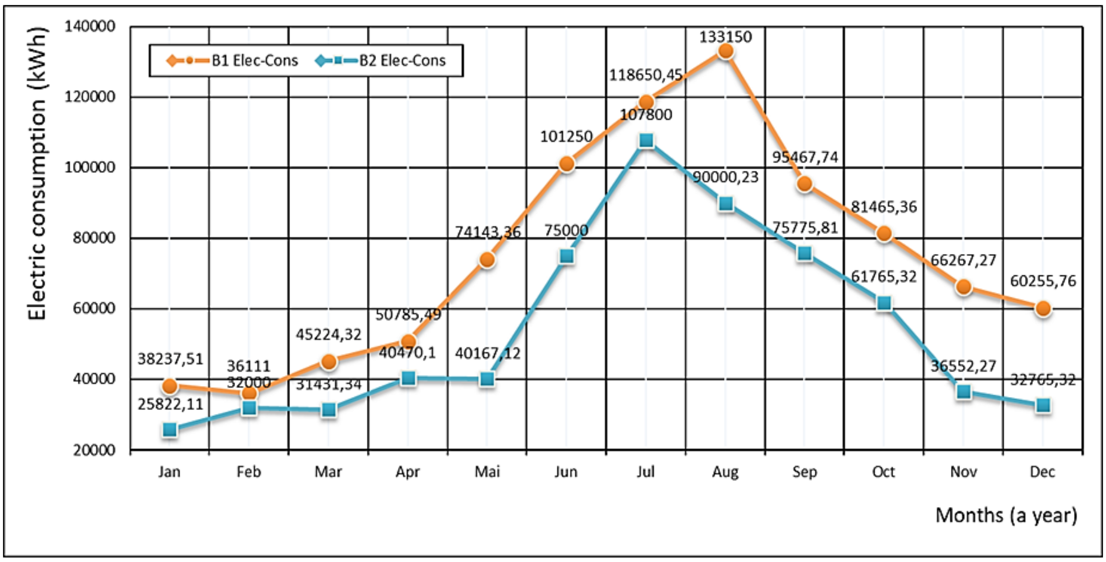


Fig. 5. *Annual electricity consumption per month (All buildings) (Source: Author).*

As indicated in the graph of Figure 5 above, annual electricity consumption varies depending on the climatic conditions of each month. Notably, electricity consumption experiences a significant increase during the summer months (especially in July and August), with an electricity consumption rate (ECR) of 13,315 kWh in Building 1, while the maximum electricity consumption rate for the building reaches 107,800 kWh in July. This increase can be attributed to the heightened demand for air conditioning (AC) systems, which are widely used to maintain indoor comfort for building occupants. The prolonged use of air conditioning during the hot summer periods significantly contributes to the overall increase in electricity consumption (OEC) during these months. This observation features the seasonal and climate-dependent nature of energy consumption trends.

4.3. Energy potential and morphological indicators of the envelope

In the contemporary context, the primary objective of pursuing nearly zero-energy buildings is the integration of transparent photovoltaic (PV) systems into their structures. This approach places significant importance on facades in addition to the roof, considering them essential for addressing challenges related to renewable energy. A promising avenue is the development of adaptable modular PV facades, strategically designed to find a harmonious balance between optimizing daylight access, solar control, and energy production. Such an approach not only addresses environmental concerns but also represents a forward-looking solution.

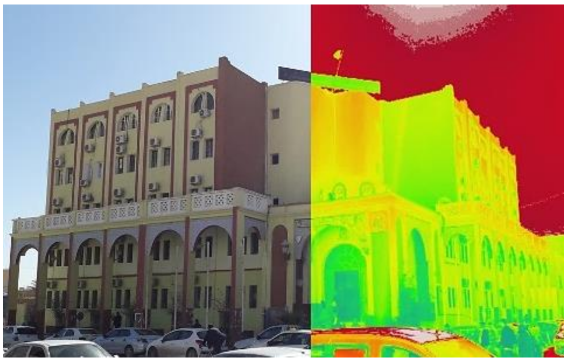
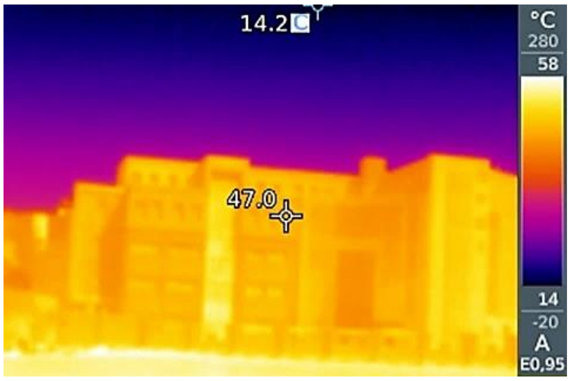
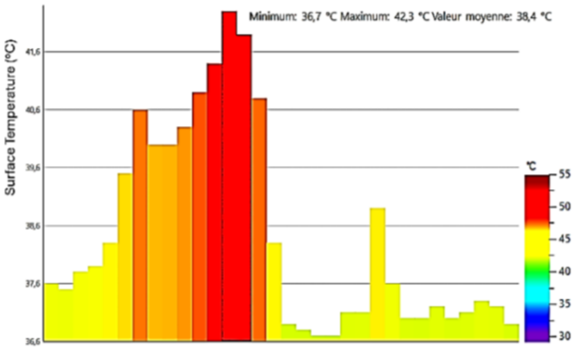
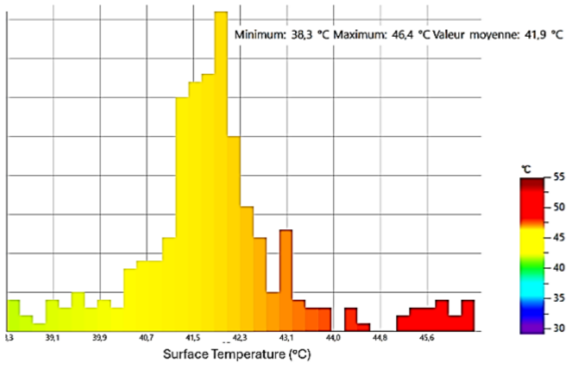
Table 3 provides an overview of the energy potential utilized by the studied buildings, emphasizing key morphological indicators such as Volume/Surface Ratio (VSR), Solar Exposure Surface (SES), and Roof Available Surface (RAS). This data offers valuable insights into the capacity of these buildings to integrate and produce renewable energy, further aligning them with the goal of achieving nearly zero-energy status.

Table 3. Energy potential indicators for the integration of PV panels in selected buildings (Source: Author).

	Energy potential indicators		
	VSR (Volume/Surface Report (%))	SSE (Surface Solar Exposur (m^2))	RAS (Roof Available Surface (m^2))
Building 1	9	672,25	920
Building 2	13	813,33	897

To assess the feasibility and effectiveness of integrating PV panels into the selected buildings for the study, we conducted thermographic measurements to evaluate the levels of solar exposure on the external surfaces of these structures. Additionally, a surface temperature assessment of the facades was performed using the IRSoft software developed for analyzing thermographic images from the thermal camera. The results of these measurements are presented in Table 4.

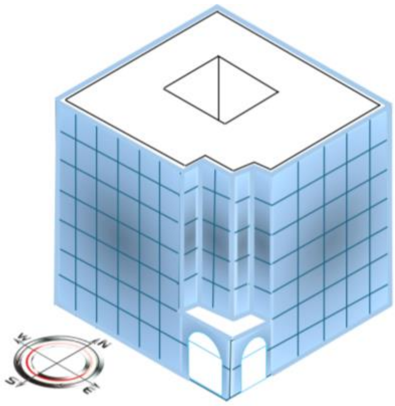
Table 4. Effect of energy potential and heat gain on the efficiency of future PV module use (all buildings). Energy potential (Buildings) (Source: Author).

Building 1	Building 2
Energy potential in southwest facade	Energy potential in southwest facade
	
Thermography (W/m2)	Thermography (W/m2)
	
Min/Max/Average surface temperature values (°C)	Min/Max/Average surface temperature values (°C)
	

Regarding the thermal environment, it is possible to enhance solar protection on external vertical surfaces through various means, including the use of cantilevered forms, double-skin facades, or overhangs with an air cavity to cool them, as observed in the case of Building 2. Concerning the energy potential of external surfaces, buildings with simpler vertical surface configurations and varied orientations (especially towards the south) present a more favorable opportunity for the integration of photovoltaic panels. This is particularly evident in the cases of Buildings 1 and 2.

These results highlight the importance of architectural considerations and the built environment when assessing the potential for integrating photovoltaic panels, as solar exposure and the number of sun-exposed surfaces play a crucial role in determining the feasibility of such installations (Fig.6).

(a) (b)



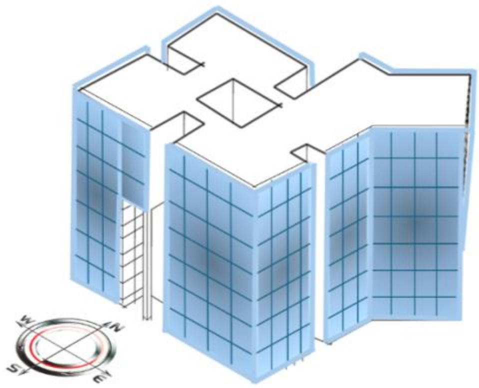


Fig. 6. *Integration of PV panels into the facades of the buildings studied (Source: Author).*

In general, the double-skin facade (DSF) offers a multitude of advantages in various aspects, particularly in terms of solar protection against external elements and enhancing indoor thermal comfort. By making judicious material choices for the second skin, one can seamlessly address aesthetic, thermal, natural lighting, and energy considerations. However, it is essential to emphasize that the choice of materials for the facade, particularly the use of metal, is not ideal for regions characterized by hot and arid climates due to their inherent thermal and energy drawbacks (Fig. 7).

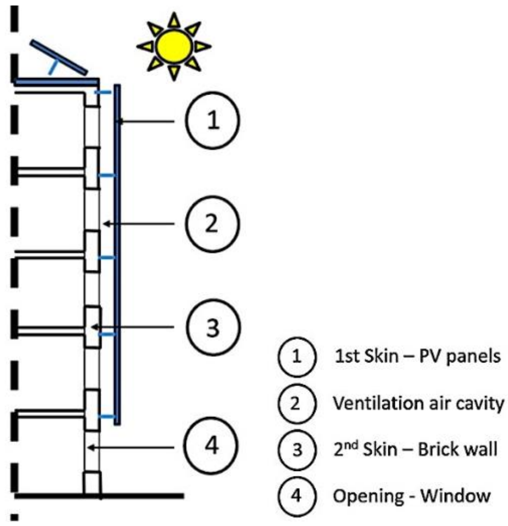


Fig. 7. *Details of the photovoltaic panels used second skin with fixing system (Source: Author).*

4.4. Calculation of the electricity production generated by the photovoltaic system

To calculate the annual energy yield of a photovoltaic solar installation (E), a comprehensive formula that serves as the basis for estimating the electricity generated by a PV system. This formula includes various factors and variables that contribute to the overall energy production of a photovoltaic system. By using this formula, the expected electricity production over the course of a year is providing a valuable tool for assessing the performance and predictive energy output of the PV installation.

$$E = A * r * H * PR \quad (1)$$

Where:
E = Energy (kWh)
A = Total solar panel Area (m2)
r = solar panel yield or efficiency (%)
H = Annual average solar radiation on tilted panels (shadings not included)
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75

The factor "r" direct to the efficiency of the solar panel, which is established by calculating the ratio between the electrical power produced (measured in kWp) by a single solar panel and the area occupied by that panel. For example, if we have a PV module with a nominal power of 250 Wp and it occupies an area of 1.6 square meters, the efficiency of the solar panel would be approximately 15.6%.

It is important to note that this minimal efficiency is provided under specific conditions known as Standard Test Conditions (STC), where factors such as irradiance (set at 1,000 W/m²), cell temperature (set at 25 °C), wind speed (assumed to be 1 m/s), and air mass (AM = 1.5) are normalized. The unit used to express the nominal power of a photovoltaic panel under these conditions is called "watt-peak" (Wp). It is worth noting that larger units such as kWp (equivalent to 1,000 Wp) and MWp (equivalent to 1,000,000 Wp) are generally used to calculate the output power of photovoltaic panels under these standardized conditions. This standardized method assists consistent and reliable comparisons between the performance of different solar panels.

The variable "H" represents the average annual solar radiation received by inclined solar panels. This value can vary significantly depending on geographic location, ranging from about 200 kWh/m².year in Norway to approximately 2,600 kWh/m².year in Saudi Arabia. You can access these specific global radiation figures from solar radiation databases that compile this data for various regions.

Table 5 provides a comprehensive classification of the different values (E) corresponding to the examined buildings. These values, grounded in the annual solar radiation received, illuminate the potential energy yield of the studied structures, considering their geographic context and solar exposure.

Table 5. Values of the produced energy E in accordance with the efficiency rate and the available surface area of the envelopes of the studied buildings (Source: Author).

Efficient rate and envelope available area values of the studied building			
	EEA (m2) (EEA=RAE+FAE)	r (%)	E (kWh)
Building 1	324	31,59	199585,62
Building 2	542	52,84	558465,96

Figure 8 provides a comparative analysis by comparing the actual annual energy consumption of the studied buildings with the predicted annual energy production generated by a photovoltaic solar installation (E). It has been demonstrated that the PV efficiency in terms of reducing the actual annual electricity consumption in Building 1 is 22.15%, while in Building 2 it is 32.15%. This graph allowed for an in-depth examination of how the energy needs of the buildings align with the predictive energy production of the solar installation. By evaluating these factors side by side, it becomes possible to assess the effectiveness of the solar installation in meeting the energy needs of the buildings and to identify opportunities for optimizing the use of PV installations for energy production in administrative buildings, which depends on factors such as shape, available surface area, and building orientation.

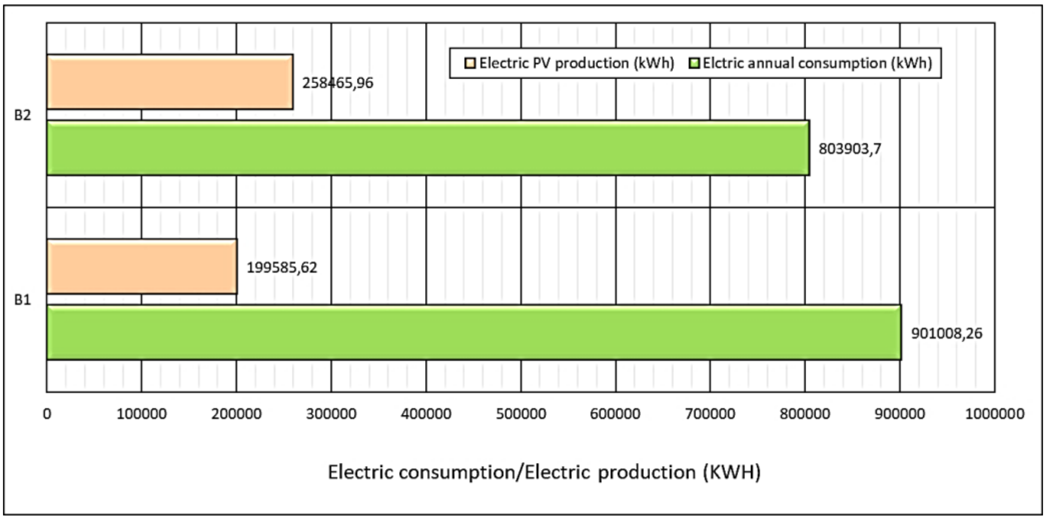


Fig. 8. *PV efficiency in terms of reduction of actual electricity consumption (building 1 and 2) (Source: Author).*

The integration of photovoltaic panels on the facades and roofs of buildings presents an interesting perspective that fundamentally transforms the appearance of the urban landscape, effectively turning the facade into an active element for potential energy production. While this extensive surface offers the potential for high energy efficiency, a significant challenge must be addressed: the orientation of the facades. However, the use of photovoltaic panels on facades provides notable advantages including:

- The ability to protect buildings from excessive solar radiation.
- Photovoltaic modules can serve as a viable alternative to costly and ornate building cladding in prestigious architectural designs.
- To address the orientation issue, PV panels can be installed on kinetic or dynamic facades, whereby this strategic placement of the modules can enhance their overall performance.
- The innovative approaches emphasize the various benefits and opportunities associated with integrating photovoltaic technology into building facades, encompassing energy efficiency, aesthetic appeal, and solar radiation management.

5. Conclusions

This research is derived from a site study conducted through empirical surveys of existing structures. The main objective of this study was to evaluate the impact of using PV panels as a double skin on the facade to improve indoor comfort and minimize energy consumption. First, it was important to analyze and explore the solar energy potential of the facades to beneficially integrate photovoltaic (PV) panels into the building's outer envelope, with the goal of recovering the overall energy efficiency of the building. Through this thorough investigation, we highlighted the implications and practical benefits of using these active techniques based on renewable energy solutions to create more sustainable and comfortable built environments with a futuristic high-tech style.

The on-site measurements conducted during this study effectively underscored the essential role played by the thermal characteristics of construction materials, particularly at the facade level, including parameters such as the thermal insulation of walls and the role of deep introverted courtyards. These measurements vividly illustrate the profound impact of these material properties on the overall thermal performance of the building. However, when a courtyard is introduced into the architectural design, it significantly enhances the thermal environment inside the building, mitigating the adverse effects of concrete facades.

This research highlights the complex interaction between construction materials, passive and active design strategies, and their influence on indoor thermal comfort, providing valuable insights into optimizing the thermal and energy performance of buildings in a hot and arid region. Based on the results of the thermographic analysis using a thermal camera to assess solar potential, the findings demonstrated that to avoid overheating of PV panels, a better oriented PV such in South-East and West that increase the exposure of the panels to solar rays, resulting in better efficiency of the PV modules that can reduce the annual electric consumption to 32%.

The results clearly indicate that the incorporation of photovoltaic panels integrated into the envelopes of buildings, particularly the facade and roof, especially in hot and arid climates with high solar potential, represents a wise strategy for reducing energy consumption. Simultaneously, this inclusion of a second skin through PV modules can effectively enhance indoor thermal conditions. An integrated photovoltaic system serves a dual purpose by contributing not only to thermal protection but also by being an integral part of the building's architectural exterior.

This research paves the way for numerous future exploration avenues, particularly in the context of optimizing energy renovations and improving the thermal conditions of existing buildings. One of these research directions concerns the selection of types of BIPV modules that suit the architectural style of facades as a double skin and their impact on thermal comfort and energy efficiency. This research has the potential to refine our understanding of how architectural and technological choices can combine to create more sustainable, comfortable, and energy-efficient building environments.

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