

Tancredi Testasecca¹, Marina Bonomolo¹, Marco Beccali¹

Using shading systems to enhance energy efficiency, visual and thermal comfort in two case studies in Southern Italy

¹Department of Engineering, University of Palermo, Viale delle Scienze Ed. 9, 90128 Palermo, Italy

Abstract

This study aims to propose a methodology that combines different tools to analyze visual comfort conditions by applying different shading systems (slatted and roller blinds), evaluating both visual and thermal comfort, and considering energy consumption in Mediterranean climate conditions. To do this, an energy model was developed by using EnergyPlus software that can serve as a guideline for designing energy-efficient yet comfortable indoor environments. The methodology has been tested for two different case studies located in Palermo and in Pantelleria (Italy). Furthermore, different scenarios were analysed by using Python. The “Base Case” has been analyzed to understand when the shading system should be closed based on the visual comfort condition with all window shadings open. Based on the Base Case results, Scenario 1 and Scenario 2 included a simulation with different shading systems to mitigate visual discomfort using dynamic shading based on solar irradiance levels. These scenarios were analyzed to assess their impact on the space heating and cooling requirements, artificial lighting needs, and overall comfort levels. The control strategies, related to visual comfort, have been implemented by considering the illuminance values on different workplanes. The results demonstrated that dynamic shading strategies reduced visual discomfort to below 0.3% of the hours at desk positions. However, artificial lighting demand increased by 14-28%, and cooling demand was reduced by up to 30% in the Pantelleria case study.

Keywords: Visual comfort, lighting, shading system, energy efficiency, daylighting, environmental comfort.

1. Introduction

Innovative technologies, strategies, and materials applied to the building envelope and the geometry of the building can provide energy saving [1] [2] [3] and better comfort conditions in the building environment [4]. Transparent envelope plays a key role in the energy balance of the buildings and on the indoor environmental conditions materials can provide disadvantages during the summer season. Indeed, the heat gain or heat loss through windows is a primary contributor to the air conditioning consumption, mainly in the warm and hot climates [14] [15] [16]. Moreover, an incorrect design of windows can provide visual discomfort issues such as glare [17] [18] [19].

Many studies presented in the literature investigated the influences of transparent envelopes and the role of shading systems, as well as innovative ones. E.g., Rizi and Etlawee [20] evaluated an adaptive facade towards visual and thermal comfort by using environmental parametric tools in the location of Iran. Shi et al. [21] investigated the visual-thermal comfort and energy performance of a hydrogel-based thermotropic glazing with different transition temperatures. In particular, they compared them with conventional double-clear glazing and low-emissivity double glazing under five climatic conditions in China.

(e.g., visual and thermal comfort) [5] [6]. Windows can provide correct contribution of natural lighting [7] [8] and, during colder seasons, an advantage in terms of solar gain [9][10][11][12]. However, they also have great potential to cause problems of excessive energy consumption for air conditioning systems and poor indoor thermal comfort [13]. On the contrary, the heat transfer coefficient (U-value) of windows being higher than that of opaque Nundi and Ghosh [22] studied both visual and thermal comfort of low heat loss switchable suspended particle device-vacuum glazing in a temperate climate. Dussault and Gosselin [23] and Li et al. [24] focused attention on the evaluation of a representative office building zone with an electrochromic glazed façade.

Anees et al. [25] developed and tested low-cost retrofit window solutions to improve the thermal efficiency of existing windows, to improve insulation, and reduce energy loss without requiring expensive renovations. The results show that the retrofit demonstrated a 45.69% reduction in energy requirements at a very affordable price.

Khosravi et al. [26] developed a Model Predictive Control (MPC) scheme with thermal and visual comfort constraints. The latter was analyzed by considering the Day-

light Glare Probability (DGP) in a semi-linear support vector regression model. As well, Yang et al. developed an MPC system to enable coordinated control of multiple building services for overall optimized energy efficiency, indoor thermal and visual comfort, as well as a hybrid model for predicting indoor visual comfort and lighting power [27]. Shum and Zhang [28] evaluated the impact of various window shade control strategies on the heating and cooling load of cold climate zone test spaces by considering the visual comfort conditions as well.

Lee and Song [29] analyzed the visual and thermal environments from various perspectives by considering smart windows in residential buildings. In Sejong City, South Korea. In the study of Rabani et al. [30], energy use and thermal comfort, and visual comfort were evaluated. They developed an optimization method that integrated building envelope, glazing parameters, HVAC setpoints, shading device, and window opening control methods. The

Table 1. Current state of art of studies on shadings systems

Ref	Case Study	Location	Sites (No.)	Type of Shading	Tools/Algorithms	Sensors	Dyn. Results?	Thermal Energy	Lighting	Thermal Comfort	Visual Comfort	Simulated?
Our	University room, meeting room	Palermo, Pantelleria (Italy)	2	Roller shutter, slatted blinds	EnergyPlus, Python	3	•	•	•	•	•	•
20	Generic room	Tehran (Iran)	1	Louvers	Grasshopper, Ladybug and Honeybee	2		•			•	•
21	Test room	Real: Xiamen University (China), Simulated: Harmin, Beijing, Nanjing Kunming	5	Hydrogel-based thermotropic glazing	EnergyPlus	-	•	•	•	•	•	•
22	Test room	Dublin (Ireland)	1	SPD-vacuum	-	-				•	•	
23	Office	Atlanta, Chicago, Miami, New Orleans, etc. (U.S.)	10	electrochromic glazing	Trnsys, Daysim	1		•	•	•	•	•
24	Test room	Singapore	1	electrochromic glazing	-	manual	•	•			•	
26	Office	Zurich (Switzerland)	1	Slatted blinds	ML	1 (visual) 4 (thermal)	•	•		•	•	
27	Test room	Singapore	1	electrochromic glazing	MATLAB and EnergyPlus	10+	•	•	•	•	•	Used for Control
28	Office room	Edmonton (Canada)	5	interior roller shades	Energyplus, WINDOW	Weather API	•	•				•
29	Residential bedroom	Sejong City (South Korea)	1	Suspended Particle Device windows	DesignBuilder	1 (outdoor)	•	•	•	•	•	Used for Control
30	Office building	Oslo (Norway)	1	Exterior venetian blinds	IDA-ICE 6.0 + Radiance, GenOpt (PSO)	1	•	•	•	•	•	•
31	Office room	Tehran (Iran)	0	Venetian blinds	EnergyPlus + jEPlus	1	•	•	•	•	•	
33	Office room	Hanoi (Vietnam)	1	Roller blinds, external fixed shading	EnergyPlus Grasshopper;	1	•	•	•	•	•	•

shading and window opening control strategies were implemented using various control methods, including the indoor air temperature, the CO₂ level, the daylight level, the wind velocity, and direct solar radiation on the façade. Baghoolizadeh et al. [31] investigated the effect of Venetian blinds on reducing the energy consumption of the building as well as improving the thermal and visual comfort of the building occupants. Chohan et al. [32] analyzed both thermal and visual comfort and power consumption, CO₂ emissions, employing simulations to analyze building structures and construction systems.

Table 1 provides a comparison between state-of-the-art literature and the contributions of the present study. As illustrated in **Table 1**, electrochromic and thermochromic glazing represent the most frequently analyzed shading systems. These glazing solutions offer flexibility and ease of control; however, their spread in existing buildings remains limited. Conversely, slatted blinds and roller shutters are widely used across Europe, particularly in residential buildings. Regarding simulation software, EnergyPlus is extensively applied to evaluate building thermal performance, while Grasshopper is preferred for visual comfort analysis. Moreover, most reviewed studies involved experimental validation conducted in test rooms (see **Table 1**). Finally, two studies utilized simulations exclusively for the purpose of training model predictive control algorithms. Despite the large number of studies conducted on the energy, thermal, and visual performance of transparent building envelopes and shadings, several critical gaps remain:

- A lack of studies conducted specifically under Mediterranean climate conditions.
- Limited exploration of control strategies for roller shutters.
- Scarce dynamic analysis simultaneously addressing thermal comfort, visual comfort, and energy performance.
- Insufficient application of such analyses in real-world scenarios.
- A notable absence of research evaluating the effectiveness of shading control strategies using sensors positioned across multiple workplanes.

The presented gaps are even more evident in Mediterranean climates, where no studies were conducted and where balancing thermal and visual comfort with energy efficiency creates special challenges. In this framework, the present research focuses on the evaluation of different shading system control strategies by analyzing two distinct case studies in Southern Italy. The objectives of this study include:

- Introducing an integrated methodology that combines multiple tools for controlling shadings and for analyzing visual comfort and energy performance;
- Examining the effectiveness of two widely adopted shading devices: roller shutters and slatted blinds;

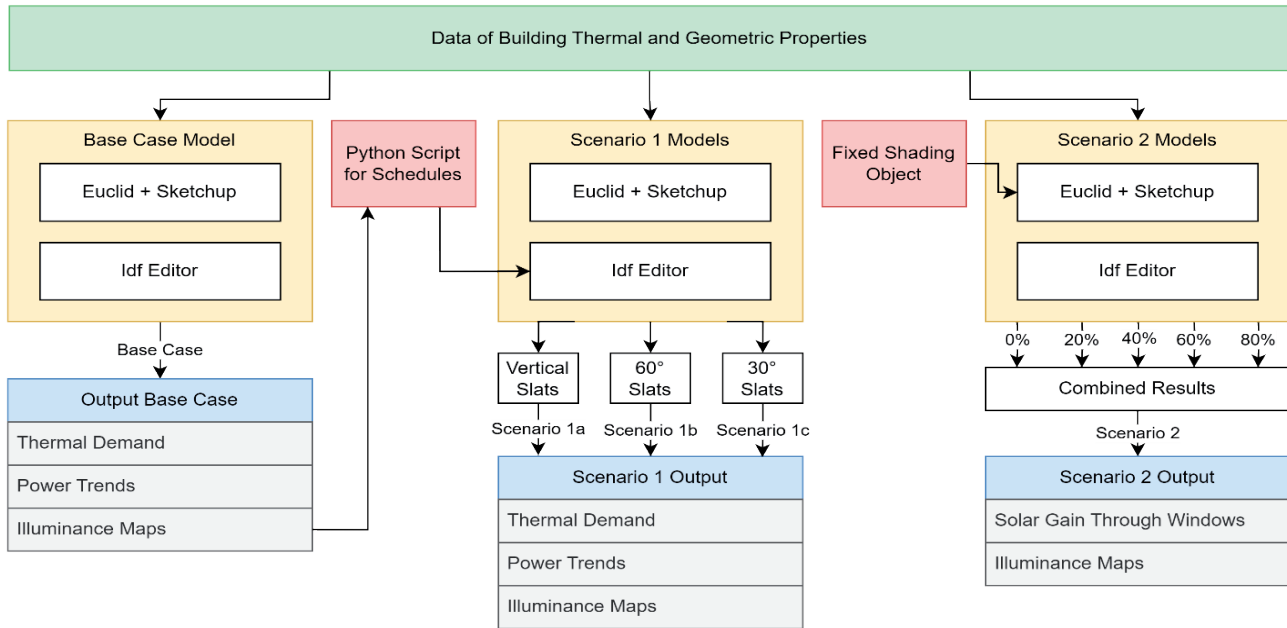
- Simultaneously evaluating shading control effects across three different workplanes;
- Conducting practical case study analyses within the Mediterranean context;
- Providing insights into thermal and visual comfort outcomes, as well as associated thermal and electrical energy loads.

First, the manuscript reported the description of the methodology applied, which includes the description of the scenarios applied and of the models developed, the shading controls considered, and the energy demand estimation method. Then, the two case studies are briefly presented. Finally, in the last part, the results are shown and commented on.

2. Methodology

The methodology applied considers the use of a combination of different tools. In particular, the first model was developed using SketchUp combined with the Euclid extension. Secondly, this model was detailed and defined using Energy+ software using the IDF editor to specify in detail the thermal characteristics of the building, the schedules, and the HVAC system. Being the aim of this work, the assessment of the visual comfort condition and the evaluation of power absorbed by the lighting system, in relation to the solar gain contribution and the relative use of the solar cooling system, two case studies and three different scenarios were analyzed (described in the next section).

The analysis was made at different points (two in the Pantelleria case study and three in the Palermo case study) of the room where the workplanes were located. The first simulation was aimed at calculating the illuminance values on the workplanes. The tool Python was used to develop a script able to set some custom schedules. These detailed the hourly functioning of shading systems on each different day for each scenario. Since using Energy+ Version 8.9 does not enable the possibility of choosing how much window is covered by the roller blinds shading system, these were simulated by using fixed shading objects, which partially cover the window differently. This approach is based on a similar methodology used by Phuong et al. [33]. Indeed, similarly to the method applied in the presented study, they conducted several simulations to investigate visual discomfort using roller shades. The methodology presented in this work is schematized in **Fig. 1**. A Base Case (BC) model was developed to study the thermal demand, the power absorbed by the lighting system, and the illuminance maps. These latter were used to develop, using Python, detailed schedules of the functioning of shading systems to avoid excessive values of illuminance issues in the three different workplanes. These schedules were considered for Scenario 1, which was further divided into Scenario 1a, 1b, and 1c depending on blind slat angles. Finally, Scenario 2a allows, by modifying the BC with fixed shading objects, the investigation of solar gain and illuminance maps.

Fig.1. Flow diagram of methodology for investigating effects of shading systems.

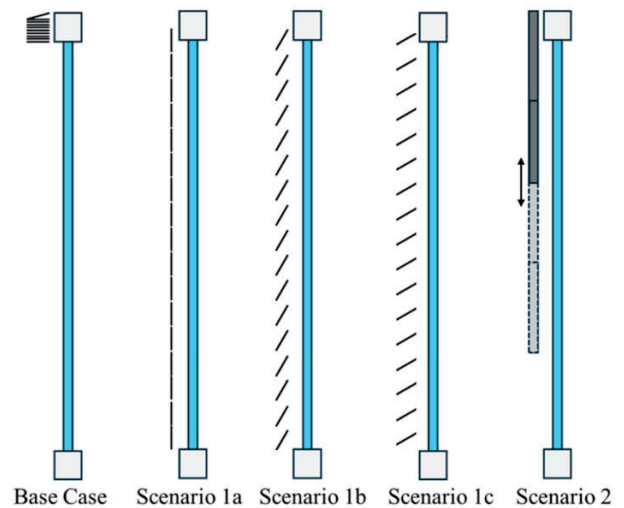
2.1 Scenarios

As mentioned, the analyses of different scenarios (**Fig. 1**) assessed the impact of various shading systems on visual comfort, thermal comfort, and energy efficiency within the space setting. In the Baseline Case, used for the comparison, the space shading systems are considered open. In this scenario, no shading system was included, so it provided an unobstructed view of daylight contributing to the space without any interventions to mitigate visual discomfort or adjust solar gains (offering insight into the space's inherent energy and lighting dynamics). **Fig. 2** shows a concept scheme of the configuration of the shading system in different scenarios.

Scenario 1 considered a proactive approach to managing visual conditions with the use of slatted blinds that are positioned externally and cover the windows completely. The activation of these blinds was determined by a custom schedule activated by the possible presence of excessive illuminance (according to the illuminance level). Notably, the slat angle undergoes different adjustments, from 90° , which means the slat is parallel to the glass, to 30° horizontally, aiming to optimize the balance between natural light utilization and visual discomfort reduction. Scenario 1a considered a slat angle of 90° , Scenario 1b considered a slat angle fixed to 60° , and Scenario 1c a slat angle fixed to 30° .

Scenario 2 explored a different shading strategy by employing a fixed shading object to simulate the effect of roller blinds. Contrary to Scenario 1, the blinds can partially cover the windows, with coverage ranging from 0 to 80%. This approach assessed the impact of partial window coverage on excessive values of illuminance mitigation and its subsequent effects on energy efficiency and indoor environmental quality. Together, these scenarios provide a comprehensive examination of various shading

interventions and their role in optimizing energy performance and occupant comfort in the space. Through comparative analysis, the study identifies effective strategies for integrating shading systems into building designs to achieve sustainability goals.

**Fig. 2.** Scheme of shading system layout for each scenario.

2.2 EnergyPlus modelling

As said, the software SketchUp with the Euclid extension was used to develop the geometry of the energy model. It is useful to develop a detailed model with thermal and geometrical characteristics. The Euclid extension provided capabilities for setting the boundaries of each surface, enabling the classification of surfaces as adiabatic (adjacent to other surfaces within similarly air-conditioned spaces) or as directly exposed to the sun, covered, among others. This level of detail extended to the consideration

of shading use (e.g., the impact of projecting roofs can be modelled through the “Shading Group Zone” feature available within the Euclid extension).

Upon the development of the model, it can be transformed into an .idf file, which is then subject to further refinement using the EnergyPlus IDF Editor to define the analytical phase from geometric and physical modelling. It was useful to evaluate the energy performance of the building under various conditions. Through this process, from defining the building geometry to refining the model in EnergyPlus [34] [35], a detailed representation of the building energy dynamics was achieved. Utilizing the IDF Editor, it was important to outline the building construction elements and the materials constituting each component. The model was implemented by selecting material properties, which vary by country and location. To do this, thermal characteristics like conductivity, density, specific heat, and materials, as well as materials, the structural aspects of the building, including walls, roofs, floors, and windows, were specified. Subsequently, shading systems, such as low-reflectance blinds, were designed and integrated into the EnergyPlus model.

The operational setpoints of the Heating, Ventilation, and Air Conditioning (HVAC) were set according to the UNI 11300 standards (temperatures were set at 26°C in summer and 20°C in winter) [36]. After establishing the building components, the operational schedules for each element were determined, covering the HVAC system, blind activation, occupancy, and lighting. As outputs of the simulation, an illuminance map and a grid assessing illuminance levels were chosen.

2.3 Shading controls simulation

One of the main contributions of this work is the development of a methodology aimed at optimizing the scheduling of shading devices based on illuminance at various locations, such as different workplanes within a room. EnergyPlus provides options to set scheduling and control for various shading systems (e.g., slats or electrochromic glass). Nevertheless, it relies on average values for single reference points. E.g., it permits the closure of shading devices like diffusive shades or slatted blinds based on predetermined glare indices or solar radiation levels, but does not allow for adjusting the slat opening or considering illuminance across multiple workplanes.

To cross these limitations, two distinct strategies were adopted. Initially, an hourly illuminance map was generated using a baseline model with inactive shading devices to assess the impact of solar radiation and illuminance at three specific points. This facilitated the identification of hours during the year when illuminance exceeds 2000 lux at least one of the workplanes, a threshold established to prevent visual discomfort for occupants. This step involved creating a Python algorithm to compile a DataFrame marking each hour with the presence or absence of excessive values of illuminance over the year.

The value of 2000 lux has been chosen according to the Useful Daylight Illuminance [37] that considers the day-

light illuminances higher than 2000 lux likely to produce visual or thermal discomfort, or both.

In particular, the algorithm creates a text file including text formatted to meet EnergyPlus requirements for the planned schedules. In this work, as specified, the algorithm checks illuminance values at different points and closes the shading in cases of excessive values of illuminance, but potentially it could be used for more complex and flexible control strategies. Unfortunately, using EnergyPlus is possible to write a limited number of rows and characters. For this reason, in the schedule, consecutive hours and days were merged when identical patterns were identified. Once the schedule was generated, this study proposes two different methods to mitigate visual discomfort: with the entire window covered and considering slatted blinds partially obscuring the window with a surface that simulates the employment of roller shutters. While the former (slatted blinds) can be readily implemented in EnergyPlus, allowing for control over blind activation and slat angles, the latter (roller shutter) is not directly supported by the software. To approximate the effect of roller shutters, a static shading device was simulated to partially obstruct the window. Then, the BC was simulated with five levels of shading coverage, from 0 to 80% in 20% increments, to evaluate solar heat gain through the windows and update the illuminance map.

2.4 Lighting energy demand estimation

Based on values of illuminance determined in the workplane, a simplified algorithm was employed to calculate the electric energy required to reach the threshold value on the workplane according to the technical standard [38] (e.g., 500 lux). In particular, the luminaires were considered switched on if the illuminance values were lower than 500 lux (as well as in moments where shading devices were closed). Once the lamps were chosen and the related electric demand was estimated, a logic ON-OFF was used to calculate hourly the electric demand of the lamps.

3. Case studies description

The methodology presented in this paper has been tested for two different case studies, one located in Palermo and one located in Pantelleria Island. The climate conditions are very similar, but the two case studies are characterized by different orientations of the windows, different opaque thermal characteristics, and different areas.

3.1 The case study in Palermo

The case study selected in Palermo is called Solarlab, and it is located at the Department of Engineering of the University of Palermo (Italy), characterized by a warm climate. It has four windows (2.40 m wide and 2.90 m high), is equipped with double glazing with aluminum frames, and is located in the South-East. Moreover, the facade is partially shaded by a solar shelter, whose area is 2.70 x 19 m, where a hybrid solar photovoltaic/thermal system is installed. The following figures (Fig. 3) show some pictures of the Palermo case study.



Fig. 3. Pictures of the Palermo case study

The envelope of the Palermo case study is composed of elements shown in **Table 2**. As can be seen, since the building was built in the 1960s, its characteristics are not efficient enough as required by current legislation. In particular, the thermal transmittance is higher than the value required by the legislation U_{lim} . However, the solar shelter was designed to reduce the solar contribution while guaranteeing an appropriate angle for the installation of the hybrid solar PV/th system.

Table 2. Information on the Palermo case study thermal envelope

Building Element	Number of Layers [-]	Thickness [m]	Thermal Resistance [m^2K/W]	Thermal Transmittance [W/m^2K]	U_{lim}
Exterior Wall	4	0.355	0.711	1.406	0.41
Interior Wall	3	0.12	0.584	1.713	-
Floor Slab	4	0.35	0.472	2.117	-
Roof Slab	5	0.36	0.499	2.004	0.32
Window (double-glazing)	3	0.012	0.256	3.905	2.5

The HVAC system includes a chilled ceiling powered by an air-cooled chiller for cooling purposes and a boiler for heating needs. This space is normally occupied by students from 8:00 AM to 6:00 PM, while the maximum occupancy is normally reached at 11:00 AM and 17:00

PM. Regarding electric equipment, the main contribution is due to the presence of PCs or printers inside the room, which leads to an increase in internal gains in combination with the presence of people. The lighting system is composed of four pendant luminaires equipped with LED sources. This information was included for modelling the Palermo case study in EnergyPlus, including the schedule for each internal load, stratigraphy of each element of the building envelope, and finally defining the HVAC and lighting system. **Fig. 4** shows a picture of the modelled Palermo case study thermal zone (highlighted in red).

The room borders two sections that correspond to rooms without air conditioning: a stairwell and a space with elevator machinery. It is important to note that the Southwest façade and the floor are treated as adiabatic, given that they are adjacent to rooms with air conditioning, maintaining identical internal conditions.

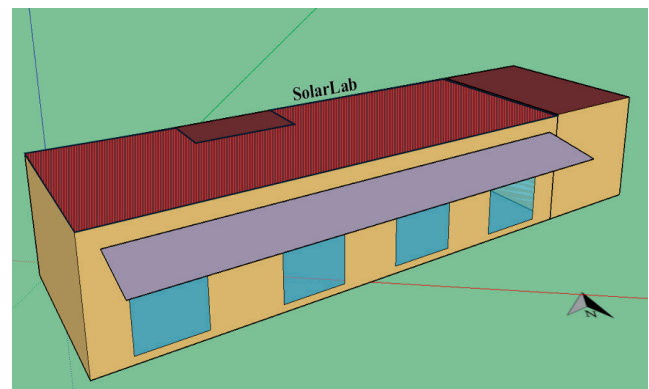


Fig. 4. Three-dimensional representation of the EnergyPlus model of the Palermo case study

3.2 The case study in Pantelleria

The case study in Pantelleria is a building used for different end-uses, and it is called Mediateca. In particular, a meeting room has been selected to test the methodology. Several retrofit actions were made in this building (**Fig. 5**). The existing external frames were replaced with new frames made with extruded profiles in modified rigid PVC from the recycling system, with high impact resistance, galvanized steel subframe and minimum dimensions of the walled frame of 60 x 70 mm, built with a multi-chamber internal section and equipped with an external ventilation and drainage pre-chamber. They are equipped with EPDM glass sealing gaskets placed on the sash in the external stop in a continuous manner excluding any cuts or joints in the corners; metal reinforcements inserted in all 4 sides of the walled frame and of the sashes with a width greater than 600 mm, in galvanized steel to provide mechanical resistance to the PVC profiles; double glazing laminated safety glass 6/7 - 16 - 8/9 with argon.

Regarding the opaque envelope of the building, an external coat was recently applied. In particular, natural cork was selected as the main insulating material. The panels are characterized by a thickness of 5 cm, a density of 160 Kg/m³, and thermal conductivity equal to 0.042 W/mK. Moreover, a sized glass fibre mesh is installed,

which gives the system the ability to resist movements due to temperature changes or shrinkage. Finally, a layer of siloxane plaster was used for aesthetic function and to protect the underlying layers from the elements and solar rays.



Fig. 5. Pictures of the meeting room of the Pantelleria case study

The building is partly covered with a flat roof in brick and cement and partly with vaults/domes typical of the island of Pantelleria. The latter is made of brickwork, except for the central one, of greater extension, made of reinforced concrete. The flat roof floors were insulated with rigid panels, in water-repellent glass wool, covered on one side with a layer of high-weight bitumen reinforced with a glass veil and a polypropylene film at the end, to make it suitable for the hot application of the subsequent waterproof covering with bituminous slate sheathing. The panels are characterised by thermal conductivity, declared at 10 °C, of 0.037 W/(m²K), and have a thickness of 5 cm. However, the roof of the meeting room considered in this study is a dome, which, to create homogeneous insulation, was insulated with polyurethane foam with a thermal conductivity of 0.025 W/mK. Details on each structure of the envelope of the Pantelleria case study are shown in **Table 3**.

The air conditioning system is of the Variable Refrigerant Flow (VRF) type with high energy efficiency. The system consists of a miniVRF heat pump external unit and 8 compact internal units distributed in the building. The lighting system consists of two LED luminaires, each characterized by an absorbed power of 51W.

Table 3. Information of the Pantelleria case study – Meeting Room thermal envelope

Building Element	Number of Layers	Thickness	Thermal Resistance	Thermal Transmittance	U_{lim}
	[-]	[m]	[m ² K/W]	[W/m ² K]	
Exterior Wall	4	0.35	2.58	0.39	0.41
Interior Wall	3	0.16	0.48	2.09	-
Floor Slab	4	0.35	0.71	1.4	0.42
Roof Slab	5	0.47	3.2	0.31	0.32
Window (double-glazing)	3	0.032	0.374	2.67	2.5

The model in **Fig. 6** was then developed in EnergyPlus, considering all the previously cited information about the HVAC plant and building envelope. Regarding the internal load, similar schedules to the Palermo case study were assumed for the occupancy. They were also used for scheduling indoor devices. In this case study, 4 people were considered the maximum occupancy, with 4 PCs and a printer in the room. Finally, except for the windowed one that faces the outdoor space, all the walls were considered adiabatic as adjacent to air-conditioned rooms.

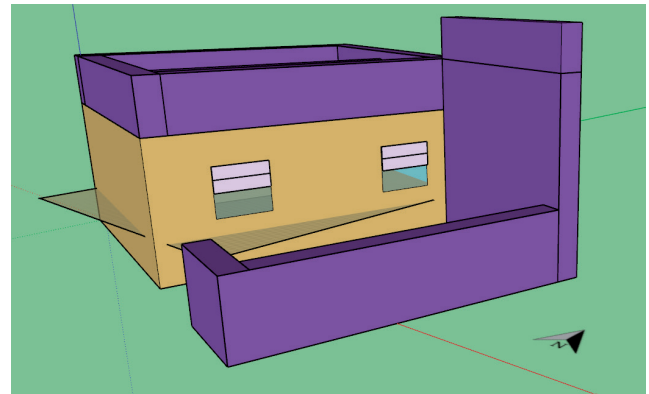


Fig. 6. Three-dimensional representation of the EnergyPlus model of the meeting room

4. Results

This chapter presents the findings from the analysis of energy efficiency and visual comfort trade-offs. Utilizing the EnergyPlus software, the balance required to maintain comfortable indoor environments while optimizing energy use was investigated. As said, three different scenarios were considered. Each scenario offers insights into different aspects of building performance. In particular, the aspects considered are the power absorbed by the lighting system, the contribution of solar gains, and, where applicable, the heating and cooling loads. The goal was to investigate indoor comfort, both visual and thermal.

4.1 Base Case

The temperature and humidity, calculated both outside and inside the zones, are shown in Fig. 7 for the Palermo case study (top) and the Pantelleria case study (bottom). When the HVAC system is active, indoor air temperatures of 20°C in winter and 26°C in summer are maintained for both case studies. During unoccupied nighttime hours, maximum and minimum temperatures of 33°C and 13°C, respectively, were simulated for the case study in Palermo. For the Pantelleria case study, the building is equipped with an efficient envelope and reduced dispersant surface, resulting in a more stable indoor air temperature, with slightly lower peaks of 31°C and 15°C, respectively. Since the Palermo case study was modeled as occupied by 4 to 6 people, relative humidity generally remained around 50%, even without humidity control. For the Pantelleria case study, the simulated annual average indoor relative humidity was 54%.

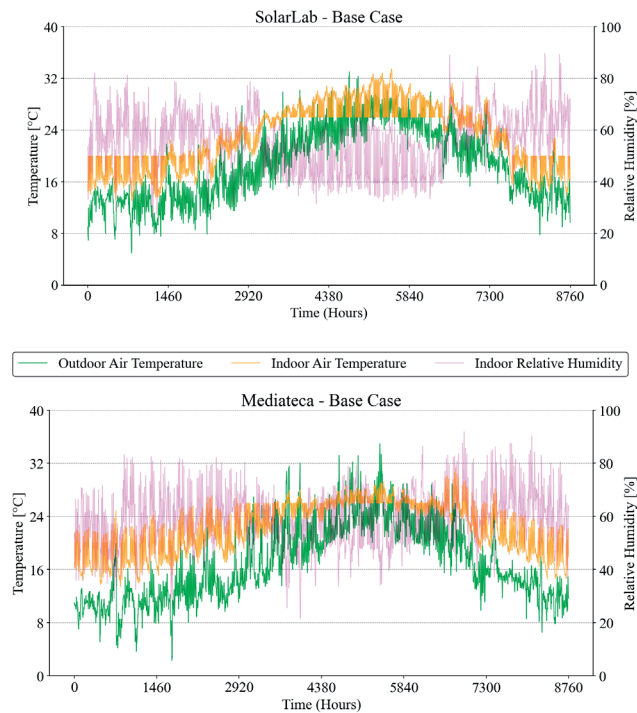


Fig. 7. Indoor and outdoor conditions in BC for the Palermo case study (above) and the Pantelleria case study (below)

Regarding thermal loads, the contribution of heating energy was lower than cooling, as expected in a hot climate such as the one in Palermo and Pantelleria (Fig. 8). Comparing the two case studies, it is possible to note different behavior of solar gains through windows. In the Palermo case study, the distribution is more uniform, with solar gains in July being 2 times the gains in November. This happens as the windows are exposed to the south-west direction, and the shelter mitigated the quantity of radiation in summer. Regarding thermal loads, the contribution of heating energy was lower than cooling, as expected in a hot climate such as the one in Palermo and Pantelleria (Fig. 8). Comparing the two case studies, it is possible to note different behavior of solar gains through windows. In the Palermo case study, the distribution is more uniform, with solar gains in July being 2 times the gains in November. This happens as the windows are exposed to the south-west direction, and the shelter mitigates the quantity of radiation in summer.

4.2 Scenario 1: use of slatted blinds

In the Scenario 1 cases, namely Scenario 1a, 1b, and 1c, to mitigate visual discomfort, slatted blinds with different slat angles were implemented. Fig. 9 illustrates the hourly thermal behaviour of loads in the Palermo case study. On the winter day (above), the heating energy demand in the BC was lower than in other scenarios. It is primarily due to the higher solar gain. Throughout a typical winter day, low heating energy was required from 10:00 to 12:00 in the BC. At 12:00, the heating demand of 1.1 kW was cal-

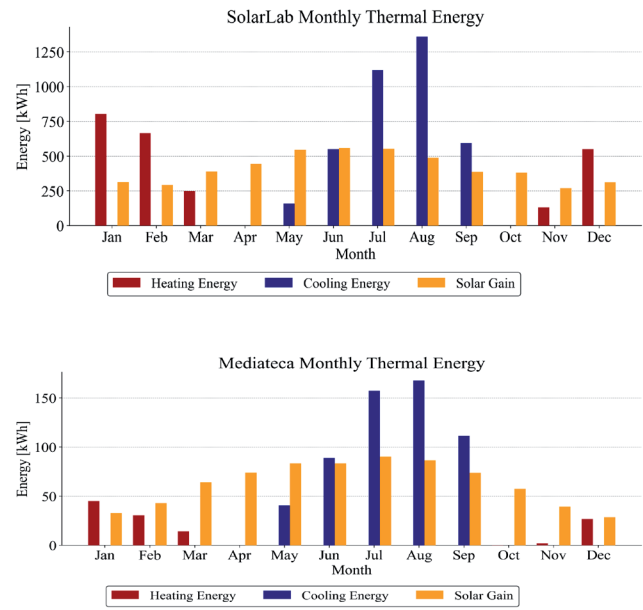


Fig. 8. Energy behaviour in BC for Palermo

culated, while in all other scenarios, the heating demand was higher than 2 kW. Focusing on illuminance values, peaks of 8000 lux have been simulated on the workstation for the BC. For the other scenarios, the illuminance values were always lower than the threshold of 500 lux, except in Scenario 1c, where illuminance values reached 900 lux. On the summer day, cooling demand in all Scenarios 1 was always lower than in the BC. However, as the solar gain was mainly related to diffuse radiation, the shape of the cooling hourly behavior is similar. On this day, maximum illuminance was lower than on the winter day, as expected, due to the presence of the solar shelter.

Results from the Pantelleria case study (Fig. 10) showed that slatted blinds increased heating energy demand in winter and reduced cooling demand in summer. In the BC, despite the presence of small windows in the Pantelleria case study, illuminance higher than 3500 lux and 29500 lux have been simulated on the winter day (above) and summer day (below), respectively. When slats covered windows, heating energy was on average 1.85 times higher on a winter day. For cooling, the slats effectively reduced solar gains, leading to a maximum daily reduction of 1.9 kWh compared to the BC in Scenario 1b. Additionally, a higher peak of cooling demand occurred after 15:00, even though windows were oriented east. This happened due to a higher assumed occupancy rate (and consequently the use of devices) after 14:00. However, the use of slats reduced daily cooling energy compared to the BC by 32.2% (Scenario 1b) to 21.5% (Scenario 1a). Comparing the Palermo case study and the Pantelleria case study, it is evident that due to different orientations and the absence of a solar shelter in the Pantelleria case study, the highest illuminance levels were simulated in summer for the Pantelleria case study and in winter for the Palermo case study.

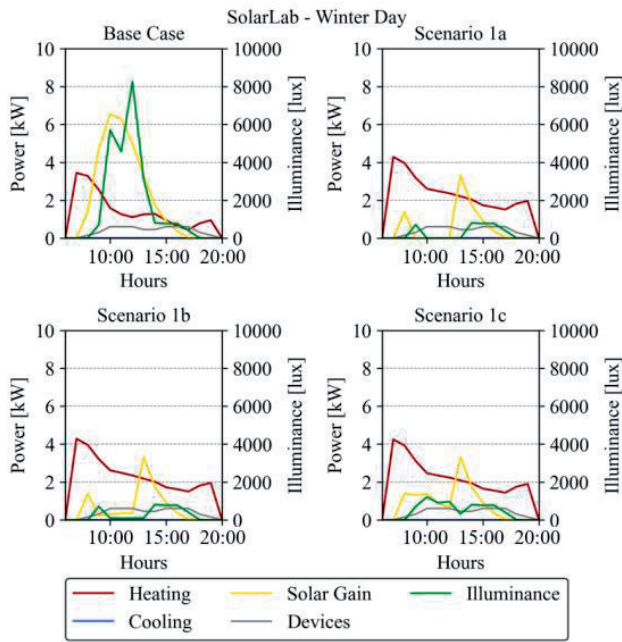


Fig. 9. Comparative analysis of hourly energy contributions in the Palermo case study in winter (above) and summer (below)

This was confirmed by the thermal behaviour in the Pantelleria case study. (**Table 4**) Indeed, in the Pantelleria case study, cooling energy demand was reduced from 29.8% to 21.2%, depending on the scenario. E.g., focusing on Scenario 1b, in the Pantelleria case study, the increase in heating energy was 142.2 kWh, and the reduction in cooling energy was 168.3 kWh. This confirms that, in Southern Italy latitudes, finding the optimal shading strategy is fundamental, even for small windows. Regarding thermal peak loads, shading devices had a minimal effect in both cases. In winter, thermal peak loads occurred early in the day due to the need to heat the air cooled overnight. In summer, with the sun at its zenith around noon, the solar

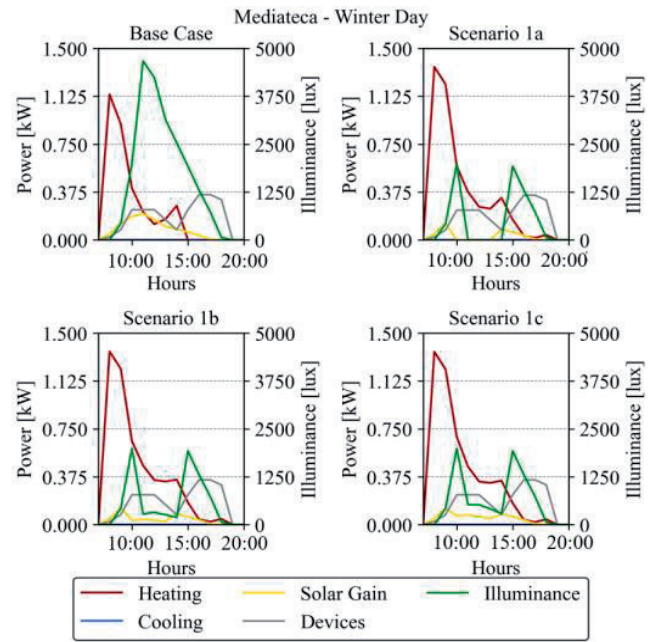


Fig. 10. Comparative analysis of hourly energy contributions in the Pantelleria case study in winter (above) and summer (below)

shelter effectively blocked direct solar radiation, and the windows in Pantelleria faced east.

Finally, a comparison of the values simulated at 11:00 AM on the 21st of December was carried out to evaluate the effectiveness of the shading solution for visual comfort (above Fig. 11). In the figure, the black dots represent points where illuminance was higher than 2000 lux, and the red rectangles represent the workstations. The rectangles in **Fig. 11** show that at 11:00 in the BC, the values of illuminance were higher than 10,000 lux. By using blinds, at that time, the illuminance was still sufficient, being about 600 lux in Scenario 1b and 1c. In all cases, there

		Scenario			
		Base Case	1a	1b	1c
Palermo case study					
Heating Demand	[kWh]	1675.5	2479.4	2462.1	2398.1
Heating Peak	[kW]	6.3	6.6	6.5	6.5
Cooling Demand	[kWh]	4178.7	3722.9	3755.4	3781.2
Cooling Peak	[kW]	9.4	9.0	9.1	9.1
Pantelleria case study					
Heating Demand	[kWh]	118.5	227.3	260.7	252.2
Heating Peak	[kW]	1.4	1.6	1.6	1.6
Cooling Demand	[kWh]	565.7	445.3	397.4	431.0
Cooling Peak	[kW]	1.3	1.3	1.3	1.3

Table 4. Annual heating and cooling energy demand across various scenarios.

were no excessive illuminance issues. As shown in **Fig. 11**, considering a typical summer day, given that the slats are vertical and considered closed, Scenario 1a results in zero illuminance at each point. However, enhanced summer solar radiation contributed to higher diffuse lighting, identifying areas with illuminance above 2000 lux in the other scenarios. However, this happened only in areas close to the window, thereby preventing excessive illuminance at the workplanes. The results of Scenarios 1b and 1c were similar due to the predominant contribution of diffuse radiation, as direct sunlight was obstructed by external shading.

Unlike the Palermo case study, the Pantelleria case study exhibited the highest illuminance values on the selected summer day (**Fig. 12**). As expected, in Scenario 1a, the illuminance was zero when slats entirely covered the window. In other scenarios, room illuminance was around 200 lux, requiring the activation of lighting systems. Comparing winter (**Fig. 12**) and summer (bottom) days, it is notable that on the winter day, no scenario exhibited illuminance higher than the 2000 lux threshold at 11:00. In Scenario 1c during a summer day, illuminance near the windows exceeded 2000 lux. However, this did not occur in the red rectangles representing the desk illuminance sensors.

Regarding the thermal comfort evaluation, Predictive Mean Vote (PMV) was studied for all scenarios to examine the impact of using slat blinds in the Palermo case study [39]. This methodology was used to assess thermal comfort and was developed by Fanger. It provides a thermal sensation index on a seven-point scale ranging from -3 (cold sensation) to +3 (hot sensation) and is determined by six environmental variables (indoor air tem-

perature, mean radiant temperature, relative humidity, and air velocity), and two factors related to occupants, namely their clothing level and metabolic rate. The HVAC system, regulated by an air temperature thermostat, was considered. As can be seen in **Fig. 13**, similar values of PMV were found for Scenarios 1a, 1b, and 1c. In all three scenarios, the control strategy for closing the slatted blinds is the same; the only variation is the angle of the slats, which changes with each scenario. Specifically, in Scenario 1a, where the slats are vertical and cover the entire window, the PMV is constantly lower than in Scenarios 1b and 1c. In Scenario 1c, the slats are tilted at 60 degrees from the vertical, resulting in less coverage of the window and leading to a higher contribution of solar radiation.

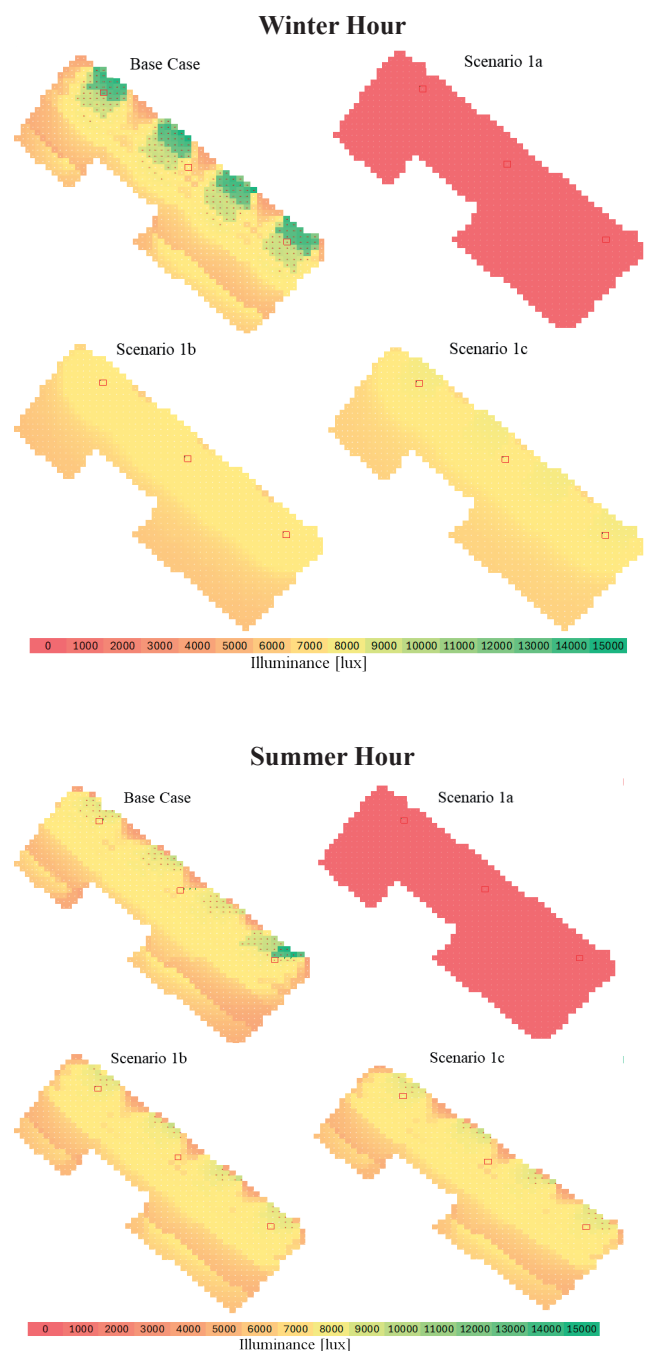


Fig. 11. Illuminance maps at 11:00 AM in the Palermo case study for a generic winter day (above) and summer

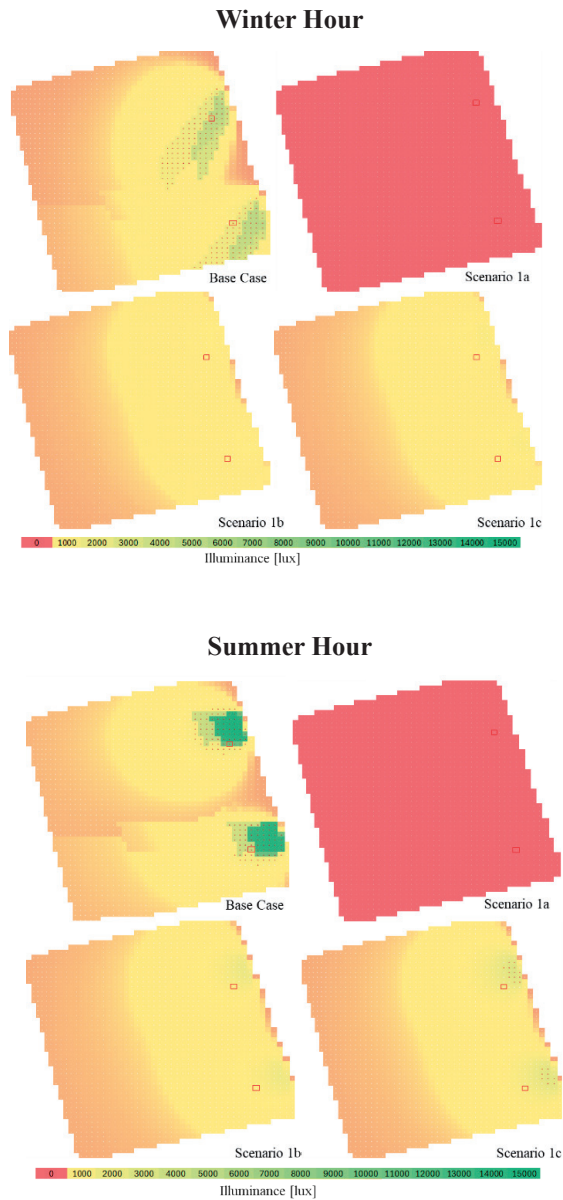


Fig. 12. Illuminance maps at 11:00 AM in the Pantelleria case study for a generic winter day (above) and sum

However, comparing the BC with Scenario 1 results, the values of PMV on the two days are different. In summer, as shown in Fig. 13, the PMV of the Base Case consistently equals or exceeds the PMVs in Scenario 1. This occurs because the direct solar radiation in the morning warms the internal surface, and the lack of shade in the afternoon promotes radiative heat gain. On the contrary, during winter mornings, the PMV is higher due to the heating effect of solar radiation on the surfaces, which results in a positive gain. During the afternoon, when the sun is sufficiently high to be obscured from the external shading, the slatted blinds reduced heat losses in Scenario 1, leading to comparable PMV values. After 13:00, the PMV of BC is again higher than Scenario 1. It is because, in both cases, the blinds do not cover the windows. Furthermore, the thermal inertia of the floor has reached a higher temperature due to solar radiation. It influences the overall mean radiant temperature and enhances thermal comfort.

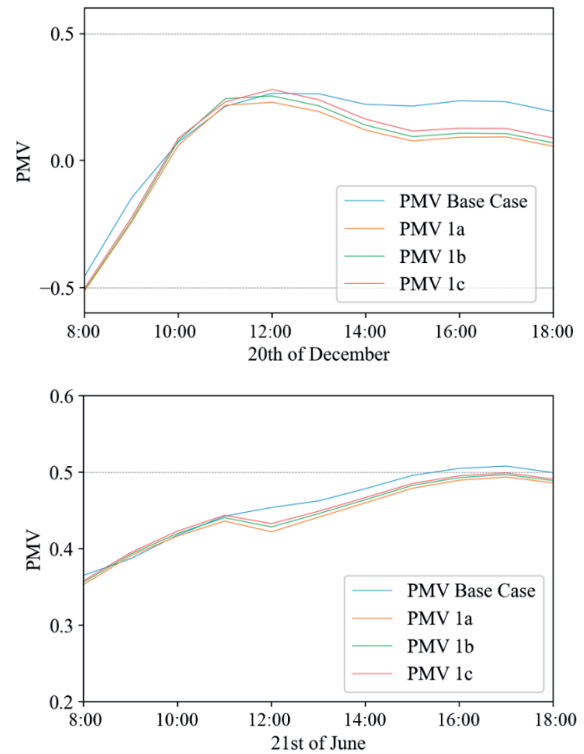


Fig. 13. PMV trend in Palermo case study in a typical winter (above) and summer (below) day during work hours

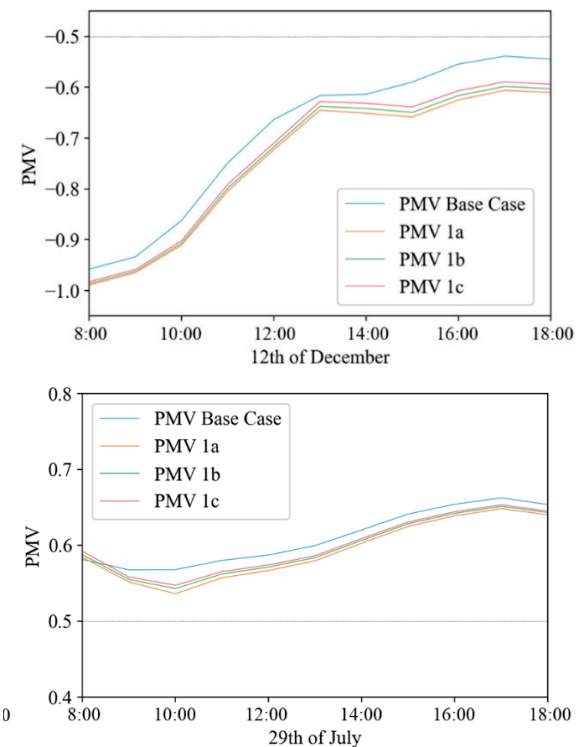


Fig. 14. PMV trend in Palermo case study, an especially cold day (above) and hot day (below) during work hours

It is important to underline that, in some cases, regulating air temperature was not sufficient to ensure indoor thermal comfort. As illustrated in Fig. 14, on distinct winter

and summer days, even though the indoor air temperature is maintained at 20°C and 26°C, respectively (in compliance with current Italian legislation), the required PMV threshold between -0.5 and 0.5 was not achieved in both instances. However, it was met for up to 64% of the working hours. Despite this, focusing on the trend of PMV in both cases, the behavior is comparable to the two days previously analyzed. This fact confirms that it is important to consider radiant temperature, and only controlling the air temperature by means of a thermostat should be insufficient to guarantee comfort conditions. Therefore, in extremely cold or hot conditions, particularly affecting uninsulated envelopes, higher setpoint temperatures (in winter) and lower temperatures (in summer) should be considered in the HVAC system.

Similarly, in the Pantelleria case study, the PMV threshold is often not reached in winter (Fig. 15), indicating that current legislation on setpoint temperature should be increased to satisfy occupants. However, in the Pantelleria case study, the PMV of the BC is always higher due to solar heat gains through the windows. Specifically, while in BC the PMV was higher than -0.5 after 12:00, in other scenarios this occurred around 16:00 due to the heat wave lag heating the surfaces. On July 30th (during working hours the PMV was always within the threshold of -0.5 to 0.5, ensuring the percentage of dissatisfied occupants was always lower than 10%. In this case, as expected, the PMV during slat use was also higher in the BC, even though differences were a maximum of 0.06.

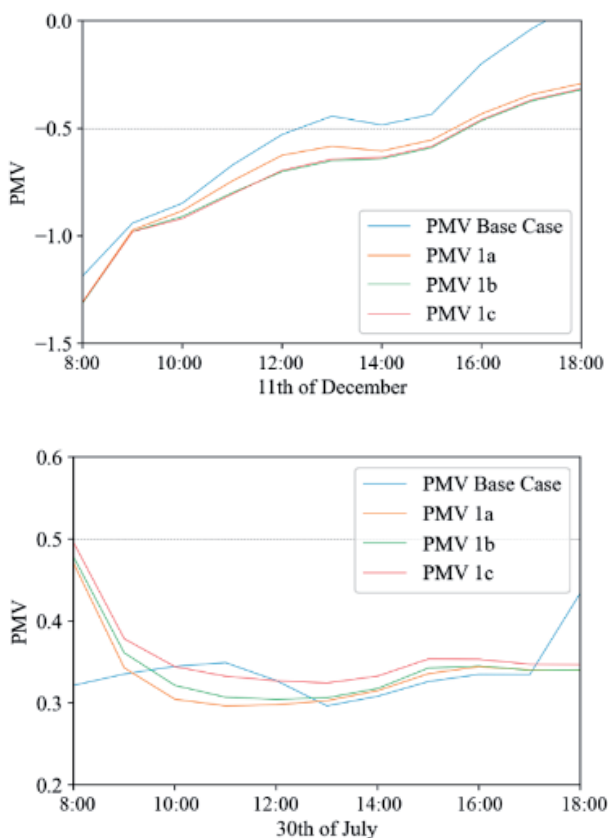


Fig. 15. PMV trend in the Pantelleria case study for a winter (above) and a summer (below) day

4.3 Scenario 2: Use of roller blinds

In Scenario 2, the influence of the roller blinds was explored using five distinct EnergyPlus model simulations. To do this, 5 simulations were run by considering respectively the shading with shades at 0%, 20%, 40%, 60%, and 80%. Results of each simulation were used to identify, for each hour, the percentage of closure of the shading system that avoided visual discomfort. This methodology allows for an examination of factors such as hourly illuminance and solar radiation through the windows, despite not being capable of simulating in detail heating and cooling demands, which are influenced by factors such as air or building inertia.

In Fig. 16 and Fig. 17, a comparison between BC and Scenario 2 during working hours is shown, focusing on heat gain through windows and illuminance. In Palermo case study (Fig. 16) illuminance in BC reached up to 5000 lux in the desks on the winter day and, conversely to Scenario 1, thanks to a shading covering between 60% and 80% of the windows it was possible to reduce visual discomfort still maintaining natural daylight achieving around 1000 lux. The highest reduction of solar radiation is also achieved on the winter day, due to the presence of the shelter. In summer, as the main contribution to solar gain is related to the diffuse radiation, this reduction was lower. For the Pantelleria case study (Fig. 17), the illuminance of around 6000 lux is encountered on the desks in winter. However, the highest solar radiation through windows and the illuminance values are up to 0.6 kW and 37000 lux, respectively, in summer. This is because the windows are not covered by a shelter (as in the Palermo case study space). Shadings effectively activate from 20 to 80%, ensuring illuminance due to natural light both in winter and summer. It, as detailed in the next section, can reduce the need for artificial light, proving that optimal shading control can be crucial. However, the shadings almost entirely cover the window to reduce illuminance on the desks for most of the time and potentially cause visual discomfort due to the coverings.

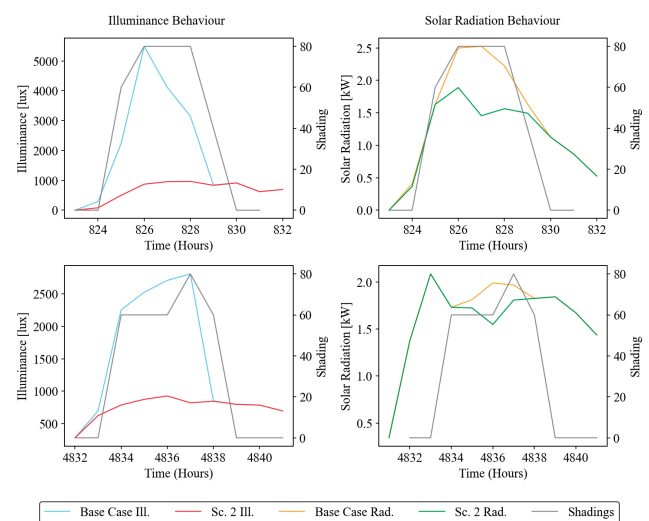


Fig. 16. Analysis of roller blind impact during typical winter (above) and summer (below) days for the Palermo case study.

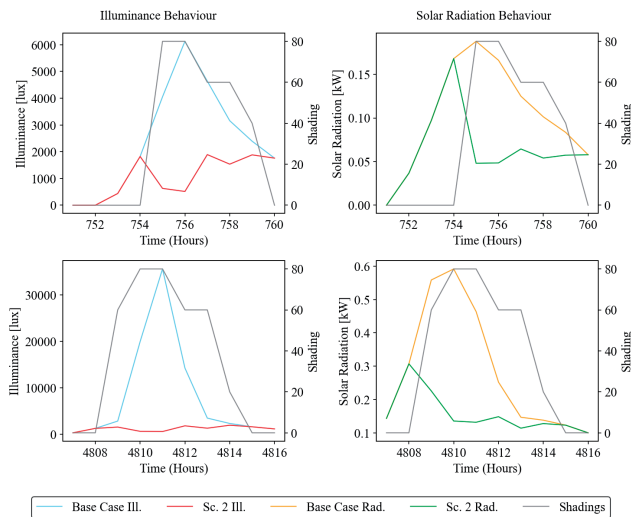


Fig. 17. Analysis of roller blind impact during typical winter (above) and summer (below) days for the Pantelleria case study.

4.4 Yearly evaluation of building energy and lighting conditions

To evaluate the efficacy of the proposed solutions and methodology for accurate shading system control, the possible visual discomfort occurrence was assessed and compared across different scenarios. As said, a threshold of 2000 lux was chosen as the upper limit for UDI causing visual discomfort. The results in **Table 5** demonstrate the effectiveness of the examined methods in mitigating visual discomfort at all workplanes for both case studies. Specifically, in the BC scenario for the Palermo case study, despite the existing shading shelter, illuminance exceeded the threshold for 900 hours annually (10.27% of the year); during work periods, this represented 20% of the time. All scenarios successfully eliminated visual discomfort in desk positions, except Scenario 1c, which only reduced this percentage to below 0.2%. This finding indicates that, for the geometry considered, the 60° inclination could still provide visual discomfort. Similarly, for the Pantelleria case study, visual discomfort was eliminated in all scenarios except Scenario 1c, as Palermo and Pantelleria have similar latitudes, resulting in similar sunray directions. However, it is noteworthy that the shelter in the Palermo case study reduced visual discomfort. In Pantelleria, even though the windowed surface is reduced compared to the Palermo case study, excessive values of illuminance could occur in desk positions for 1910 hours annually. Considering only working hours, this translates to a 47% possibility of visual discomfort at least one desk. However, as mentioned, this issue was eliminated with the proposed solution, with Scenario 1c resulting in excessive values of illuminance only 0.3% of the time.

According to the aim of this paper, once the influence of the shading systems on visual comfort was, the heating and cooling demands were analyzed.

Table 5. Analysis of excessive illuminance value occurrences across scenarios

	Base Case	Sc. 1a	Sc. 1b	Sc. 1c	Sc. 2
Palermo case study					
Visual Discomfort Hours	900	0	0	9	0
Yearly	10.27%	0.00%	0.00%	0.10%	0.00%
Work period	20.21%	0.00%	0.00%	0.22%	0.00%
Pantelleria case study					
Visual Discomfort Hours	1910	0	0	10	0
Yearly	21.80%	0.00%	0.00%	0.11%	0.00%
Work period	46.88%	0.00%	0.00%	0.28%	0.00%

For the BC, as well as Scenarios 1a, 1b, and 1c, heating and cooling energy demand could be calculated using EnergyPlus. However, Scenario 2a calculations require post-processing of five different simulation results. It makes it impossible to precisely estimate real heating consumption. This is because each simulation includes parameters dependent on the thermal inertia of air and the building. Therefore, **Table 5** focuses on solar gains through windows and lighting consumption. When slats in Scenario 1 entirely cover the windows, heat gain is reduced in winter from 1862 kWh in the BC to 735 kWh in Scenario 1a. Similarly, solar heat gains in summer are reduced depending on the scenario, from 7% to 29%, leading to a possible reduction in cooling energy demand. In the Palermo case study, it is interesting to evaluate how the increase in lighting electric consumption due to shadings is only 1.13 times higher, thanks to the modulation of Scenario 2 roller blinds. Scenario 1 solutions require higher consumption as they entirely cover the window, ranging from 2 to 1.7 times the BC consumption. In the Pantelleria case study, similar behavior was noted (**Table 6**). However, while in the Palermo case study winter solar heat gains reduced from 60.5% in Scenario 1a to 26.4% in Scenario 2, in the Pantelleria case study, this reduction is higher, varying from 75.9% to 47%, respectively. Additionally, it must be noted that the use of shadings could also be useful for reducing cooling consumption in the summer period. The solar gains are reduced from 7% to 29% in the Palermo case study in the summer period, while in the Pantelleria case study, the reduction could reach 77% in Scenario 1a. However, in this scenario, lighting consumption increases by a factor of 4.9 as the slats are vertical and entirely cover the window. An interesting trade-off was noted in Scenario 2. The solar gains in the Pantelleria case study during summer were 106.2 kWh (less than the BC), while lighting consumption for the whole year increased by only 9.6 kWh.

Table 6. Comparison of solar gain and lighting consumption among scenarios

Yearly Results [kWh]	Base Case	Sc. 1a	Sc. 1b	Sc. 1c	Sc. 2
Palermo case study					
Winter S.G.	1862.1	735.3	822.6	964.8	1370.4
Summer S.G.	1904.5	1354.7	1443.3	1504.7	1763.6
Lighting	154.3	306.2	306.2	268.6	175.4
Pantelleria case study					
Winter S.G.	123.5	29.8	48.5	65.6	65.3
Summer S.G.	253.2	57.7	98.3	129.8	147.0
Lighting	34.1	168.7	114.5	78.6	43.7

5. Discussion

In this work, visual comfort and energy efficiency were analyzed in two Southern Italian case studies. Through the proposed approach, visual comfort should be significantly improved. Indeed, excessive illuminance (>2000 lux) was avoided throughout all the working hours. Exception for the case of Scenario 1c (60° slats), where discomfort was still reduced significantly. Compared to slats, the use of roller blinds maintained daylight illuminance around 1000 lux, while still eliminating the risk of glare. From an energy perspective, slatted blinds scenarios led to an increase in heating energy consumption due to reduced solar gains in winter. This reach up to 48% in Palermo case study and 120% in Pantelleria case study compared to BC. Conversely, cooling demands decreased by up to 32% in Palermo case study and nearly 30% in Pantelleria case study. Peak thermal demands were relatively unchanged. Roller blinds provided an acceptable compromise, substantially limiting lighting energy increases to just 14–28%.

This study expands previous literature examining widely used shading systems and their effects on energy performance and occupant comfort. Recent research primarily investigated advanced glazing technologies, such as electrochromic or thermochromic solutions, under various climates, predominantly non-Mediterranean. For instance, Shi et al. [21] assessed thermotropic glazing performance in multiple Chinese cities achieving building energy saving up to 16.3%. The experimental test conducted by Nundi and Ghosh [22] with vacuum glazing offered a comfortable colour rendering index of 94.83. However, using roller shutters, less analyzed in literature, led in the Pantelleria case study to a 41.9% reduction in summer solar gains. Additionally, few studies comprehensively address both visual and thermal comfort simultaneously. Rabani et al. [30] and Phuong et al. [33] introduced dynamic shading strategies; however, these studies were limited to non-Mediterranean contexts. The current study addressed these gaps by proving the benefits of shading

control systems for thermal and visual comfort behaviour. In particular, in both the analysed case studies and using shadings, illuminance was successfully maintained below the 2000 lux threshold and the PMV in the summer period was reduced.

The findings highlight that both the improvement of the occupant well-being and the potential energy saving can be achieved. The modular roller blind strategy emerged as particularly effective, offering a balance between maintaining adequate natural daylight and limiting solar heat gains. Fully closed slat configurations, notably increased artificial lighting demand. Additionally, the results show that occupant comfort is only minimally affected by slat angle positioning, especially under Mediterranean solar conditions. The main strengths of this research include the realistic analysis conducted in two occupied case studies, integrating multiple software tools (SketchUp, Energy-Plus, Python) to improve the simulation capabilities. The consideration of multiple occupant workplanes provides detailed insights into occupant-centric comfort conditions, enhancing practical relevance. Furthermore, assessing thermal, visual, and energy outcomes simultaneously offers a comprehensive evaluation.

This study, however, faces some limitations. First, both case studies lie in the same Mediterranean climate zone; testing the methodology in other Mediterranean sub-climates would better clarify the impact of the shading strategies. Second, thermal comfort was estimated only with a widely used PMV index. Incorporating adaptive or more novel metrics would yield to better estimation of occupant perception. Third, the visual analysis focused on horizontal illuminance, omitting uniformity and glare indices that capture spatial quality but require more intricate modelling. Bridging these limitations would provide a more complete view of the effects of the proposed strategies.

6. Conclusion

This research addresses the critical issue of exploring the trade-off between thermal and visual comfort and energy consumption. The analysis was applied to two different case studies in Southern Italy: the Palermo case study of the Engineering Department of the University of Palermo, and the meeting room of the Pantelleria case study. The analyses reported in this manuscript were performed by using a combination of different tools: Sketchup, Euclid, Python, and Energy+. The presented methodology considered, first, results obtained by BC simulations to create custom schedules through Python, which were used to effectively control shading systems.

Additionally, an approach to simulate the behavior of roller blind control was also presented. For identifying possible visual discomfort issues, different points in the room, on desks close to the windows, were considered for the illuminance simulations. For the Palermo case study, the analysis was made in three different points of the room, where the workplanes were located, and for two in the Pantelleria case study. Five different scenarios for each case study were considered. Results show that in all sce-

narios, there are no visual discomfort issues in desk positions, with Scenario 1c being the exception since it only reduced this percentage below 0.3% in both case studies. Furthermore, using a shading system, the heating demand increases even if the presence of high illuminance values was notably reduced. In the Palermo case study, the cooling thermal demand decreased up to 11%, but heating increased by 48% compared to BC. Indeed, the presence of the shelter in summer led to minimal cooling savings. For the Pantelleria case study, comparing Scenario 1b with the BC, heating demand increased up to 142 kWh while cooling thermal demand was reduced to 168 kWh.

Although adjusting the angle of the slats was feasible, the effectiveness of this adjustment heavily relies on the sun position, and its hourly scheduling is limited by the character and text limit for EnergyPlus schedules. For this reason, using a fixed slat angle results in a substantial decrease in desk illuminance and a consequent more frequent reliance on artificial lighting systems. Scenario 2 considers using modularly adjusted roller blinds. For this reason, the electrical demand for lighting systems differs from the BC by 14% and by 28% in the Palermo case study and the Pantelleria case study, respectively.

The methodology proposed is useful for simulating the effects of two different shading devices. Moreover, it can be used to implement new control strategies extending EnergyPlus possibilities (i.e., roller shutter is not available in the included shading systems library). Moreover, the Python script developed was used to create a new shading schedule based on the illuminance monitored in three different workplanes. The findings of this research could be valuable for architects, engineers, and environmental designers, offering insights into the complexities of creating energy-efficient, comfortable, and sustainable indoor spaces. Furthermore, this analysis can be used as input to design building automation control systems and to develop control strategies.

Acknowledgements

The study presented part of the result of a collaboration between ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) and the DII (Department Engineering) of the University of Palermo in the framework of the “Studio di fattibilità di soluzioni per l’efficientamento energetico delle Isole Minori” Innovazioni impiantistiche per climatizzazione, illuminazione e ACS nelle isole minori” Italian scientific research project. Furthermore, this work partially received funding by European Commission - Next Generation EU - PNRR M4 - C2 -investimento 1.1: Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN) - PRIN 2022 cod. 2022YWW9B8 “Study for a tool for DEsign, COntrol and COMmissioning of Lighting Control systems, Finanziamento PRIN 2022 bando D.D. n. 104 del 02-02- 2022. CUP: B53D23006660006.

References

- [1] Santamouris, M., & Vasilakopoulou, K. (2021). Present and future energy consumption of buildings: Challenges and opportunities towards decarbonisation. *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, 1, 100002.
- [2] Bashir, M. T., Khan, A. B., Khan, M. M. H., Rasheed, K., Saad, S., & Farid, F. (2024). Evaluating the implementation of green building materials in the construction sector of developing nations. *Journal of Human, Earth, and Future*, 5(3), 528542.
- [3] Salameh, M., & Touqan, B. (2024). Designing Climate Adaptive Buildings: Impact of Courtyard Geometry on Microclimates in Hot, Dry Environments. *Civil Engineering Journal*, 10(8), 26982718.
- [4] Marwan, M., Hamdani, H., Purwito, P., Aksan, A., Thahir, M., Ruslan, L., ... & Pangkung, A. (2024). Temperature Control Strategy to Mitigate Electrical Energy Cost for Air Conditioning. *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, 7, 100410.
- [5] Kuhn, T. E. (2017). State of the art of advanced solar control devices for buildings. *Solar Energy*, 154, 112133.
- [6] Mainini, A. G., Bonato, D., Poli, T., & Speroni, A. (2015). Lean strategies for window retrofit of Italian office buildings: Impact on energy use, thermal and visual comfort. *Energy Procedia*, 70, 719728.
- [7] Lotfabadi, P., & Hançer, P. (2023). Optimization of visual comfort: Building openings. *Journal of Building Engineering*, 72, 106598.
- [8] Day, J. K., Futrell, B., Cox, R., Ruiz, S. N., Amirazar, A., Zarrabi, A. H., & Azarbayjani, M. (2019). Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies. *Building and Environment*, 154, 107121.
- [9] Bueno, B., CejudoLópez, J. M., Katsifaraki, A., & Wilson, H. R. (2018). A systematic workflow for retrofitting office façades with large window to wall ratios based on automatic control and building simulations. *Building and Environment*, 132, 104113.
- [10] Detsi, M., Manolitsis, A., Atsonios, I., Mandilaras, I., & Founti, M. (2020). Energy savings in an office building with high WWR using glazing systems combining thermochromic and electrochromic layers. *Energies*, 13(11), 118.
- [11] He, Q., Ng, S. T., Hossain, M. U., & Skitmore, M. (2019). Energy efficient window retrofit for highrise residential buildings in different climatic zones of China. *Sustainability*, 11(22), 118.
- [12] Shum, C., & Zhong, L. (2023). A review of smart solar shading systems and their applications: Opportunities in cold climate zones. *Journal of Building Engineering*, 64, 105583.
- [13] de Araujo Passos, L. A., van den Engel, P., Baldi, S., & De Schutter, B. (2023). Dynamic optimization for minimal HVAC demand with latent heat storage, heat recovery, natural ventilation, and solar shadings. *Energy Conversion and Management*, 276, 117383.
- [14] Suzuki, E. H., Lofrano, F. C., Kurokawa, F. A., Prado, R. T., & Leite, B. C. (2022). Decisionmaking process for thermal comfort and energy efficiency optimization coupling smartwindow and natural ventilation in the warm and hot climates. *Energy and Buildings*, 266, 112027.

- [15] Alaoui, A. L., Amrani, A. I., Merrouni, A. A., Salhi, J. E., Boulerhcha, O., Daoudia, A., ... & Halimi, M. (2023). Thermal and energy efficiency study of passive heating and cooling systems in Morocco's cold desert climate. *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, 6, 100355.
- [16] Dlimi, M., Agounoun, R., Kadiri, I., Saadani, R., & Rahmoune, M. (2023). Thermal performance assessment of double hollow brick walls filled with hemp concrete insulation material through computational fluid dynamics analysis and dynamic thermal simulations. *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, 3, 100124.
- [17] Xie, J., & Sawyer, A. O. (2021). Simulation-assisted data-driven method for glare control with automated shading systems in office buildings. *Building and Environment*, 196, 107808.
- [18] Ayoub, M. (2018). Integrating illuminance and energy evaluations of cellular automata controlled dynamic shading system using new hourly-based metrics. *Solar Energy*, 170, 336351.
- [19] Sorooshnia, E., Rashidi, M., Rahnamayiezekavat, P., Mahmoudkelayeh, S., Pourvaziri, M., Kamranfar, S., ... & Moezzi, R. (2023). A novel approach for optimized design of lowE windows and visual comfort for residential spaces. *Energy and Built Environment*, 4, 100083.
- [20] Rizi, R. A., & Eltaweel, A. (2021). A user detective adaptive facade towards improving visual and thermal comfort. *Journal of Building Engineering*, 33, 101619.
- [21] Shi, F., You, Y., Yang, X., & Hong, X. (2024). Annual evaluation of the visual thermal comfort and energy performance of thermotropic glazing in a reference office room of China. *Building and Environment*, 247, 111378.
- [22] Nundy, S., & Ghosh, A. (2020). Thermal and visual comfort analysis of adaptive vacuum integrated switchable suspended particle device window for temperate climate. *Renewable Energy*, 156, 13611372.
- [23] Dussault, J. M., & Gosselin, L. (2017). Office buildings with electrochromic windows: A sensitivity analysis of design parameters on energy performance, and thermal and visual comfort. *Energy and Buildings*, 153, 5062.
- [24] Li, W., Shah, K. W., & Li, Y. (2023). Effects of electrochromic glass window on energy efficiency, thermal and visual performances under tropical climate. *Energy for Sustainable Development*, 76, 101300.
- [25] Anees, A. S., Ahmad, S., Lone, R. A., & Ganie, Z. A. (2024). Innovative Solutions for Sustainable Space Heating: Integrating Solar Air Heaters and LowCost Retrofitting Windows for Hilly Region of Kashmir. *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, 100872.
- [26] Khosravi, M., Huber, B., Decoussemaeker, A., Heer, P., & Smith, R. S. (2024). Model Predictive Control in buildings with thermal and visual comfort constraints. *Energy and Buildings*, 306, 113831.
- [27] Yang, S., Wan, M. P., Ng, B. F., Dubey, S., Henze, G. P., Chen, W., & Baskaran, K. (2021). Model predictive control for integrated control of airconditioning and mechanical ventilation, lighting and shading systems. *Applied Energy*, 297, 117112.
- [28] Shum, C., & Zhong, L. (2023). Optimizing automated shading systems for enhanced energy performance in cold climate zones: Strategies, savings, and comfort. *Energy and Buildings*, 300, 113638.
- [29] Lee, S. J., & Song, S. Y. (2023). Energy efficiency, visual comfort, and thermal comfort of suspended particle device smart windows in a residential building: A fullscale experimental study. *Energy and Buildings*, 298, 113514.
- [30] Rabani, M., Madessa, H. B., & Nord, N. (2021). Achieving zeroenergy building performance with thermal and visual comfort enhancement through optimization of fenestration, envelope, shading device, and energy supply system. *Sustainable Energy Technologies and Assessments*, 44, 101020.
- [31] Baghoolizadeh, M., RostamzadehRenani, M., RostamzadehRenani, R., & Toghraie, D. (2023). Multiobjective optimization of Venetian blinds in office buildings to reduce electricity consumption and improve visual and thermal comfort by NSGAI. *Energy and Buildings*, 278, 112639. (2024).
- [32] Chohan, A. H., Awad, J., Ismail, M. A., & Arar, M. S. (2024). Integrating Technology and Heritage Design for Climate Resilient Courtyard House in Arid Region. *Civil Engineering Journal*, 10(3), 928952.
- [33] A simulation-based workflow to calculate overall thermal transfer value when implementing daylighting-oriented shading control. *Journal of Building Engineering*, 108616. <https://doi.org/10.1016/j.job.2024.108616>
- [34] EnergyPlus. (2024, December). Retrieved from <https://energyplus.net/>
- [35] Tsay, Y. S., Yeh, Y. C., & Jheng, H. Y. (2023). Study of the tools used for early-stage carbon footprint in building design. *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, 4, 100128.
- [36] UNI/TS 11300-1:2014. (2014). *Prestazioni energetiche degli edifici - Parte 1: Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale*.
- [37] Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings*, 38(7), 905913.
- [38] UNIEN 12464-1. (2021). *Luce e illuminazione - Illuminazione dei posti di lavoro - Parte 1: Posti di lavoro in interni*.
- [39] ISO 7730. (2005). *Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*.