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Original Research Article

Optimising the Design of Solar Photovoltaic Cantilevers on Building Façades to Enhance Energy Efficiency

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ABSTRACT

In dense urban areas, limited available space constrains the deployment of renewable energy systems, motivating alternative solutions. Solar photovoltaic cantilevers on building façades offer a promising approach, generating electricity and shading that enhance building energy efficiency. A methodology is proposed to determine the optimal tilt angle, considering both electricity generation and shading-related energy savings. The method is applied to a university building in a Mediterranean climate to evaluate performance under realistic conditions. Results indicate that the optimal photovoltaic cantilever reduces cooling demand by 7% and increases heating demand by 5%, supplies 14% of the building's electricity with a 4% surplus, and can reduce overall electricity consumption by 16–20%. Although focused on a specific case, the findings support broader applications of this approach and highlight its potential as a spatially efficient strategy for advancing energy sustainability in urban buildings.

KEYWORDS

Renewable Energy, Solar Photovoltaic Cantilevers, Building Façades, Building Energy Efficiency, Energy Simulation, Urban Sustainability, Decarbonisation of Cities.

INTRODUCTION

Climate change has emerged as one of the most pressing global challenges in recent years, particularly in cities [1]. Consequently, transitioning to more sustainable electricity production systems is necessary. Solar photovoltaics (PV) have become a widely adopted technology for

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generating clean, locally produced electricity [2]. Although rooftop solar PV systems have been widely implemented and shown to be effective, available space is often limited. Gómez Navarro et al. [3] analysed the potential for rooftop PV production in Valencia, considering technical, economic, and environmental factors, and highlighted constraints related to roof availability. Slootweg et al. [4] examined the geographical potential of rooftop PV systems, identifying space competition with other urban amenities, swimming pools, terraces, and green roofs.

The exploration of alternative spaces for integrating solar PV technology within urban environments has gained increasing attention, with a particular focus on building façades. Freitas and Brito [5] reviewed the potential of solar façades in cities, discussing design strategies, technological options, and their role in increasing on-site renewable generation in dense urban areas. Polo et al. [6] assessed the feasibility of photovoltaic generation on vertical façades using satellite-derived solar resource data, demonstrating the applicability of this approach for estimating façade energy yield in urban contexts.

Temiz and Dincer [7] proposed building-integrated solar canopies as part of a multi-generation system coupled with hydrogen production and storage, highlighting their contribution to building energy self-sufficiency. Deshmukh and Pearce [8] evaluated photovoltaic awnings over parking areas, showing their potential to support electric vehicle charging. Sánchez et al. [9] analysed photovoltaic systems under non-optimal orientations, demonstrating that canopy-type structures can still provide significant energy yields. Xiang and Matusiak [10] investigated cantilevered façade-integrated photovoltaics for high-rise buildings, examining the balance between daylight, aesthetic quality, and energy production. Soni and Bhagat Singh [11] documented the implementation of a net-zero energy building with cantilevered PV elements, illustrating their practical contribution to high energy performance.

Previous studies have typically examined the active and passive components separately. Biyik et al. [12] reviewed BIPV systems, emphasising passive energy savings through shading and façade integration. Singh et al. [13] highlighted the role of building-applied and integrated PV in improving building energy performance through passive and active strategies. Ghosh [14] analysed adaptive BIPV skins that reduce energy demand while maintaining thermal comfort. Zhang et al. [15] focused on photovoltaic-integrated shading devices (PVSDs), showing their capacity to combine electricity generation with passive cooling benefits.

Regarding active energy generation, Zhang et al.[16] investigated bifacial PV façades, considering factors that affect electricity production and life cycle performance. Kant Paliwal et al. [17] mapped research trends in BIPV systems, identifying key advances supporting electricity self-consumption. Liu and Duan [18] evaluated BIPV energy efficiency under different power configurations, quantifying potential electricity production for buildings.

While some studies have examined active and passive components individually, to the authors' knowledge, no methodology has yet been proposed to optimise the arrangement of solar PV cantilevers that simultaneously maximises electricity self-consumption and enhances energy efficiency by reducing cooling demand through their shading effect, i.e., by considering both active and passive components (see **BACKGROUND AND RESEARCH GAP**).

Building on this gap, the present research addresses the dual objective of balancing the combined effects of active self-consumption and passive energy savings in the design of PV cantilever integration to maximise the energy efficiency of buildings. To this end, a methodology is proposed to determine the optimal tilt angle of solar PV cantilevers on façades. To illustrate its applicability, the method is tested on the Faculty of Fine Arts building at the Polytechnic University of Valencia (Spain), located in a Mediterranean climate, providing a detailed and replicable guide for practical implementation.

The study is structured as follows: **Background and Research Gap** describes the context of this research and formulates the research question. **Material and Methods** outline the methodology used, while **Case Study** presents the specific application and its inputs. **Results**

and Discussion analyse the findings of this study, and **Conclusion** summarises the key outcomes, policy implications, and directions for future work.

BACKGROUND AND RESEARCH GAP

The integration of solar PV panels on building façades can fall under the categories of Building Attached Photovoltaic (BAPV) and Building Integrated Photovoltaic (BIPV) technologies [19]. BAPV involves the installation of solar PV technologies on the external surfaces of existing buildings, whereas BIPV refers to the direct integration of solar PV technologies into the building envelope and architectural design.

The integration of BIPV/BAPV technologies with building envelopes has gained significant attention since the early 1990s as a viable solution to contribute to building energy demands and alleviate peak electrical loads. Biyik et al. [12] presented a detailed assessment of BIPV system configurations, performance parameters, and the technical and economic barriers limiting wider deployment. Singh et al. [13] examined technological progress in both applied and integrated photovoltaic systems, emphasising developments in materials, system efficiency, and environmental performance. Ghosh [14] analysed the potential of integrated and attached photovoltaic systems as adaptive building skin solutions, highlighting their capacity to reduce energy demand while enhancing façade functionality.

Among these applications, solar PV cantilevers are classified as a type of façade shading device (FSD) for buildings, specifically as either inclined single panels or inclined multiple panels, depending on whether a single row or multiple rows of panels are installed on the façade [15].

The factors that most influence the performance of solar PV on façades as cantilevers include the angles of orientation and tilt of the PV panels, as well as shading effects on both the panels and the building. Zhang et al. [16] conducted a factor influence analysis combined with life cycle assessment for bifacial photovoltaic systems applied to building façades, demonstrating how orientation, tilt configuration, and façade integration conditions affect both energy yield and environmental performance. Kant Paliwal et al. [17] provided a bibliometric and scientific mapping of research trends in building integrated photovoltaic systems, identifying orientation optimisation, façade integration strategies, and performance assessment as central and evolving research themes. Liu and Duan [18] valuated the energy efficiency of BIPV systems under different configurations, highlighting the influence of system design and electrical layout on overall performance outcomes. Hussein et al. [20] experimentally evaluated PV module performance under different tilt angles and orientations, demonstrating the strong dependence of electrical output on geometric configuration and solar incidence conditions. Their findings confirm the importance of façade orientation and inclination in optimising energy production. In façade-mounted cantilever configurations, these geometric parameters directly influence electrical generation efficiency and also modify the building's thermal requirements through shading effects, thereby affecting overall energy performance.

Angles in Solar Photovoltaic Cantilevers on Building Façades

To describe the angles in solar PV cantilevers, a precise representation can be carried out, taking into account four angles: azimuth (α) and tilt (β) to reference the PV systems, and solar azimuth (αs) and solar elevation (γs) to reference the sun trajectory and the interaction with the solar PV cantilevers set as a reference point. These angles are used in the mathematical formulation, modelling, design, and optimisation of solar PV. Several studies can be consulted in the literature using this nomenclature e.g Yunus Khan et al. [21] investigated the optimal location and tilt angle for solar PV panels, showing how panel orientation directly affects energy yield. Hannoudi et al. [22] studied the impact of glass properties on energy efficiency in multi-angled façade systems, highlighting how angle selection interacts with material characteristics to influence overall performance. Chang [23] analysed the sun's apparent position to determine optimal tilt angles in the northern hemisphere, providing foundational correlations for angle calculations. Talebizadeh et al. [24] proposed new correlations to determine optimum slope angles for solar collectors, emphasising the importance of angle adjustments for maximising solar capture. Abdelaal et al. [25] experimentally verified the optimal tilt angles for PV panels in Egypt, confirming that proper inclination significantly improves energy generation.

Its graphical representation can be seen in Fig. 1, where: i) PV Azimuth (α) is the compass direction to which a PV array is oriented. ii) PV Tilt (β) denotes the angle of inclination of a PV array relative to the horizontal plane. iii) Solar azimuth (αs) refers to the compass direction from which sunlight reaches a specific point on the Earth's surface. This angle determines the orientation of the sun in the sky, and iv) Solar elevation (γs) depicts the sun's altitude above the horizon at a given location and time.

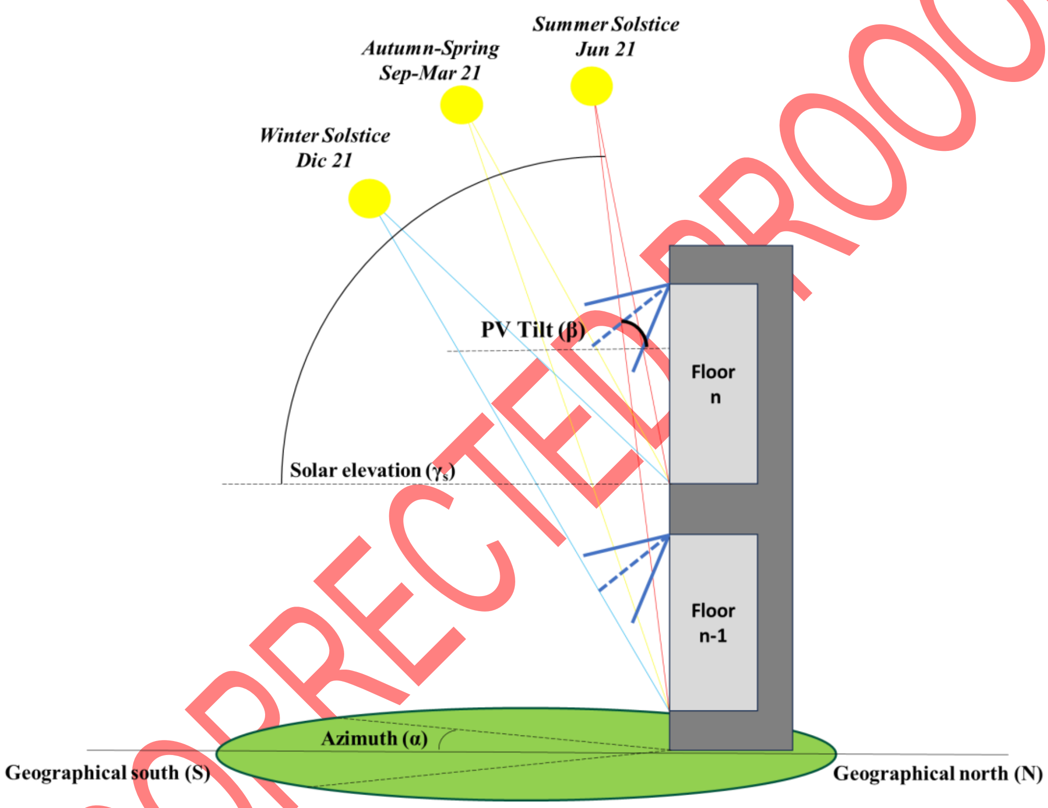

Fig. 1 Graphical representation of the angles involved in the solar interaction with the photovoltaic cantilever systems on the façade and the building. Author elaboration.

While αs and γs describe the sun's trajectory, α and β are necessary for aligning solar panels optimally to maximise irradiation exposure. Optimal α (αop) is primarily influenced by the geographic location in the hemisphere, typically oriented towards geographical north or south [26]. However, when implementing solar PV cantilevers on façades in urban areas, α often deviates from the cardinal points due to the diverse orientations of buildings. Hence, α is largely constrained by the wall's orientation, leaving minimal or no flexibility for adjustments. For this reason, β represents the variable where there is room for manoeuvre and was the focus of this examination.

While optimal β (βop) is widely discussed in the literature, it depends on the optimum sought [15]. βop can be selected to maximise the annual, summer, winter, seasonal, or specific daily energy production. Gaiddon et al. [27] highlighted lessons from large-scale urban PV projects, showing how seasonal and monthly energy yields can guide tilt selection. Boxwell

[28] provided practical guidance on choosing βop for specific periods, such as summer, winter, or individual days, emphasising the need to adapt tilt angles to the intended energy outcome. For a practical implementation, β can be estimated by using the formulas (1), (2), (3) for the specific case where "θ" represents the latitude of the place under examination [29].

$$\beta op\_annual \approx \text{Latitud}\ (\theta) \quad (1)$$

$$\beta op\_winter \approx \theta + 15.6° \quad (2)$$

$$\beta op\_summer \approx \theta - 15.6° \quad (3)$$

However, these formulas should be considered as an initial approximation. For more accurate results, correlations can be developed through experimental methods, utilising data from meteorological stations alongside computational tools and mathematical modelling, as suggested in previously presented studies [23,24]. Furthermore, this process also includes evaluating the influence of the specific climatic and topographical conditions of the studied areas, as recommended by Jacobson et al. [30].

This underscores the importance of accounting for site-specific factors, including local climate, when determining the most suitable β for a given location. While latitude serves as a baseline reference, βop is dynamic and requires careful consideration of each installation site's unique characteristics.

Shades in Solar Photovoltaic Cantilevers on Building Façades

On the other hand, the presence of shadows generated by solar PV cantilevers can influence two relevant aspects. First, the active component is due to the electricity produced by the PV system that may be used directly by the building (self-consumption). Second, the passive component, associated with potential energy savings due to shading on the building envelope, which may reduce cooling demand [16].

Shadows affecting PV generation are categorised into two types: external and self-shading. External shading refers to shadows cast on solar modules by objects outside the solar PV cantilevers, such as buildings, trees, or other structures, impacting the system's sunlight exposure [31]. Self-shading (own shadows) occurs when components within the solar PV cantilevers cast shadows on other parts of the same system, obstructing sunlight and potentially reducing electrical generation [32]. In addition, the self-shading cast by the solar PV cantilevers onto the building can reduce solar heat gain, which can lower cooling demand and contribute to energy savings, especially in warm climates or during summer [16]. The latter is of particular interest in this study, as it may introduce additional shading on the building, potentially influencing its overall energy efficiency. Fig. 2 provides a graphical representation of the shadows cast by solar PV cantilevers, illustrating two tilt configurations (β): panel a) a case where self-shading affects the PV system while also contributing to reduced cooling demand in summer, and panel b) a case where self-shading falls solely on the building envelope, offering passive cooling benefits without compromising PV electricity generation.

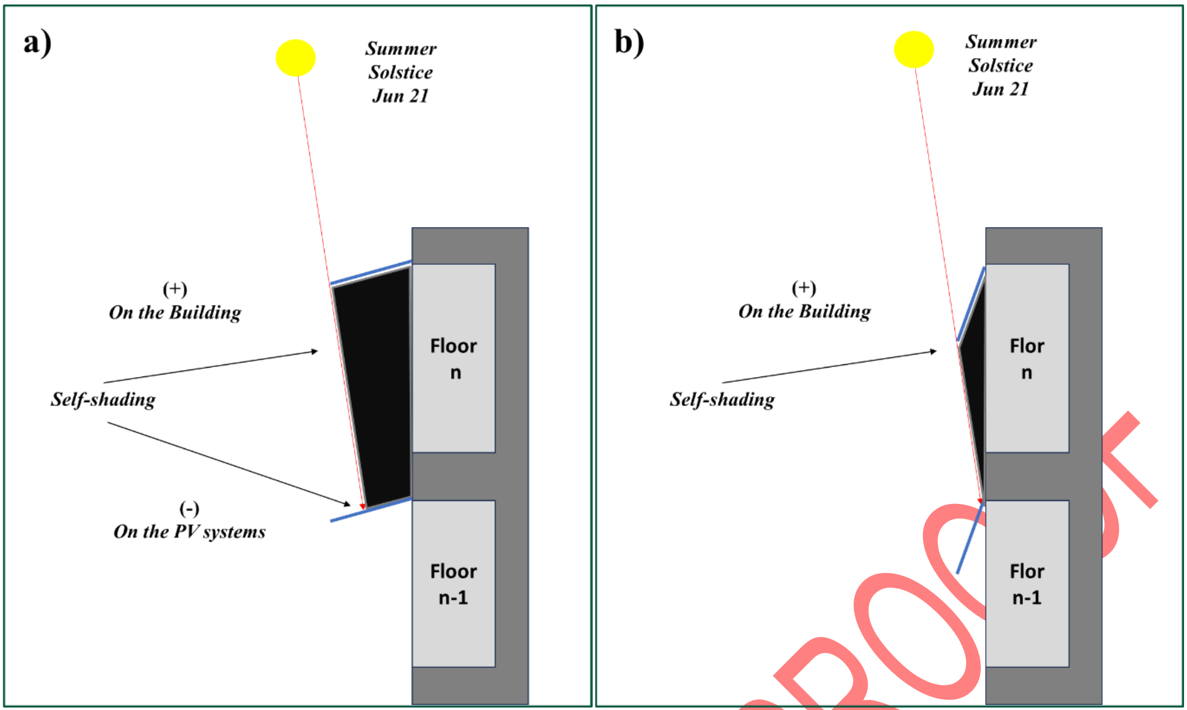

Fig. 2 Graphical representation of the solar photovoltaic cantilever shades. Examples for two different tilts. a) Self-shading on the photovoltaic system and the building. b) Self-shading only on the building envelope.

To simulate the interaction of these multiple variables over time, advanced simulation can serve as a valuable tool for developing and analysing such dynamic models. Addressing shadows in solar PV cantilevers requires a site-specific analysis that considers the geographical location, the surrounding environment, and potential shading sources. Woyte et al. [32] reviewed partial shading effects on photovoltaic arrays across different system configurations, combining literature and field test results to highlight how shading impacts electrical output. Chepp et al. [33] proposed a methodology for predicting and assessing shading on PV systems, emphasising the role of site-specific modelling in accurately estimating performance losses. Ahmad et al. [34] presented an analytical approach supported by literature to study partial shading effects on PV arrays, providing insights into how shading patterns influence energy generation and system efficiency.

Advanced PV energy assessment studies aims to mitigate the considerable impacts of shadows on solar electrical generation. Fialho et al. [35] analysed the effects of shading on series-connected solar modules through simulation and experimental testing, showing how partial shading can significantly reduce output. Gallardo-Saavedra et al. [36] conducted simulation, validation, and analysis of shading effects on a PV system, demonstrating the importance of accurate modelling for performance prediction. Eke et al. [37] evaluated shading effects on two identical PV systems installed on a building façade, highlighting the influence of shadows on energy ratings and overall system efficiency. To evaluate the impact of shadows on a building's thermal performance, building energy simulation tools can model the building under defined conditions, considering variables such as occupancy, climate, building orientation, thermal properties of the envelope, and some tools allow for calibrating the model to real consumption values of the building [38].

Research Gap Identification

The review on solar PV cantilever installations highlights key advances and identifies gaps that motivate the present study. Although vertical PV façades have been implemented and their energy and comfort benefits explored, few studies address PV cantilever configurations, particularly quantifying the combined effects of active electricity generation and passive shading, while complementary design considerations for optimising these systems in buildings remain limited.

First, vertical PV façades, while increasingly applied, have rarely been implemented as cantilevers—a configuration that remains relatively unconventional in the literature. Freitas & Brito explored the potential of solar façades in urban environments, highlighting their advantages over traditional rooftop PV systems [5], while Polo et al. developed a method to estimate photovoltaic generation on vertical façades using satellite-derived solar data [6]. Temiz & Dincer assessed integrated solar-hydrogen systems in buildings, demonstrating the potential of façade-mounted PV for sustainable energy supply [7]. Deshmukh & Pearce investigated PV canopies in parking lots, illustrating how building-adjacent PV surfaces can support energy demand [8]. Despite these implementations, PV cantilever configurations remain largely unexplored.

Second, several studies emphasise the energy and comfort benefits of façade PV and shading devices. Zhang et al. [15] reviewed photovoltaic integrated shading devices, analysing their electrical performance and impact on building thermal behaviour. Jelle et al. [39] provided a comprehensive assessment of BIPV systems, highlighting their influence on heating and cooling loads depending on orientation and configuration. Biyik et al.[12] and Singh et al. [13] discussed the performance and applications of BIPV systems. Ghosh studied the potential of how BIPV/BAPV can create adaptive, energy-efficient building skins [14].

Third, very few studies quantify the passive shading benefits of PV cantilevers in numerical terms. Tripathy et.al [40] determined the optimum tilt angle of BIPV panels considering insolation and shading effects, with emphasis on electrical yield. Sánchez et al. studied non-optimal PV orientations in buildings, emphasising the energy potential of façade surfaces beyond ideal angles [9]. Zhang et al. investigated bifacial PV on façades [16], Kant Paliwal et al. mapped trends in BIPV research [17], and Liu & Duan evaluated energy efficiency for different PV system configurations [18]. These studies highlight PV performance, yet the quantitative assessment of energy savings due to shading in buildings remains limited.

Complementary design considerations have been addressed in a few cases. Xiang & Matusiak designed façade-integrated PV systems for high-rise buildings, balancing energy production with daylight and aesthetic considerations [10], while Soni & Bhagat Singh documented a net-zero energy building in India, which included façade PV as part of its integrated energy strategy [11]. Together, these works confirm that PV integration on façades is established, but the specific configuration of cantilevered PV panels, with optimisation of both active electricity generation and passive shading-induced energy savings, remains unaddressed.

This motivates the present study. No methodology has yet been proposed to determine the optimal tilt angle of solar PV cantilevers that maximises both active generation and passive energy savings. Assuming that there is a β that maximises electricity generation (βop_PV) and another β that maximises energy savings due to shading effects (βop_ESS), the research question guiding this study is: *"How can the optimal tilt angle of solar PV cantilevers be determined to maximise both electricity self-consumption and shading-induced energy savings, thereby enhancing overall building energy efficiency?"*

This tilt will be denoted as βop_MaxEE, which represents the target value to be identified. The relevance of this work lies in its combined focus on methodology, practical application, and dual optimisation of energy benefits for building-integrated PV cantilevers, guiding future façade PV design strategies.

MATERIALS AND METHODS

To address this study, the methodology formulated can be seen in Fig. 3. The process begins with an assessment of the candidate building façade. The next step involves determining the

PV cantilever capacity (kWp) by analysing the potential PV output based on the façade characteristics. This is followed by modelling the solar PV cantilevers for multiple tilt angles (β_i) using advanced simulation tools. These simulations include shadow mapping to account for both external and self-shading effects. Then, building modelling is conducted for the same set of tilt angles (β_i) to estimate two critical factors: i) self-consumed electricity (active component) and ii) energy savings due to induced shading effects (passive component). These results are integrated into an assessment of the overall energy efficiency for the multiple β_i to finally identify the βop_MaxEE.

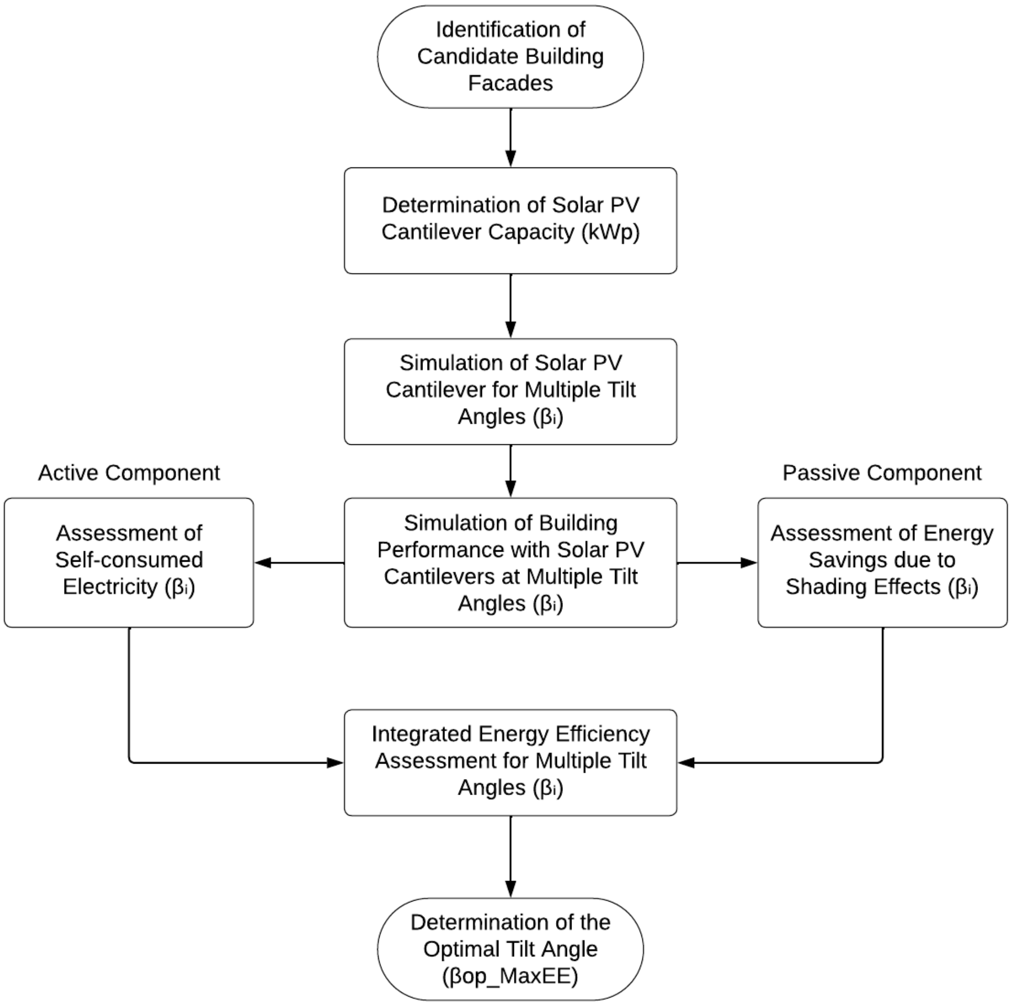

Fig. 3 Methodology to design optimal photovoltaic cantilevers on façades and maximise the energy efficiency of buildings.

The methodology is straightforward, flexible and adaptable, supporting the use of diverse simulation tools instead of relying on specific software. For this study, HelioScope was used for photovoltaic system simulations, and EnergyPlus V23.1 was employed for building energy simulations; however, these tools are provided as illustrative examples, and alternative software could be applied without affecting the methodology. This ensures its applicability to various building types and contexts. Each step of the methodology presented in Fig. 3 is explained in more detail below.

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Step 1: Identification of Candidates Building Façades

This process begins with an analysis of satellite imagery to examine façade orientation, shading from surrounding structures, and potential constraints. In the Northern hemisphere, south-facing façades are prioritised for optimal solar exposure (the opposite situation is presented in the southern hemisphere, where northern-facing façades should be prioritised)[41]. While the east and west façades should be carefully analysed due to the lower production. Additionally, energy-related data, including annual electricity consumption (smart-meters data in hourly or quarter-hourly format along a year, preferably), is collected to support subsequent modelling steps [42]. Field verification is necessary to confirm the alignment between collected data and the building's current condition, addressing discrepancies such as undocumented modifications or shading elements.

Step 2: Determination of Solar Photovoltaic Cantilever Capacity

A preliminary design of the solar PV cantilevers is proposed, aiming to maximise the installed capacity across all selected façades. The design considers varying numbers of PV rows in the façade—typically one row per floor and horizontal layout—installed above the windows or, where feasible, using tilted PV panels mounted (non-coplanar to the façades). Posteriorly advanced simulation tools are necessary for addressing the PV energy performance (consult examples in [43]). Generally, the process begins by configuring site-specific details, including meteorological and satellite data, to ensure accurate solar irradiance and shading analysis. A detailed 3D model of the building is developed based on the dimensions presented in the structural prints of the building. The solar PV cantilevers are modelled with façade-aligned orientation, an initial tilt angle (equal to the latitude of the specific location as a preliminary input), and selecting standard panel types and inverter configurations.

Shadow mapping studies are carried out to evaluate the impact of both external and self-shading elements, with heat maps used to identify shaded panels. An initial simulation estimates system performance, accounting for energy production and shading-related losses. Based on these results, the design is refined iteratively by adjusting acceptable shading loss thresholds (e.g., removing panels with losses exceeding 20%, 30%, etc.). This process helps define the system's efficiency and performance while determining the maximum feasible PV capacity, which serves as a reference for subsequent methodological steps. Expert input can be integrated to validate the design and confirm the system's peak power capacity.

Step 3: Simulation of Solar Photovoltaic Cantilever for MultipleTilts

This step focuses on modelling the PV cantilever system under various β_i to analyse its self-production performance and determine the generation power curves. Two boundary conditions can be used as references for seasonal extremes: i) βop_summer = θ - 15º, corresponding to higher generation during summer and ii) βop_winter = θ + 15º, corresponding to higher generation during winter.

This results in a 30º range of variation around the latitude angle (θ), within which the optimal tilt (βop_MaxEE) for maximum energy efficiency is expected to lie. Therefore, the search for βop_MaxEE is constrained within this interval. For comparison purposes, additional reference tilts are also considered, for example, β_lat = θ, which is the conventional approximation assuming an aligned orientation with the cardinal points, and βop_(α): retrieved from PVGIS [44]. which estimates the annual maximum generation tilt corrected by building orientation (α).

To refine the analysis, simulations are carried out with incremental changes in tilt angle, typically increases of 5º, to evaluate the sensitivity of generation across the range.

Step 4: Simulation of Building Performance with Solar Photovoltaic Cantilevers at Multiple Tilts

This step aims to evaluate the impact of PV cantilever tilt angles (β_i), defined in Step 3, on the building's energy performance. A detailed energy model of the building is constructed to address the energy efficiency [38]. Several tools are available for energy simulations with different levels of complexity and methodological approaches. The choice of software depends on the study's objectives, the level of detail required, the phase of the project, and the user's experience.

The model should ideally integrate the building's geometry, envelope characteristics, heating-ventilation-air conditioning (HVAC) system configuration, lighting, and operational schedules that reflect actual occupancy and equipment use. Local weather files can enhance the accuracy of simulating representative climate conditions. Furthermore, the model should be calibrated to reproduce the building's actual energy performance under standard operating conditions. The calibration process can follow the methodology described in [45], using monthly measured electricity consumption and indoor temperature data as benchmarks. Iterative adjustments are applied to internal load profiles, occupancy schedules, infiltration rates, and equipment efficiencies until the model output aligns within acceptable deviation ranges from the observed data (examples of calibration can be consulted in [46]).

Once the calibrated model is established, the PV cantilever system is incorporated. Each configuration corresponded to tilt angles (β_i), defined in Step 3. For each β_i, the cantilever geometry is modelled as a dynamic shading element. As described before, this angle influences both PV energy generation and façade shading. Increased shading can improve thermal comfort during warm seasons, thereby reducing electricity consumption for air conditioning. However, it should also be acknowledged that more shading during colder months can increase the demand for heating to maintain thermal comfort. However, it should also be considered that this same shading can reduce passive solar gains in colder months, potentially increasing the need for space heating to maintain acceptable indoor conditions. This effect may be particularly relevant in buildings with significant heating demand.

Once the building simulation model has been validated, it is used to simulate how different β_i on the cantilever solar PV cantilevers affects energy consumption, i.e., the impact of shading on the building envelope and its interior. This approach builds on the comparative energy efficiency analysis conducted by Javier et al. [38] who assessed the performance of existing buildings using multiple simulation tools. It is important to note that, in general terms, the concept of "energy savings" must be approached with caution when comparing buildings supplied by different energy vectors, such as electricity and natural gas, due to differences in conversion efficiencies, emission factors, and cost structures. To simplify the analysis and enable consistent comparison, this study covers the assessment of a fully electrified building. This assumption enhances methodological coherence in the evaluation of self-consumption and electricity savings associated with the PV cantilever system.

Step 5: Integrated Energy Efficiency Assessment for Multiple Tilts

This step evaluates the combined effect of varying the PV cantilever's tilt angle (β_i) on the building's overall energy efficiency. The total yearly electricity savings resulting from the PV implementation are quantified using Equation (4), which considers active and passive components:

$$EE = E_{PVsc} + E_{ESS} \tag{4}$$

Where: EE is the net electricity savings after the integration of the PV cantilever system, E_{PVsc} represents the self-consumed PV electricity within the building (active component), E_{ESS}

accounts for the net electricity saving associated with cooling and heating due to the induced shading effect of the PV cantilever through a year (passive component).

Please note that in this study, a conservative approach was adopted by excluding surplus electricity exported to the grid from the calculation of energy savings—particularly during summer months, peak hours, and weekends. This reflects real-world situations in which many PV installations cannot directly feed electricity into the main grid, or where energy storage systems (BESS) for managing surpluses are not always available. The potential contribution of exported electricity to overall energy savings will be discussed in "RESULTS AND DISCUSSION", as it can represent a significant portion of total energy performance in certain scenarios.

The data is turned into a graph to examine the influence of different tilt angles on both electricity generation and savings. These visuals aid in determining the optimal tilt angle for maximising integrated energy efficiency, denoted as βop_MaxEE.

In this study, E_{PVsc} is prioritised as a key performance metric because it directly reflects the degree of synchronisation between on-site generation and consumption, aligning with the goals of enhancing energy resilience and reducing dependence on the grid. Nonetheless, it is acknowledged that in configurations equipped with energy storage, the optimal tilt angle may favour maximum total generation rather than self-consumption. In any case, this parameter should ideally be addressed and discussed.

Step 6 Determination of the Optimal Tilt

The final step aims to present the optimal design of the PV cantilever, integrating technical, energy efficiency, and consumption parameters. Detailed simulations, including both PV and energy building efficiency, highlight the system's potential impact. A comparative analysis between the business-as-usual (BAU) and project-implemented scenarios offers insights into the system's benefits. This step provides a comprehensive evaluation of the PV cantilever's role in the building's energy transition. To illustrate the methodology, a case study will be presented.

CASE STUDY

Valencia, situated on the eastern Mediterranean coast of Spain, has undergone a significant transformation in sustainability in recent years. As part of this trajectory, Valencia was designated the European Green Capital for 2024 [47]. Within this context, the Polytechnic University of Valencia (UPV) is a reference in public higher education institutions committed to sustainability. UPV currently serves approximately 40.000 individuals, including students and staff [48]. UPV-Vera campus hosts more than 60 buildings with diverse academic, administrative, and service functions. Among these, one representative building was selected for analysis. The chosen structure belongs to the Faculty of Fine Arts, specifically block 3N/3M, and features a predominantly south-facing façade with high solar exposure and presents a high consumption in refrigeration during summer (almost 40% of the electricity consumption is for air conditioning). Given Valencia's Mediterranean climate, with hot summers and mild winters, PV cantilevers as façade shading devices can reduce solar heat gain during the summer (more restrictive period), thereby lowering cooling needs. This approach follows the findings of Semprini et al. [49] who demonstrated that sun shading devices significantly improve energy efficiency, thermal comfort, and lighting conditions in warm semi-arid Mediterranean climates and is supported by the work of Mohammed et al. [50] who showed that building shading devices can substantially reduce cooling loads in a tropical climate case study.

This orientation and geometry make it particularly suitable for evaluating PV integration strategies, especially as cantilevers on building façades to simultaneously provide external shading and on-site energy generation. Fig. 4 shows the location of the selected building within the UPV-Vera campus. The resource consumption of the Vera campus is published online in an open-access format [51]. Furthermore, the energy consumption for each building is published in a yearly and monthly format. For more information on the case study, consult [52].

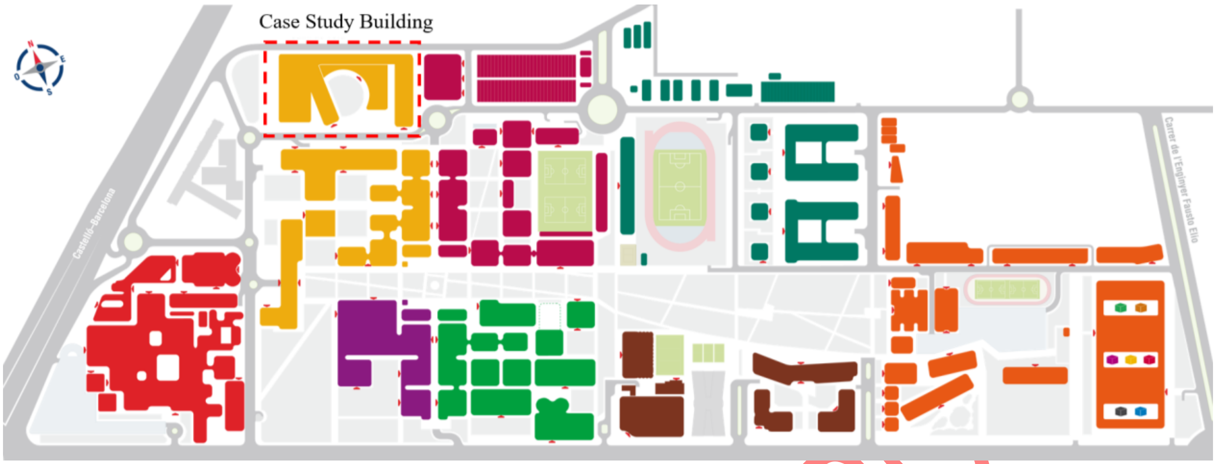

Fig. 4 Universitat Politècnica de València-Vera campus buildings. Case study: Faculty of Fine Arts 3N/3M outlined in red [53]

For the PV simulation, the tool HelioScope was used [54]. The tool accounts for the incident solar radiation on inclined surfaces, including the decomposition into direct, diffuse, and reflected components. The meteorological dataset implemented was 10 km spatial resolution from Meteonorm for the location (39.50, -0.30) and time zone UTC+1. The dataset corresponds to a Typical Meteorological Year (TMY), representing the weather conditions for the simulations. Other tools can also be employed, as long as they include analysis of shading, both from the panels themselves and from external sources.

For the building energy simulation, the tool EnergyPlus V23.1 was used. However, other tools can also be employed, as long as they offer hourly dynamic simulation capabilities (for example, consult [29,38]). The façade of this case study consists of 12 cm white precast concrete panels separated by an air chamber from an exterior finish of high-pressure decorative laminate panels. The interior includes 4 cm of rock wool for thermal and acoustic insulation, covered with double-laminated plasterboard, resulting in a thermal transmittance of 0.68 W/m²K. The studied façade is glazed, with overhanging floor slabs providing solar shading. Windows have a thermal transmittance of 2.90 W/m²K and a solar factor of 0.75. The building features an inverted, flat, walkable roof insulated with 4 cm of extruded polystyrene, with a total thermal transmittance of 0.62 W/m²K.

It should be noted that the building under study has a total living area of 14,870 m2, with an annual electricity consumption of 921,642 kWh/year, of which the annual air conditioning consumption is 339,857 kWh/year (37% of total). The simulation process is based on detailed building modelling, including all the information referred to, and is followed by solving physical equations representing the energy flows between the environment, the envelope, and the interior. Phenomena such as heat transfer by conduction, convection, and radiation; internal gains by occupants, equipment, and lights; air infiltration; and the dynamic behaviour of air conditioning systems are considered. This approach follows the methodology presented by Montero et al. [55] who applied detailed energy simulation to improve building efficiency and sustainability, and is further supported by Clarke [56] who provides a comprehensive framework for modelling energy flows and system dynamics in buildings. The site-specific hourly climate data for the building site are incorporated to achieve representative results. As mentioned above, the methodology is compatible with other tools, provided they allow shading analysis and offer hourly dynamic simulation capabilities.

RESULTS AND DISCUSSION

The results derived from the application of the methodology are presented in a step-by-step format. Each step is examined with a focus on the outcomes and their implications for achieving the study's objectives. The results are discussed, highlighting observations and the broader significance of the findings.

Step 1: Identification of Candidates Building Façades

The structural blueprints indicate that the building is 32 m in height. The south façade orientation is 20º south-west direction (α=200º). The energy generation across various façades is compared with a rooftop layout as the reference, yielding 1,543 kWh/kWp for a tilt equal to the latitude (β=39º for this case). The South Façades, with coplanar panels attached on the surface (90° to the horizontal), showed a 29% decrease, the West Façade 54%, the East Façades 37% and the North Façades had a substantial 72% decrease in energy generation. Therefore, the South Façade will be the candidate for the PV integration as a solar cantilever, as can be seen shaded in yellow in Fig. 5. The separation between floors is 4 m. There is a possibility to integrate four rows of panels with a total length of 532 linear meters (133 mts per row).

The on-site visit revealed significant structural discontinuities along the concrete rows of the south façade, which limit the installation of continuous PV cantilevers (see Fig. 5b). This finding highlights the gap between satellite-based energy potential and the architectural reality of the building. To maintain the applicability of our methodology, the optimisation is performed selectively on the feasible façade segments. Areas where cantilevers cannot be installed are excluded from the optimisation, but the method still provides guidance on how to deploy PV panels in the remaining sections. For older or non-modular façades, partial cantilever implementations or lightweight support structures could be considered to expand PV coverage. This approach illustrates the scalability and adaptability of the method, providing a practical strategy even when architectural limitations prevent full cantilever deployment. This assessment highlights the method's flexibility and limits, showing how PV cantilevers can be optimised locally on feasible façade segments, even in complex or discontinuous buildings, exemplifying its practical relevance and broader applicability.

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Fig. 5 Faculty of Fine Arts at Universitat Politècnica de València. a) South façade, highlighted in yellow, indicates the area for the implementation of the photovoltaic cantilever. b) Structural constraints along the rows

The yearly electrical load curve was provided by the Environmental Department of the Vice Rectorate for Sustainable Development of the Campus at UPV [51] (see

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A, Fig. 14). The data is converted into monthly energy consumption of the building, as can be seen in Fig. 6 showing the MWh per month. The yearly consumption of the building is 921.6 MWh, with an average of 76 MWh/month. Note that there are 3 months above the average monthly consumption (Jun, Jul, Sep). Valencia's hot season lasts for 3.0 months, from June 18 to September 19, with an average daily high temperature between 27-30°C [57].
[57]

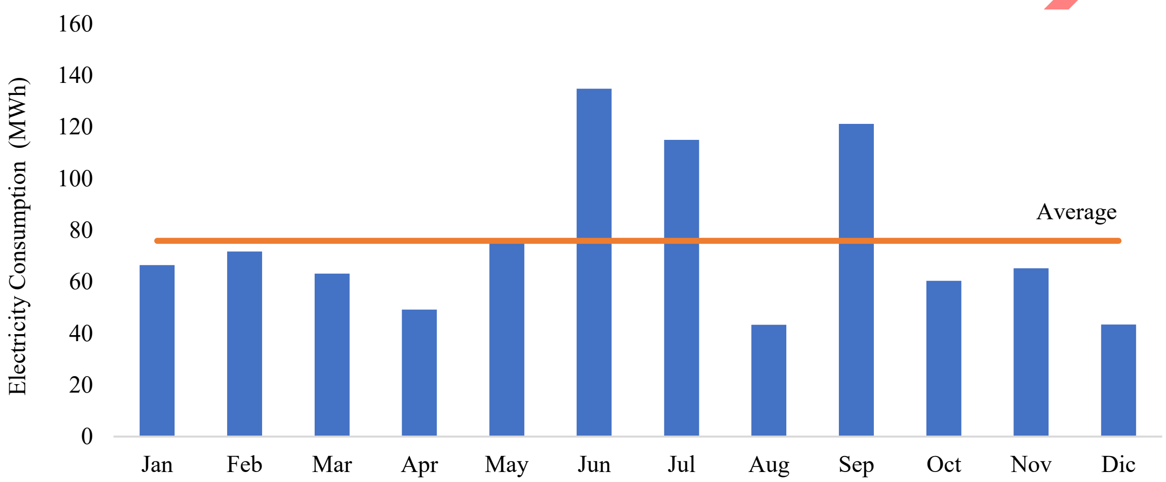

Fig. 6 Building electricity consumption per month

The hottest month of the year in Valencia is August; however, its consumption is below the average due to the academic holiday period. The cool season lasts for 4.0 months, from November 19 to March 18, with an average daily low temperature between 6-10°C; however, its electricity consumption is significantly lower than the warm season, as it is possible to appreciate in Fig. 6, in the colder months, the electricity consumption is lower than the average value. The coldest month of the year in Valencia is January [57]. This suggests that the implementation of PV cantilevers can result in significant potential for energy savings, particularly during the hot season.

Step 2: Determination of Solar Photovoltaic Cantilever Capacity

To model the first configuration, β was set equal to the latitude (39° for this case study). The shadow mapping can be seen in Fig. 7, revealing red panels (bottom row and laterals) with 30% lower performance compared to green panels (top row and centre) with higher solar exposure. Simulation results indicate a maximum of 21% losses for the most impacted panel. For this configuration, the overall shading losses result in 7%. Tolerable loss thresholds may vary depending on the specific objectives and constraints of other studies.
[58][59]

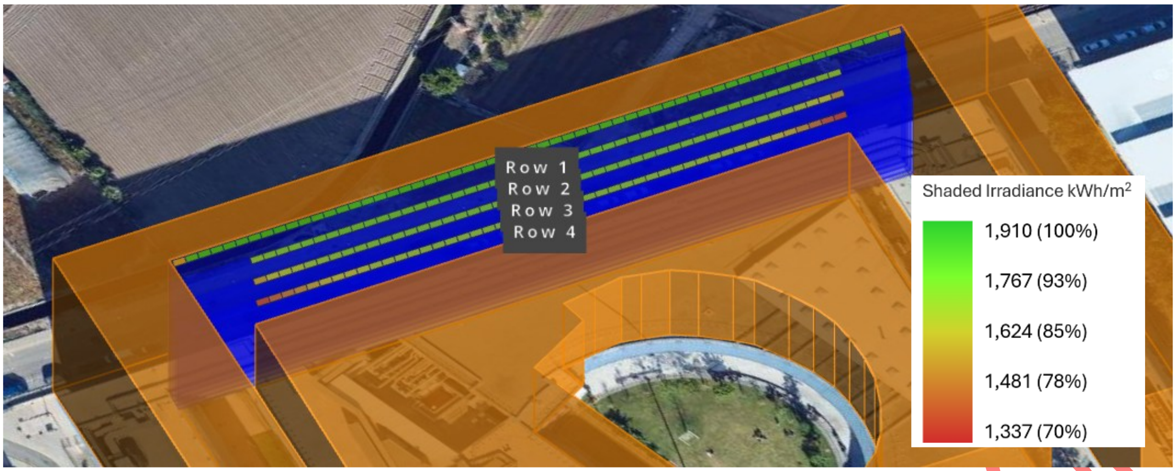

Fig. 7 Modelling the solar photovoltaic cantilever. Mapping shadow losses and total losses for the maximum PV capacity configuration

For this case study, it is assumed that a tolerable loss in a panel is 21%, and 7% in the overall system as well. However, further optimisation of solar PV cantilevers configurations can be performed to minimise shading losses e.g. strategies to reduce mismatch such as use power optimisers or microinverters for panel-level MPPT, selecting panels with similar electrical characteristics through module binning, carefully design string configurations to group panels under similar shading conditions, bypass diodes to manage partial shading, or avoid partial shading with careful site analysis among others. These approaches are supported by the work of Sinapis et al. [58], who evaluated the selective deployment of power optimisers in residential photovoltaic systems to improve energy yield under shading conditions, and by Osmani et al. [59], who reviewed methods for mitigating partial shading effects through PV array reconfiguration and other system-level optimisation strategies.

Step 3 Simulation of Solar Photovoltaic Cantilever for Multiple Tilts

As explained before, it is expected to find the optimal tilt βop_MaxEE in the range (θ ± 15°), which is equal from 24º to 54º for the case study. However, to provide a more complete panorama of the phenomena under study, a wider range of tilts was be considered. The β_i to model are 20º, 36º (max generation corrected by building orientation α), 39º (case study's θ), 45º, 50º, 60º and 70º. The main results of this step are the power generation curves for the PV cantilever system under various tilt angles. Simulations were conducted, and the resulting data were extracted from HelioScope software and processed. Fig. 8 depicts the differences in the average power generation profiles for various simulated tilt angles.

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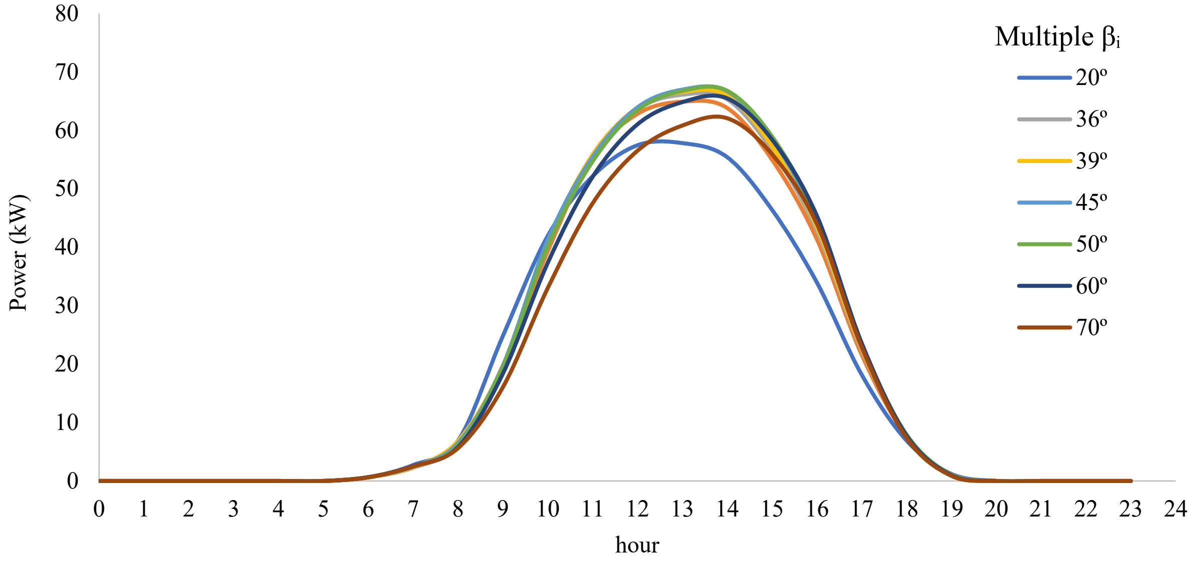

Fig. 8 Average daily generation load curve for multiple tilts

The graph shows slight variations in production, with angles close to the latitude offering more balanced generation. However, these differences support the selection of the tilt angle that best suits the building's energy consumption and seasonal needs.

Step 4 Simulation of Building Performance with Solar Photovoltaic Cantilevers at Multiple Tilts

The outcome of this step is the calibrated virtual model implemented in EnergyPlus that can be seen in Fig. 9. Simulations were performed for each tilt angle configuration (β_i), and the resulting data were extracted for subsequent analysis. The detailed results of the building energy performance simulations under varying β angles (20º, 30º, 40º, 45º, 50º, and 60º) are presented in

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A, Table 2; including heating and cooling energy demands before and after intervention, as well as their respective differences (Δ Heating and Δ Cooling), expressed in kWh/m²·year. Additionally, net energy savings are quantified both in absolute terms and as percentages relative to baseline consumption.

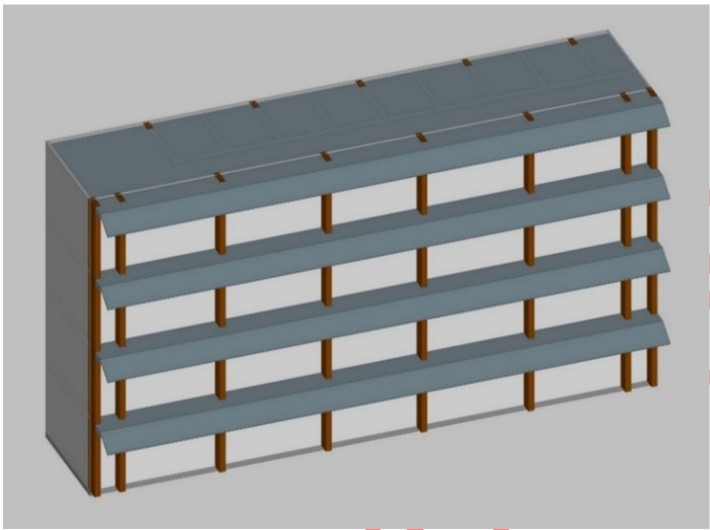

Fig. 9 Building modelling showing the façade under study with the solar photovoltaic cantilever as shading devices

It should be noted that, although Valencia has a relatively mild winter climate, the fixed and non-seasonal nature of the PV cantilevers creates a permanent shading condition throughout the year. As shown in Table 2, this leads to an increase in heating demand at higher tilt angles (up to +17.91 kWh/m²·year), resulting in a shading penalty that, in specific configurations, partially offsets the cooling benefits during warmer periods.

These results provide insight into the influence of β on thermal demand and overall energy performance, supporting the subsequent analysis and discussion.

Step 5 Integrated Energy Efficiency Assessment for Multiple Tilt

The main parameters that constitute Equation 4 are analysed separately:

i) Self-consumed electricity is determined by crossing the electrical load curve of the building with the different generation load curves by varying β_i. The result of this analysis is summarised in Fig. 10 showing an optimum at 45º, with an electricity self-consumption of 131 MWh/yr. Note that the difference between 40º and 50º is relatively negligible in total terms 1 MWh/yr (less than 1% in relative values). This suggests that within this range, there is not considerable variation in terms of self-consumption; however, there is an optimum that can be identified. From a practical perspective, this indicates that the optimum at 45° should not be interpreted as a statistically rigid value, but rather as a representative point within a relatively flat performance region. Therefore, a flexible tilt range of approximately ±5° around this value could be adopted in architectural design without significantly affecting the overall energy performance.

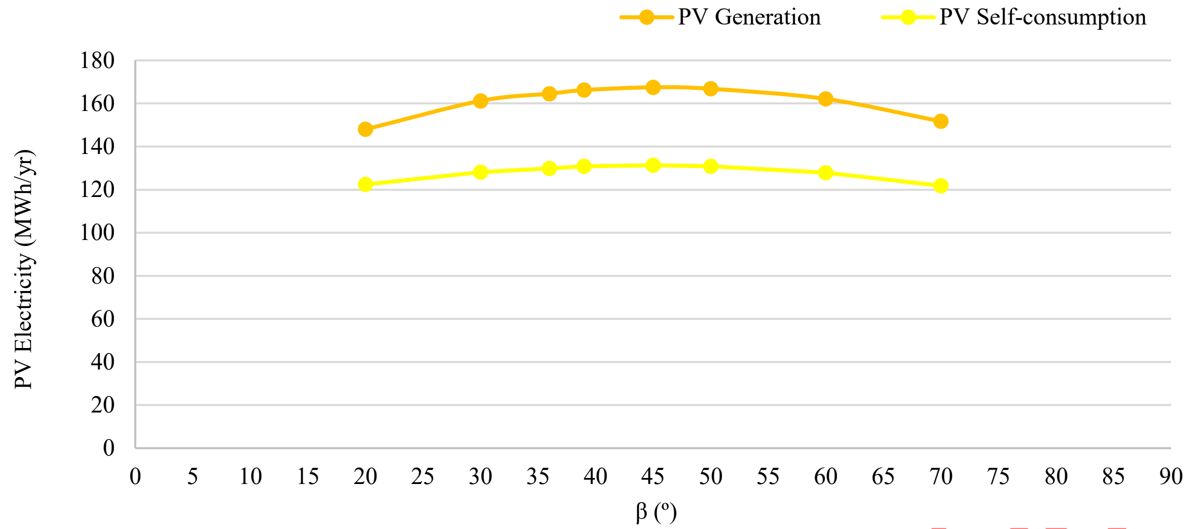

Fig. 10 Yearly electricity generation and self-consumption for multiple tilt angles of the photovoltaic cantilever system

ii) Electricity savings due to shading effects. Assessed through the cooling and heating impact of the PV cantilever on the building. The results are summarised in Fig. 11, showing there is practically no optimum. While the tilt is reduced, so does the cooling saving, but in return, the extra heating needed increases, so the combined impact remains relatively the same at 20 MWh/yr. Similarly, at a higher tilt, when the cooling savings are fewer, the extra heating maintains the net electricity balance at the same value.

As expected, savings from cooling are greater than the additional heating requirements, albeit in a small proportion, representing, on average, 6.5% cooling savings versus 4.3% extra heating compared with the total yearly consumption of the building (921 MWh). The impact of shading for this study represents a 2.2% reduction compared to the building's electricity consumption.

It should be noted that this analysis assumes a fully electrified building, where both heating and cooling demands are supplied by electricity. In buildings using mixed energy vectors, such as natural gas for space heating, the increase in winter heating demand from permanent shading would have different economic and carbon implications. While this does not affect the methodological validity of the present analysis, a detailed assessment of mixed-energy scenarios is beyond the scope of this study. It is identified as a relevant direction for future research.

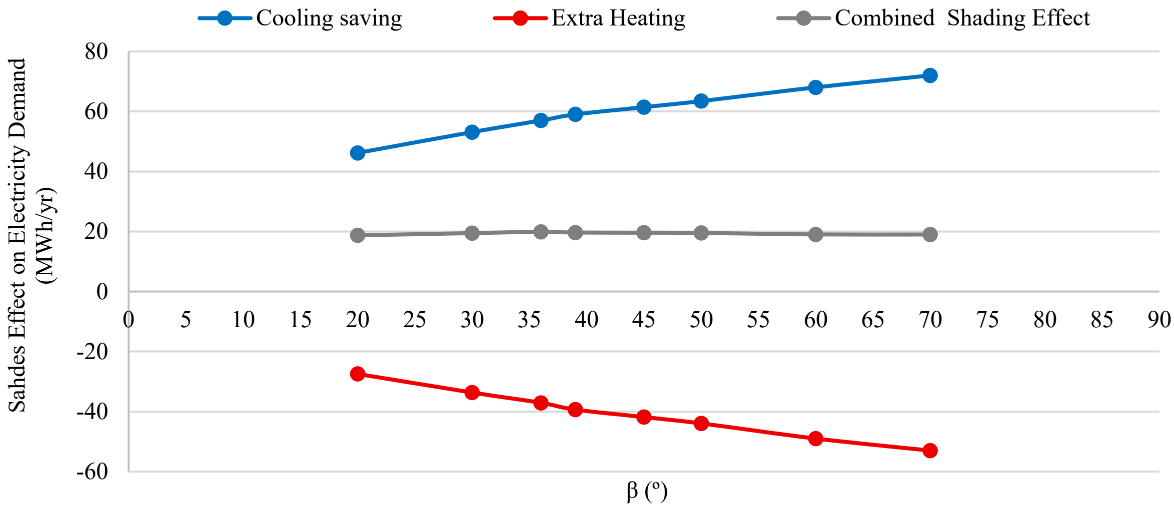

Fig. 11 Yearly variation in electricity demand for cooling and heating due to shading effects from the photovoltaic cantilever system across multiple tilt angles

Furthermore, the present analysis considers fixed cantilever configurations. The use of adjustable or seasonally variable cantilevers could potentially reduce the additional heating demand observed during winter while enhancing cooling savings during summer. However, such adaptive solutions would introduce additional structural complexity, operational requirements, and associated costs. Their evaluation is therefore beyond the scope of the present study and is identified as a relevant direction for future research.

Step 6 Determination of the Optimal Tilt

To find βop-MaxEE, Fig. 12 was created, using the results of equation 4 presented in Section 3. It shows the net annual electricity saving by varying β_i. The maximum benefit is found for a tilt of 45º and is 152 MWh/yr. For β equal to 40º and 50º, there is a difference of 1 MWh/yr compared with βop-MaxEE. Although a difference of 1 MWh may appear negligible in comparison to the 152 MWh/year savings or the building's total annual electricity consumption of 921 MWh, such differences may become significant when considering a larger deployment scale.

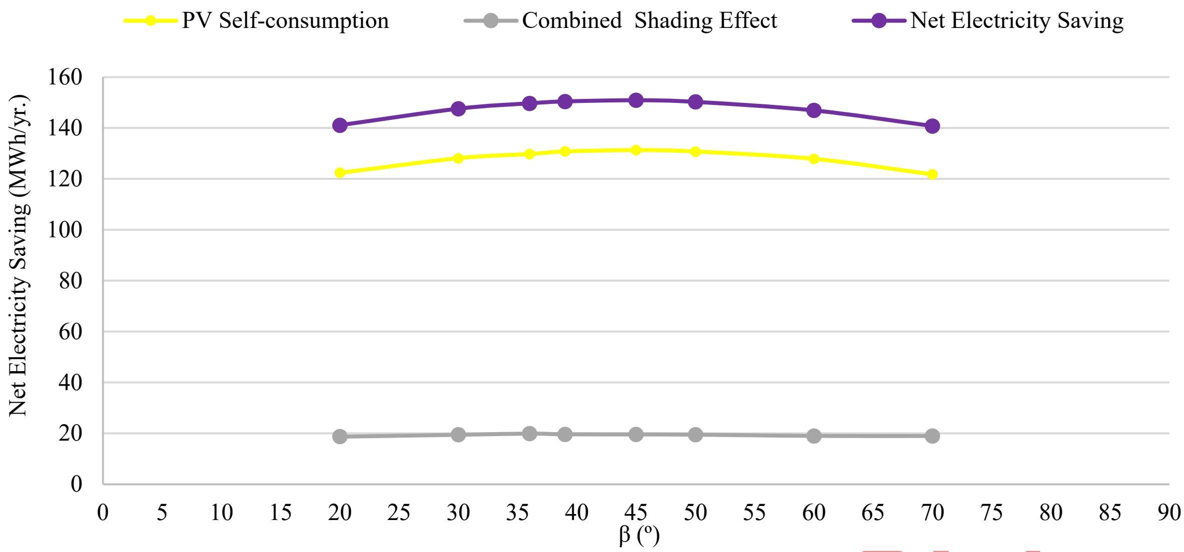

Fig. 12 Finding the optimum tilt that maximises the net electricity saving of the building with the photovoltaic cantilever

The final design results in a PV cantilever system of 199 panels, accounting for 112.5 kWp with a tilt of 45º (row 1: 58 panels, row 2 to 4: 47 panels). The overall system presents an energy yield of 1490 kWh/kWp, with a performance ratio (PR) of 78%. Shading losses of the solar PV cantilevers represent 6%. The results of the energy efficiency related to cooling and heating demand, comparing the pre- and post-intervention, can be seen in Table 1. Note that ΔHeating and ΔCooling are defined as Post-intervention minus Pre-intervention (Δ = Post − Pre). In this convention, negative values indicate a reduction in energy demand (savings) after PV cantilever installation, while positive values indicate an increase in demand.

Table 1 Comparison of the building energy certificate pre- and post-intervention. Impact on the energy ratings of the building due to the induced shading effect

Type of Demand	Pre-intervention (kWh/m² per year)	Post-intervention (kWh/m² per year)	Relative impact (kWh/m² per year)
Heating	31	44	+13
Cooling	61	42	-19
Total	92	86	-6

Fig. 13 summarises the main results of the PV cantilever's impact on the building case study. The PV cantilever can save 7% on cooling consumption but increase heating demand by 5%. Furthermore, 14% of the building's electricity consumption is expected to be covered by the PV cantilever, with a surplus equivalent to 4% of the building's actual consumption. This surplus can be shared with surrounding buildings (if possible) or managed through battery energy storage systems. Overall, this solution can result in a 16% to 20% progress towards achieving the energy transition in the building case study.

Although the passive shading component has a limited influence on the final optimal tilt angle (since the reduction in cooling demand is largely offset by the increase in heating demand), adopting a dual-optimisation approach remains practically justified in this case. The resulting optimal tilt angle (45°) is similar to that obtained through a photovoltaic-only optimisation for this latitude; however, the proposed methodology addresses additional spatial and architectural constraints that are critical in real buildings. In the present case study, the building roof has a limited available area, and a significant portion is already occupied by technical installations and equipment, which limits the feasibility of conventional rooftop photovoltaic systems.

Under these conditions, integrating photovoltaic modules into the building façade via cantilevered elements provides a viable alternative that extends the building's usable solar envelope beyond the rooftop. The dual optimisation framework, therefore, goes beyond merely adjusting the tilt angle and ensures that the selected configuration is energetically sound while remaining architecturally coherent. Moreover, the façade-integrated solution allows the photovoltaic system to be harmoniously incorporated into the building envelope without compromising its aesthetic integrity. This approach establishes a relevant precedent for other buildings facing similar rooftop limitations, where façade-based photovoltaic integration (evaluated through combined active and passive performance) may represent an effective and transferable design strategy.

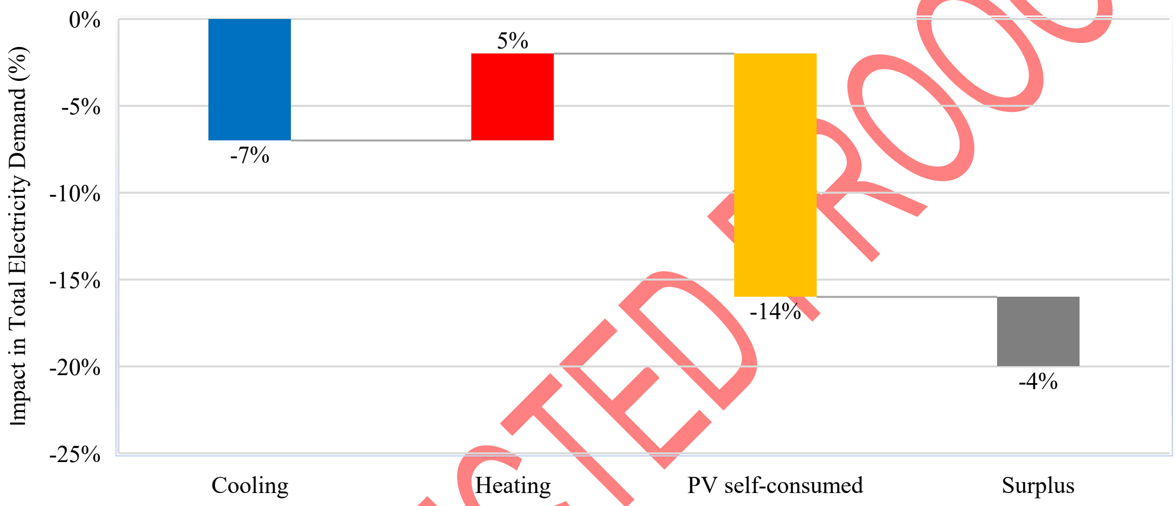

Fig. 13 Summary of annual building electricity balance. Comparison between pre- and post-intervention: impacts of induced shading effect on cooling and heating, photovoltaic self-consumption, and surplus electricity

To complement the energy performance assessment, a 25-year feasibility analysis of the optimised 112.5 kWp with a tilt of 45º PV cantilever system was conducted, considering both financial and environmental aspects. The system involves a capital expenditure (CapEx) of 1,800 €/kWp, including 1,100 €/kWp for typical rooftop installations and an additional 700 €/kWp to cover the structural requirements of façade-mounted cantilevers. Operational and maintenance costs (OpEx) were assumed at 10 €/kWp per year, with a module degradation rate of 0.7% per year and a scheduled inverter replacement at year 15 costing 115 €/kWp. A discount rate of 4% and an annual OpEx increase of 2% were applied, with all costs including VAT and based on current electricity prices (0.1525 €/kWh flat tariff based on averages using bill data from the organisation). No subsidies, incentives, loans, or financial credits were considered (see

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A for more details on the economic analysis)

Based on these assumptions, the system exhibits a simple payback period of approximately 9 years, a return on investment (ROI) of 232%, a net present value (NPV) of 211,000 €, an internal rate of return (IRR) of 11%, and a levelized cost of electricity (LCOE) of 0.08 €/kWh.

From an environmental standpoint, an estimation of GHG emissions life cycle assessment was conducted to quantify the carbon footprint of the PV cantilever installation. This assessment covered material production, transportation, installation, operation, maintenance, end-of-life, and decommissioning phases, using an upper-bound emission factor of 45 gCO_2eq/kWh for PV generation in southern Europe, as documented in [60], and a local grid emission factor of 154 gCO_2eq/kWh, as published in the Valencia's Climate and Sustainable Energy Action Plan [61]. The system is expected to prevent approximately 18 metric tons of CO_2eq annually, totalling around 453 metric tons over its 25-year lifespan. With total embodied emissions estimated at 187 metric tons CO_2eq, the carbon payback period is roughly 10 years.

Overall, these results indicate that the projected energy gains of 16–20% can be achieved while remaining financially and environmentally viable, reinforcing the relevance and practicality of the proposed design optimisation approach for PV cantilever integration on building façades.

CONCLUSION

This study addressed the research gap concerning the optimisation of solar PV cantilevers by jointly assessing their contribution to electricity self-consumption and shading-induced energy savings. While previous works have analysed these aspects separately, they have never addressed both in combination within the context of solar PV cantilever configurations. The methodology developed allows for a comprehensive evaluation of their combined effect on overall building energy efficiency, thereby offering a more complete framework for façades PV design.

The findings suggest that PV cantilevers primarily act as renewable electricity generators that reduce grid consumption, while also serving as passive design elements that can lower cooling demand. Importantly, the analysis showed that a range of tilt angles can deliver comparable performance, providing flexibility in design and implementation, although an optimal system configuration still exists and can be identified. These results highlight the potential of optimised PV cantilever systems to contribute to urban energy efficiency and renewable energy targets. Their adoption could be encouraged through building codes, incentives, or integrated urban energy strategies, particularly to complement rooftop installations or in contexts where rooftop space is limited or impractical.

The case-specific results of this work correspond to a Mediterranean climate and a particular building typology. While the numerical findings provide a valuable reference, the methodology itself is replicable and scalable. Future research should apply this methodology across different building types, floor heights, and climates to evaluate its robustness and adaptability. In addition, to maximise the practical applicability of façade-integrated PV systems, future "PV-ready" buildings should prioritise continuous horizontal structural elements to avoid limitations caused by structural discontinuities, as identified in this study. Investigating alternative PV technologies, such as bifacial or thin-film panels, as well as dynamic or adjustable shading solutions, could further enhance combined energy savings. Moreover, integrating battery energy storage systems and demand-side management strategies could optimise the utilisation of surplus electricity. Pilot implementations and long-term monitoring are encouraged to validate model predictions and support evidence-based development. Finally, fostering interdisciplinary collaboration among architects, engineers, and energy planners will be essential to maximising benefits and advancing sustainable urban energy transitions.

DECLARATIONS

Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the author used OpenAI to improve language and readability. After generating suggestions with this tool, the author reviewed and edited the content as needed and takes full responsibility for the final version of the manuscript.

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AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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Abbreviations

BAU	Business as usual
BAPV	Building Attached Photovoltaics
BESS	Battery Energy Storage System
BIPV	Building Integrated Photovoltaics
EE	Net electricity savings (total energy efficiency indicator)
E_{ESS}	Electricity savings due to shading effects (passive component)
E_{PVsc}	Self-consumed photovoltaic electricity (active component)
FSD	Façade shading device
HVAC	Heating, Ventilation and Air Conditioning
kWp	Kilowatt-peak (installed PV capacity)
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System

PR	Performance ratio
TMY	Typical Meteorological Year
UPV	Universitat Politècnica de València

Symbols

α PV azimuth angle

αs Solar azimuth angle

β PV tilt angle

β_i Simulated tilt angle i

β_{lat} Tilt equal to latitude

β_{op} Optimal tilt angle

γs Solar elevation angle

θ Latitude

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APPENDIX

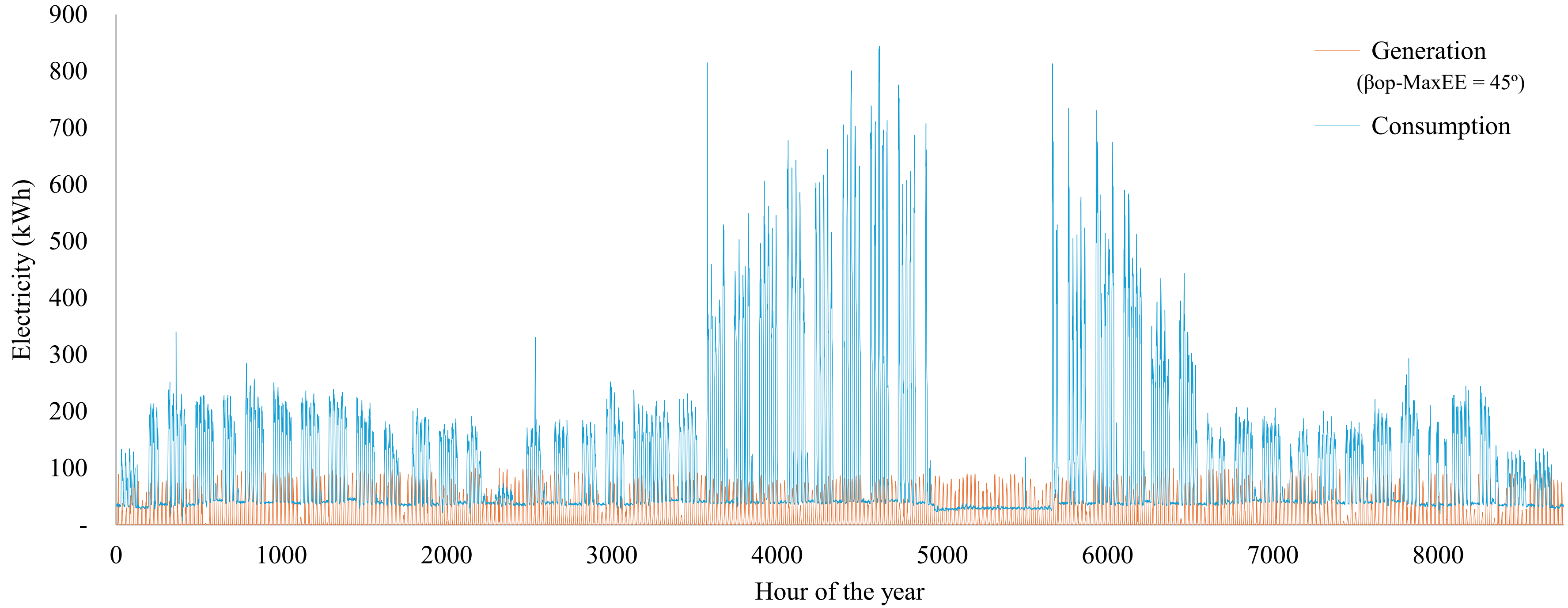

Fig. 14 Renewable electricity generation from optimal solar photovoltaic cantilever with optimal tilt (45º) and building consumption profileTable 2 Results of building energy performance simulation under multiple tilt angles

Category	**Indicator**	**Unit**	**20º**	**36º**	**39º**	**45º**	**50º**	**60º**	**70º**
Thermal Demand	Heating (Pre)	kWh/m²·year	18.42	18.42	18.42	18.42	18.42	18.42	18.42
	Heating (Post)	kWh/m²·year	23.54	24.70	25.76	26.22	26.61	27.56	28.52

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Category	Indicator	Unit	20º	36º	39º	45º	50º	60º	70º
	Δ Heating	kWh/m²·year	−5.12	−6.28	−7.34	−7.80	−8.19	−9.14	−10.10
	Cooling (Pre)	kWh/m²·year	53.12	53.12	53.12	53.12	53.12	53.12	53.12
	Cooling (Post)	kWh/m²·year	40.48	38.59	36.98	36.31	35.77	34.52	33.40
	Δ Cooling	kWh/m²·year	+12.64	+14.53	+16.14	+16.81	+17.35	+18.60	+19.72
	Net Saving	kWh/m²·year	8.12	8.25	8.80	9.01	9.16	9.46	9.62
	Net Saving	%	11.29	11.53	12.30	12.59	12.80	13.22	13.45
Total Energy Demand	Heating (Pre)	kWh/m²·year	34.66	31.02	31.02	31.02	31.02	31.02	31.02
	Heating (Post)	kWh/m²·year	45.96	41.60	43.39	44.17	44.83	46.42	48.93
	Δ Heating	kWh/m²·year	−11.30	−10.58	−12.37	−13.15	−13.81	−15.40	−17.91
	Cooling (Pre)	kWh/m²·year	61.05	61.05	61.05	61.05	61.05	61.05	61.05
	Cooling (Post)	kWh/m²·year	46.53	44.35	42.50	41.74	41.11	39.68	38.11
	Δ Cooling	kWh/m²·year	+14.52	+16.70	+18.55	+19.31	+19.94	+21.37	+22.94
	Net Saving	kWh/m²·year	6.28	6.12	6.18	6.16	6.13	5.97	5.03
	Net Saving	kWh/year	19978.40	19473.80	19664.80	19601.10	19505.70	18996.50	18357.3
	Net Saving over Global Use	%	2.03	2.11	2.13	2.13	2.12	2.06	2.00
	Net Saving over HVAC Use	%	5.51	5.73	5.79	5.77	5.74	5.59	5.46

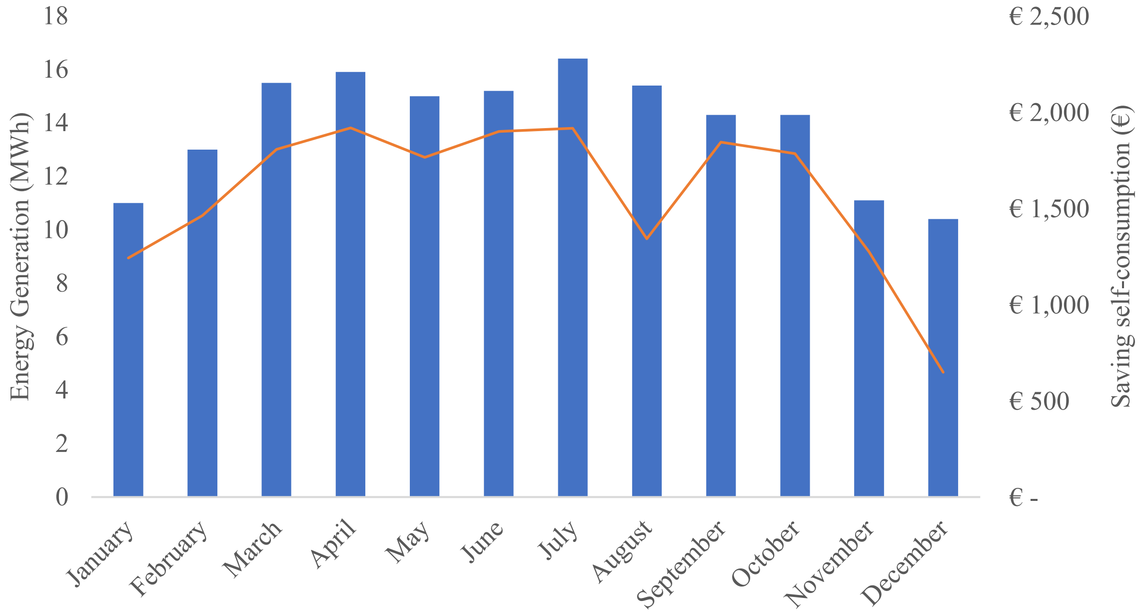

Fig. 15 Monthly energy generation and self-consumption savings for the proposed solar photovoltaic cantilever

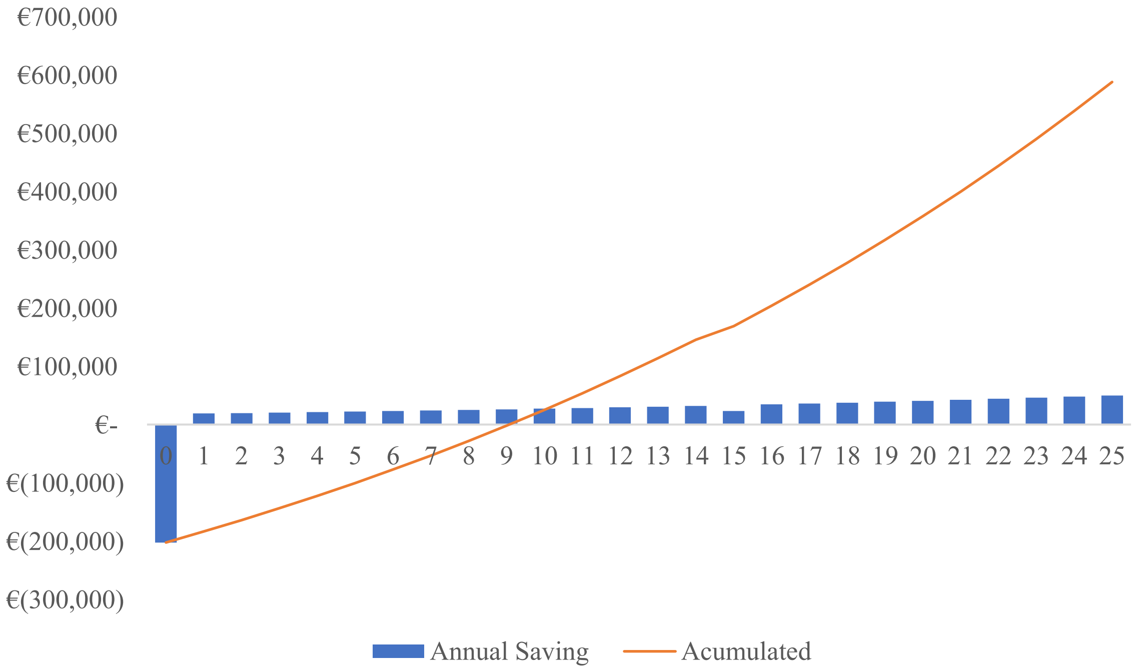

Fig. 16 Annual and cumulative cash flows for the proposed solar photovoltaic cantilever