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Photovoltaic cells with transparency for glass coverage: case study in party space

Células fotovoltaicas com transparência para cobertura de vidro: estudo de caso em espaço de festa

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***Abstract**: Sustainable energy and technological development in electricity generation processes offer opportunities for the development and utilization of new photovoltaic technologies in construction. Photovoltaic cells for glazed surfaces, known as double glass or double-skin, have been applied in modern buildings due to their attributed characteristics that can enhance thermal comfort, provide natural lighting for internal areas, ensure privacy in external environments, and reduce energy consumption. The objective of this study is to investigate the viability of using double glass in the glazed roof of a family party venue. The qualitative method, a case study, was employed to assess the demand for electrical energy in the building and the potential use of double glass photovoltaic technologies. Market research was initially conducted with technology suppliers, enabling the evaluation of characteristics for the technological and economic feasibility of the project. The results show that the installation of double glass photovoltaic technology offers 40% transparency to solar radiation through the roof, resulting in thermal and luminous comfort. In terms of economic viability, the study demonstrates the possibility of return on investment in 4.6 years, considering energy generation, reduced building energy costs, and installation expenses. The installation of double glass technology, according to market research, is economically viable and generates local electrical energy for residents, providing comfort in the environment and enhancing the quality of life for occupants.*
Keywords: party space, photovoltaic technologies, energy sustainability, thermal comfort, renewable energy.

Resumo: A sustentabilidade energética e o desenvolvimento tecnológico nos processos de geração de eletricidade oferecem oportunidades para o desenvolvimento e utilização de novas tecnologias fotovoltaicas para a construção civil. Células fotovoltaicas para superfícies envidraçadas, conhecidas como *double glass* ou double-skin, têm sido aplicadas em edifícios modernos, pois são atribuídas a características que podem auxiliar no conforto térmico, iluminação natural para a área interna, privacidade no ambiente externo e redução consumo de energia. energia. O objetivo deste estudo é investigar a viabilidade da utilização de *double glass* na cobertura envidraçada em ambiente de festa para uso familiar. O método qualitativo, do tipo estudo de caso, onde foram avaliadas a demanda de energia elétrica na edificação e a possibilidade de utilização de tecnologias fotovoltaicas de *double glass*. Inicialmente foram realizadas pesquisas de mercado com fornecedores de tecnologia, o que possibilitou avaliar características para a viabilidade tecnológica e econômica do projeto. Os resultados mostram que a instalação da tecnologia fotovoltaica de *double Glas* oferece 40% de transparência à radiação solar através da cobertura, o que resulta em conforto térmico e luminoso. Em termos de viabilidade econômica, o estudo mostra a possibilidade de retorno dos investimentos em 4,6 anos, considerando geração de energia, redução de custos de energia na edificação e custos de instalação. A instalação da tecnologia de *double glass*, segundo pesquisas de mercado, mostra

que é economicamente viável e gera energia elétrica local para os moradores, proporcionando conforto no ambiente e qualidade de vida aos ocupantes.
Palavras-chave: espaço de festas, tecnologia fotovoltaica, sustentabilidade energética, conforto térmico, energias renováveis.

1 Introduction

The increase in population and economic development has contributed to the transformation of city architecture by skyscrapers. Changes in urban architecture can impact environmental comfort, leading to an increase in electricity consumption in buildings (Preet, Mathur and Mathur, 2022). In Brazil, technological changes were driven by the possibility of shared energy use with the electrical grid (Drumond Jr, de Castro and Seabra, 2021), contributing to the development and application of photovoltaic technologies in various construction contexts.

In modern society, humans seek comfort and sustainability in energy use in its various forms. The United Nations, through the establishment of Sustainable Development Goals (SDGs), proposes in SDG 7 the production and use of energy, aiming by 2030 to ensure universal access to reliable, modern, and affordable energy services (SDG 7.1); substantially increase the share of renewable energy in the global energy mix (SDG 7.2); and double the global rate of improvement in energy efficiency (SDG 7.3), to ensure reliable, sustainable, modern, and affordable access to energy for all (ONU, no date).

The pursuit of energy sustainability, and cost reduction, coupled with technological advancements in electricity transformation and management, provides opportunities for changes in science and mathematics education in engineering (Reis and Serrano, 2022). Driven by the STEM (Science, Technology, Engineering, and Mathematics) movement, photovoltaic technology stands out in the transformation of light into energy in the teaching of the photoelectric effect in Modern and Contemporary Physics (Dark, 2011; Reis and Serrano, 2017).

As a result, this topic allows applications in engineering and architecture research that can encompass the three photovoltaic generations: (i) Mono or polycrystalline rigid silicon photovoltaic cells (Reis, Reis Júnior and Perin, 2020; Baghel and Chander, 2022; Tang et al., 2022): (ii) Amorphous flexible photovoltaics for application on wavy or irregular surfaces (Pagliaro, Ciriminna and Palmisano, 2008; Schönell et al., 2020); (iii) Photovoltaic technologies with light transparency for glazed facades, with the possibility of electricity generation on both sides (Ahmed, Habib and Javaid, 2015; Jankovic and Goia, 2021; Sun et al., 2021).

This third generation of bifacial photovoltaics, consisting of transparent or semi-transparent cells, can be used in roofing or glazed facades, contributing to electricity production (Sinha *et al.*, 2021). Among these technologies, organic photovoltaics (OPV) are flexible and have high transparency, but their energy conversion efficiency is still lower than traditional rigid panels (Yu, Zheng and Huang, 2014; Sun *et al.*, 2021).

The "double glass" solar technology consists of a layer of silicon surrounded by double glass surfaces, allowing the generation of electrical energy in building structures, outdoor partitions, roofs, building facades, or other situations with solar exposure (Năstase *et al.*, 2016). In recent years, the technology has been researched to increase energy efficiency and reduce heat transfer on building facades (Shakouri *et al.*, 2022). The double glass facade has become an important architectural element in modern buildings, studies show that its use contributes to thermal comfort, natural lighting for the internal area, privacy for the external environment, and also in energy generation for the location (Preet *et al.*, 2021; Preet, Mathur and Mathur, 2022).

Office buildings often feature extensive glazed facades in their envelopes, and in this characteristic, energy efficiency can be achieved through bifacial photovoltaic technology in double glass layers, known as double glass or double-skin (Năstase et al., 2016; Preet et al., 2021). The main difference from buildings with opaque external structures, concerning those with transparency, lies in the thermal insulation characteristic, allowing mechanical and natural ventilation between the glass surfaces (Năstase et al., 2016). On surfaces with direct solar exposure, double glass can reduce heat transfer to the internal environment and contribute to electricity generation, especially in office and residential buildings (Velasco et al., 2017; Jankovic and Goia, 2021). Investigations provide evidence of the technology's effectiveness in reducing heat transfer between external and internal environments. Based on results with solar incidence area, double glass windows show the potential use of this technology to achieve higher energy efficiency and lower energy consumption (Shakouri et al., 2022).

The development of bifacial technologies, such as organic photovoltaics (OPV) and double glass technology, allows more effective use of available natural light and photovoltaic conversion (Gambogi et al., 2020). Both technologies are applied to glass surfaces, resulting in a triple layer, contributing to sound suppression and heat transfer by conduction, resulting in thermal and acoustic comfort in the environment (Năstase et al., 2016). Among the feasibility justifications, the efficiency in conserving photovoltaic energy can alleviate a portion of the global energy consumption demand. Also, studies indicate that for environmental influences, double glass provides greater resistance to wind, moisture, and temperature variation (Lien et al., 2018).

This research originated from a conversation in Modern and Contemporary Physics classes (Physics III) in the Civil Engineering course when the student and owner of a party venue requested help for the project to increase the energy efficiency of the space. According to the owner, artificial air conditioning is necessary for the use of the venue, resulting in high energy consumption. Moreover, high temperatures and direct solar radiation made it impossible to use the space during daylight hours. Considering the relevance of technologies and the need for their dissemination in the construction industry, this study aims to investigate the feasibility of using photovoltaic technologies with light transparency for application in roofing and glazed facades in a family party environment.

2 Object of study: party venue

The research focused on a case study of a residential party venue with glazed facades and roof as its object of study. The methodology was conducted in two stages: in the first stage, there was a literature and market research to assess available technologies in the market and estimate associated costs. The literature review aimed to demonstrate the feasibility of installing traditional double glass with organic photovoltaics (OPV) and double-sided photovoltaic panels, such as double glass. Both technologies (OPV or double glass) offer enhanced thermal comfort and electricity generation for on-site use, while preserving the initial concept proposed in the project, such as transparency to the external environment of the party area (Figure 1). For this stage, electronic contacts were made with companies supplying these products.

Figure 1. Photographic record of the researched party venue.

In the second phase, an economic feasibility study was conducted, considering the costs of technologies in Brazilian real per square meter (R$/m^2), values provided by companies, electricity generation, and consumption in the residence. Aspects such as durability, energy efficiency, installation cost, and flexibility of application in the proposed project were also investigated. The evaluation of energy consumption was carried out in 2018 and 2019. The average household consumption in 2018 was 406 kWh (Kilowatt-hour), and in 2019, it was 433 kWh, resulting in an average consumption over the two years of 419 kWh. The yellow line (Figure 2) represents the monthly average consumption between 2018-2019, with higher values in January and June, the months of increased use of air conditioning due to high temperatures in summer (January), and low temperatures in winter (June).

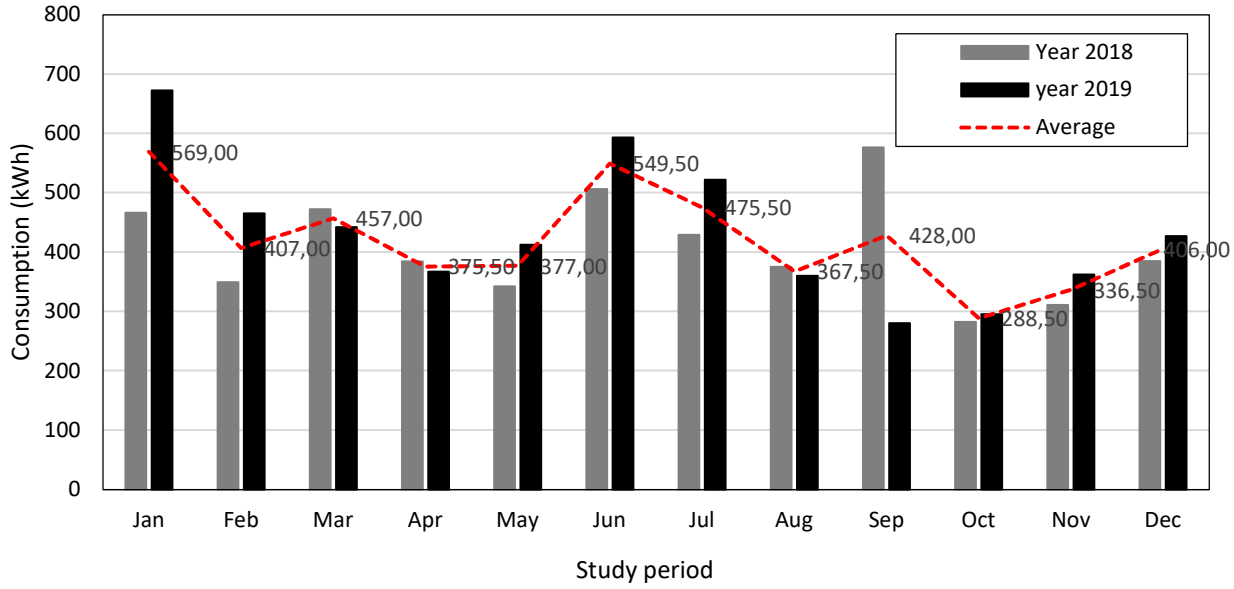

Figure 2. Residence energy consumption (kWh). Source: Authors with data from the client's energy bill.

ANEEL Normative Resolution 499 (2012), allows mini and microgeneration systems to be connected to the electrical distribution network, which allows consumers to use a compensation mechanism. This mechanism allows the energy generated in the months of highest production to be used in months with the highest consumption. And, as it is an environment for parties, this becomes an important advantage in the project.

3 Feasibility in the Proposal of Retrofitting the Environment

After verifying the energy consumption demand, contact was made via email with companies responsible for selling these technologies to assess the cost of purchasing and installing the technology in the party environment. This marketing research was conducted during the period of 2019/2020 when social isolation was declared due to the occurrence of the COVID-19 pandemic. This was a limiting factor for accessing companies, and only two out of the 5 companies responded to the electronic correspondence sent. The presented data were partial due to transportation and importation issues.

One of the responses was from a local company, which enabled the development of the project based on the needs of the enterprise: mitigating heat transfer in the environment and generating electrical energy for the building. As a proposed solution, the double glass technology was to be installed on the roof of the studied area (Figure 3).

Figure 3. Model of the proposed panels for installation on the roof of the party venue. Source: Image presented in the project estimated by the responsible company.

Double Glass photovoltaic modules have 40% transparency for solar radiation, contributing to an increase in the thermal and lighting comfort of the environment. The external glass has an anti-reflective film, which allows more radiation to be absorbed into the cells and increases the energy generated by the system.

As a disadvantage, in double glass modules, the literature points to the possibility of failures due to: lack of air permeability, which prevents pollutants from EVA degradation from being released, causing corrosion; changes in internal tension, as the external and internal glass have different thermal variations; or the possibility of cracking during brace installation or thermal performance testing. Therefore, studies show that double glass photovoltaic modules have been an important area of research for many companies and institutes in recent years, such as Dupont, Trina, Apollon, SERIS, MIT, Meyer Burger and Talesun. (Tang *et al.*, 2017). Another critical design change to be considered in bifacial modules is the increase in current generated compared to monofacial systems (Sinha *et al.*, 2021).

The budget proposal presented in 2020 was revised in 2022 after adjustments to the project and a new assessment of energy consumption in the residence. The proposed technology consists of 8 monocrystalline bifacial silicon photovoltaic modules with a power of 540W. The inverter proposed for the project is 5kW, single-phase, for a voltage of 220V, with Wi-Fi monitoring and a visually compatible display for any environment. According to the technology representative, the estimated monthly generation power is 534 kWh, and the initial investment was budgeted at R$ 23,322.00 (Table 1).

Table 1. Plant data presented in the budget. Source: Actors with data from the market research.

Descripition	Values
Total investment value	R$ 23.322,00
Energy savings in the first month	R$ 419,00
Payback period for investments	4,6 years
Total savings generated during the project's useful life	R$ 589.096,00
Estimated daily generation	18 kWh
Estimated monthly generation	534 kWh
Estimated annual generation	6404 kWh

A simulation was carried out to pay in 60 fixed installments of R$ 520.20 or 70 installments of R$ 457.40, with an interest rate of 1%. Considering the data on energy generation in the system, reduction in building energy costs, and installation costs, the study demonstrated the possibility of return on investment in 4.6 years after the system's installation. The calculations did not account for the reduction in energy consumption for air conditioning. Monthly costs for household energy consumption were used for this calculation, based on invoices provided by the electricity supplier.

Therefore, the energy generation from this roof in the party area results in sustainability for the entire residence. Given that the panels can reduce transparency for solar radiation incidence by 40%, it is expected to increase thermal and luminous comfort in the internal environment of the party venue.

These expected results align with research in other countries, demonstrating economic viability and thermal comfort in the use of double glass photovoltaic technologies (Rodrigues, Carlo, and Oliveira Filho, 2018). The study did not include gains in acoustic comfort, a result that can be provided by the double glass layer on the roof. Finally, during the study, there was the possibility of applying OPV on the glazed facades of the party area; however, the technology is still limited in the region.

As a disadvantage of technology in double glass modules, the literature points to the possibility of failures due to: lack of air permeability, which prevents the release of pollutants from the degradation of EVA, causing corrosion; changes in the internal tension of the module, as the external and internal glass have different thermal variations; or the possibility of cracking during strap installation or thermal performance testing. Therefore, studies show that double glass photovoltaic modules have been an important area of research for many companies and institutes in recent years, such as Dupont, Trina, Apollon, SERIS, MIT, Meyer Burger, and Talesun. (Tang et al., 2017). Another critical design change to be considered in bifacial modules is the increase in current generated compared to monofacial systems (Sinha et al., 2021). In short, projects of this

nature can be an excellent opportunity for scientific exploration and technological changes in double glass photovoltaic modules.

4 Conclusion

The case study on the application of double glass technology in the party venue has proven to be economically viable. The technology comes with a manufacturer-guaranteed lifespan of 20 years, with a financial return of 4.6 years. The project can contribute to the dissemination of new technologies and enhance the value of the building.

In terms of technical feasibility, the structure of the party venue is compatible with the installation of the technology. According to the product information provided by the manufacturer, it can be concluded that the installation of double glass technology on the roof reduces the incidence of solar radiation in the internal environment, resulting in comfort for the party venue. Regarding the electrical energy generated by the photovoltaic system, it enables a reduction in electricity demand in the residence, contributing to ensuring sustainability.

The main limitation of this study was the fact that it was a project evaluation. It is suggested that after installation indicators of thermal and lighting comfort in the environment are evaluated. Furthermore, evaluation of the energy generated and comparative electricity consumption in the building can prove the system's efficiency and economic viability.

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