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The Role of Double Skin Façades to Enhance Energy Performance of Social Housing in Egypt: A Simulation-Based Model Study

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Abstract

Energy saving strategies is an important issue to achieve "Egypt's Vision for Sustainable Development 2030". Given Egypt's predominantly desert climate, which features hot, arid summers and mild winters, there is a need for innovative design approaches to enhance energy efficiency and occupant comfort. The residential sector, which accounts for over 70% of Egypt's buildings, is the largest energy consumer compared to other sectors.

Social housing in Egypt represents a substantial portion of the residential sector in Egypt. They, consequently, significantly influences the country's energy consumption patterns. This research paper seeks to explore the use of double skin facades with an integrated perforated outer screen (DSFPS) as an effective approach to improving the thermal performance of social housing in Egypt. While such housing is crucial in addressing the housing crisis, the dependence on repetitive prototype designs with minimal consideration for the site and environment presents various environmental challenges. This new method represents a vital step toward creating sustainable and liveable residential environments.

A simulation-based tool is herein implemented on a prototype design of one of the high-rise social housing projects in Cairo, Egypt to evaluate the thermal performance of (DSFPS). The findings are intended to provide valuable insights for architects regarding facade design and to explore the potential of integrating perforated outer screens to improve energy performance of the building and reduce environmental impact.

Keywords: Double skin facades, social housing projects, thermal comfort, dynamic facades, energy conservation, simulation programs

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Research Problem

Social housing projects often overlook the impacts of heat gain especially from facades, leading to increased energy consumption for cooling purposes.

The research problem centers on the implications of repeating design prototypes in these projects along with the use of uniform facade treatments. There is little consideration of crucial orientation factors and specific window features such as shape, size, material, and insulation properties. This, one-size-fits-all methodology, can have significant negative effects on energy efficiency and sustainability in buildings.

Research Hypothesis

The research assumes that the use of double skin facades with integrated perforated screens (DSFPS) in social housing in Egypt, can lead to substantial reductions in cooling loads within the buildings. It will greatly contribute to achieving thermal comfort for users, promoting a regular and homogeneous distribution of lighting inside the space, providing an aesthetic form and enhance users' privacy.

Research Goal

This research aims to fill the knowledge gap considering the relation between double skin facades with perforated screens and heat gain in hot climates like Egypt. They are herein implemented for the first time in social housing projects in Egypt to minimize the direct exposure to sunlight.

The study will utilize Design Builder software for conducting simulations that aid in understanding the implications of this new design method on indoor thermal comfort and energy efficiency.

Research Methodology

In the present work, the applied methodology is structured into two phases as shown in figure (1). The initial phase is the theoretical phase which includes a literature review on double skin facades. This section provides background information on their types and applications in buildings, referencing to previous research that highlights their effectiveness in reducing energy consumption and enhancing thermal comfort and natural lighting within indoor environments.

The applied phase involves selecting a prototype design from one of Cairo's high-rise social housing projects in Egypt. Subsequently, an innovative design method using perforated outer screens in front of the original building's facades is implemented.

The simulation tool "Design Builder" is utilized to assess the feasibility of integrating this method, focusing on thermal performance, into social housing projects in Egypt (El-shorouk city). This was achieved without making significant alterations to the existing plans and still incorporating glass in the building's facades.

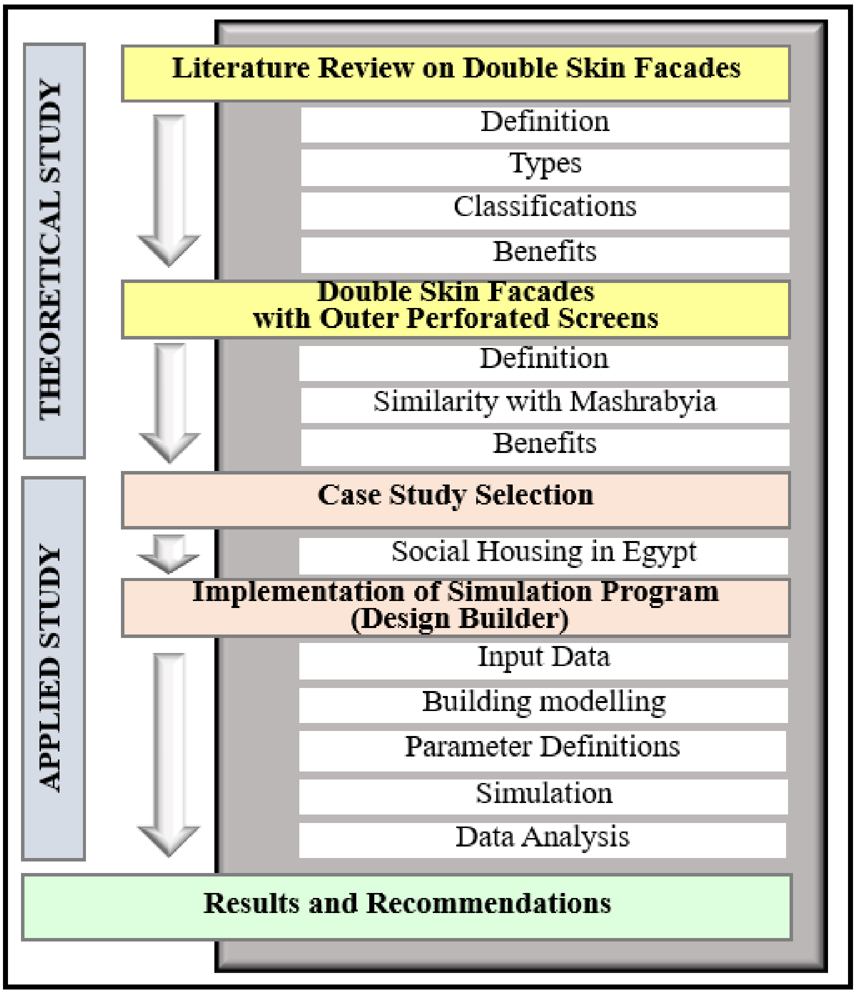


Fig. (1): Research Methodology, Source: Authors

1-Introduction

Climatic change and global warming have significant implications in the energy sector. Addressing these implications is critical for overcoming the current and coming problems of limited energy resources and ensuring a sustainable future.

Regarding the residential sector in Egypt, it represents over than 70% of Egypt's buildings [1]. The problem is the increasing cooling load values during the summer months to achieve thermal comfort in living spaces. This research paper focuses on social housing projects, which represent a significant portion of the residential sector in Egypt [2]. A primary factor contributing to high energy consumption in these buildings is the repeated use of design prototypes that pay little attention to site characteristics and the surrounding environment. Moreover, all building facades are designed with the same treatments without considering their orientation and window features.

The study aims to enhance the thermal performance of a chosen building prototype of one of the social housing projects in Cairo, Egypt at (El- shorouk city) by incorporating double skin facades with outer perforated screens. To validate the effectiveness of this innovative approach, the research utilizes a simulation program, Design Builder, to compare the cooling loads generated by using these modified facades against those of the original building's facades both during summer and winter seasons.

2-Literature Review of Double Skin Facades

This literature review explores the various dimensions of double skin facades, including their definition, types, environmental benefits, and their role in sustainable architecture.

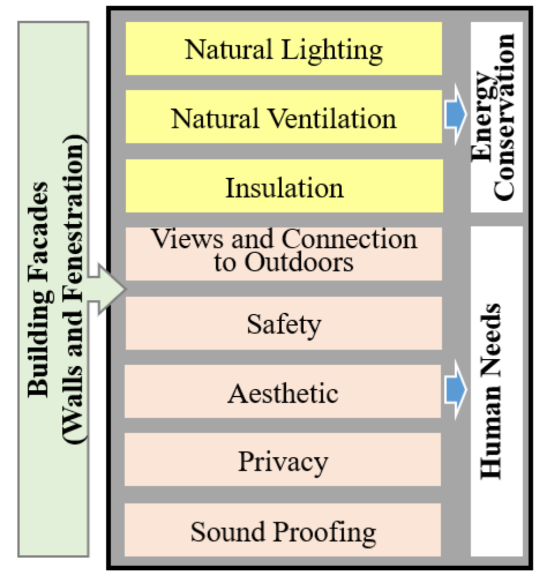


Fig. (2): Main functions of building facades
Source: Authors

2-1-Significance of building's facades

The building envelope, which is the barrier that separates the building internally from the external environment, significantly impacts the energy efficiency of the building. An environmentally benign envelope is a promising solution for energy conservation. It must be designed to be a part of the whole building's metabolism including energy production, storage and consumption as it has a long-term effect on the ecosystem throughout the building's operation and contributes to a high rate of energy consumption [3].

Facades are important components of any building envelope. They include walls and fenestration and are responsible for many functions in buildings, figure (2). They are recognized as the primary source of heat gain within the building due to solar radiation in hot climates. Environmentally designed and insulated façades show significant energy savings and reduced dependence on mechanical heating and cooling systems [4].

Walls form the structural support and the outer skin for thermal insulation, providing sound proofing, protection from weather and security and representing an aesthetic element to give the building its character.

On the other hand, fenestration plays a big role by controlling day lighting, admitting natural ventilation and permitting views while considering privacy.

They also promote energy efficiency through insulation, shape, size and orientation to minimize heat gain together with their contribution to the architectural style and visual appeal of the building.

2-2-Definition of double skin facades

A Double Skin Facade (DSF), as illustrated in figure (3), has gained popularity due to its claimed advantages in energy conservation, which support sustainable development [5].

In most research papers it is defined as a facade system made up of two layers, usually glass, separated by a gap [6, 7].

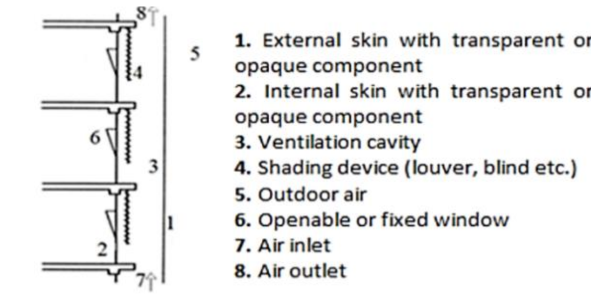


Fig. (3): Double skin facade structure
Source: Alemdağ, E., Beyhan , F., Soyadı, Y., " A Research on Construction Systems of Double Skin Facades", Gazi University Journal Of Science 30(1):17-30, March 2017

The external layer protects the inner layer from direct sunlight, reducing heat gain and improving thermal comfort inside the building. The gap between the two layers varies in width and can be naturally ventilated to further enhance the cooling effect. Moreover, double skin facades allow for thermal insulation and acoustic performance enhancements.

The most common topics discussed in previous research papers related to double skin facades include: the thermal performance and energy efficiency, ventilation strategies, acoustic performance, day lighting and visual comfort, impact on aesthetic value and architectural design, climatic adaptation, sustainability and design optimization and simulation studies [8,9,10,11,12].

2-3- Types of double skin façades

Double skin facades can be classified to many types including:

2-3-1-Productive façades

Productive facades transform from passive barriers into active generators, further contributing to sustainability, figures (4, 5).

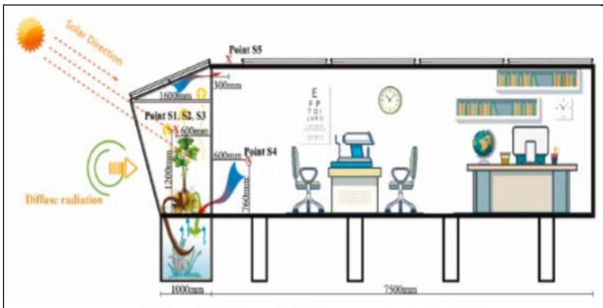


Fig. (4): Productive double skin facade
Source: Zhang, Y., Li, Z., "A novel productive double skin façades for residential buildings: Concept, design and daylighting performance investigation ,"Building and Environment, Volume 212, 15 March 2022

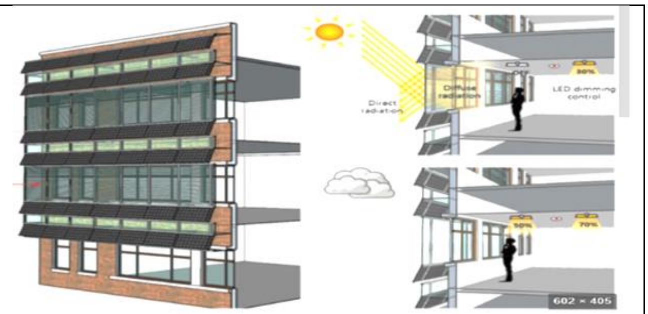


Fig. (5): Photovoltaic double skin facade.
Source: Lee, C., Lee, H., Choi, M., Yoon, J.," Design Optimization and Experimental Evaluation of Photovoltaic Double Skin Facade", Energy and Buildings, Volume 202, November 2019

Façades can be utilized effectively by installing photovoltaic panels. Additionally, plants can be integrated as a vertical green façade or used as shading elements for the double-skin façade [13]. They improve insulation, regulate temperature and improve air quality by filtering pollutants and carbon dioxide from the air.

2-3-2- Aluminium wall panelled facades

The aluminium wall panels have many advantages such as light specific weight, high strength, waterproof, fire prevention, low maintenance cost, corrosion prevention and a long service life.

They can be made with different shapes, and the surface can be sprayed into varying colours, figure (6).

Fig. (6): Exterior wall architectural perforated metal aluminum facade cladding panels providing privacy screen.
Source: https://langbestvs.live/product_details/109770353.html

2-3-3-Ventilated double skin façades

This type has openings in the outer skin to allow air to circulate through the air cavity. This helps to naturally ventilate the building.

2-3-4- Dynamic shading double skin facades

They are designed to adjust to the changing conditions outside a building to control the amount of light and heat that penetrates the building.

2-4-Classifications of double skin facades according to air flow

Based on their airflow organization, double-skin façades can be categorized into four types: box-window, shaft-box, corridor, and multi-story types [14, 6], as illustrated in figure (7).

- Box-window façades feature horizontal and vertical partitions at the floor level, along with vertical partitions between the windows. Each air space allows for natural ventilation.
- Corridor façades consist of uninterrupted horizontal air voids for each floor level.
- Shaft-box façades resemble corridor façades but include vertical shafts for airflow.
- Multi-story façades possess continuous air cavities that extend the full height and width of the building.

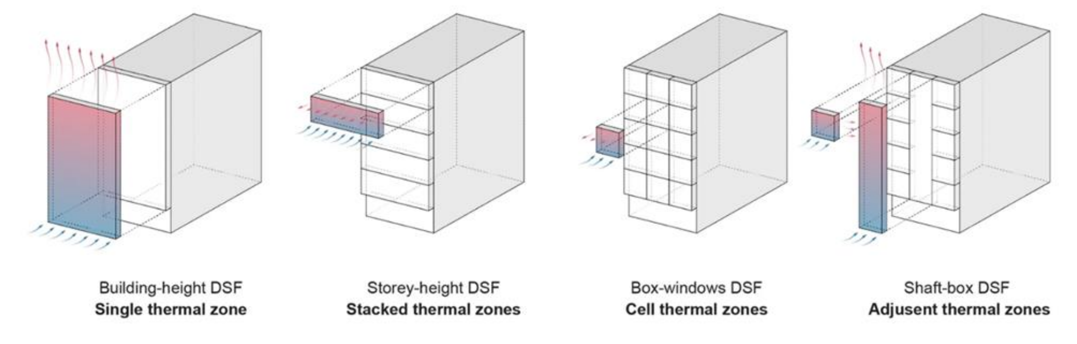


Fig. (7): The role of double skin façade configurations in optimizing building energy performance source: Naddaf, M., Baper, S., " The role of double-skin facade configurations in optimizing building energy performance in Erbil city", Nature Scientific Reports, volume 13, article number: 8394 , May 2023

3-Double Skin Façades with Integrated Perforated Outer Screen

Egypt's climate, as mentioned by the climate change knowledge portal, is dry, hot, and dominated by desert [15]. Fully shaded openings can reduce solar heat gain by as much as 80% [16].Due to this; the implementation of (DSFPS) is a promising design approach. Its use implies two passive interventions for indoor thermal comfort: solar protection and natural ventilation [17]. This has a direct effect on energy consumption and consequently on CO_2 emissions.

It is estimated to offer a sophisticated solution for improving energy efficiency and comfort in residential buildings, particularly in hot climates like Egypt.

They are proposed to reduce the need for mechanical cooling systems and lower energy consumption through their shading capabilities. They can be designed in various shapes, sizes and angles to optimize shading according to the sun's movement throughout the day and can also be integrated with solar panels to generate renewable energy for the building. Their integration should be an inseparable part in the design process of facades.

3-1-Similarities between Mashrabiya and (DSFPS)

According to the climatic conditions in Egypt, buildings are required to feature small windows, deep reveals, and shading elements. The mashrabiya, a wooden latticework, proved for years to be a successful treatment for openings that copes with the environment and culture of Egypt, figures (8, 9).It serves multiple purposes by encouraging airflow, decreasing solar heat gain and diffusing natural lighting that is penetrating through openings [18]. Moreover, it provides privacy, adds aesthetic appeal, and reflects cultural significance.

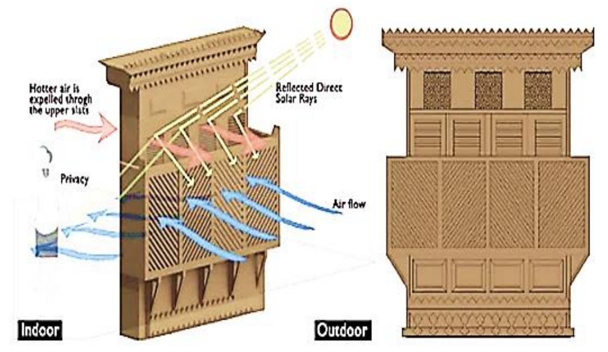


Fig.(8):Main functions of mashrabia
Source: Bagasi, A.A.; Calautit, J.K. Experimental field study of the integration of passive and evaporative cooling techniques with Mashrabiya in hot climates. Energy Build. 2020, 225, 110325

Fig. (9): The use of modern mashrabiya in residential facades
Source: Reimagining The Mashrabiya: Functionality and Symbolism in Contemporary Architecture, March, 2024

Double skin facades, featuring outer perforated screens, retain the essence of mashrabiya environmentally, socially and atheistically. This new method demonstrates how the past can inform and enhance the future of building design in a modern context. Both designs prioritize the regulation of light and air, facilitating natural ventilation and reducing reliance on artificial climate control.

3-2-Benefits of double skin façades with integrated perforated screens

Implementing double-skin facades is an effective method for achieving energy efficiency in buildings. The use of perforated outer screen represents a passive treatment for building facades in Egypt that adds extra environmental advantages to traditional double skin facades.

The use of (DSFPS) affects positively many parameters in the building. These parameters are as follows:

- Energy efficiency by assisting to maintain a cool environment in the summer and a warm one in the winter, as the air gap between the two layers is naturally ventilated.
- Natural ventilation by helping to cool the building naturally and thus improving indoor air quality and comfort.
- Natural lighting by controlling the amount of sunlight entering the building, optimizing indoor light levels and reducing glare.
- Sound and wind pressure by decreasing them and thus creating a more peaceful and comfortable living environment for residents.
- View and privacy
- Aesthetics through a visually stunning and distinctive appearance.

3-3- Considerations and Challenges

There are some considerations that must be kept in mind when designing (DSFPS). They include cost being more expensive compared to traditional facades but on the long run, they can proof to be fruitful. Also, they require maintenance to ensure that they continue to perform effectively, and the design must be adapted to local climatic conditions.

Overall, integrating (DSFPS) in residential buildings in Egypt can be a forward-thinking approach to improving energy efficiency but it needs to be carefully planned and tailored to the specific climatic and economic context.

4-Social Housing Projects in Egypt, a Case Study

Recently, social housing projects in Egypt have emerged as an effective solution for providing residential units that are compatible with the economic conditions of Egyptian society. They were implemented in the period from 2014 up till now with a percentage of 73% in 2022 compared to for- profit housing as show in figure (10)

4-1-Energy related problems of social housing projects in Egypt

Residential buildings account for 70% of all building types in Egypt and are responsible for approximately 60% of the country's total energy consumption[1].

Social housing projects in Egypt represent a great contribution in energy consumption that can impact the quality of life for residents and the overall sustainability of housing projects.

Figure (11) shows a southern façade of one of the social housing projects in El-shorouk city in Cairo, Egypt. The use of curtains and air conditioning devices gives an insight of the residents' interventions to attain internal thermal comfort due to the high exposure to solar radiation and heat gain.

This urges an understanding of each façade in accordance with their orientation and to explore innovative architectural solutions to minimize cooling loads in summer.

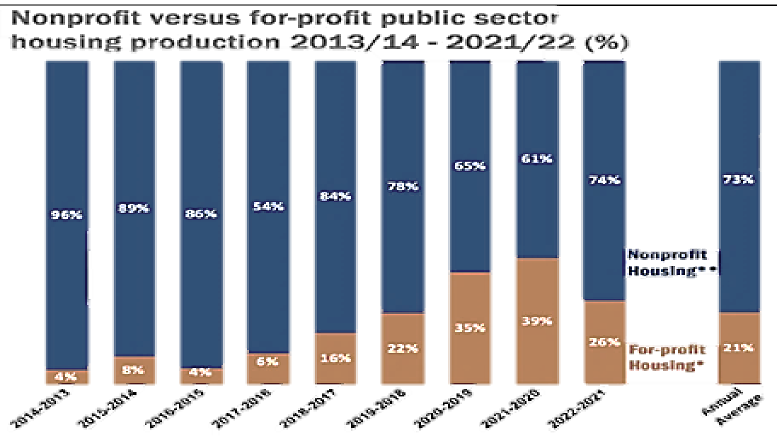


Fig. (10): Number of low-cost housings built by Egyptian government according to Central Agency for Mobilization and Statistics Issue
Source: The building environment observatory, July 2022

Fig. (11): Social housing in El shorouk city, showing the the use of curtains in the southern façade to avoid direct sun light
Source: Author

4-2- Case study

In the present work, a social housing prototype in Cairo, Egypt is selected, figure (12). The building consists of 5stories, each store has 4 apartments. The apartment is divided into 7 spaces: namely three bedrooms, reception, dining, kitchen and bathroom.

4-3- Proposed architectural modifications in the case study

(DSFPS) is implemented with different treatments for all facades according to building orientation. The material used for the outer perforated screen is made of titanium dioxide [19]. It features air purification, self-cleaning, and sterilization capabilities, positioning it as an innovative green building material with considerable promise for future energy-saving and emissions-reduction uses.

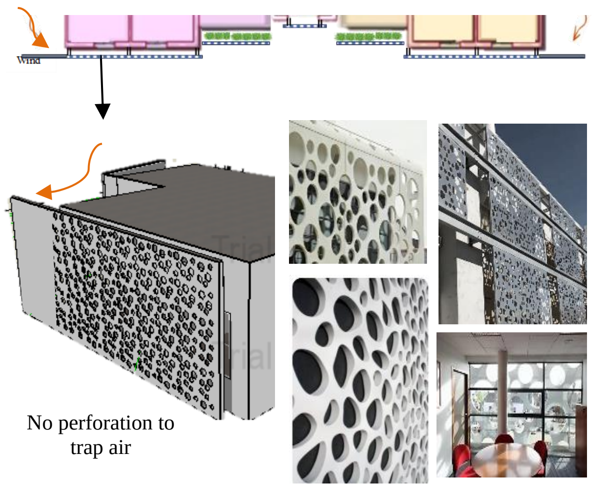
The Southern façade, figure (13), receives a great amount of solar radiation. Infront of the windows, a continuous perforated screen along the total height of the building is applied to prevent direct sun rays, admit natural lighting, and provide view and privacy. The screen projects from the sides with no perforation to trap the wind and directs air inside the gap between the two facades layers.

In front of the balconies, tilted manually operable louvers are present to control sun rays, light , view and privacy. At the tilted top, solar panels are found and in the gap between both facades are plants making this part of the façade a productive one.

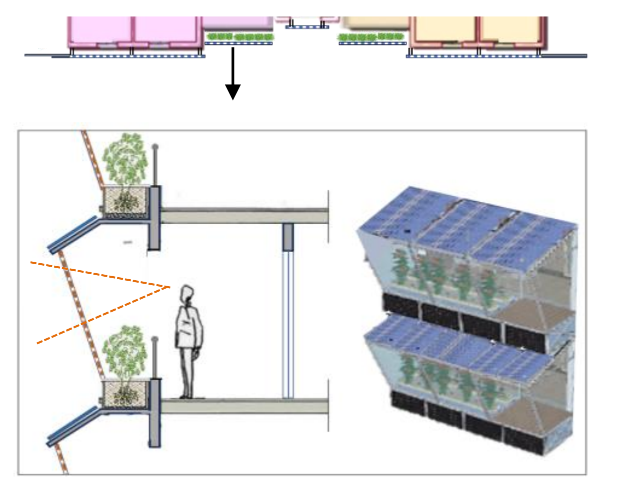
The northern façade, figure (14), faces the prevailing winds that come from the northwest. The perforated screen in front of the windows have wider openings to capture wind while in front of the balconies are manually operable louvers and plants to control sun rays, light , view and privacy.

For the eastern facade, figure (15), tilted perforated screens in front of windows along the building height are used to trap prevailing wind and light. For the western facade, figure (16), tilted perforated screens with wider openings compared to the eastern facade, are used to trap prevailing wind and light.

Fig. (12): Plan and elevation of social housing prototype.

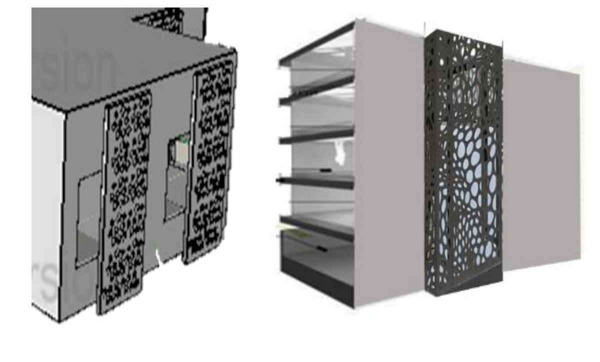


Treatment in front of windows

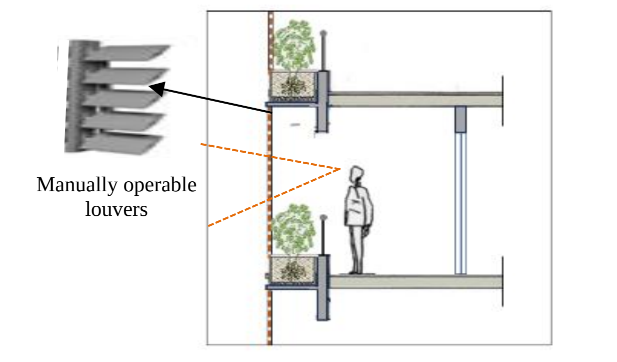


Treatment in front of balconies

Fig. (13): Treatments for the southern façade, Source: Authors



Treatment in front of windows



Treatment in front of balconies

Fig. (14): Treatments for the northern façade, Source: Authors

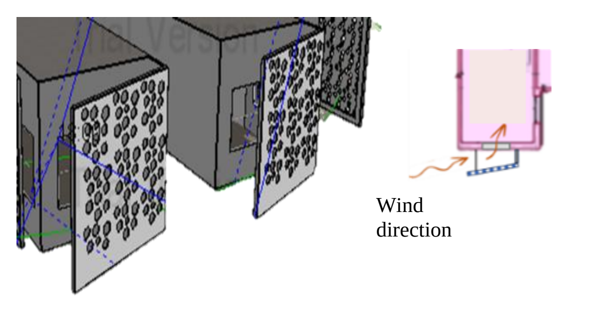


Fig. (15): Treatments for the eastern façade
Source: Authors

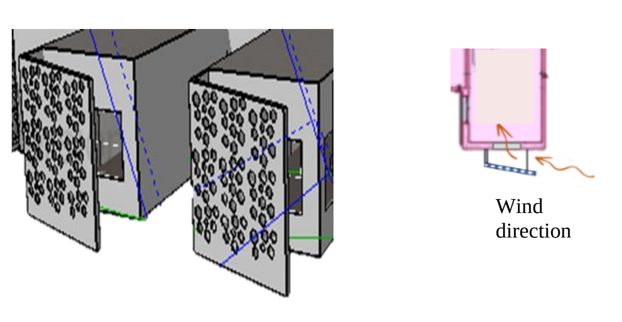


Fig. (16): Treatments for the western façade
Source: Authors

5-Simulation Program

The analytical part includes an applied study by using a simulation program "Design Builder" which provides valuable insights into the performance of (DSF) from the thermal point of view, allowing for new innovative and energy efficient ideas for the design of future facades in social housing in Egypt.

A model of one of the buildings of a social housing project in Cairo is implemented in the simulation program with and without the use of a double skin with perforated outer screen according to the weather of Cairo both in summer and winter.

A simulation of the building's energy use was conducted to calculate the annual cooling loads, particularly during the summer and winter seasons. This analysis highlights the significant impact of temperature variations on energy consumption, especially during the summer months when energy demand is at its highest.

5-1-Simulation input data

Data implemented in the simulation program includes:

- Site data: Cairo was selected for the building location (El-shorouk city).
- Building Facade: the walls' materials (layers) as used in the base case (current status) are shown in figure (17).

  They are from the inside: (Plastic paint / plaster / cement brick external plaster / external plaster) and the window is (3 mm glass panel).

Fig. (17): The wall materials
Source: Authors

5-2-Building modeling for simulation

The three-dimensional building without any additions was drawn in the simulation program, which was used as the base case (Current status at El- shorouk city), figures (18,19).

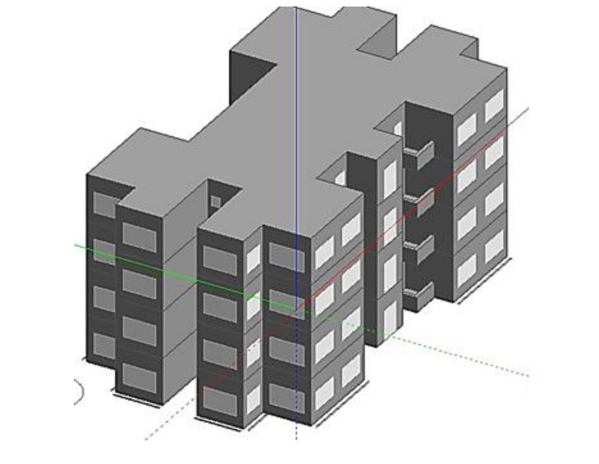


Fig. (18): Southern façade (base case)
Source: Authors

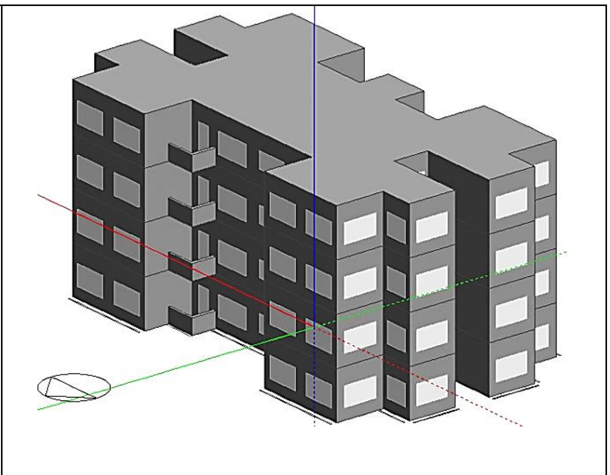


Fig. (19): Northern façade (base case)
Source: Authors

The building after the application of the (DSFPS) for the four facades is then drawn, figures (20, 21).

5-3-Building simulation (Before and after)

Simulations are performed on the building before and after the new treatments of perforated screens. They are done during the months of the year, focusing on August and January months. August is chosen as the one of heat intensity greatly increases and consequently increases hours of operating cooling devices to provide thermal comfort in summer. While in January is chosen as the one of cold intensity greatly increases and consequently increases hours of operating heating devices to provide thermal comfort in winter, figures (20, 21).

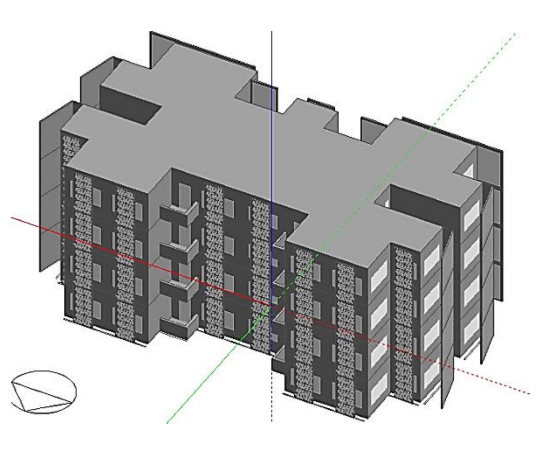
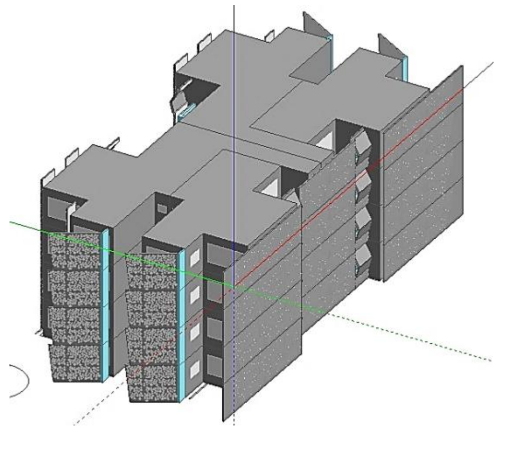
	

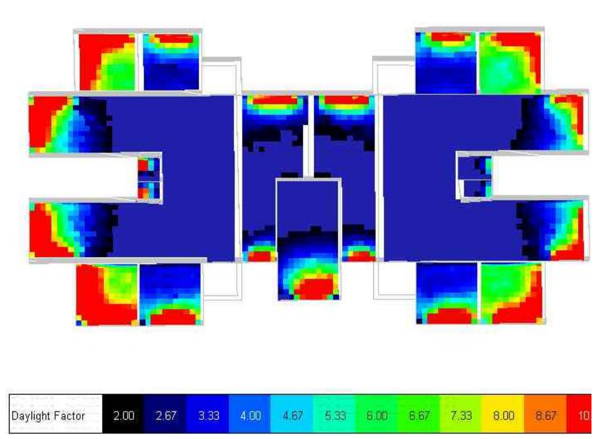
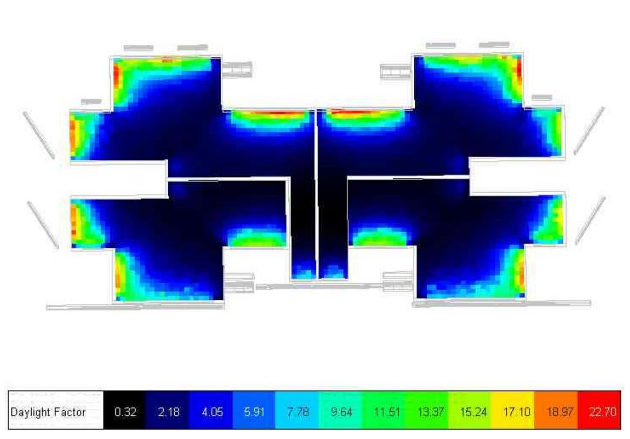
Fig. (20): Southern façade (after treatment) Source: Authors	Fig. (21): Northern façade (after treatment) Source: Authors

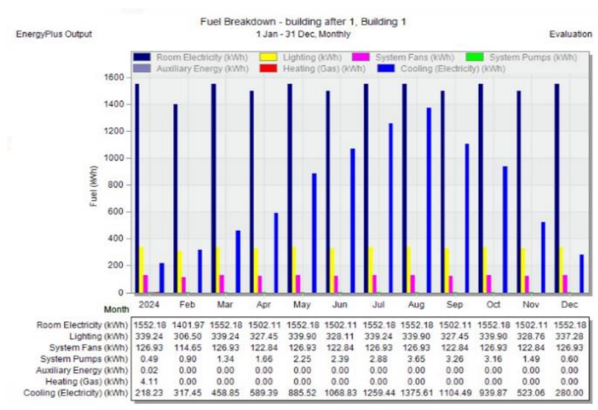
5-4-Results

After applying the simulation process on the building, the results can be summarized for each of the two cases (before and after the addition of the perforated outer screen).

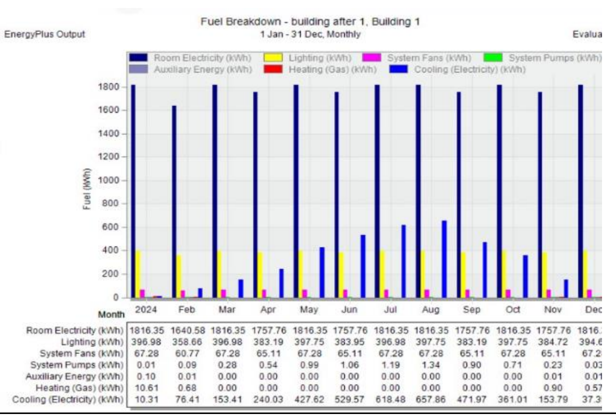
Table (1) demonstrates day lighting ranging from - red to black - where red is used for brightest parts and black is used for the darkest. It determines how adequately a space receives natural daylight to enable the intended activities to be performed without relying on artificial lighting.

Table 1: Simulation process for day lighting and temperature (before and after) , Source: Authors

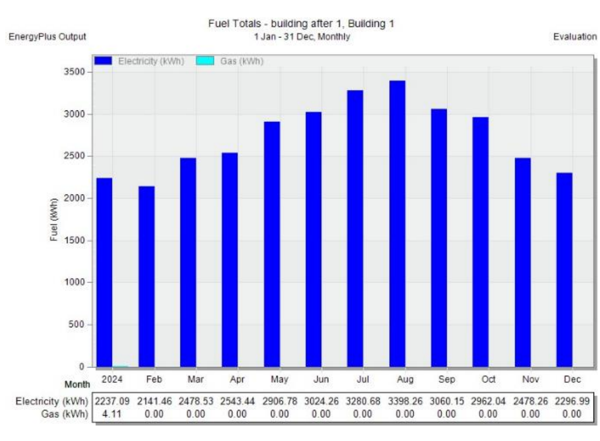
Before	After
	
Day lighting and temperature contours, for the base case	Day lighting and temperature contours, for the modified case



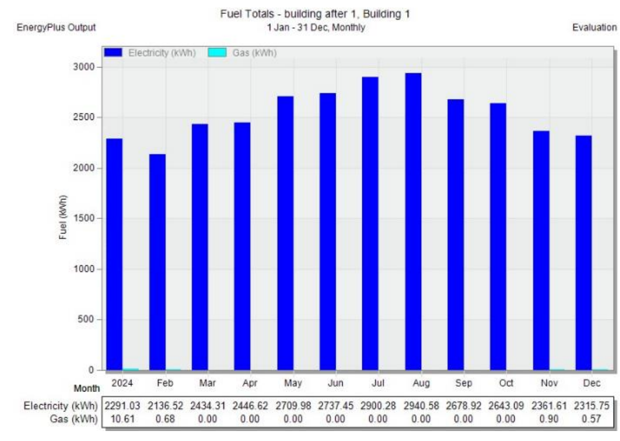
Cooling rate throughout the months of the year for the base case



Cooling rate throughout the months of the year for modified case



Fuel breaks down for the base case



Fuel breaks down for modified case

Regarding temperature and the associated cooling load, the analysis focuses on the summer (August month) and winter (January month), as illustrated in table (2) and chart (1).

In the base case during summer, the cooling load was significantly high about 8083.96 kWh/m². However, in the modified case, where a perforated screen made of titanium dioxide (TiO_2) was utilized, the cooling load decreased to 4493.60 kWh/m². This represents a reduction of 44.4% across all four façades, with a gap distance of 30 cm on the southern and northern façades, and an angle of 30 degrees on the eastern and western façades.

In winter (January), the base case exhibited a cooling load of 2425.188 kWh/m², as shown in chart 1, while the modified case reduced this load to 1349.88 kWh/m², as shown in table (2).

Comparison of Cooling Loads of The Building (Summer- Winter)				
Point of Comparison / Month	Base Case	Modified Façade (DSFPS)	Difference in Cooling Load	The Effect
Summer (August)	8083.96 KWh/m2	4493.60 KWh/m2.	Decreases by 3590.3 KWh/m2.	Positive with a decrease in cooling load by 44.4%
Winter (January)	2425.188 KWh/m2 .	1349.88 KWh/m2.	Decreases by 2.423.651 KWh/m2.	Positive with a decrease in cooling load by 44.3%

Table (2): Comparison of cooling loads of the building (summer- winter) Source: Authors

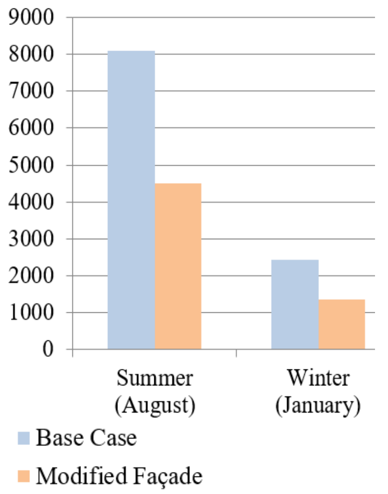


Chart (1): Comparison of cooling loads of the building (summer- winter), Source: Authors

6-Conclusion:

In conclusion, the authors propose that the results obtained using the Design Builder simulation program indicate that employing a perforated screen made of titanium dioxide (TiO_2) as a double façade in social housing in Egypt can effectively reduce cooling loads, particularly when considering the orientation of different façades. This aligns with the research objectives and supports the overarching goal of energy conservation, which is essential for sustainability.

The integration of double skin facades with outer perforated screens presents a compelling solution for modern architectural design, offering a harmonious blend of aesthetics, functionality, and sustainability. This innovative approach contributes positively to the ecological footprint of our built environments and especially to energy efficiency by minimizing reliance on artificial heating and cooling systems. It serves as a striking visual element, allowing designers to experiment with light and shadow while enhancing the building's overall appearance.

7-Recommendations

The use of (DSFPS) in residential buildings in Egypt is recommended particularly given the country's hot climate and need for energy efficiency. These facades help to regulate indoor temperatures by creating a buffer zone that provides insulation against extreme heat while allowing for effective natural ventilation. The perforations have an aesthetic appeal and can control sunlight penetration, reduce glare and heat gain while allowing for views and daylight illumination. Overall, the implementation of double skin facades can significantly contribute to sustainability, comfort, and architectural innovation in Egyptian residential architecture.

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