

A Proposed Methodology for Designing Green Walls to Reduction Carbon Footprint in Residential Buildings in Cairo (Case Study: Dar Misr Buildings)

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Abstract:

In hot climates, green walls are a recommended sustainable environmental solution for residential buildings. They effectively protect buildings from direct sunlight, enhancing thermal performance. Additionally, plants help produce oxygen through photosynthesis and reduce carbon dioxide emissions, which in turn mitigates the bad impacts of global warming, the primary driver of climate change. This research addresses the problem of increased carbon dioxide emissions in residential buildings due to the inefficient building envelope. The main aim is to reduce carbon dioxide emissions by applying green walls to the building envelope of the middle-income housing units under study. This study utilizes the Design Builder v7.0 simulation to assess the performance of residential buildings, focusing on a case study of middle-income housing units in Greater Cairo. The results showed that adopting green walls in middle-income housing units in Greater Cairo resulted in a reduction of carbon dioxide emissions by more than 16 % compared to the baseline.

Keywords:

Green walls, Carbon Footprint, CO2 Emissions, Residential Buildings.

1- Introduction:

In the context of the ongoing efforts by Egyptian government to develop the housing sector in Egypt, various housing initiatives have been launched to accommodate the rapid growth in demand for urban projects, particularly in urban areas such as Cairo⁽¹⁾, while improving the standard of living for middle-income groups. These efforts come back to global encounters related to global climate change, as highlighted in the report by the High-level Board on Global climate change (IPCC)⁽²⁾, which emphasized the responsibility of industrialized nations for exacerbating this phenomenon due to their persistent neglect in addressing or mitigating its effects over the past decades. The United Nations Environment Programme (UNEP) has warned of the consequences of climate change and acknowledges the need for effective measures to protect the environment, especially in the construction sector.⁽³⁾ The World Resources Institute (WRI) has highlighted the importance of the construction sector in mitigating global warming and its effects and reducing CO2⁽⁴⁾. The International Energy Agency (IEA) has highlighted the contributions of innovative environmental technologies and treatments, such as green walls, to building designs and their ability to improve the environment and promote sustainability in urban areas.⁽⁵⁾ The American Institute of Architects (AIA) has developed guidelines and a manual for environmentally friendly building methods, including green walls⁽⁶⁾. At the global level, a plan for sustainable development for the year 2023 was set in 2015 AD⁽⁷⁾, which includes 17 goals of sustainable development, especially Goal 11, which aims to create complete,

urban, strong, and environmentally friendly cities. ⁽⁸⁾ The World Green Building Council emphasized the importance of pioneering and innovative environmental technologies and treatments such as green walls and the importance of sustainable urban development. ⁽⁹⁾ The study (Tang, K. H. D., 2023) indicated the importance of treating green walls and designing them in building facades to reduce toxic waste in the air and that they work to improve energy in buildings ⁽¹⁰⁾. Applied research has demonstrated the significant advantages of incorporating green walls into residential projects. For instance, a 2023 study by Shushunova et al. 2023 ⁽¹¹⁾ provided concrete evidence of how advanced green wall systems contribute to better urban air excellence. Similarly, an earlier study conducted in 2022 by the same researchers ⁽¹²⁾ emphasized the benefits of these systems in noise insulation and enhancing the structural resilience of buildings. Additionally, Matheson et al. (2023) ⁽¹³⁾ explored the potential of green walls in decreasing indoor levels of volatile organic compounds (VOCs), highlighting their role in creating a healthier indoor environment. During the treatment of wastewater, according to a paper by Wang et al., 2024 ⁽¹⁴⁾, high unit's green wall systems were developed, high concentration to treat black water, which promotes environmental stability in the construction sector. In addition, an examination of CyBopoBa et al., 2021 ⁽¹⁵⁾ emphasized the value of reduction the carbon footprint of constructions as a means of increasing sustainable growth, a stage that can be supported by using technologies such as green walls. From the perspective of a life cycle with low carbon building, Sing, X. J., a study of 2012 ⁽¹⁶⁾ gave a thorough evaluation of the nature of green residential buildings and their positive impact on permanent cities. In addition, Erin and USLuer, 2022 ⁽¹⁷⁾ conducted an intensive study on the psychological and environmental effects of using green walls in indoor places, highlighting their contribution to improving the quality of life of users. Finally, a study of Abdullahi and Alibaba, 2016 ⁽¹⁸⁾ discovered applications of green aspects as an important element in achieving a sustainable urban environment.

2- Research Problem:

High CO₂ emissions from middle-income housing units are attributed to the absence of green walls on the surface of facades.

3- Research Objectives:

This research focuses on analyzing the impact of using green walls as a means of reducing carbon dioxide emissions within the design of medium-income housing units in the Dar Misr project. To achieve this, the Design Builder simulation software version 7.0 was used.

4- Research Questions:

- How can thermal and energy performance be improved and carbon dioxide emissions reduced for the Dar Misr medium-income housing unit model using green walls with different orientations in the hot climate of Egypt?

5- Research Hypothesis:

Green walls reduce carbon dioxide emissions within the Dar Misr medium-income housing unit model in the Greater Cairo region of Egypt.

6- Methodology:

To realize the study aims, a theoretical methodology was adopted, founded on a review of literature review to analyze the findings and their effect on the present study, while identifying the need for this study and understanding the concepts adopted therein. An analytical approach was also used to extract the optimal model for Dar Misr's medium-income housing units. Additionally, the research adopted an applied approach based on simulation techniques using DesignBuilder v 7.0 to Study the prevailing ecological aspects architectural styles. The study included the application of green walls to the exterior envelope of buildings and the analysis of simulation results for each case separately, which enabled the clarification and comparison of the results. In this way, the research objectives were achieved while leveraging previous studies and their findings.

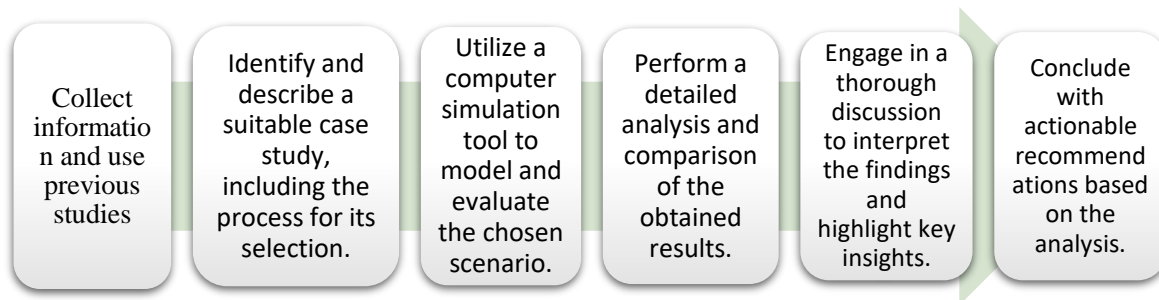


Figure (1) shows the research methodology.

7- literature review:

The accelerating pace of urbanization and the ever-increasing consumption of resources are proceeding at an unsustainable pace, resulting in severe social and environmental impacts. ⁽¹⁹⁾ Challenges such as global climate change, health issues, the degradation of natural ecosystems, and increased exposure to natural disasters highlight the urgent need to reintegrate nature into the urban landscape. (Olubunmi, Xia, & Skitmore, 2016). ⁽²⁰⁾ Nature-based solutions are provided offer practical strategies for mitigating these issues by harnessing nature's processes to support urban renewal. These solutions include measures like street vegetation, innovative urban drainage systems, vegetated roofs, and vegetated walls. Which, when implemented collectively, be able to create synergies and successfully address a range of environmental and societal challenges (European Commission, 2015). ⁽²¹⁾

A study by (Wang's, 2022) ⁽²²⁾ emphasizes vertical afforestation as an innovative approach that is becoming increasingly significant in tackling environmental challenges while promoting a sustainable ecosystem. The research examined these systems through technological, functional, and architectural lenses, underscoring their contributions to ecological, economic, and societal scope. While much of the existing literature focuses on the environmental advantages of vertical afforestation, the study points out that its technological aspects, along with its social and economic benefits, remain underexplored.

Green walls are an important environmental treatment in urban planning because they are considered a practical solution to most environmental challenges, including contributing to improving indoor air quality. Most studies have demonstrated the importance of green walls as an environmental treatment that contributes to reducing volatile organic compounds (25). A study by Shushunova et al., 2023 ⁽²⁴⁾ confirmed the ability of vegetation and green walls to eliminate toxic compounds and the ability of plant solutions to adapt to various indoor pollutants, in addition to purifying the air. Wang et al., 2024, designed a newly innovative, multi-unit green wall model with a special ability to treat blackwater on-site. This system demonstrates the dual benefits of environmental treatment and resource recovery through the application of green wall treatment to building facades ⁽²⁶⁾. Meanwhile, the building industry is a major source of greenhouse gas emissions—has been proactively exploring methods to reduce its ecological impact. (Cyborova et al., 2021) ⁽²⁷⁾ stressed the importance of analyzing carbon footprints in comparison to conventional construction methodologies, while (Gao, 2012) ⁽²⁸⁾ emphasized integrating advanced energy systems, technologies, and supportive government policies to develop sustainable residential infrastructure. Green walls exemplify this shift toward eco-conscious building design by incorporating live plant systems on building interiors or exteriors. (Erçin and Usluer, 2022) ⁽²⁹⁾ Green walls are classified into two main types: green walls and living, each offering ecosystem advantages such as sound decrease, air excellence enhancement, and cognitive health improvements. Further analysis by (Tang, 2023) ⁽³⁰⁾ focused on their efficacy in filtering airborne pollutants like particulate matter, NO₂, O₃, SO₂, and CO, pinpointing contributing factors such as plant selection, ambient humidity levels, and structural height. Complementarily, (Abdullahi and Alibaba., 2016) ⁽³¹⁾ The effect of green walls in reducing the urban heat island effect, while enhancing local climates and supporting biodiversity, has been studied.

8- Classification of Green Wall Systems:

As green wall technology continues to evolve, there is a growing need for a precise classification of existing systems based on their construction methods and defining characteristics. This classification encompasses living wall technology, which falls under the broader category of green walls. Green walls, in general, aim to enhance vertical surfaces such as facades, as well as interior and exterior walls, through the use of carefully selected plant species. These systems are designed either to support plant growth on buildings or to seamlessly integrate plants into the building structure itself. Within this framework, this paper introduces a classification system that delineates the various types of green walls while also examining their specific features (refer to Figure 2). Green walls are broadly categorized into two main types: green facades and living walls, each distinguished by unique attributes. Green facades usually employ climbing plants that grow on a structural framework attached to the vertical surface. In contrast, living walls represent a more modern innovation, leveraging advanced materials and technologies to support diverse plant growth in a **balanced manner on vertical surfaces.** ^{(32), (33)}

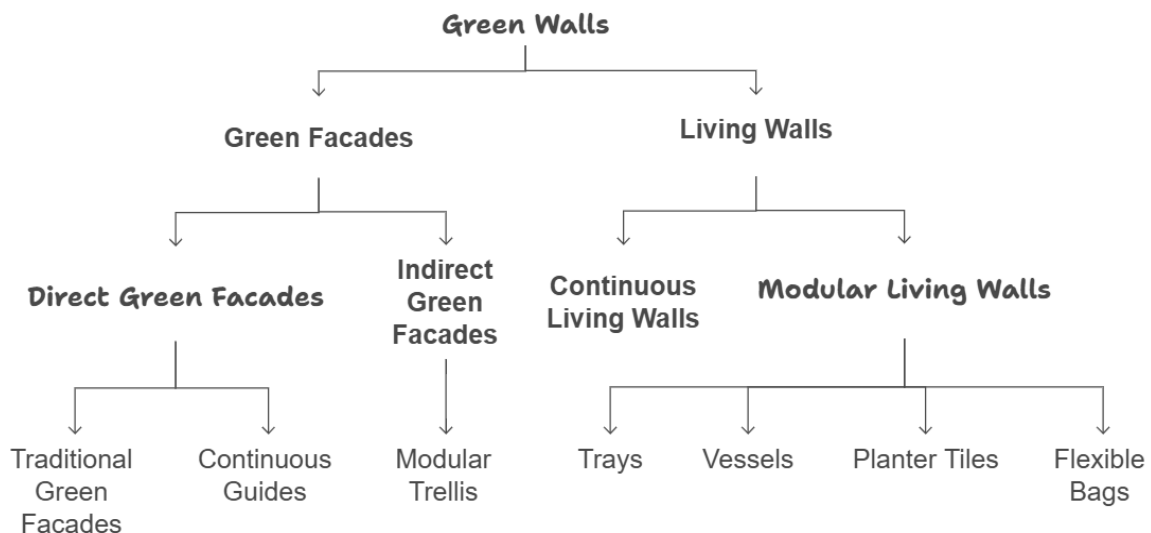
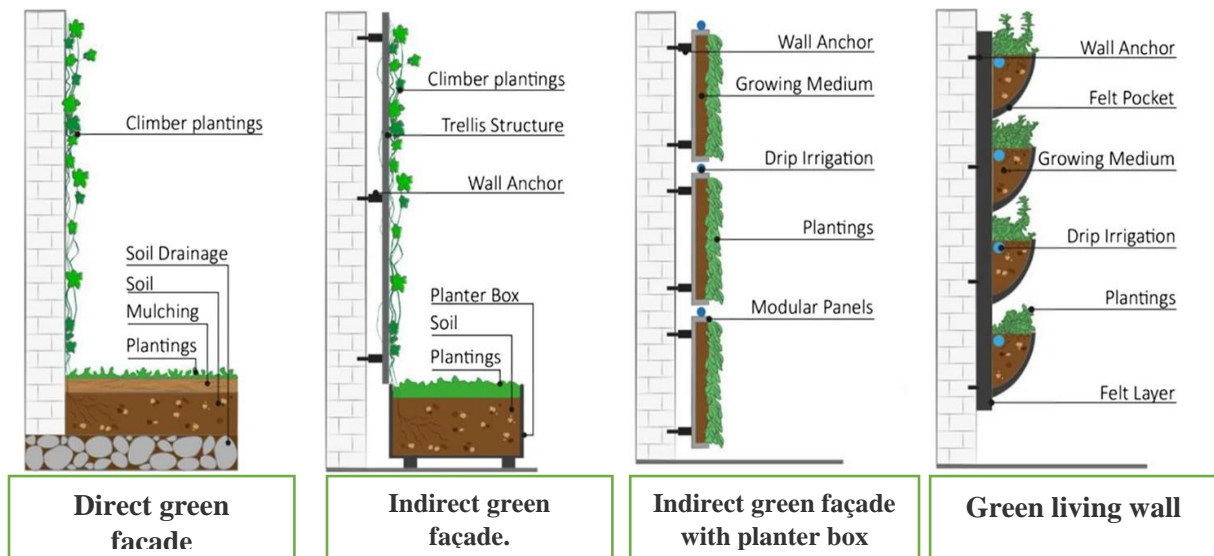


Figure (2) shows categorization of green walls. ^{(34), (35)}

1. Green wall: ^{(34), (35)}

- **Direct Green wall:** Vegetations grow immediately on the wall surface.

- **Traditional Green wall:** Utilize self-climbing vegetation fixed in the earth.

- **Indirect Green wall:** Feature a support shape for the vegetation to climb on.

- **Continuous Guides:** A single guiding framework that directs plant growth.
- **Modular Trellis:** Comprised of modular components with pots or vessels for plant rooting and individual support systems.

2. Living Walls (LWS): ^{(35), (36)}

- **Continuous Living Walls:** Lightweight, breathable panels with plants placed individually.

- **Modular Living Walls:** Consist of modular units containing growing media, either supported by a structure or mounted on the wall.

- **Trays:** Rigid, interconnectable containers for plant growth.
- **Vessels:** Secured to vertical frameworks or linked together for planting purposes.
- **Planter Tiles:** Modular systems designed with aesthetic spaces for plants to grow.
- **Flexible Bags:** Made from elastic polymeric materials, these bags hold growing media and can adapt to various surfaces.

9- Benefits of green walls:

green walls offer numerous benefits by optimizing urban space usage and fostering a more welcoming environment for building residents. ⁽³⁷⁾ They help compensate for the scarcity of green areas in rapidly expanding metropolises and provide significant environmental and social advantages, even when considering their economic costs. For instance, vertical gardens enhance building insulation by reducing heat gain or loss, promote biodiversity and ecological value, improve both outdoor and indoor comfort, elevate air excellence, and bolster the societal and spiritual well-being of urban inhabitants. Additionally, ^{(38),(40)} Vertical gardens can be integrated into both new builds and existing properties to help mitigate the urban heat island effect. In addition to these advantages, ⁽³⁹⁾ they can serve diverse purposes, including urban agriculture, gardening, or simply as striking decorative features. ⁽⁴¹⁾

10- Requirements for Installing Green Walls in Residential Buildings in Egypt. Shows Figure (4) and Table (1): ^{(42), (43), (44)}



Figure (4) shows Green Wall System Requirements ^{(42), (43), (44)}

Table (1) shows Requirements for Installing Green walls in middle-income housing buildings in Egypt:

To successfully implement green walls in middle-income housing buildings in Egypt, a set of technical, environmental, economic, and social requirements must be considered. Below are the main requirements along with suggested references: ^{(42), (43), (44)}

	Item	Description
1	Technical Requirements:	<p>a. Support Structure: Weather-Resistant Materials: Such as galvanized steel or aluminum to guarantee the endurance of the frame. Strong and Effective Design: The load system must be able to support the weight of the soil and various types of plants. Green Wall Insulation: This protects the building walls from water leakage from the irrigation system and from moisture.</p> <p>b. Irrigation System:</p> <ul style="list-style-type: none"> • A modern irrigation system: This ensures water distribution, such as drip or sprinkler irrigation systems. • Use of Modern Technology and Automated Control: This involves using modern smart systems to improve water management and consumption. • Installing a Water Drainage System: Ensure the water drainage system is efficient and works to prevent water accumulation to prevent structural damage. <p>c. Growing Media:</p> <ul style="list-style-type: none"> • Selecting the appropriate soil according to the type of system used. • Ensuring that plants receive the essential nutrients they need for their development and growth. • Providing Nutrients: Ensure that plants receive the essential nutrients necessary for their growth and development.
2	Environmental Requirements:	<p>a. Plant Selection:</p> <ul style="list-style-type: none"> • Drought- and heat-resistant plants: such as heat- and drought-resistant ornamental plants. • The plants that are widely used to cover fences and walls are climbing plants, which add an aesthetic touch. • Plants such as mint and basil, which provide a wonderful combination of health benefits and refreshing aromas, are aromatic plants. <p>b. Climatic Conditions:</p> <ul style="list-style-type: none"> - Providing adequate light: avoiding strong direct sunlight. - Providing plants that can withstand strong winds. <p>c. Water Management: Using smart irrigation systems to reduce waste water. Water Reuse: Utilize treated water for irrigation where possible.</p>
3	Economic Requirements:	<p>a. Initial Costs: The cost of purchasing a green wall system, including materials such as a support structure, plants suitable for the design, and a smart irrigation system. The cost of installing a green wall system, including the required equipment and the wages of trained workers.</p> <p>b. Operational Costs: Regular maintenance costs, including pruning plants, providing nutrients to plants, and maintaining the smart irrigation system.</p>

		<p>Energy costs are used to operate additional lighting and modern smart irrigation systems.</p> <p>c. Economic Returns: High commercial property value because of improving the aesthetic image of the property. Save Energy: Reducing the use of cooling systems thanks to the thermal insulation properties provided by green walls.</p>
4	<p>Social Requirements:</p>	<p>a. Awareness: Work to train and educate residents on the benefits of green walls and how to care for them. Prepare a guide that provides comprehensive information about green walls, their most important benefits, and how to maintain them.</p> <p>b. Community Engagement: Strengthening the role of residents in contributing to the planting and maintenance of green walls. Organizing community events aimed at planting new plants or renovating existing green walls.</p>
5	<p>Legal and Regulatory Requirements:</p>	<p>a. Official Approvals: Obtaining building permits: Ensure all required approvals from relevant authorities are completed. Compliance with standards: Commitment to implementing safety standards, environmental conservation, and other relevant requirements.</p> <p>b. Environmental Standards: Adherence to Sustainability Guidelines: Such as LEED certificate.</p>

11- Developing proposed methodology the design of sustainable and effective green walls in residential buildings in Egypt, contributing to improved quality of life and enhanced environmental sustainability. Shows Figure (5) and Table (2):^{(45),(46)}



Figure (5) shows Developing proposed methodology the design of sustainable and effective green walls in middle-income housing buildings in Egypt^{(45),(46)}

Table (2) shows Proposed Methodology for Designing green walls in middle-income housing buildings in Egypt: Designing green walls in middle-income housing buildings in Egypt needs an integrated method that considers the climatic, social, and economic context. Below are the essential steps for designing and implementing these walls in an innovative and sustainable manner: ^{(45),(46)}

	Item	Description	
1	Site and climate analysis:	<p>Local Climate Characteristics: Egypt experiences a hot and dry climate for most of the year, with mild winters and limited rainfall.</p> <p>Light Direction Analysis: To ensure plants receive adequate light without exposure to harsh sunlight.</p> <p>Prevailing wind analysis aims to select suitable plants and improve the environmental design to effectively resist weather conditions.</p> <p>b. Community and Resident Needs Study:</p> <p>Aesthetic Preferences: Consider residents' aesthetic preferences to ensure an integrated and acceptable design.</p> <p>Health Benefits: Focus on improving quality of life through benefits such as air purification and creating comfortable environments.</p> <p>c. Cost-Benefit Analysis:</p> <p>Initial Costs: Include material, installation, and maintenance costs.</p> <p>Environmental and Economic Returns: Lower energy usage, enhance air quality, and boost property profit.</p>	
2	Design phase:	<p>a. Selecting the Appropriate System:</p> <p>Hydroponic System (Soilless): Apposite for locations with limited space but need advanced irrigation systems.</p> <p>Traditional System (Using Soil): Fit for higher, stronger vegetation and suggests better durability, though it needs continuing maintenance.</p> <p>b. Plant Selection:</p> <p>Local and Climate-Adapted Plants: Such as ivy and cacti.</p> <p>Choose aromatic plants: such as chamomile and basil, to provide beauty benefits and enhance feelings of psychological comfort.</p> <p>c. Designing the Support Structure and Irrigation System:</p> <p>Material Selection: Choose highly weather-resistant materials such as aluminum or galvanized steel to ensure long-lasting functionality and good appearance.</p> <p>Irrigation System Design: Design an efficient irrigation system, whether drip or sprinkler, that ensures even water distribution throughout the green wall.</p> <p>Waterproofing Selection: Use waterproofing techniques and materials to protect the building from leaks, extending the life of the facility.</p> <p>d. Integrating the Green Wall with Architectural Elements:</p> <ul style="list-style-type: none"> • Shading Design: Make green walls an integral part of the design to act as shading elements, helping to reduce heat transfer. • Thermal Insulation Design: Enhance the building's energy efficiency by improving its thermal insulation and reducing the need for air conditioning systems. 	
3	Implementation Phase:	<p>a. Site Preparation: Work on cleaning the walls and treating any existing damage before starting to install the structural frame and advanced irrigation system.</p> <p>b. Planting:</p>	

		Work on arranging plants in a thoughtful and balanced manner to ensure optimal green coverage. c. Installing and Operating the Irrigation System: Ensure system efficiency through pre-operation testing.
4	Maintenance Phase:	a. Ongoing Care: Regular watering, providing necessary fertilizers, and pruning to maintain plant health and appearance. b. Monitoring and Evaluation: Monitor plant growth and watch for pests or diseases that may affect the green wall.
5	Awareness and Community Engagement:	a. Educating Residents: Conduct workshops and distribute guides on green wall care and their health and aesthetic benefits. b. Involving Residents: Encourage residents to participate in planting or renewing green walls when needed.
6	Final Evaluation and Future Improvements:	a. Measuring Benefits and Analyzing Performance: Monitor the effectiveness of green walls in lowering CO2 emissions and enhancing indoor air quality. b. Design Modifications and System Improvements: Implement changes based on evaluation results to achieve higher sustainability and efficiency in the future.

12- Case Study: ⁽⁴⁷⁾

A study was conducted on the spaces of residential buildings for the Dar Misr model, a medium-sized housing project in Greater Cairo.

Project Name: Dar Misr Medium-Sized Housing Buildings. **Climate:** Hot and Dry. **Location:** Giza. The Dar Misr project consists of areas ranging from 100 m² to 150 m², consisting of three fully finished



bedrooms and a living room, including numerous amenities. It includes a shopping mall, a mosque, a school, landscaped gardens, elevators, markets, shops, separate services, security, and an iron fence surrounding the project, making it a closed compound to provide privacy for citizens, as Figures (6)- (7)- and (8):

Illustration (6) a model of Dar Misr medium-income housing units.

Source: : http://admin.mhuc.gov.eg/Dynamic_Page/637363603165751899.pdf 12-12-2024 ⁽⁴⁷⁾

12-1- Performance Assessment of co2 Emission Rates for the Example Study:

The assessment of CO₂ emission levels in the Dar Misr middle-income housing units functions as a measure of how effectively these spaces attain thermal comfort, shaped by the selection of materials and the design of the external envelope. By first outlining the principles of green building design and examining the implementation of green walls, a comparative analysis is conducted to assess how well these green walls within the building envelope contribute to thermal comfort in the Dar Misr housing units. This analysis also considers the materials used in the walls and glazing, with the goal of minimizing carbon dioxide emissions associated with the Dar Misr middle-income housing units.

12-2- Basis for Selecting the Case Study:

Studying regions with hot, dry climates and not treating the housing units of Dar Misr's middle-income housing units with environmental treatments and converting them to green buildings resulted in increased carbon dioxide emissions within the housing units, negatively impacting users. To achieve the study objective, the following should be considered:

- The project study is in more than one specific climate region, namely Greater Cairo.
- Preparing the necessary information for the simulation and the following evaluation phase involves:
 - Identifying projects focused on analyzing the influence of building materials in meeting efficiency and environmental suitability standards.
 - Developing models that incorporate environmental design principles and examining the materials used, along with their impact on co₂ emissions.

12-3- Scientific Methods for Gathering and Documenting Data for the Chosen Project Studies:

following methods were used to collect information related to the case studies:

- Field visits, photographic documentation, and research observations.
- Architectural and aerial maps of the case studies.
- Previous research and studies that addressed the project studies.

12-4- Applied Research Approach:

A- Evaluation of climatological information for the research area.

B- Analytic explanation of the building under analysis (architectural explanation, green walls, and occupancy rate).

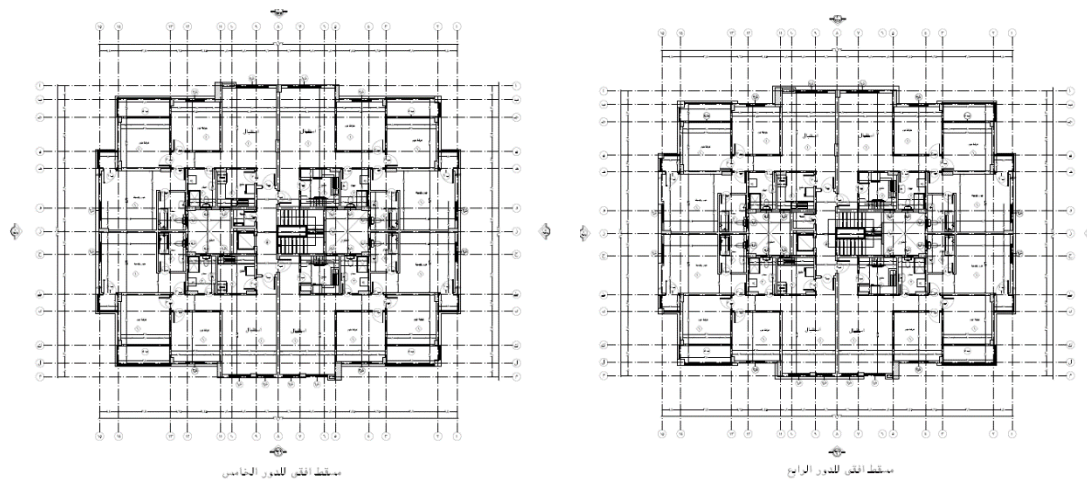


Figure (7) shows the building under study, the projections, plans for the model of the medium-income housing units of Dar Misr. Source: The researcher

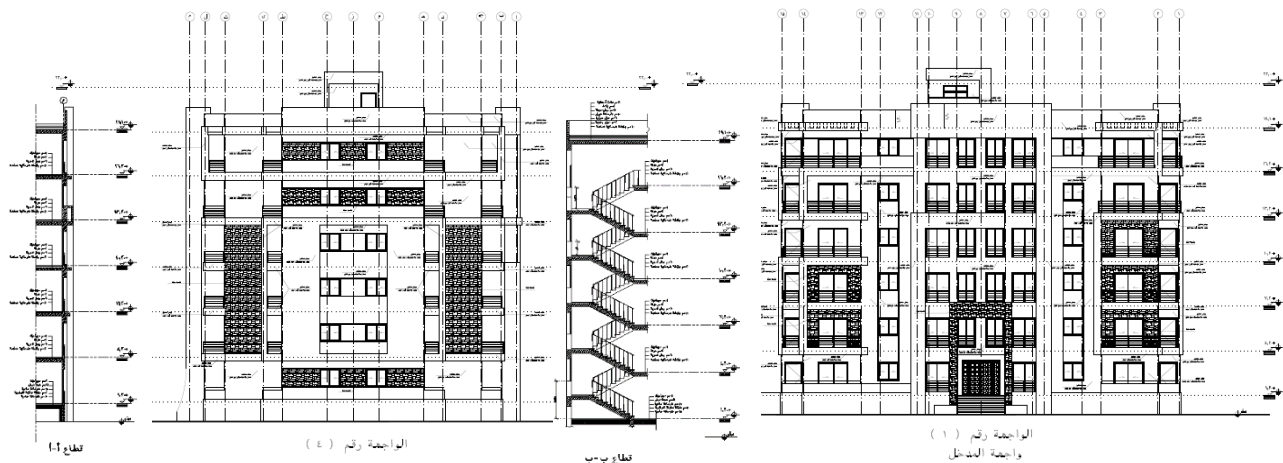


Illustration (8), the projections, facades and the section for the model of the medium-income housing units of Dar Misr.

C. Utilizing simulations, the baseline case for Dar Misr's middle-income housing units was evaluated using the Design Builder v7.0 simulation program. This phase laid the groundwork for understanding existing performance metrics.

D. Alternative solutions were developed by applying the proposed methodology to specific case studies. To achieve optimal outcomes, green walls were examined using a simulation program to evaluate their impact on reducing carbon dioxide emissions in Dar Misr's housing models. This step aims to identify the most effective strategies for sustainable design enhancements.

E. Results were compared and analyzed to determine the most effective options. This approach facilitates an understanding of various design and material alternatives, assisting in selecting solutions that enhance thermal performance while minimizing carbon dioxide emissions.

The goal of these simulations includes:

- A. Investigating the potential of green walls to mitigate carbon dioxide emissions in residential buildings.
- B. Examining the types of green vegetation applied to the exterior facades of Dar Misr's housing units and their effects on indoor environmental conditions.
- C. Simulating methods for lowering carbon dioxide emissions and projecting improvement rates for Dar Misr's middle-income housing units.

12-5 Analysis of Dar Misr's middle-income housing units involved several steps:

A- Assessing climate information for Cairo, the study region, using Climate Consultant 6.0 software:

-Psychometric map: A psychometric chart

- Psychometric map analysis was conducted to explore the interplay between temperature and relative humidity on its respective axes (horizontal and vertical). The chart highlights the climate characteristics of Greater Cairo by identifying the thermal comfort zone, determined by temperature, humidity levels, occupancy rates, clothing, and activity levels. These findings are depicted in Illustration (9).⁽⁴⁸⁾

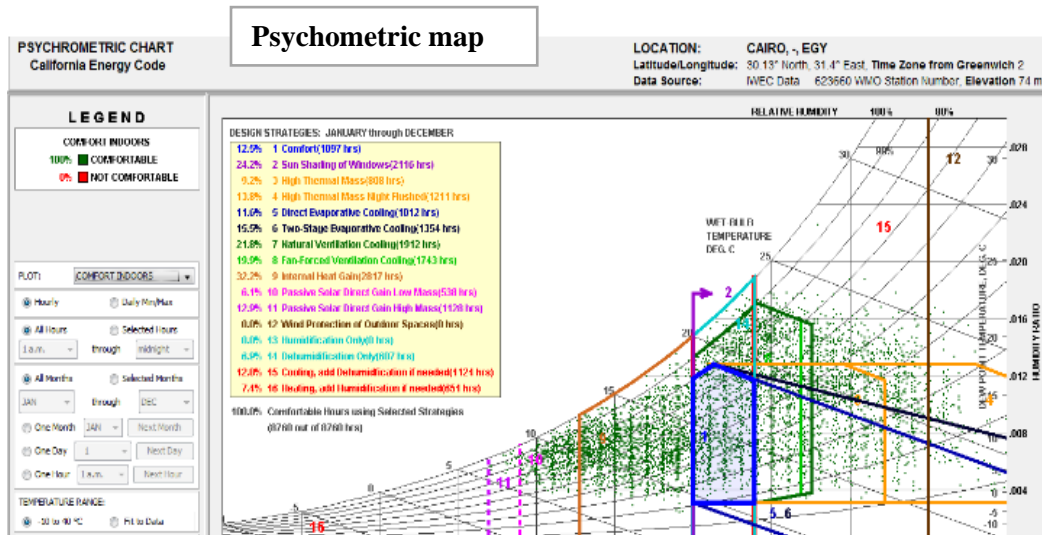


Illustration (9) the Climate Consultant 6.0

B- Data for the Dar Misr Middle-income Housing Unit Models:

- Architectural Design Data:

The study aims to evaluate the Dar Misr Middle-income Housing Unit Model before and after variations, focusing on the effect of green walls in reducing carbon co2 and the role of orientation in relation to the housing units' architectural measurements. It will involve comparing the existing conditions of the Dar Misr Middle-income Housing Units with the modified versions developed through proposed alternatives. The comparison will examine essential design aspects, including horizontal projections, wall thickness, and orientation variations.

12-6- Assessment of Dar Misr Middle-Income Housing Unit Models Utilizing Simulation. The process involves:

A- Simulation Methodology:

The program inputs the building specifications and dimensions to generate a simulation model that replicates the real structure. This model provides a detailed simulation of all factors related to the building's carbon dioxide emission rates, as illustrated in the example derived from DesignBuilder v 7.0. The software evaluates the inputs comprehensively throughout the entire case study.

B- Building Operation Data:

- Building Operation Period: Operation period per day, 24 / 7 / a week. (- Density 0.55. - Clothing: In winter = 0.9 clo, in summer = 0.49 clo.) (4)
- Space User Burn Rate (standing/walking) = 1.0 - Computer.
- Setting the Operation Schedule: Operation period per day, 24 / 7 a week

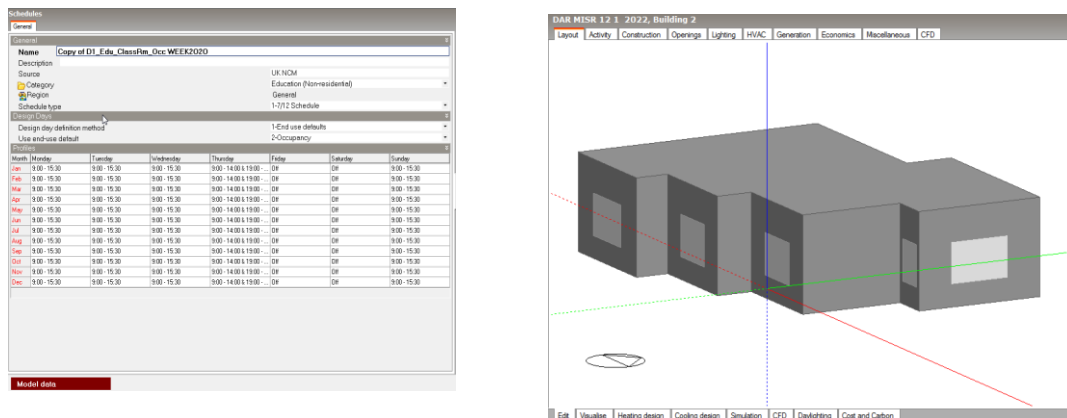


Figure (10) shows a model of case study in the DesignBuilder V 7.0 program. Source: <https://designbuilder.co.uk> 10-12-2024 (49)

12-7- The Results:

Evaluation of the CO2 emission rate for the Dar Misr medium-income housing unit model:

- **Case One:** Analysis of simulation outcomes for CO2 emission rates in the base case compared to various orientation configurations for the Dar Misr medium-income housing unit model: This assessment involves a 25 cm thick red brick wall combined with 6 mm single-layer UV (1.661) glass. in Illustration (11):

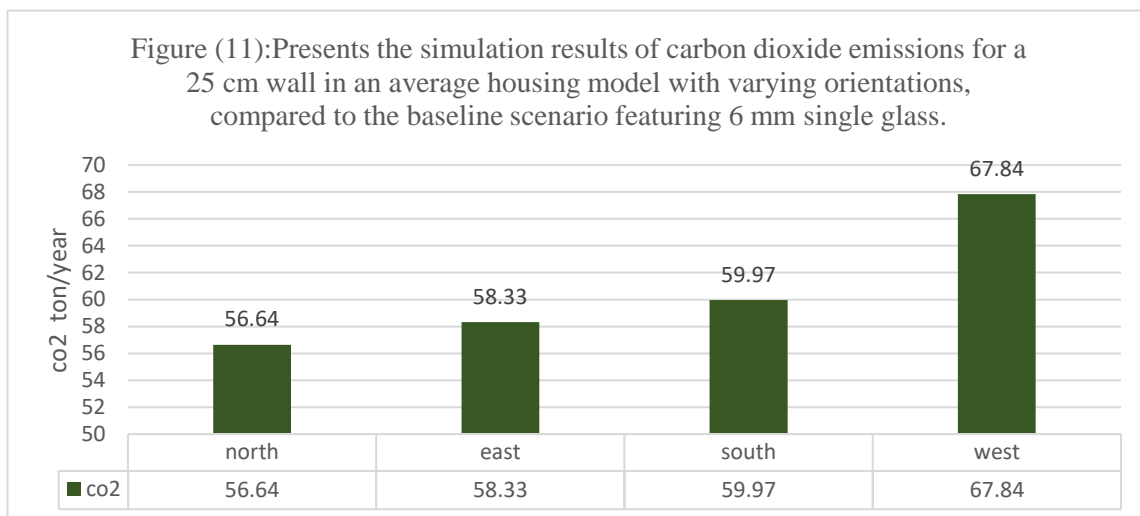


Figure (11) a Presents the simulation results of carbon dioxide emissions for a 25 cm wall in an average housing model with varying orientations, compared to the baseline scenario featuring 6 mm single glass.

Analysis of Figure (11) reveals that carbon dioxide (CO2) emission rates vary significantly based on building orientation. Simulation results indicate that the highest annual CO2 emission rate for the middle-income housing units in Dar Misr, Cairo, occurs with the westward orientation. A red brick wall with a thickness of 25 cm, this orientation results in an emission rate of 67.84 tons per square meter, the highest among all the studied orientations. In contrast, the northward orientation shows the lowest emission rate at 56.64 tons per square meter, reflecting a 16.5% decrease compared to the northward orientation. The southward orientation records an annual CO2 emission rate of 59.97 tons per square meter, while the eastward orientation records 58.33 tons per square meter.

- **Case two:** involves comparing the simulation results of CO2 emission rates across various orientation types for the Dar Misr medium-income housing unit's model. This comparison specifically focuses on the scenario with a green wall (UV 0.322), as illustrated in Figure 12.

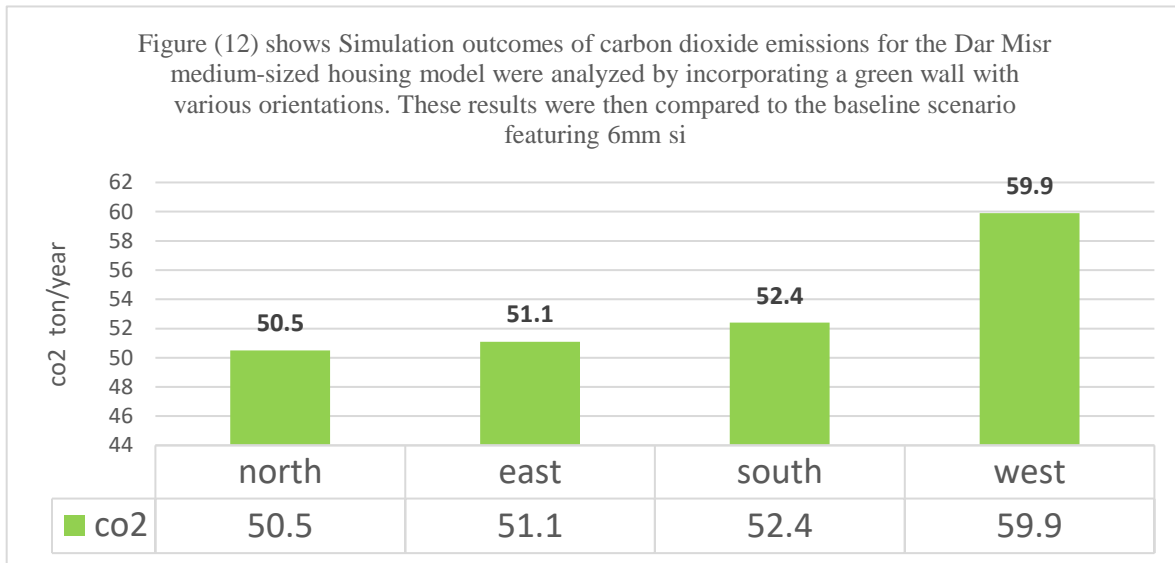


Figure (12) provides an analysis of simulation outcomes illustrating the CO2 rates for an average housing model across various orientations. These results are analyzed against the baseline scenario, incorporating a green wall and 6 mm single dark glass.

By Analyzing Figure (12), it becomes evident that carbon dioxide (CO2) emission rates fluctuate based on orientation. The simulation outcomes indicate that the westward alignment of the Dar Misr middle-income housing units in Cairo generates the highest CO2 emission rate when utilizing a 25 cm thick red brick wall under the green wall scenario, reaching an annual rate of 59.9 tons per square meter. This represents the peak CO2 emissions among all observed orientations for these units. In contrast, the northward orientation records the lowest emission rate, with 50.5 tons per square meter annually, marking a 15.7% reduction compared to the westward orientation. Meanwhile, the southward orientation produces an annual CO2 rate of 52.4 tons /m2 , and the eastward orientation stands slightly lower at 51.1 tons per square meter.

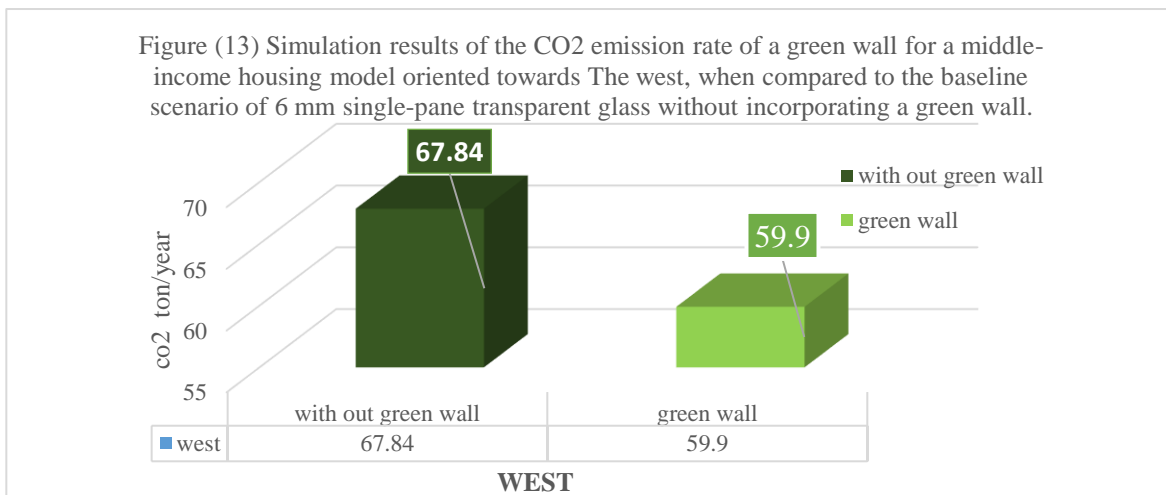


Figure (13) Simulation results of the CO2 emission rate of a green wall for a middle-income housing model oriented towards The west, when compared to the baseline scenario of 6 mm single-pane transparent glass without incorporating a green wall.

Analysis of Figure (13) shows that the simulation results indicate a comparison of the CO2 rate (tons /m2/ annually) for the middle-income housing units in Dar Misr, Cairo, with a westward orientation before installing green walls and a 25 cm thick red brick wall. This orientation results in a CO2 emission rate of 67.84 tons /m2/ year. In contrast, a westward direction with green walls results in a CO2 emission rate of 59.9 tons /m2/ year, annually, a decrease of 11.7%.

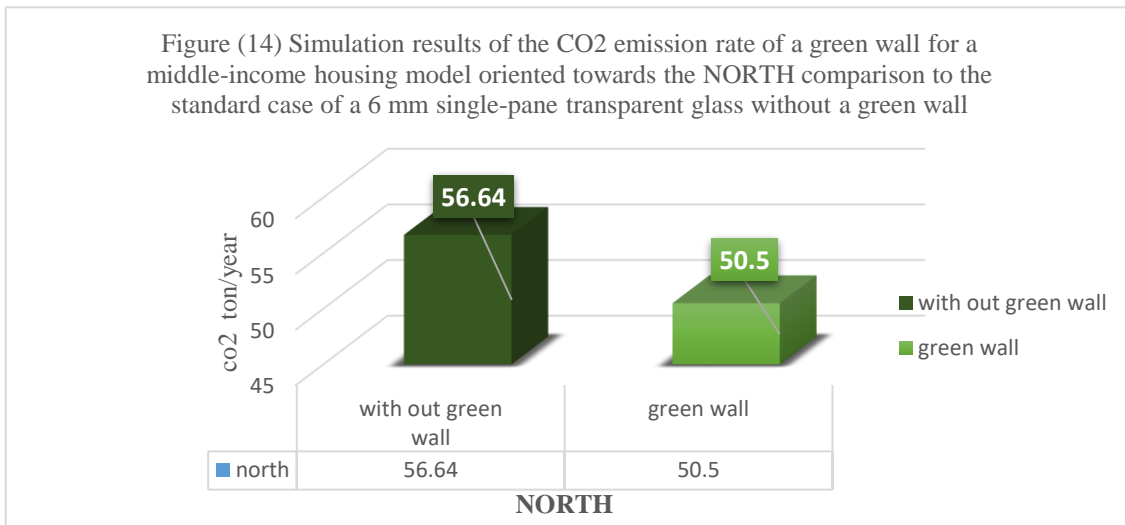


Figure (14) Simulation results of the CO2 emission rate of a green wall for a middle-income housing model oriented towards the NORTH In comparison to the standard case of a 6 mm single-pane transparent glass without a green wall.

Analysis of Figure (14) shows that the simulation results indicate a comparison of the CO2 rate (tons /m2/ annually) for the middle-income housing units in Dar Misr, Cairo, with a eastward orientation before installing green walls and a 25 cm thick red brick wall. This orientation results in a CO2 emission rate of 56.64 tons /m2/ year. In contrast, a westward direction with green walls results in a CO2 rate of 50.5 tons m2/ year, annually, a decrease of 10.84%.

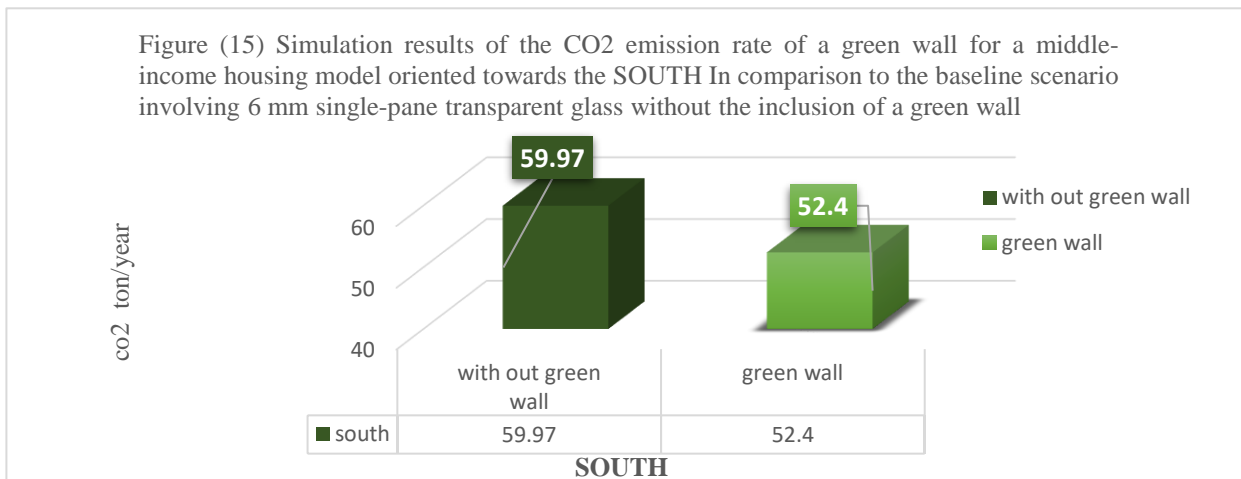


Figure (15) Simulation results of the CO₂ emission rate of a green wall for a middle-income housing model oriented towards the SOUTH In comparison to the baseline scenario involving 6 mm single-pane transparent glass without the inclusion of a green wall.

Analysis of Figure (15) shows that the simulation results indicate a comparison of the CO₂ emission rate (tons /m²/ annually) for the middle-income housing units in Dar Misr, Cairo, with a southward orientation before installing green walls and a 25 cm thick red brick wall. This orientation results in a CO₂ emission rate of 59.97 tons /m² year. In contrast, a westward direction with green walls results in a CO₂ rate of 52.4 tons /m²/ year, annually, a decrease of 12.6%.

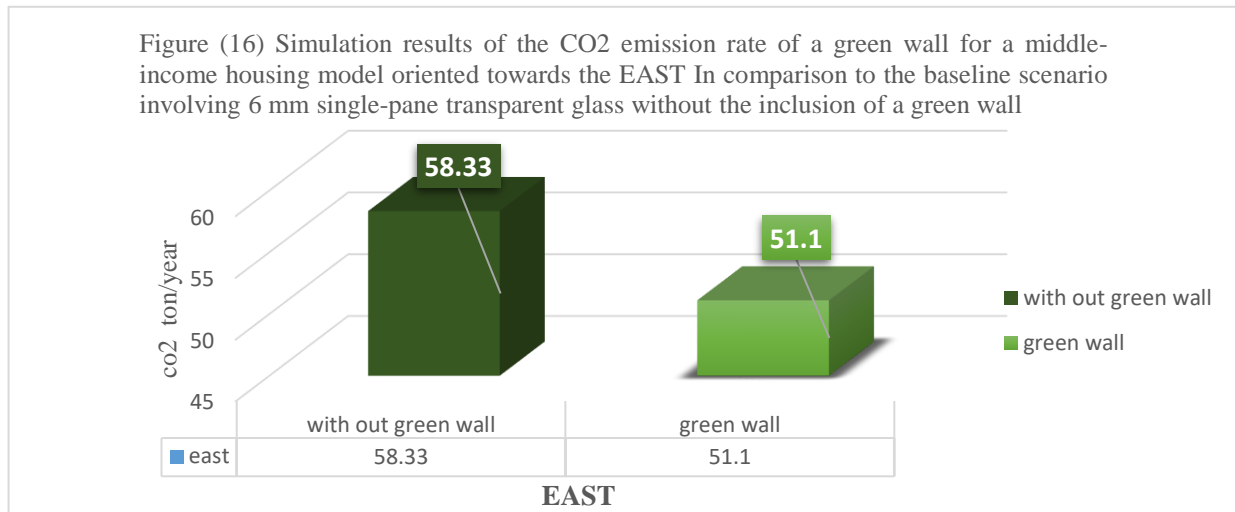


Figure (16) Simulation results of the CO₂ emission rate of a green wall for a middle-income housing model oriented towards the EAST In comparison to the baseline scenario involving 6 mm single-pane transparent glass without the inclusion of a green wall

Analysis of Figure (16) shows that the simulation results indicate a comparison of the CO₂ rate (tons /m²/annually) for the middle-income housing units in Dar Misr, Cairo, with a eastward orientation before installing green walls and a 25 cm thick red brick wall. This orientation results in a CO₂ emission rate of 58.33 tons /m²/ year. In contrast, a westward direction with green walls results in a CO₂ emission rate of 51.1 tons /m²/ year, annually, a decrease of 12.4%.

13- Discussion of Results: -

The carbon dioxide emission rate of the building is directly influenced by design decisions. This study focused on three architectural variable orientations, opening ratios, The incorporation of green walls and their impact on reducing CO₂ emission levels of the Dar Misr medium-income housing model. These factors were analyzed to ascertain their relative importance and overall environmental impact.

- Findings revealed that orientation significantly affects carbon dioxide emissions. Specifically, a **northward orientation** resulted in a 16% lower emission rate compared to a westward orientation in the Dar Misr housing model located in Greater Cairo.

- Further analysis examined the influence of green walls on the model's emission rate. Simulations confirmed that adopting green walls positively impacts reducing emissions. For buildings with a **northward orientation**, the carbon dioxide emission rate was observed to be 15.7% lower than that of the westward-oriented baseline case.

14- Recommendations: -

The problem of carbon dioxide emissions in buildings is one of the major challenges facing the effects of climate change. Addressing these emissions is determined by architectural design choices, as choosing the

appropriate solutions falls under the responsibility of the architect and their ability to understand the importance and role of appropriate design in addressing these emissions. By studying the various factors affecting the building, such as the building's orientation and the installation of green walls on the building's facade, a significant reduction in carbon dioxide emissions can be achieved through the following adjustments:

1- Choosing the appropriate building orientation. It is preferable to choose a northern orientation, followed by an eastern orientation, as simulation results in urban areas such as Cairo have shown that these orientations significantly contribute to reducing carbon dioxide emissions.

- For the Dar Misr project under study, the eastern orientation with the installation of green walls on the facades can achieve a 15.7% reduction in carbon emissions compared to the western orientation. The northern orientation also contributes to a 14.7% reduction in carbon dioxide emissions compared to the baseline.

2. Installing green walls on exterior facades:

- It is proposed to install green walls on the exterior and interior sides of buildings to improve air quality and reduce carbon emissions.

3. Designing openings appropriately for natural ventilation:

- Windows and openings must be appropriately designed to provide a natural flow of natural ventilation by optimally directing them to reduce the use of air conditioning.

4. Implementing thermal insulation appropriate to the climate in accordance with the energy code:

- Using innovative insulation panels treated with nanotechnology for walls and ceilings to reduce energy consumption.

5. Sustainable water management: This is achieved by adopting modern and smart irrigation systems and adopting gray and black water treatment systems for use in green wall irrigation systems.

6. Increase in consciousness and construction capacity:

- Conducting educational and awareness courses for engineers and real estate developers on choosing environmental treatments in buildings, their efficiency, and the economic feasibility of these environmentally friendly products.

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