

Evaluating The Performance Of Green Facades Using Smart Agriculture In Residential Buildings To Improve Energy Efficiency In The Cairo Region (Case Study Of Dar Misr Buildings)

Dr. Mahmoud Attiya Mohamed Ali ¹, Dr. Sahar Sayed Abdelaziz Gado², Dr. Basma Saad El-Din El-Sayed Ahmed³

¹-Associate Professor at Department of Architecture, October High Institute for Engineering and Technology, 6th of October, Giza, Egypt. Email: attiyagroup@gmail.com, <https://orcid.org/0000-0002-6852-325X>

²- Lecture of Architecture, Faculty of Engineering - Misr University for Science & Technology (MUST), 6th of October, Giza, Egypt. Email: saharjoe73@gmail.com

³-Assistant Professor-Department of Architectural Engineering - Higher Technological Institute- 10th Of Ramadan city – Egypt. Email: Basma.saad@hti.edu.eg

Abstract:

Green Facades are a recommended sustainable environmental solution for residential buildings in hot climates, providing effective protection from direct sunlight. Plants also contribute to oxygen production through photosynthesis, improving thermal performance and enhancing energy efficiency. This, in turn, mitigates the negative effects of global warming, which contributes to global climate change. This study tackles the issue of excessive energy consumption in Medium-income housing units resulting from the inefficiency of building envelopes. The aim of this research is to formulate a comprehensive methodology for evaluating the energy performance of green walls integrated with smart agriculture technologies on the envelopes of residential buildings. The study assesses energy performance of encapsulated green walls using vertical hydroponic systems and plant growth stimulations in Medium-income housing units in Cairo with an energy efficiency focus on sensitive hot dry climate zones. The study uses Dar Misr residential project as a case study and combines automation and empirical approaches to building system assessment, employing DesignBuilder v7.0 simulation software to evaluate thermal performance and energy efficiency of building envelopes. The findings suggest that the addition of green walls to the outer envelopes of the Dar Misr Medium-income housing units in Greater Cairo enhances energy performance by approximately 29% in comparison to the baseline scenario.

Keywords:

Energy Efficiency, Green Facades, Smart Agriculture, Building Envelope, Residential Buildings.

1- Introduction:

More innovative environmental solutions should be considered to improve thermal comfort within enclosed residential spaces and reduce energy consumption, especially in Greater Cairo, which is a hot and dry region ⁽¹⁾. The construction sector in Egypt, especially residential, is one of the most energy-intensive sectors due to the accelerating demand for energy consumption resulting from population growth and urbanization, which is the migration of people from rural to urban areas in residential apartments and residential complexes, and the use of cooling and air conditioning in buildings, especially in the summer months ⁽²⁾. Green facades have proven, as an environmental refuge over the past few years, to be an innovative solution and effective technology in improving the energy efficiency of buildings by treating the outer envelope of residential buildings ⁽³⁾. The use of green facades in residential buildings is a form of green infrastructure that adds value to urban design by integrating natural elements and contributes to creating a more responsive and effective urban environment because it mitigates the phenomenon of global warming, which helps in

solutions that face climate challenges by applying design related to reducing temperatures using the local climate to improve energy efficiency and achieve thermal comfort requirements ⁽⁴⁾. Green facades block a certain amount of Direct solar radiation leads to effective thermal insulation and thus creating lower temperatures that suit residential spaces ⁽⁵⁾. In design work, the use of green facades is a positive step towards sustainability and green design for residential buildings, because the use of these environmental treatments and solutions contributes to improving energy efficiency, protecting the environment, and reducing air pollution. More than half of the world's population now lives in cities, where users spend up to 80% of their time inside closed spaces, which makes controlling the indoor air quality of these spaces very important ⁽⁶⁾. Reducing energy consumption is one of the main challenges facing architects and engineers, and one of the most important methods that work effectively to address the lack of green spaces in cities is unused building surfaces such as roofs and walls to create green spaces on them and exploit them to solve the energy problem by reducing the thermal performance of the outer envelope and reducing pollution by increasing green spaces ⁽⁷⁾. Urban climates can be effectively modified through the intelligent use of plants within built urban environments, which can also improve the thermal performance of building facades. Green facades are a popular environmental solution whereby a building envelope is covered with plants to achieve tangible cooling of building facades and architectural spaces. Plants absorb a large portion of solar radiation for their growth and vital functions, such as respiration, photosynthesis, transpiration, and evaporation of water from the leaves of these plants. ⁽⁸⁾ Plants on green facades reduce the absorption of solar radiation during the day on building facades due to their reflective properties. The absorption coefficient of a wall surface covered with plants is estimated at approximately one-third of that of a traditional surface not used for these plants. As a result, maximum temperatures and the resulting differences between the interior and exterior are reduced, limiting the entry of unwanted heat and reducing its flow. In addition to providing thermal comfort within enclosed residential spaces, green facades contribute to reducing the impact of winds and controlling humidity within urban areas. ⁽⁹⁾ Green facades are promising solutions for greening cities, especially in urban environments where green spaces are scarce, and land areas are limited ⁽¹⁰⁾. The effect of green facades depends on several influential factors such as the percentage of plant coverage, density and leaf width of the selected plants, as they play an important role in determining the effectiveness of green facades and their plant cover. Most studies focus on the effect of these factors under different environmental constraints. ⁽¹¹⁾ Green facades gained significant popularity in the late 1980s. Their long-standing benefits have been recognized, as they contribute to improving energy performance and providing numerous social, environmental, and climate services, such as enhancing the aesthetic appearance of buildings, restoring urban ecosystems, removing pollutants from the air, and reducing noise. They also mitigate and reduce urban heat islands in cities, limiting air temperature fluctuations, and thus helping to achieve better outdoor thermal comfort. ⁽¹²⁾ The terms "green facades," "vertical gardens," "living walls," and "vertical landscape systems" describe plants that grow on the vertical surfaces of interior or exterior walls. ⁽¹³⁾ Green facades reduce the need for cooling and air conditioning in residential buildings and improve energy efficiency by cooling urban environments. The vegetation cover of green facades on a building reduces heat transfer through the exterior envelope, thus reducing air conditioning energy and, consequently, energy consumption in the building. Therefore, this study aims to propose an approach to estimating the performance of green facades in residential building envelopes to improve energy efficiency in the Cairo area, with a particular focus on Dar Misr buildings as a case study.

2- Study Problem:

The problem lies in the increased energy drain within the spaces of middle-income housing units due to the inefficiency of the outer envelope, the lack of environmental treatments, the failure to use innovative environmental solutions, and the failure to activate green facades.

3- Study Objectives:

The aim of the research is to improve energy performance by using green facades as a sustainable environmental treatment and improve thermal performance within a middle-income housing unit model in Dar Misr City, using the Design Builder v7.0 simulation program.

4- Study Questions:

- Using green facades on the exterior envelope of residential buildings, how can energy efficiency and thermal performance of the Dar Misr medium-sized housing units be improved using green facades with different orientations in Cairo, in Egypt's hot climate?

5- Study Hypothesis:

Green Facades improve thermal performance and, consequently, energy performance within the Dar Misr medium-income housing unit model in the Greater Cairo region of Egypt.

6- Methodology of study:

To realize the research aims, a theoretical methodology was adopted, based on a review of Literature Review, their findings and their effect on the present study, the extent of the need for the current study. An analytic methodology has been adopted to generate the most suitable model for the Dar Misr, the medium income housing. An applied approach was used, employing a simulation method using the Design Builder v7.0 simulation tool, and studying ecological views and overcoming designs. This was achieved by by means of Green Facades and smart agricultural in the building envelope to improve the energy performance of the Dar Misr medium-income housing unit model. The simulation results were then presented for each case, followed by clarifying and assessing the results, thereby achieving the research objectives and previous studies and their outcomes.

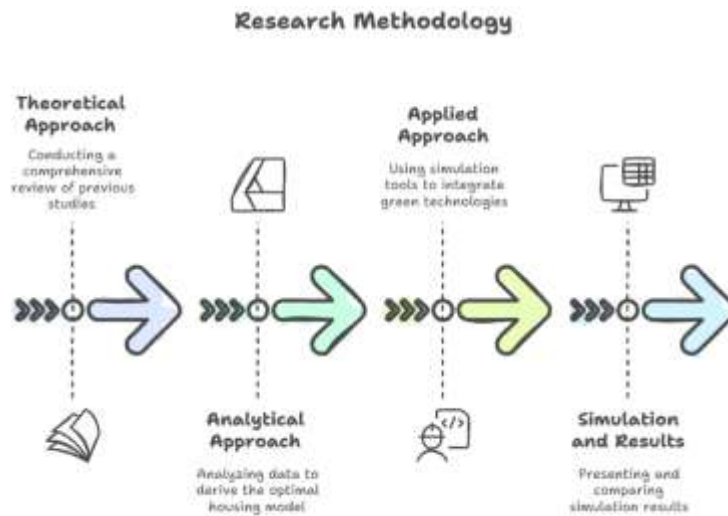


Figure (1) shows the Research Methodology.

7- Literature Review

The residential sector represents a large percentage of energy consumption in Egypt, due to the use and demand for various air conditioning systems, especially during the summer months. (Vignola et al., 2019) .⁽¹⁵⁾ Cairo's climate is characterized as hot and arid, with long stretches of high temperatures and intense solar radiation that significantly increase energy demand for cooling purposes (Fahmy et al., 2020) .⁽¹⁶⁾ Traditional building methods typically involve materials with high thermal conductivity, which enhances indoor heat accumulation and results in higher energy expenses and a greater carbon footprint (Aldawi, F., & Alam, F. 2016).⁽¹⁷⁾ Additionally, the densely populated nature of Cairo, coupled with minimal vegetation, This leads to an increase in the heat island phenomenon, which leads to an increase in demand for air conditioning systems. (Oke, 1982).⁽¹⁸⁾ In accordance with passive cooling strategies proposed by (Bibbiani et al. 2018), green facades lessen the impact heat has on building facades and increase cooling via evaporative plant transpiration. ⁽¹⁹⁾ Moreover, plants offer physical shading which decreases the solar radiation penetration and helps in temperature control at or on building surfaces, as pointed out by (Pérez-Urrestarazu et al., 2015). ⁽²⁰⁾ The cooling of the nearby microclimate is aided by the natural process of evapotranspiration, whereby water vapor is emitted into the atmosphere by plants, as noted by (Susorova et al., 2013). ⁽²¹⁾ Numerous authors advocate the remarkable influence of Green Facades on the thermal performance of a building. For instance, (Djedjig et al. 2018) ⁽²²⁾ confirms the claim that Green Facades can decrease the surface temperature of building facades by 10°C, greatly minimizing the rate of heat transfer

into the building. (Likewise, Radujković, Versele, and Breesch 2024)⁽²³⁾ documented a reduction of 2–3° in the indoor air temperature in buildings with Green Facades. Through the alteration of the building envelope, Green Facades assist in the reduction of conductive and radiative heat transfer (Kontoleon & Eumorfopoulou, 2010).⁽²⁴⁾ In combination with the passive cooling features of buildings, green facades trigger a notable decrease in the need for cooling energy. Research by (Perini et al. 2015)⁽²⁵⁾ demonstrated that the use of Green Facades on buildings helps in optimizing the cooling load by as much as 30%. This is advantageous for areas such as Cairo, where energy consumption predominantly goes towards cooling. Their simulation studies also show considerable reductions in peak cooling demands and total energy costs, (Preciado-Pérez and Fotios 2017).⁽²⁶⁾ Green Facades constitute an additional means of adjusting the local microclimate by lowering air temperatures while increasing relative humidity levels around the building (Alexandri et al., 2008).⁽²⁷⁾ This not only improves the thermal comfort of occupants but also decreases energy consumption in the surrounding buildings. The cooling effects can aid in implementing wider policies aimed at mitigating the urban heat islands effect (Bowler et al., 2010).⁽²⁸⁾ The efficiency of Green Facades is highly dependent on the criteria such as the type of plants selected, the materials used for the substrate, the irrigation system, as well as the overall aesthetic design of the façade. The cooling benefits are maximized by plants that are dense and have high evapotranspiration rates. (Whittinghill et al., 2013).⁽²⁹⁾ Choice of substrate determines the retention of water and the supply of nutrients, which are critical for healthy growth of the plant as well as the cooling with the rate of evaporation, (Jim, 2015).⁽³⁰⁾ To protect vegetation and maximize cooling potential, effective irrigation systems are important (Köhler, 2008).⁽³¹⁾ Drought-tolerant plant species must be incorporated with irrigation technology to perform consistently in the arid climate of Cairo. Nadeem, S. (2025).⁽³²⁾ The study focuses on the implementation of green wall technology in Cairo to decrease energy consumption, improve quality of life, and mitigate the effects of urban heat and other sustainability issues on the city. It aims to analyze the role of Green Facades as a responsive approach to an urban problem while still being in line with global climate change initiatives. In addition to energy-saving, Green Facades provide many more economically and environmentally advantageous returns. Such structures have the capability to increase property value, improve air and noise pollution, and increase biodiversity (Kohaler, 2008).⁽³¹⁾ These supports are useful in the context of Cairo owing to the pollution and lack of green areas within the city (Abdel-Aziz, 2019).⁽³³⁾ Green Facades, despite providing many benefits, are restricted in their widespread use due to challenges such as high cost of implementation, maintenance, and low awareness of the producers and decision-makers. In Cairo, additional obstacles such as water shortages and high temperatures are also present (Ibrahim, N. M. 2025).⁽³⁴⁾

8- Types of Green Wall Systems:⁽³¹⁾

With the rapid development of technology, it has become important to classify green walls according to their construction methods and main characteristics. This classification includes living walls, which are part of a broader classification known as green facades. These are systems designed to design and distribute plants on vertical surfaces such as blind walls, partition walls, or facades using selected plant species. This category aims to achieve a dense distribution of plants and promote their growth on building walls or integrate them into them. Green facades can be classified according to the different systems and construction characteristics used (see Figure 2) into two types: green facades and living walls. There is a difference between each type, as green facades include climbing plants that usually grow along the wall surface and cover the plants. The second type, living walls, is a more advanced method and approach, as it uses materials and techniques that enable a group of plants to grow harmoniously on the vertical surface.^{(35), (36)}

1. Green Facades:

- **Direct Green Facades:** In these systems, plants grow straight on the wall surface.
 - **Green facades:** These green facades rely on self-climbing plants, planted directly in the soil.
- **Indirect Green Facades:** These involve a supporting framework that allows plants to climb.
 - **Continuous Guides:** This system uses a unified framework that directs the growth of plants.
 - **Modular Trellis:** Made up of modular components with pots or containers for rooting and individual support systems.

2. Living Walls (LWS):

- **Continuous Living Walls:** These walls use lightweight and breathable panels where plants are placed individually.

- **Modular Living Walls:** Consisting of modular units supplied with growing media, these units can be fixed to a supporting structure or mounted directly onto a wall surface.

- **Trays:** Sturdy, connectable containers designed for plant cultivation.
- **Vessels:** These are attached to vertical frameworks or interconnected for planting needs.
- **Planter Tiles:** Modular systems are engineered to provide decorative spaces for plant growth.

Flexible Bags: Crafted from elastic polymeric materials, these bags contain growing media and can be shaped to fit various surfaces. ^{(38), (39)}

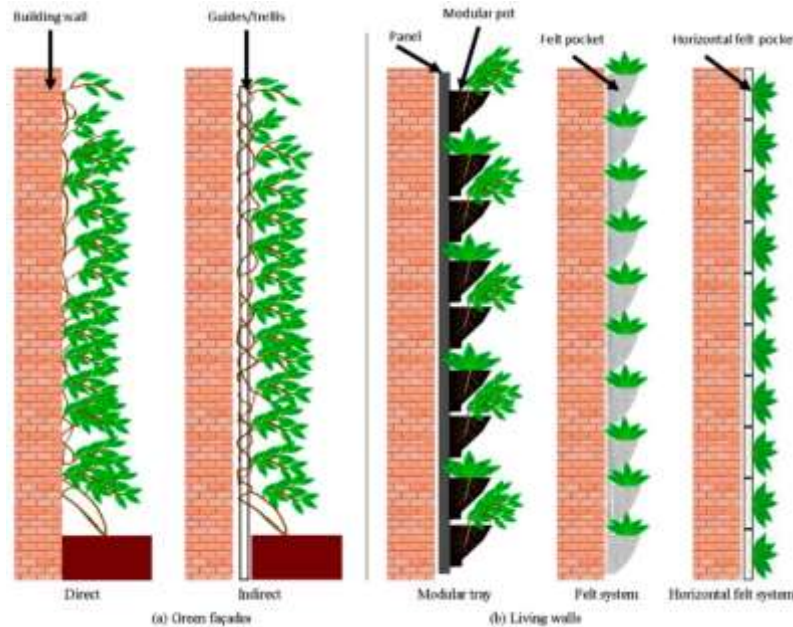


Figure (2) shows the classification of Green Facades systems. ^{(37), (38)}

9- Benefits of Vertical Gardens (Green Facades): ^{(40), (41), (42), (43), (44)}

Vertical gardens, or Green Facades, offer an innovative fusion of aesthetics and functionality, delivering significant environmental, economic, and social advantages. The scientific insights underpinning the diverse advantages of vertical gardens, as noted below, are essential.

1. Enhancing Building Aesthetics and Property Value:

Undoubtedly, green walls add significant value to facades which increases the aesthetic appeal by transforming them into landmarks. The economic value of the property increases as well because more people will find the property attractive.

2. Prolonging Building Lifespan:

The protective covering that vertical gardens provide to structures elongates building material life by reducing damage from harsh environmental threats, like ultraviolet rays and acid rain. In addition, vertical gardens also reduce the thermal stress cycles of building materials, therefore increasing construction durability.

3. Noise and Vibration Control:

Green facades also serve as natural acoustic barriers which significantly minimize external noise and vibration and shift Green Facades the quieter for occupants.

4. Reducing the effect of the heat island phenomenon:

Vertical gardens help in cooling down heat absorption by urban cities while simultaneously reducing air pollution by using the Biofilter method. Air quality is improved when used per square foot of vertical garden

and cultivates air space 100 Zones and Areas which can increase significantly dozens and even hundreds depending on the arrangement of the Vertical Garden.

5. **Curbing Dust and Harmful Microorganisms:**

Green Facades promote health by reducing dust and indoor molds, as well as bacteria. Spaces enclosed with plants' installations were found to have 50-60% lower harmful microorganisms than the non-planted rooms.

6. **Increasing Air Quality Within Buildings:**

The plants in the Green Facades defend against airborne toxins, helps to stabilize temperatures indoors, and increases the energy efficiency of the building by working as a natural insulator. During summer, they cool the interiors and during winter, they retain heat. This decreases the expenditure on energy to heat or cool the building.

7. **Improving Mental Health and Productivity:**

The presence of the plants has been shown to have beneficial impacts on mental health by reducing stress, improving mood, and increasing productivity in the workplace.

8. **Reducing Pesticide Usage:**

The vertical positioning of the plants makes them less susceptible to pest and disease, thus lessening the use of chemical pesticides and improving environmental safety.

9. **Encouraging Biodiversity:**

Vertical gardens provide niches for local wildlife. Living spaces for insects, birds and various other species are sustained which strengthens urban biodiversity.

10. **Efficiency of Energy Consumption:**

The green façades act as an insulator, hence no longer relying on air conditioners or heating systems. There is less energy consumed which reduces costs.

10- Smart agriculture and Green Facades in buildings:

Smart agriculture and Green Facades in buildings are becoming innovative approaches for sustainable urban development. Green facades integrated into smart structures can enhance energy efficiency, improve air quality, and boost sustainability (Theingi Aung et al., 2023).⁽⁴⁵⁾ The integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies in agriculture facilitates more effective resource management, autonomous farming, and improved predictions for crop health (S. Qazi et al., 2022).⁽⁴⁶⁾ Vertical gardens and urban farming can be optimized with smart materials and IoT-connected sensing systems, fostering stable ecosystems on building facades (Martina Decker et al., 2016).⁽⁴⁷⁾ A modular Smart Green-Roof system has been proposed as an advanced and adaptable way to make use of neglected urban and rural spaces, encouraging sustainable development (R. Siddiqui et al., 2022).⁽⁴⁸⁾ While these innovations hold great promises for creating sustainable urban areas, challenges in implementation and adoption persist.

Figure (3) shows offer a visual overview of the IoT framework for smart agriculture.⁽⁵⁶⁾



1. Understanding Smart Agriculture in Buildings

Smart agriculture in buildings represents a shift beyond traditional practices by optimizing all aspects of plant growth using technology. Regulated environments control variables such as light level, temperature, and humidity, as well as the precise provision of nutrients, and CO₂ levels to create favorable growing

conditions year-round. This system promotes efficient resource usage and improved crop quality. Central to the concept are technologies like sensors, artificial intelligence, data analytics, and automation that provide real-time feedback and enable precise adjustments for maximizing yields (Benke & Tomkins, 2017).⁽⁴⁹⁾

2. Essential Technologies and Tools

- **Controlled Environment Systems:** These systems maintain stable internal conditions like airflow, temperature, and humidity through devices such as HVAC units, dehumidifiers, and circulators.
- **LED Lighting:** Energy-efficient light-emitting diodes enable customizable light spectra for various plant species, facilitating optimal photosynthesis and growth (Barbosa et al., 2015).⁽⁵⁰⁾
- **Hydroponics and Aeroponics:** These soil-free cultivation techniques deliver nutrients directly to plant roots with minimal water usage. While hydroponics uses nutrient-rich solutions, aeroponics employs misting systems to maximize efficiency (Despommier, D., 2017).⁽⁵¹⁾
- **Sensors and Monitoring Tools:** Devices track parameters like pH, electrical conductivity (EC), temperature, humidity, and light levels, providing valuable data for adjusting growing conditions as needed.
- **Data Analytics and AI:** Advanced platforms paired with machine-learning models analyze sensor data for optimizing processes. These tools predict yield rates, diagnose diseases early, and automate environmental adjustments (Wolfert et al., 2017).⁽⁵²⁾
- **Automation Systems:** Automated irrigation, lighting setups, and nutrient delivery mechanisms reduce manual labor while ensuring consistent conditions. Robots can also handle tasks like planting and harvesting effectively.
- **Vertical Gardening Systems:** These systems improve productivity in confined areas through multi-layer shelving/ stacking arrangements.

3. Key Advantages of Smart Agriculture in Buildings:^{(53),(54)}

- **Maximized Productivity:** Enhanced cultivation conditions in smart greenhouses lead to even greater increases in productivity relative to open-field farming.
- **Water Use Efficiency:** Hydroponic and aeroponic systems are estimated to use 90% less water compared to conventional practices.
- **Pesticide Use Efficiency:** Ecosystems with controlled pest management strategies naturally deter pests without the need for heavy chemical intervention.
- **Optimized space:** Vertical frameworks are ideal for high-density planting as it permits climatically controlled horticulture, enabling location-independent crop production.
- **Weather Resilience:** External weather changes do not influence crop growth.
- **Reduced Transportation Emissions:** Urban farms enable proximity to consumers, thus reducing transportation costs and emissions associated with food supply chains.

4. Design Considerations and Challenges:⁽⁵⁵⁾

- **Effective Use of Energy:** Different approaches to smart agriculture require specific lighting, heating, ventilating, and changing air-conditioning (HVAC) systems. Careful management is required to make farming economically viable.
- **Return on Investment:** Rapid advancement in smart agriculture technologies is not paired with adequate planning in financial schemes.
- **Technical Expertise:** Successful operation and maintenance require a blend of expertise in horticulture, engineering, and data analytics, posing challenges for workforce training and development.
- **Produce Selection:** Choosing the most appropriate crops for maximizing yield and quality while keeping costs low is important for achieving profitability in the indoor farming business.
- **Approach Integration:** For smooth running of operations, adequate coordination and integration of various subsystems and technologies is vital.

- **Eco-Ecological Supervise:** Managing the temperature, humidity, light, and CO₂ concentration with high precision is crucial for the optimal growth of the plants.
- **Artificial Pollination:** Some crops require artificial pollination due to lack of natural pollination resources in specific areas.

11- Requirements for Installing Green Facades and Smart Agriculture in Residential Buildings in Egypt. Shows Table (1): ^{(57),(58),(59),(60)}

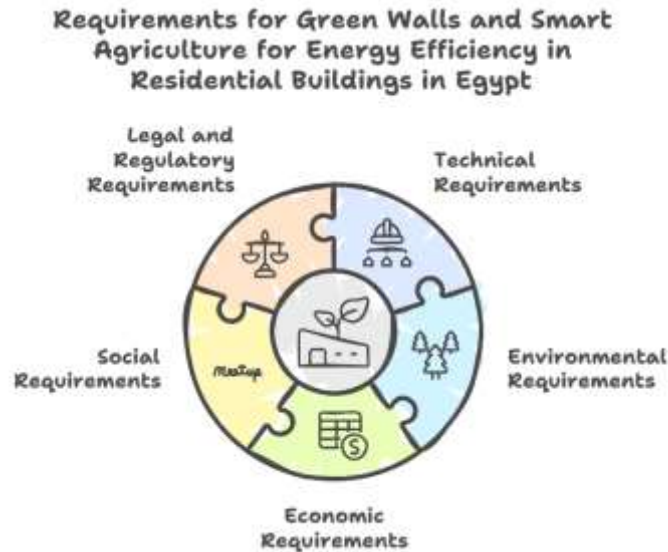


Illustration (4) shows Requirements for Installing Green Facades and Smart Agriculture in Buildings.

Table (1) Technical requirement needs for the application of smart agriculture and green facades for the energy efficiency vertical living walls in units of Dar Misr medium-income housing in Egypt: ^{(57),(58),(59),(60),(61)}

Technical requirements for achieving energy efficiency in residential buildings in Egypt are of a multi-focus nature. It is necessary to deal with the environmental, legal, social, and economic factors along with these systems' successful implementation. By following these guidelines, stakeholders can ensure sustainable development by promoting biodiversity and community engagement.

	Item	Description
1	Technical Requirements:	<p>1.1 Structural requirements</p> <ul style="list-style-type: none"> ▪ Load -bearing capacity assessment for vertical vegetable systems With weight ▪ modular panel system ≤ 35 kg/m (dry weight) ▪ Koric-resistant support structures (galvanized steel or aluminum) ▪ 20-Varterproofing Membrane with the year of the year ▪ Resistance design for speeding up to 90 km/h <p>1.2 Watering system</p> <ul style="list-style-type: none"> ▪ Drip irrigation with emissions of pressure darkness ▪ Sil moisture sensor (accuracy ν 2% vvc) ▪ PH and EC sensor to monitor nutrients ▪ Water flow rate: Summer 2-4 l/Square/Day, 1-2 l/m in winter <p>1.3 Smart control system</p> <ul style="list-style-type: none"> ▪ -Loravan or with NB-IoT connections-yot ▪ -Minimet sensor matrix: temperature, moisture, solar radiation, soil moisture ▪ -With mobile app intersection -Cloud -based monitoring platform ▪ With bacnet/modbus <p>1.4 Energy system</p> <ul style="list-style-type: none"> ▪ -Solar PV panel (minimum 200W/square meter Green Facade) ▪ -Dc-operated irrigation pump (12V or 24V)

		<ul style="list-style-type: none"> ▪ -72 -Hour for autonomous operation -butry backup
2	Environmental Requirements:	<p>2.1 Plant Selection</p> <ul style="list-style-type: none"> ▪ Utilize a list of native species approved by the Egyptian Environmental Affairs Agency (EEAA). ▪ Ensure that at least 70% of plant species used are native. ▪ Select species that are drought-tolerant, with water use efficiency (WUE) greater than or equal to 3 grams per liter. ▪ Adhere to compliance regarding prohibited invasive species. <p>2.2 Water Management</p> <ul style="list-style-type: none"> ▪ Limit the use of potable water to no more than 0.5 liters per square meter each day. ▪ Treat greywater to meet Class B standards as per the Egyptian Code 501/2015. ▪ Implement a rainwater harvesting system capable of collecting 50 liters per square meter of roof area. <p>2.3 Biodiversity Enhancement</p> <ul style="list-style-type: none"> ▪ Plant at least three species within every 10 square meters. ▪ It includes flowering species to support pollinators. ▪ Incorporate structural designs that provide nesting opportunities for birds.
3	Economic Requirements:	<p>3.1 Cost Parameters</p> <ul style="list-style-type: none"> ▪ Set a maximum budget for installation costs. ▪ Aim for a payback period that does not exceed seven years. ▪ Cap annual maintenance costs at 15% of the initial installation cost. <p>3.2 Initial Costs:</p> <ul style="list-style-type: none"> ▪ Material Costs: Cover the support structure, irrigation system, and plants. ▪ Installation Costs: Include labor and required equipment. <p>3.3 Operational Costs:</p> <ul style="list-style-type: none"> ▪ Regular Maintenance: Encompass watering, fertilization, and pruning tasks. ▪ Energy Consumption: Consider expenses for smart irrigation systems or extra lighting if applicable. <p>3.4 Economic Returns:</p> <ul style="list-style-type: none"> ▪ Increased Property Value: Improve the building's aesthetic appeal and boost its market value. ▪ Energy Savings: Lower cooling requirements through the thermal insulation offered by Green Facades.
4	Social Requirements:	<p>4.1 Community Engagement</p> <ul style="list-style-type: none"> ▪ Training programs for residents focused on system maintenance ▪ Allocation of community gardening spaces, ensuring at least 5% of the wall area ▪ Incorporation of visual privacy elements in design <p>4.2 Health and Safety</p> <ul style="list-style-type: none"> ▪ Selection of non-toxic plant species ▪ Inclusion of mosquito control strategies in irrigation design ▪ Implementation of fall prevention measures for safe maintenance access <p>4.3 Aesthetic Standards</p> <ul style="list-style-type: none"> ▪ Guidelines for color palettes that complement local architecture ▪ Requirements for seasonal flowering ▪ Rules governing symmetry and pattern design Green Facades.

5	<p>Legal and Regulatory Requirements:</p> <p>5.1 Building Codes</p> <ul style="list-style-type: none"> - Following the Egyptian Code for Green Buildings (ECP 306-2017) - Adhering to the Vertical Greenery Standard (HBRC 2021) - Meeting fire safety regulations for vertical gardens <p>5.2 Water Regulations</p> <ul style="list-style-type: none"> - Obtaining a greywater use permit from the Ministry of Housing - Complying with the Water Resources Law 48/1982 - Adhering to irrigation water quality standards as per MWRI Decree 92/2013 <p>5.3 Energy Regulations</p> <ul style="list-style-type: none"> - Fulfilling renewable energy integration requirements (NREA 2020) - Ensuring net metering compliance for solar systems - Meeting energy efficiency standards outlined in Law 119/2008 <p>5.4 Permitting Process</p> <ul style="list-style-type: none"> - Securing municipal approval for structural modifications - Gaining approval from the Ministry of Agriculture for edible walls - Conducting an Environmental Impact Assessment for projects exceeding 500m²
---	--

12- Developing a proposed methodology to assessment the effect of green facades on energy efficiency in Egyptian residential buildings, with the aim of contributing to promoting sustainable development and environmental conservation. Table (2) shows: ⁽⁶²⁾

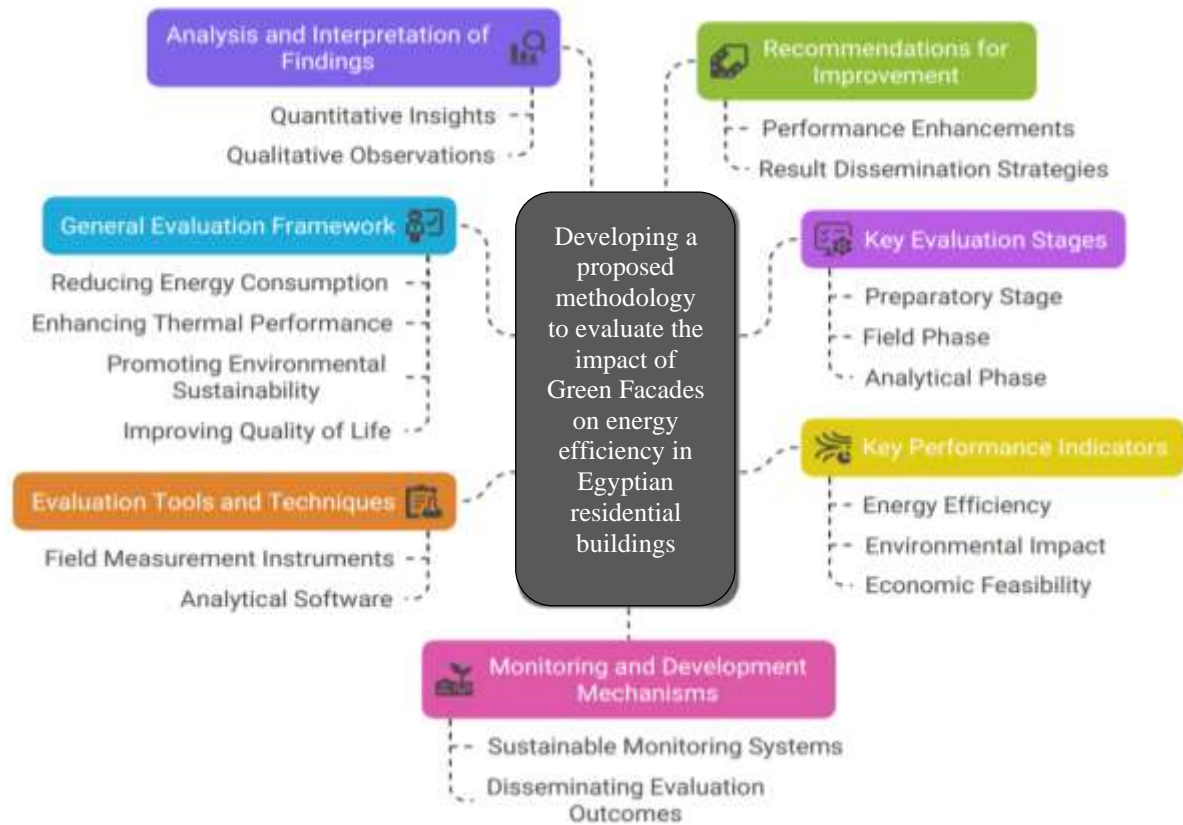


Figure (5) shows Developing a proposed methodology to assessment the effect of green facades on energy efficiency in Egyptian residential buildings, with the aim of contributing to promoting sustainable development and environmental conservation

Table (2) shows Developing a proposed methodology to assessment the effect of green facades on energy efficiency in Egyptian residential buildings, with the aim of contributing to promoting sustainable development and environmental conservation: ^{(62),(63),(64),(65)}

<p>1</p> <p>General Evaluation Framework (Purpose of Assessment) :</p>	<p>The evaluation aims to determine the effectiveness of Green Facades in:</p> <ul style="list-style-type: none"> - Reducing energy usage, especially for cooling systems, -improving the thermal efficiency of buildings. - Promoting environmental sustainability. - Improving residents' quality of life. <p>The scope includes assessments of:</p> <ul style="list-style-type: none"> - Both newly constructed and existing residential buildings. - Various construction techniques, including concrete and structural systems. - Different climatic regions across Egypt.
<p>2</p> <p>Key Evaluation Stages (Evaluation Process):</p>	<p>A. Preparatory Stage:</p> <p>1. Defining Objectives:</p> <ul style="list-style-type: none"> - Setting targeted energy consumption reduction percentages. - Establishing goals for thermal comfort improvement. - Specifying objectives for carbon emission reductions. <p>2. Selecting Study Samples:</p> <ul style="list-style-type: none"> - Analyzing 3–5 representative residential buildings. - Exploring varying types of Green Facades. - Covering diverse geographic locations for broader applicability. <p>B. Field Phase:</p> <p>1. Device Installation:</p> <ul style="list-style-type: none"> - Surface and indoor thermal sensors to track temperature changes. - An energy monitoring device captures the level of energy consumption. - Improvement in the environment is measured via air quality sensors. <p>2. Baseline Data Collection:</p> <ul style="list-style-type: none"> - Data collection for the time frame of three months prior to the green facade installation. - Seasonal variation is capturing for the summer and winter months. <p>C. Analytical Phase:</p> <p>1. Data Processing:</p> <ul style="list-style-type: none"> -Analyzing the data that has been collected. -Outcomes are checked against standard measures in the specific field to determine relevance. -Performance models are developed, utilizing sophisticated modeling software.
<p>3</p> <p>Key Performance Indicators (Criteria for Measurement):</p>	<p>A. Energy Efficiency</p> <ol style="list-style-type: none"> 1. Energy Investments: Innovation in the operational cooling systems energies utilizing the equipment’s thermal performance ratios. 2. Thermal Effectiveness: Improvement of the domain’s surface temperatures and the provided thermal insulation’s effectiveness. <p>B. Environmental Impact:</p> <ol style="list-style-type: none"> 1. Production Saving: Reduction of greenhouse gases by tangible measurable amounts of CO₂ and improved atmospheric quality. 2. Sustainability Metrics: Effective utilization of water resources and enhancement of biodiversity. <p>C. Economic Feasibility:</p> <p>1. Cost-Benefit Outcomes:</p> <p>Assessed by resorting to the defined payback periods and investment returns calculated on an annual basis.</p>

	2. Estimate Additional Metrics: The inflationary value of the property and the maintenance cost savings accrued over time.
4	<p>Evaluation Tools and Techniques (Instrumentation and Analysis Methods)</p> <p>A. Field Measurement Instruments:</p> <ol style="list-style-type: none"> 1. Thermal Evaluation Tools: Include thermal imaging cameras or data loggers. 2. Measurement of Energy Consumption: Includes smart energy meters and electrical load analyses. <p>B. Analytical Software:</p> <ol style="list-style-type: none"> 1. Thermal Developing: Performance analysis with design and engineering details integrates the use of EnergyPlus and DesignBuilder among other specialized tools.
5	<p>Analysis and Interpretation of Findings:</p> <p>A. Quantitative Insights:</p> <ol style="list-style-type: none"> 1. Variation Analysis: the analysis of reversing the result with the value being targeted while looking for significant anomalies or issues. 2. Feeling Analyses: assessing climate impacts on system response under various conditions. <p>B. Qualitative Observations:</p> <ol style="list-style-type: none"> 1. Effect Evaluation: gauging impacts like value appreciation and satisfaction of residents as intangible benefits. 2. Topic Classification: outlining problems like maintenance and seasonal inefficiencies.
6	<p>Recommendations for Improvement:</p> <p>A. Performance Enhancements:</p> <ol style="list-style-type: none"> 1. Enhancing planting methods through optimized selection of vegetation and refined irrigation systems. 2. More efficient construction of design features by adapting improved materials and methods for planting. <p>B. Result Dissemination Strategies:</p> <ol style="list-style-type: none"> 1. Developing step by step, actionable procedures and comprehensive standards detailing implementation flow and design. 2. Promoting evaluators' understanding using guides, workshops, and capacity-building programs.
7	<p>Monitoring and Development Mechanisms</p> <p>A. Sustainable Monitoring Systems:</p> <ol style="list-style-type: none"> 1. Institute routine evaluations based on quarterly or semi-annual performance review schedules. 2. Adapt measurement standards and tools to new results while evolving over time. <p>B. Disseminating Evaluation Outcomes:</p> <ol style="list-style-type: none"> 1. Designing visual documents that embed results with narrative reports to store in reference databases. 2. Inter-networking technical report authors for wider publication and free access to report supplies online.

13- Case Study: ⁽⁶⁶⁾

Research was carried out on residential units in the Dar Misr model, which is the medium income housing project in the Greater Cairo area.

The project, situated in Giza, is designed for a hot and dry climate. Dar Misr offers units ranging from 100 to 150 square meters, each comprising three fully finished bedrooms, a living room, and various amenities. The compound includes a shopping mall, a mosque, a school, landscaped gardens, elevators, markets, shops, dedicated services, security measures, and is secured by an iron fence. This design ensures privacy for residents and encapsulates the community within a closed compound, Illustration (6) , (7), and (8) :



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

Source: : http://admin.mhuc.gov.eg/Dynamic_Page/637363603165751899.pdf 11-10-2024 ⁽⁶⁶⁾

13-1- Performance Evaluation of Energy Consumption Rates for the Case Study:

The assessment of energy consumption for Dar Misr Middle-income housing units serves as an indicator of how effectively these areas provide thermal comfort, primarily influenced by the selection of materials used and the design of the exterior envelope. This is achieved by highlighting green building design principles and analyzing the green facades applied to these units. We can compare their effectiveness in providing thermal comfort within the Building Envelope of Dar Misr housing. Additionally, attention is given to the materials used in walls or glass to reduce Energy Consumption rate for these middle-income units.

13-2- Rationale Behind Choosing the Case Study:

In regions characterized by hot, dry climates, the lack of environmental treatments for Dar Misr's middle-income housing units has led to increased energy consumption, which adversely affects users. To meet the objectives of this study, several key factors should be considered:

- The case study should encompass multiple climate regions, particularly focusing on Greater Cairo.
- It is essential to provide the information required to prepare for the next stages of simulation and evaluation.
- Selected projects must include a study of the impact of building materials on efficiency and their compliance with environmental standards.
- These models require an environmental design analysis and an evaluation of the materials used and their impact on energy consumption.

13-3- Technical Methods for Gathering and Recording Data:

The methods employed to gather information for the case studies included:

- Undertaking field visits, supplemented by photographic documentation and detailed research notes.
- Examining architectural and aerial maps relevant to the case studies.
- Evaluating prior research and studies that focused on the same case studies.

13-4- Applied Research Method:

A- Examination and evaluation of climatic data specific to the study area. B- Detailed analytical assessment of the building in focus, covering aspects such as architectural features, green facades, and occupancy rates.

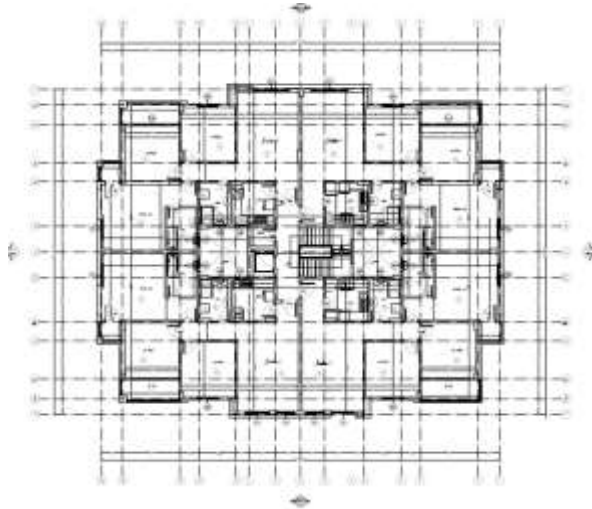


Figure (7) shows the building under study, the projections, plans for the model of the medium-income housing units of Dar Misr. Source: The author

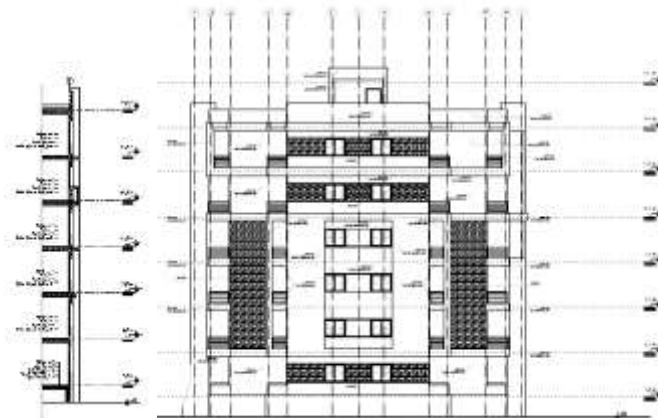


Illustration (8), the plans, facades and the section for the model of the medium-income housing units of Dar Misr. Source: The author

C. Assess the baseline scenario through simulations for models of Dar Misr's middle-income housing units under consideration using the Design Builder v7.0 software.

D. Explore alternative approaches by applying the proposed methodology to case studies using appropriate processing tools. Green Facades were examined to achieve optimal results, utilizing simulation software to evaluate the performance of energy consumption for a model of Dar Misr's middle-income housing units.

E. Compare and discuss the outcomes.

This approach allows the evaluation of different options and materials to select the best solutions that enhance thermal performance and decrease energy consumption.

The aim of simulation includes:

A. Analyze the effect of Green Facades on lowering energy operation in Dar Misr's middle-income housing units.

B. Analyze the outdoor plantings used on Dar Misr's middle-income housing units' exterior and their effect on the indoor environment.

C. Perform a simulation to decrease energy consumption and estimate improvement rates for Dar Misr's middle-income housing units.

12-3 Analysis of Dar Misr's middle-income housing units is conducted through:

A. Climate data analysis for Greater Cairo, using computer software Climate Consultant 6.0.

- **A psychrometric map, also referred to as a psychrometric chart**, visually depicts the relationship between temperature (horizontal axis) and relative humidity (vertical axis). This tool is utilized to analyze Greater Cairo's climate by pinpointing the thermal comfort zone based on temperature and humidity levels. Additionally, it evaluates factors such as occupancy rates, clothing types, and activity levels, offering a comprehensive insight into the region's climatic attributes, as represented in the accompanying illustration. (9). (67)

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

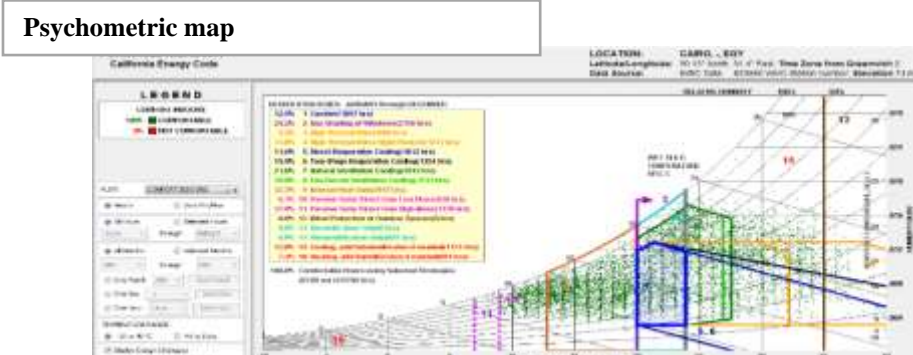


Illustration (9) presents the psychrometric map of thermal comfort for the case study, generated using the Climate Consultant 6.0 program.

- Architectural Design Data:

The objective of studying the Dar Misr Middle-income Housing Unit The purpose of comparing the model before and after the modifications is to evaluate the impact of implementing Green Facades. on reducing energy consumption and orientation based on the different architectural dimensions of the Dar Misr Middle-income Housing Units. A comparison will be made between the status of the Dar Misr Middle-income Housing Units and the modifications after the alternatives have been developed. The comparison will address key design elements such as (horizontal projections, opening ratios, walls, and orientation).

13-6- Assessment of Dar Misr Middle-income Unit by Simulation.:

A- Simulation Methodology:

The program incorporates the building's specifications and dimensions to generate a simulation model that accurately represents the actual structure. This model evaluates all aspects of the building's energy consumption rate, as demonstrated by the example created using Design Builder v7.0. The software processes and analyzes the inputs for the entirety of the case study.

B-Building Operation Data:

- Operation Period: 24 /day, 7 day a week
- Occupant Density: 0.55
- Clothing Insulation Levels: Winter = 0.9 clo, Summer = 0.49 clo (4)

- Space User Burn Rate (standing/walking) = 1.0 - Computer.

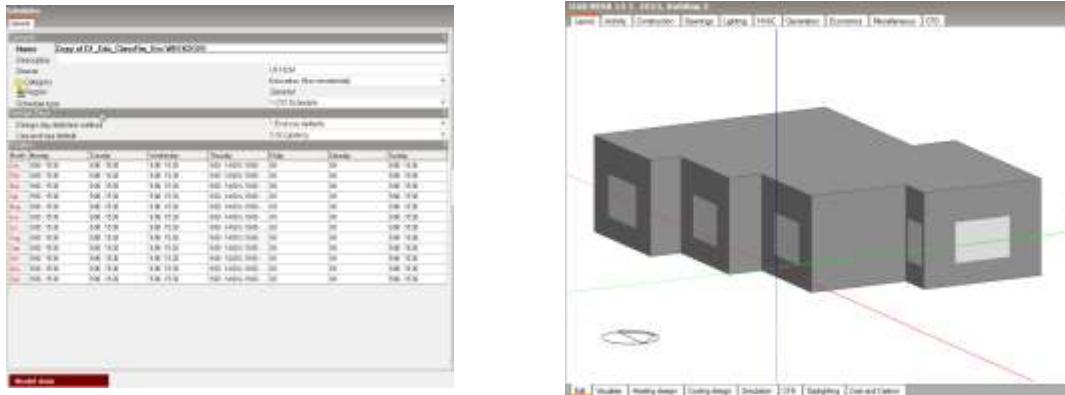


Figure (10) presents a model of the case study created using the DesignBuilder V 7.0 software.
 Source: <https://designbuilder.co.uk> 10-12-2024 ⁽⁶⁸⁾

14- Discussion of results:

Evaluating the Energy Consumption Rate of Medium-Sized Housing Units in the Dar Misr Project:

Case 1: Analysis of simulation outcomes for the energy consumption rates of medium-sized housing units within the Dar Misr Project, considering various orientation types. The study utilizes a 25 cm thick red brick wall, 6 mm thick single-glazed opaque glass, and materials with a specified UV value of 1.661 are used. Figure (11) shows more details about these models.

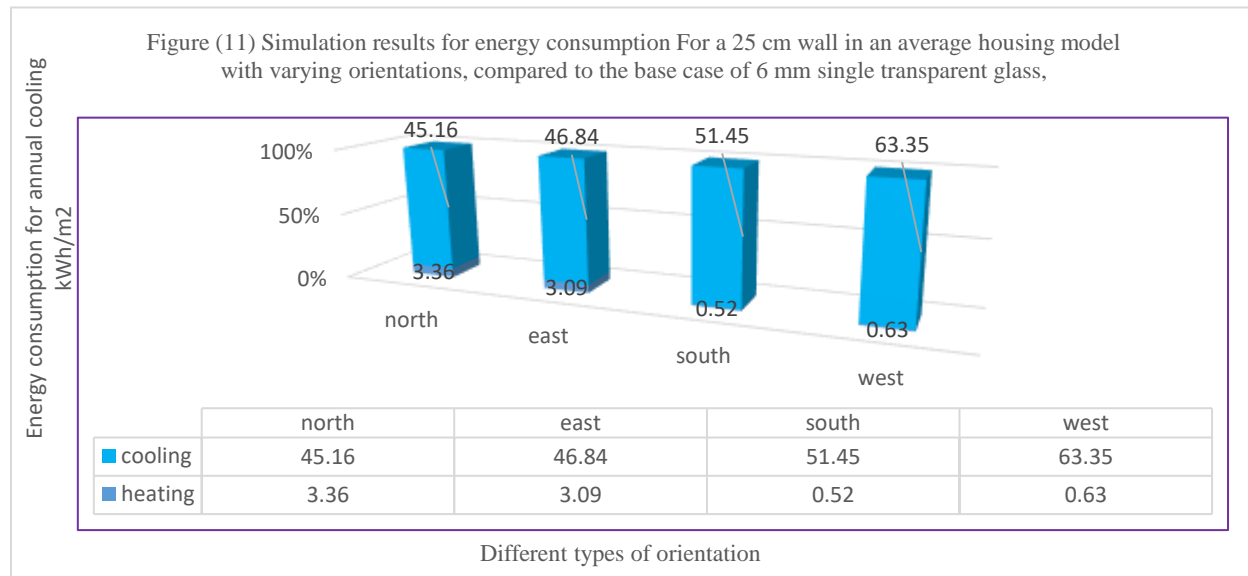


Figure 11 Presents a comparison of simulation outcomes for the average energy consumption rate of a standard housing model when the orientation is altered relative to the base case. The analysis considers a construction setup featuring 25 cm thick red brick walls combined with 6 mm thick opaque single glazing.

Analysis of Figure (11) reveals that energy consumption rates vary significantly based on building orientation. Simulation results indicate the middle-income housing units in Dar Misr, Cairo exhibit the highest annual energy use when oriented westward. This orientation, combined with a 25 cm thick red brick wall, leads to an elevated energy consumption rate. of 63.35 kWh/m² per year, the highest among all the studied orientations. In contrast, the northward orientation shows the lowest energy consumption rate at 45.16 kWh/m² per year, reflecting a 28.73% decrease compared to the westward orientation. The southward orientation records yearly energy use rate of 51.45 kWh/m² per year, while the eastward orientation records 46.84 kWh/m² per year.

Case 2: The second case is related to comparing the results of simulation of the energy consumption rate built on different orientation types for the average housing unit model in the Dar Misr project, in the case of using a Green Facade with a UV value of 0.322, which is shown in Figure 12.

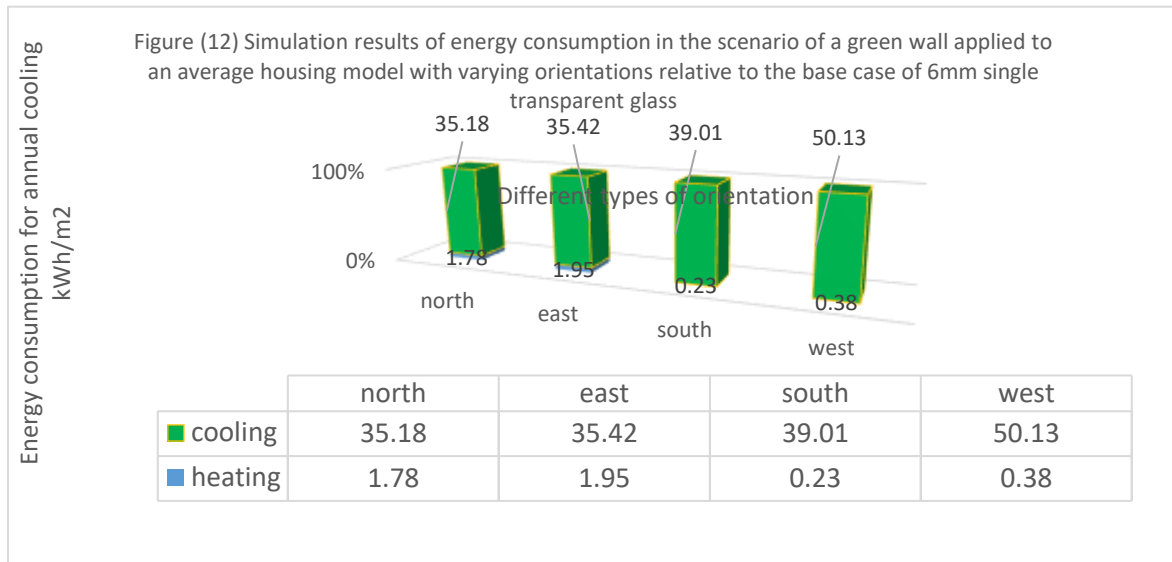


Figure (12) Simulation results of energy consumption in the scenario of a green wall applied to an average housing model with varying orientations relative to the base case of 6 mm single transparent glass.

Analysis of Figure (12) reveals that energy consumption rates vary significantly based on building orientation. The results of Simulation reveal that the annual energy consumption rate for middle-income housing units in Dar Misr, Cairo reaches its peak when the buildings are oriented westward. Utilizing 25 cm thick red brick walls in this orientation leads to a notable energy use rate. of 50.13 kWh/m² per year, the highest among all the studied orientations. In contrast, the northward orientation shows the lowest energy consumption rate at 35.18 kWh/m² per year, reflecting a 29.82% decrease compared to the westward orientation. The southward orientation records a yearly energy use rate of 39.01 kWh/m² per year, while the eastward orientation records 35.42 kWh/m² per year.

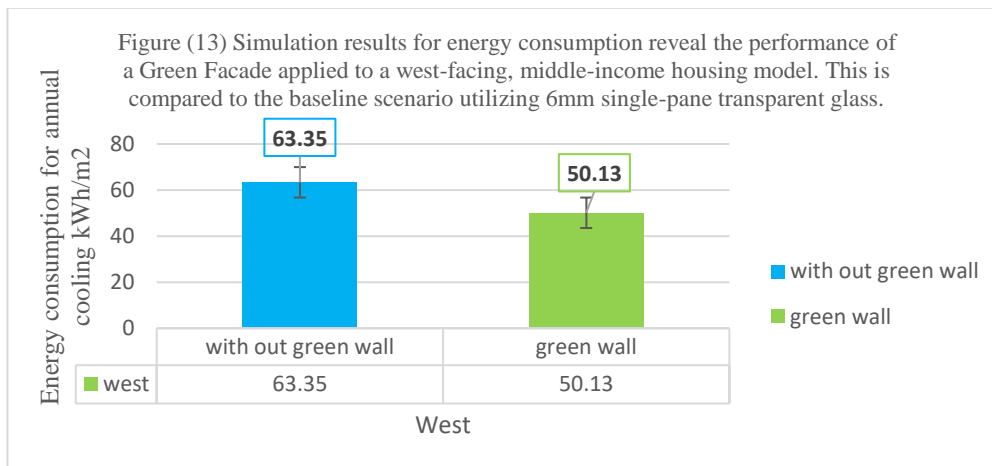


Figure (13) Simulation results for energy consumption reveal the performance of a Green Facade applied to a west-facing, middle-income housing model. This is compared to the baseline scenario utilizing 6mm single-pane transparent glass.

Analysis of Figure (13) reveals that the simulation results indicate a comparison of the annual energy consumption (kWh/m² per year) of the middle-income housing units in Dar Misr, Cairo, with a westward orientation before the installation of Green Facades and a 25 cm thick red brick wall. This orientation calculations in an energy use rate of 63.35 kWh/m² per year. In contrast, the westward orientation with the installation of Green Facades shows an energy use rate of 50.13 kWh/m² per year, reflecting a decrease of 20.8%.

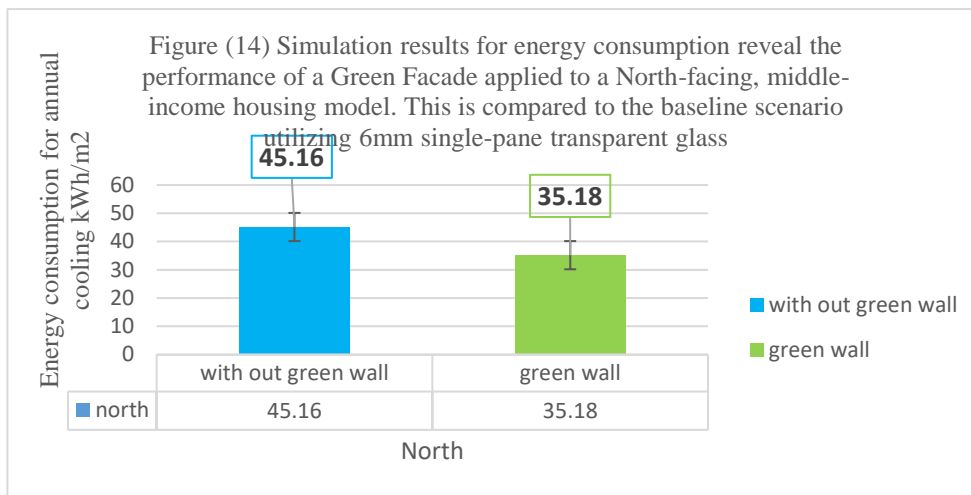


Figure (14) Simulation results for energy consumption reveal the performance of a Green Facade applied to a North-facing, middle-income housing model. This is compared to the baseline scenario utilizing 6mm single-pane transparent glass.

Analysis of Figure (14) shows that the simulation results highlight a comparison of the yearly energy use (kWh/m²) for middle-income housing units in Dar Misr, Cairo, facing north, these units, with 25 cm thick red brick walls, had an energy usage rate measured before the installation of Green Facades of 45.16 kWh/m² annually. Conversely, the north-facing units with Green Facades results in an energy consumption rate of 35.18 kWh/m² per year, reflecting a decrease of 22.1%.

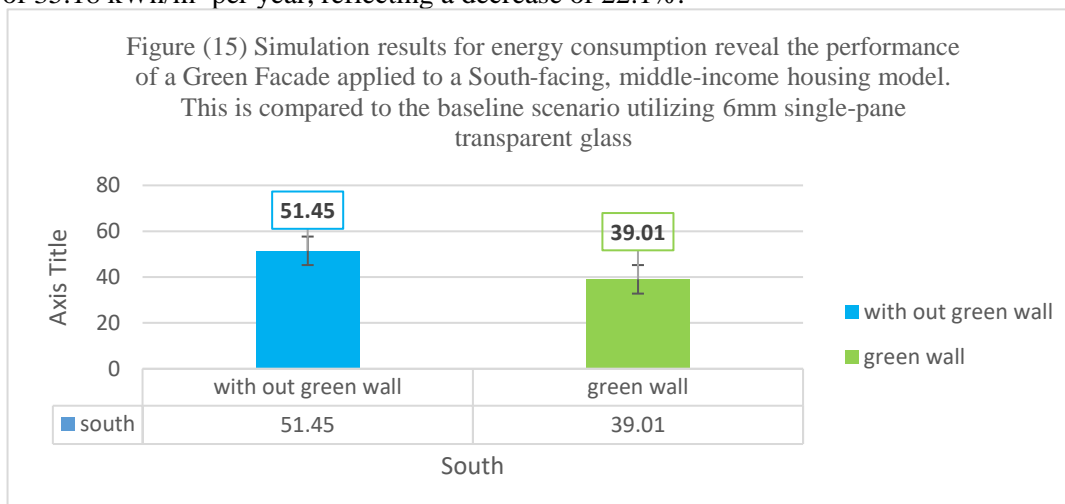


Figure (15) Simulation results for energy consumption reveal the performance of a Green Facade applied to a South-facing, middle-income housing model. This is compared to the baseline scenario utilizing 6mm single-pane transparent glass

Analysis of Figure (15) reveals that the simulation results indicate a comparison of the yearly energy use (kWh/m²) of the middle-income housing units in Dar Misr, Cairo, positioned with a south-facing orientation prior to the implementation of Green Facades, was compared to a 25 cm thick red brick wall. This orientation influences the resulting energy consumption rate of 51.45 kWh/m² per year. In contrast, the south-facing orientation with the installation of Green Facades results in an energy consumption rate of 39.01 kWh/m² per year, reflecting a decrease of 24.17%.

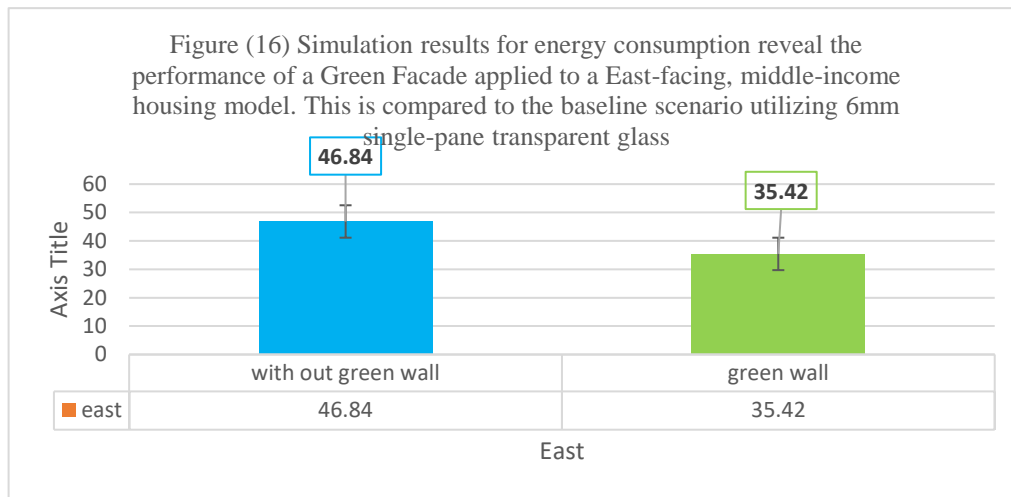


Figure (16) Simulation results for energy consumption reveal the performance of a Green Facade applied to a East-facing, middle-income housing model. This is compared to the baseline scenario utilizing 6mm single-pane transparent glass

Analysis of Figure (16) reveals that the simulation results indicate a comparison of the yearly energy use (kWh/m²) of the middle-income housing units in Dar Misr, Cairo, An eastward orientation prior to the installation of Green Facades, as opposed to a 25 cm thick red brick wall, leads to an energy consumption rate of 46.84 kWh/m² per year. In contrast, the eastward orientation with the Green Facades results in an energy consumption rate of 35.42 kWh/m² per year, reflecting a decrease of 24.38%.

15- The Results:

-The annual energy consumption of a building is heavily influenced by design choices, particularly in selecting suitable environmental strategies. This study investigated three architectural design factors: building orientation, the ratio of openings, and the integration of wall plantings. These aspects were assessed for their relevance and impact on the yearly energy usage of an average housing unit model from the Dar Misr project.

- The findings highlight that building orientation plays a pivotal role in significantly reducing the energy consumption rate of typical housing units in Greater Cairo. Orienting a building northward lead to an average energy reduction of 28.73% compared to a westward orientation.
- For housing models utilizing green facades within the region, the results similarly demonstrate the importance of north orientation. In these cases, annual energy consumption decreases by 29.82% in comparison to the baseline scenario featuring a westward orientation.

16- Recommendations:

First: Research and Practical Recommendations:**A-Recommendations for using Green Facades in Egypt:**

- **Water use:** An effective system for drip irrigation or equivalent should be implemented along with methods for recycling waste water.
- **Plant choice:** Use of indigenous or naturalized species that are resilient towards extreme heat, drought and maintenance should be preferred.
- **Price and maintenance:** upfront costs for the installation and ongoing maintenance such as watering, feeding, and cutting should all be factored.
- **Structural suggestion:** Check that the building's structure can accommodate the added load from the Green Facade system.

B-Adopting Integrated Smart Agriculture Systems

- **Smart irrigation technologies,** like hydroponic and aeroponic systems, permit up to 70% reduction in water consumption while providing efficient plant growth.
- **Interface IoT sensors to humidity,** temperature, and light for green facades allowing the green facades to self-regulate and conserve the environment.

C-Improving Energy Efficiency in Buildings

- **Assess the green facade's** impact on a building's thermal insulation as they can help in reducing energy usage for air conditioning by 20 to 30 percent in hot dry areas like Cairo.
- **Renewable energy systems** such as solar panels can be integrated for greener sustainability for green fences.

D-Choosing Plants Suitable for the Egyptian Climate

- Center the focus towards climbing native plants like cacti or ivy which are drought resistant and require minimal upkeep, surviving in high temperatures.
- Vertical planting is a solution to expand greening of the area without using horizontal depletion space.

E-Continuous Environmental Performance Evaluation

- Measure touch temperature on external surfaces periodically and strive for lowering the temperature.
- Improve air quality by lowering CO₂ and particulate matter emission.
- Investigate the influence of humidity released by plants on the thermal comfort of spaces indoors.

F-Integration with Urban Planning Policies

- Encourage both the government and the private sector to adopt Green Facades in new residential projects, like the Dar Misr project, by providing them with tax breaks or offering technical assistance.
- Include the application of these technologies in the Egyptian building code for easier enforcement as sustainability practices.

G-Raising Community Awareness

- Conduct Green Facades education campaigns focused on the energy, cost savings, and enhancement of living standards.
- Construct some pilot models in Select Dar Misr units to gauge resident's feedback on system pre-implementation efficiency.

Second: Future Research Recommendations

- Undertake a cost analysis and Green Facade return on investment assessment for large scale residential developments.
- Create digital twin simulation models to evaluate greenhouse creep scenario variables of climate change on the Green Facade performance.
- Explore options of locally sourced genetically modified plants designed for hotter climates and minimal water use.

17- References:

- 1-Fahmy, M., Mahmoud, S., Elwy, I., & Mahmoud, H. (2020). A review and insights for eleven years of urban microclimate research towards a new Egyptian era of low carbon, comfortable and energy-efficient housing typologies. *Atmosphere*, 11(3), 236.
- 2- Abdollah, M. A. F., Scoccia, R., Filippini, G., & Motta, M. (2021). Cooling Energy use reduction in residential buildings in egypt accounting for global warming effects. *Climate*, 9(3), 45.

- 3- Assimakopoulos, M. N., De Masi, R. F., de Rossi, F., Papadaki, D., & Ruggiero, S. (2020). Green wall design approach towards energy performance and indoor comfort improvement: A case study in Athens. *Sustainability*, 12(9), 3772.
- 4- Habibi, A., & Kahe, N. (2024). Evaluating the role of green infrastructure in microclimate and building energy efficiency. *Buildings*, 14(3), 825.
- 5- Bakhtyari, V., Fattahi, K., Movahed, K., & Franz, A. (2024). Investigating the effect of living walls on cooling energy consumption in various urban microclimates, building heights, and greenery coverage areas. *Sustainability*, 16(2), 920.
- 6- Yungstein, Y., & Helman, D. (2023). Cooling, CO2 reduction, and energy-saving benefits of a green-living wall in an actual workplace. *Building and Environment*, 236, 110220.
- 7- Karimi, K., Farrokhzad, M., Roshan, G., & Aghdasi, M. (2022). Evaluation of effects of a green wall as a sustainable approach on reducing energy use in temperate and humid areas. *Energy and Buildings*, 262, 112014.
- 8- Kontoleon, K. J., & Eumorfopoulou, E. A. (2010). The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. *Building and environment*, 45(5), 1287-1303.
- 9- Gao, Y., Farrokhirad, E., & Pitts, A. (2023). The Impact of Orientation on Living Wall Façade Temperature: Manchester Case Study. *Sustainability*, 15(14), 11109.
- 10- Charoenkit, S., & Yiemwattana, S. (2016). Living walls and their contribution to improved thermal comfort and carbon emission reduction: A review. *Building and environment*, 105, 82-94.
- 11- Perez, G., Rincon, L., Vila, A., Gonzalez, J. M., & Cabeza, L. F. (2011). Green vertical systems for buildings as passive systems for energy savings. *Applied energy*, 88(12), 4854-4859.
- 12- Susca, T., Zanghirella, F., Colasuonno, L., & Del Fatto, V. (2022). Effect of green wall installation on urban heat island and building energy use: A climate-informed systematic literature review. *Renewable and Sustainable Energy Reviews*, 159, 112100.
- 13- Wong, N. H., Tan, A. Y. K., Tan, P. Y., & Wong, N. C. (2009). Energy simulation of vertical greenery systems. *Energy and buildings*, 41(12), 1401-1408.
- 14- Vox, G., Blanco, I., & Schettini, E. (2018). Green façades to control wall surface temperature in buildings. *Building and Environment*, 129, 154-166.
- Vignola, G., Kiracofe, R., & Dietrich, U. (2019, September). Passive strategies for buildings in hot and dry 51 climates: Optimisation of informal apartment blocks in Cairo. In *IOP Conference Series: Earth and Environmental Science* (Vol. 329, No. 1, p. 012009). IOP Publishing.
- 16-Fahmy, M., Mahmoud, S., Elwy, I., & Mahmoud, H. (2020). A review and insights for eleven years of urban microclimate research towards a new Egyptian era of low carbon, comfortable and energy-efficient housing typologies. *Atmosphere*, 11(3), 236.
- 17-Aldawi, F., & Alam, F. (2016). Residential building wall systems: Energy efficiency and carbon footprint. In *Thermofluid Modeling for Energy Efficiency Applications* (pp. 169-196). Academic Press.
- 18-Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly journal of the royal meteorological society*, 108(455), 1-24.
- 19-Gargari, C., Bibbiani, C., Fantozzi, F., & Campiotti, C. A. (2016). Environmental impact of green roofing: the contribute of a green roof to the sustainable use of natural resources in a life cycle approach. *Agriculture and Agricultural Science Procedia*, 8, 646-656.
- 20-Pérez-Urrestarazu, L., Fernández-Cañero, R., Franco-Salas, A., & Egea, G. (2015). Vertical greening systems and sustainable cities. *Journal of Urban Technology*, 22(4), 65-85.
- 21-Susorova, I., Angulo, M., Bahrami, P., & Stephens, B. (2013). A model of vegetated exterior facades for evaluation of wall thermal performance. *Building and Environment*, 67, 1-13.
- 22-Djedjig, R., El Ganaoui, M., Belarbi, R., & Bennacer, R. (2017). Thermal effects of an innovative green wall on building energy performance. *Mechanics & Industry*, 18(1), 104.
- 23-Radujković, M., Versele, A., & Breesch, H. (2024). Exploratory Analysis of a Novel Modular Green Wall's Impact on Indoor Temperature and Energy Consumption in Residential Buildings: A Case Study from Belgium. *Energies*, 17(21), 5267.
- 24-Kontoleon, K. J., & Eumorfopoulou, E. A. (2010). The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. *Building and environment*, 45(5), 1287-1303.
- 25-Perini, K., & Rosasco, P. (2013). Cost-benefit analysis for green façades and living wall systems. *Building and Environment*, 70, 110-121.
- 26-Preciado-Pérez, O. A., & Fotios, S. (2017). Comprehensive cost-benefit analysis of energy efficiency in social housing. Case study: Northwest Mexico. *Energy and Buildings*, 152, 279-289.
- 27-Alexandri, E., & Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and environment*, 43(4), 480-493.

- 28-Bowler, D. E., Buyung-Ali, L. M., Knight, T. M., & Pullin, A. S.(2010). A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC public health*, 10, 1-10.
- 29-Whittinghill, L. J., Rowe, D. B., & Cregg, B. M. (2013). Evaluation of vegetable production on extensive green roofs. *Agroecology and sustainable food systems*, 37(4), 465-484.
- 30-Peng, L. L., & Jim, C. Y. (2015). Seasonal and diurnal thermal performance of a subtropical extensive green roof: The impacts of background weather parameters. *Sustainability*, 7(8), 11098-11113.
- 31-Köhler, M. (2008). Green facades—a view back and some visions. *Urban Ecosystems*, 11, 423-436.
- 32-Nadeem, S. (2025). Selecting Green Wall Adoption Best Solutions Using Optimization: Addressing Barriers and Maximizing Benefits [Master's Thesis, the American University in Cairo]. AUC Knowledge Fountain. <https://fount.aucegypt.edu/etds/2493>
- 33-Abdel-Aziz, M. M., & Mohamed, R. S.(2019) Green Buildings on The Egyptian Coast: Prospects and Obstacles. *architecture*, 8, 9.
- 34-Ibrahim, N. M. (2025). Investigating the Challenges of Implementing the Vertical Greenery Systems in Egypt from the Public's Perception. *Fayoum University Journal of Engineering*, 8(1), 116-130
- 35- Manso, M., & Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews*, 41, 863-871. <https://doi.org/10.1016/j.rser.2014.08.076>
- 36- Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2011). Vertical greening systems: A classification and comparison of existing technologies. *Journal of Green Building*, 6(3), 143-161. <https://doi.org/10.3992/jgb.6.3.143>
- 37-Radujković, M., Versele, A., & Breesch, H. (2024). Exploratory Analysis of a Novel Modular Green Wall's Impact on Indoor Temperature and Energy Consumption in Residential Buildings: A Case Study from Belgium. *Energies*, 17(21), 5267.
- 38- Bustami, R. A., Belusko, M., Ward, J., & Beecham, S. (2018). Vertical greenery systems: A systematic review of research trends. *Building and Environment*, 146, 226-237.
- 39-Jain R, Janakiram T (2016) Vertical gardening: A new concept of modern era. *Commerc Horticult* 1:527–536
- 40- Golasz-Szolomicka, H., & Szolomicki, J. (2019, September). Vertical gardens in high-rise buildings—modern form of green building technology. In *IOP conference series: materials science and engineering* (Vol. 603, No. 2, p. 022067). IOP Publishing.
- 41- Sarkar, A. N. (2018). Fertigation and irrigation management systems of vertical gardens and green roofs. *Int J Soil Sci Agron*, 5, 179-199.
- 42- Rakhshandehroo, M., Mohd Yusof, M. J., & Arabi, R. (2015). Living wall (vertical greening): Benefits and Threats. *Applied Mechanics and Materials*, 747, 16-19.
- 43- Tarboush, O. (2019). *Living Walls and Green Facades: A Study in Nicosia* (Doctoral dissertation, Near East University,).
- 44- Sharma, P. (2015, November). Vertical Gardens—An Innovative Element of Green Building Technology. In *Proceedings of the Internal Conference (GYANODAY 2015), Greater Nodia, India* (Vol. 42).
- 45- Aung, T., Liana, S. R., Htet, A., & Bhaumik, A. (2023). Implementing green facades: A step towards sustainable smart buildings. *Journal of Smart Cities and Society*, 2(1), 41-51.
- 46- Qazi, S., Khawaja, B. A., & Farooq, Q. U. (2022). IoT-equipped and AI-enabled next generation smart agriculture: A critical review, current challenges and future trends. *Ieee Access*, 10, 21219-21235.
- 47- Decker, M., Hahn, G., & Harris, L. M. (2016). Bio-Enabled Façade Systems. *Material Studies| Applications*, 603-612.
- 48- Siddiqui, R., Muzammil Khan, M., Khalique, A., & Hussain, I. (2022, January). Smart green roof: a prototype toward sustainable smart agriculture. In *Proceedings of International Conference on Intelligent Cyber-Physical Systems: ICPS 2021* (pp. 91-100). Singapore: Springer Nature Singapore.
- 49- Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: science, practice and policy*, 13(1), 13-26.
- 50- Lages Barbosa, G., Almeida Gadelha, F. D., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., ... & Halden, R. U. (2015). Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. *International journal of environmental research and public health*, 12(6), 6879-6891.
- 51- Despommier, D. (2017). Vertical farming using hydroponics and aeroponics. In *Urban soils* (pp. 313-328). CRC Press.
- 52- Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming—a review. *Agricultural systems*, 153, 69-80.
- 53- Gocheva, M., Kuneva, V., & Gochev, G. (2021). The Internet of Things in agriculture—the advantages and opportunities. *Agricultural Sciences/Agrarni Nauki*.
- 54- Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agriculture*, 12(10), 1745.
- 55- Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges
- 56- Morchid, A., El Alami, R., Raezah, A. A., & Sabbar, Y. (2024). Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges. *Ain Shams Engineering Journal*, 15(3), 102509.

- 57-Tamási, A., & Dobszay, G. (2015). Requirements for designing living wall systems–analysing system studies on Hungarian projects. *Periodica Polytechnica Architecture*, 46(2), 78-87.
- 58-<https://openknowledge.fao.org/server/api/core/bitstreams/b21f2087-f398-4718-8461-b92afc82e617/content> 10-10-2024
- 59-<https://www.nexsel.tech/blog/general-awareness/indoor-vertical-green-wall-a-sustainable-and-stylish-way-to-transform-your-space.php> 10-10-2024
- 60-<https://www.renewableenergyhub.co.uk/main/green-roof-information/green-walls-living-walls> 11-10-2024
- 61-Ali, M. A. M., & Khalifa, D. H. A. E. M. (2023). Enhancing Environmental Sustainability in University Buildings: The Role of Green Walls and Smart Agriculture in Mitigating Energy consumption Across Varied Egyptian Climates. *Journal of Survey in Fisheries Sciences*, 10(1S), 7113-7128.
- 62-Requirements for Designing Living Wall Systems – Analysing System Studies on Hungarian Projects.
- 63- Abdeen, N., & Rafaat, T. (2024). Assessing vertical green walls for indoor corridors in educational buildings and its impact outdoor: A field study at the universities of Canada in Egypt. *Results in Engineering*, 21, 101838.
- 64- Nasr, Y., El Zakhem, H., Hamami, A. E. A., El Bachawati, M., & Belarbi, R. (2024). Comprehensive Assessment of the Impact of Green Roofs and Walls on Building Energy Performance: A Scientific Review. *Energies*, 17(20), 5160.
- 65- Wahba, S. M., Kamel, B. A., Nassar, K. M., & Abdelsalam, A. S. (2018). Effectiveness of green roofs and green walls on energy consumption and indoor comfort in arid climates. *Civil Engineering Journal*, 4(10), 2284-2295.
- 66-http://admin.mhuc.gov.eg/Dynamic_Page/637363603165751899.pdf 12-12-2024 11-10-2024
- 67-<http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php> 7/10/2024
- 68-<https://designbuilder.co.uk> 10-10-2024
- 69- Abdin, A. R., El Bakery, A. R., & Mohamed, M. A. (2018). The role of nanotechnology in improving the efficiency of energy use with a special reference to glass treated with nanotechnology in office buildings. *Ain Shams Engineering Journal*, 9(4), 2671-2682.