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The Role of Green Walls in Achieving Sustainability on Campus Using Simulation Programs: An Applied Study to Improve Energy Efficiency in Egyptian University Buildings

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Abstract: Green walls are an innovative and promising solution to address the environmental challenges facing university buildings, especially in hot climates. This analysis aims to evaluate the validity of claims regarding the effectiveness of green walls in university buildings, focusing on their ability to protect buildings from solar radiation, improve air quality, and reduce energy consumption of the external envelope, thus contributing to the fight against climate change. The research addresses the problem of increasing energy consumption for classrooms in university buildings due to the inefficiency of the Building envelope. The main objective of the research was to improve energy consumption using green walls for classrooms in the university buildings under study, through an applied study using the simulation program Design Builder v 7.0 for classrooms, which is a case study of the October Higher Institute of Engineering and Technology. The results indicate that the use of green walls for classrooms in university buildings improves the energy consumption rate by more than 18 % over the base case.

Keywords: *Environmental Sustainability, Green Walls, Smart Agriculture, Energy Efficiency, University Buildings.*

1 Introduction:

The use of green walls and plants in buildings is a suitable passive approach that leads to integration with limited urban green spaces, reducing the problems and negative effects resulting from the urban heat island effect (UHI), and improving the energy performance of buildings by reducing the internal temperature, regulating humidity, and creating thermal insulation for walls. (1) Reducing energy use is a major issue in architecture and engineering. Creating green spaces on unused areas of university buildings (such as roofs or walls) is one way to compensate for the lack of green space in cities. (2) Green walls can be basically defined as climbing plants that grow either directly against or on support structures embedded in the exterior walls of buildings. Similar to other types of green infrastructure, they are in the spotlight due to their remarkable benefits such as reducing indoor building temperatures, mitigating building energy consumption and facilitating urban adaptation to a warming climate.(3) In the context of climate change and with the aim of improving the quality of life and health within urban areas, especially within university campuses, urban planners are increasingly considering the thermal component of climate in order to develop comfortable urban areas (4). In this sense, cooperation with urban climate experts to develop human bioclimatic studies becomes essential (5). The rapid growth of the global human population and the resulting urbanization have severely impacted the natural environment in several ways. The global urban population in 1950 represented only 30% of the world’s population, which increased to 55% in 2018, and two-thirds of the world’s population is projected to be urban by 2050 (6). As the global challenges of failing to adequately address the negative impacts of climate change have become increasingly apparent, (7) major industrialized nations have neglected to address the causes of climate change or take action to correct them over the past century or the present. Calls from environmental organizations around the world, warning of the devastating effects and issuing calls to act to mitigate the effects of climate change in all aspects of life, have gone unheeded. (8) A vast majority of urban development projects in recent years have been moving towards low-impact development projects. Many environmentally sustainable building strategies, designs, and practices have become a preferred choice in urban development (9). Green infrastructure including green walls and green roofs is the most sought-after form of architecture recently, aiming to capture sustainable benefits and compensate for some of the environmental benefits lost through urban development (10),(11). The construction sector should contribute to solving the

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problem of global warming by reducing energy consumption through the use of smart agriculture in green walls. (12) With the increasing awareness of climate data and the emergence of sustainable building ideas (13), which led to the development of green design standards (14), meeting the requirements of good indoor environments in architectural spaces, free of environmental pollutants, is of great importance. Therefore, this paper will discuss how to reduce the energy consumption rate in university classroom buildings using green walls (15).

2 Research Objectives and Practical Study:

This research paper aims to study the effect of using green walls and smart agriculture as treatments that work to reduce the rate of energy consumption inside classrooms in university buildings, using the simulation program Design Builder v 7.0.

3 Research Questions:

How to improve energy consumption inside classrooms in university buildings by using green walls and using smart agriculture in hot climates?

4 Research Hypothesis:

It is hypothesized that the incorporation of green walls and smart agriculture will yield a significant improve energy consumption within university classroom settings.

5 Methodology:

To achieve the research objectives, the theoretical approach was followed, which includes reviewing previous studies and their impact on the current study, studying the adopted concepts, and the analytical approach to deduce the optimal model for classrooms in university buildings. The applied approach was also used, which relies on simulation through the Design Builder v7.0 program to study environmental aspects and prevailing patterns and study the rate of energy consumption in university buildings by using green walls and smart agriculture in the outer envelope and simulating each case separately and presenting and comparing the results, ultimately achieving the research objectives and the objectives and results of previous studies.

6 Green Wall:

Green walls are gaining popularity as a sustainable cladding solution for buildings, offering various advantages for the built environment and human well-being (16). Green wall is a general term that refers to every form of vertical surface covered with vegetation. It can be vegetation growing attached to a building's façade or supported by a structure (17). Green walls can be differentiated into categories according to the various features of their functional elements. The two main macro-categories are Green Facades (GFs) and Living Walls (LWs), which in turn are classified into two more sub-categories direct and indirect for the GFs and continuous and modular for the LWs (18),(19),(20),(21). The most recent attention to (green wall) vertical greenery systems started in 1988 by the renowned French investigator and designer Patrick Blanc for his contributions to vertical gardening. Blanc has pioneered innovative concepts and methodologies for establishing vertical gardens, which have largely shaped contemporary design practices in this arena. Equally influential in this realm is Malaysian architect Ken Yeang, credited with over 200 building designs that incorporate the principles of vertical terrace gardening. Yeang's paradigms are highly esteemed and widely studied within the field (22), (23), (24) .The realistic visualization of plants and trees through computer technology has attracted great interest from users and researchers. Green building has become a crucial element in addressing the climate crisis, in addition to its importance in protecting human health and natural resources, (25),(26) and its economic benefits (Figure 1). Reducing energy consumption in the construction sector is of great importance, especially in university buildings. Building construction and operation account for 37% of global energy consumption related to energy, according to a recent report by the United Nations Environment Program. Green building represents a golden opportunity to reduce energy consumption (27).

Fig (1) Exterior Living Wall at University of York, United Kingdom
Source: https://www.viritopia.com/learn/case-studies/exterior-living-wall/university-of-york 30-8-2023

7 Smart Agriculture:

Smart Agriculture has never been easier. The need for Smart Agriculture has grown to a greater extent in the production of various crops. The Internet of Things (IoT) has recently revolutionized all major business sectors and industries around the world. The Internet of Things involves many things that interact with each other to produce actionable information (28). The Internet of Things can remotely determine the status and working conditions of equipment (closed or open, running or stopped, full or empty, etc.). Smart Agriculture, also known as digital farming, is a manifestation of the Fourth Industrial Revolution and is made possible by digital technologies (29). The entry into the field of smart and precision farming, which relies on the use of modern technologies such as remote sensing, geographic information systems, the Internet of Things, and artificial intelligence systems (30), has become a feature of the era. Smart farming, also known as Farming 4.0 or digital farming, is the application of information technology and data to improve complex agricultural systems. It includes individual machines and all farm operations. Smart Agriculture integrates information and communication technology into machines (31), equipment, and sensors used in agricultural production systems. Technologies such as the Internet of Things (32) and cloud computing are furthering this development by introducing more robotics and artificial intelligence into agriculture, allowing farmers to use smartphones and tablets to access real-time data on the condition of almost anything involved in their daily operations, (33) including soil, plants, terrain, weather, asset location, asset condition, and resource utilization. Smart Agriculture practices generate a wealth of data and information, which farmers can use to make data-driven decisions and take action to improve productivity (34).

7.1 Internet of Things (IoT):

It allows remote control of machines through the network infrastructure. (35) It creates opportunities for direct integration between the physical world and digital systems. Smart agriculture operates using smart farming tools and devices connected to the internet. A sensor device is an electronic device that measures physical quantities from the environment and converts these measurements into a signal that can be read and interpreted by a tool. The measurements that have been read include, for example, temperature, humidity, light, pressure, noise, speed, direction, volume, and weight. (36) We need smart agriculture because "the smartest" agriculture is no longer an "advanced" tactic for smart farmers only, but it has become an increasingly necessary way to improve and sustain human and natural resources.(37) Agricultural labor is becoming increasingly scarce due to urban migration and aging populations. Intensifying climate change leads to less predictability in growth conditions. Consequently, land resources and biodiversity are diminishing. Smart farming tools can help reduce these impacts, (38) mitigate environmental constraints, and decrease production costs in agricultural activities. Smart farming tools offer a new level of technology in agriculture, including mapping, Robotics, Geometrics, Automation, decision-making, and statistical processes.(44)

7.1.1 The Transformative Impact of IoT in Agriculture:

The integration of the Internet of Things (IoT) into agriculture represents a significant paradigm shift, yielding an array of benefits and advancements across various facets of farming practices; Internet of Things (IoT) has revolutionized various industries, and agriculture is no exception. By connecting devices and sensors to the internet, IoT enables farmers to collect, analyze, and utilize data to make informed decisions and optimize their operations. (39), (40).

8 Climatic regions in Egypt: [41]

The climatic regions include 8 different regions, under which many governorates fall, as shown

1-North Coast Region	
2-Delta region and Cairo	
3-North Upper Egypt Region	
4-South Upper Egypt Region	
5-East Coast Region	
6-High Plateau Region	
7-Desert region	
8-Southern Egypt region	

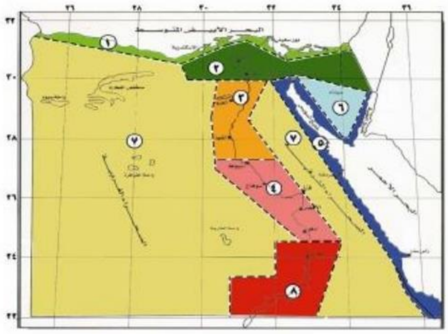


Fig (2) Climatic regions of the Arab Republic of Egypt

The following table shows the distribution of governorates according to the different regions, as shown in the energy code for buildings.

In this research endeavor, four provinces situated in distinct geographical regions were meticulously selected as study sites for the assessment and measurement of the Energy consumption within university buildings. The investigation hinged on a practical approach, harnessing the capabilities of simulation programs. The primary objective was to elucidate the tangible effects of implementing smart agricultural practices within building walls to mitigate the Energy consumption. The simulation process unfolded in several key phases:

a) Environmental Performance Evaluation:

The initial step involved a comprehensive evaluation of the proposed model's environmental performance. This entailed a detailed scrutiny of climate data relevant to each selected province and an in-depth analysis of solar radiation patterns.

b) Energy consumption Rate Identification:

The heart of the study was devoted to pinpointing the rate of the Energy consumption, considering several pivotal factors. These encompassed the integration of green walls as an eco-conscious solution, the implementation of smart agriculture techniques, the assessment of various types of glass employed in building openings, an examination of the occupancy ratio within university buildings, and a meticulous analysis of the proportions of openings within the building's structure.

This multifaceted approach aimed to unravel the intricate interplay between smart agricultural interventions and the Energy consumption within university buildings spanning diverse climatic regions. The study's goal was to offer valuable insights into sustainable building practices and environmental stewardship.

9 Case Study:

The study focused on the classrooms of higher education buildings in the October High Institute of Engineering and Technology. The characteristics of the classroom model in university buildings were determined, considering the different climatic regions in Egypt. The project name was October High Institute of Engineering and Technology, and the climate was hot and dry. The location was Giza. The renovation was completed in 2008.

The October Higher Institute of Engineering and Technology project consists of the ground floor, first floor, and second floor, as well as electrical and security rooms, site coordination, and services. The ground floor primarily includes student services units, accounts, the library, the academic counseling unit, the administrative section, classrooms, laboratories, and auditoriums. The first floor includes administrative offices, classrooms, drawing halls, upper management, and computer labs. The second floor includes the remaining classrooms, drawing halls, laboratories, and control rooms, as shown in figure (3).

Fig (2) shows the building of the October High Institute for Engineering and Technology, indicating the location of the classrooms in the university buildings under study.

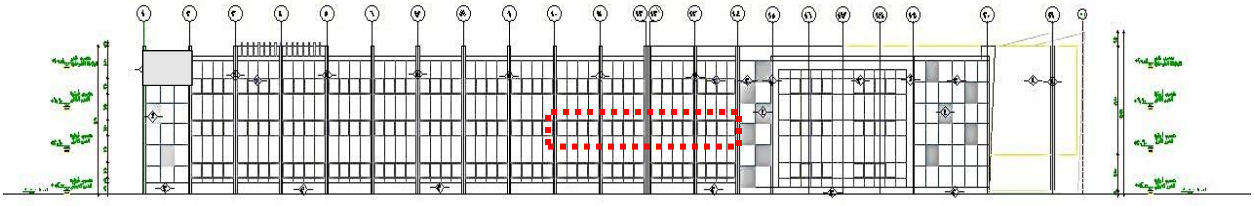


Fig (3) shows the northern facade of the October Higher Institute for Engineering and Technology building, showing the location of the classrooms in the university buildings under study. Source: researcher

9.1 Evaluation of Energy consumption Performance for the Case Study:

The evaluation of Energy consumption rates for classrooms serves as an indicator of the extent to which the spaces achieve thermal comfort, which is influenced by material selection and the external envelope. After clarifying the principles of green building design and analyzing the green walls used, a comparison is made to assess the extent to which the green walls in the external envelope achieve thermal comfort within the classrooms in university buildings, considering the materials used for walls, glass, or opening ratios. The aim is to reduce the Energy consumption rates for classrooms in university buildings**.**

9.2 Basis for Choosing the Case Study:

The study focuses on assessing classroom models within various climatic regions in Egypt, with particular emphasis on hot and dry areas. It addresses the current lack of environmental enhancements in university building classrooms and aims to transition them into eco-friendly, green building models. This transformation has led to an increase in the Energy consumption rates within these classrooms, which has a detrimental impact on the occupants' well-being. To achieve the study's objectives, several crucial factors must be taken into account. Firstly, the chosen case study models should be representative of the specific climatic region under investigation. Secondly, the availability of necessary information for the simulation and evaluation phases is vital. Additionally, the selection of projects should prioritize those that require an in-depth examination of building materials to meet efficiency and environmental suitability standards. Lastly, these selected models must undergo thorough environmental design scrutiny, including an assessment of the materials used and their influence on the Energy consumption rates.

9.3 Technical Method for Collecting and Documenting Data for the Selected Case Studies:

The collection and documentation of data for the chosen case studies were carried out through a combination of meticulous techniques, ensuring comprehensive and accurate information retrieval. The following methods were adopted for this purpose:

Field Visits, Photographic Documentation, and Researcher Observations: Researchers conducted field visits to the selected case study locations, during which they meticulously observed and documented relevant data. Photographic documentation played a pivotal role in capturing visual aspects and conditions, enabling a comprehensive understanding of the case studies.

Architectural and Site Maps: Detailed architectural and site maps of the case studies were utilized to extract crucial spatial and structural information. These maps provided an invaluable foundation for comprehending the physical layouts and configurations of the chosen sites.

Previous Research and Studies: Existing research and studies that pertained to the selected case studies were thoroughly reviewed and analyzed. This included a comprehensive examination of previous investigations that had delved into the same subjects, thereby enriching the pool of available data and insights.

By employing this multifaceted approach, the data collection and documentation process aimed to ensure the completeness and accuracy of information pertaining to the selected case studies. This, in turn, facilitated a robust foundation for subsequent analysis and research endeavors.

9.4 Methodology of the Applied Study:

The applied study was conducted employing a structured methodology that encompassed the following key elements:

a) Analysis of Climate Data for the Study Area:

The initial phase involved a meticulous analysis of climate data specific to the study area. This comprehensive examination aimed to gain insights into the prevailing climatic conditions, including temperature, humidity, precipitation patterns, and other relevant meteorological parameters. The climate data analysis provided a foundational understanding of the environmental context within which the study was situated.

b) B. Analytical Description of the Building Under Study:

In this critical phase, a comprehensive analysis of the building under investigation was conducted. It encompassed architectural attributes, the presence and impact of green walls, occupancy ratios, and the proportions of openings. These factors were visually presented in figures (4) and (5), providing a clear representation of the building's characteristics and their relevance to the study's objectives.

Through this comprehensive methodology, the applied study sought to provide a robust foundation for the evaluation and assessment of the Energy consumption in the selected building. The integration of climate data analysis and a detailed building description facilitated a holistic understanding of the environmental dynamics influencing the Energy consumption within the study area.

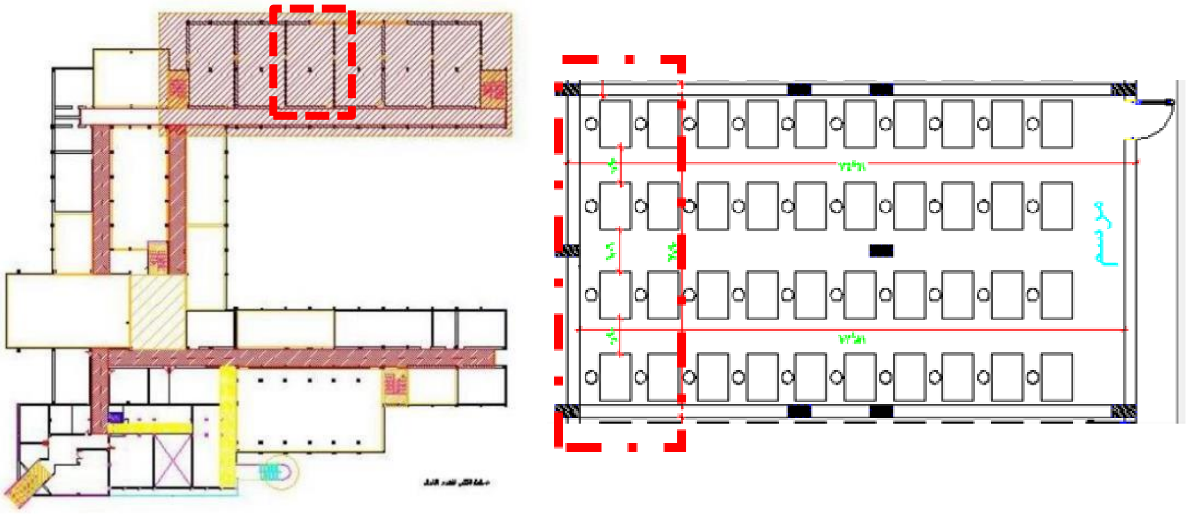


Fig (4) shows the plans of the model of classrooms in university buildings in the study case. Source: Researcher.

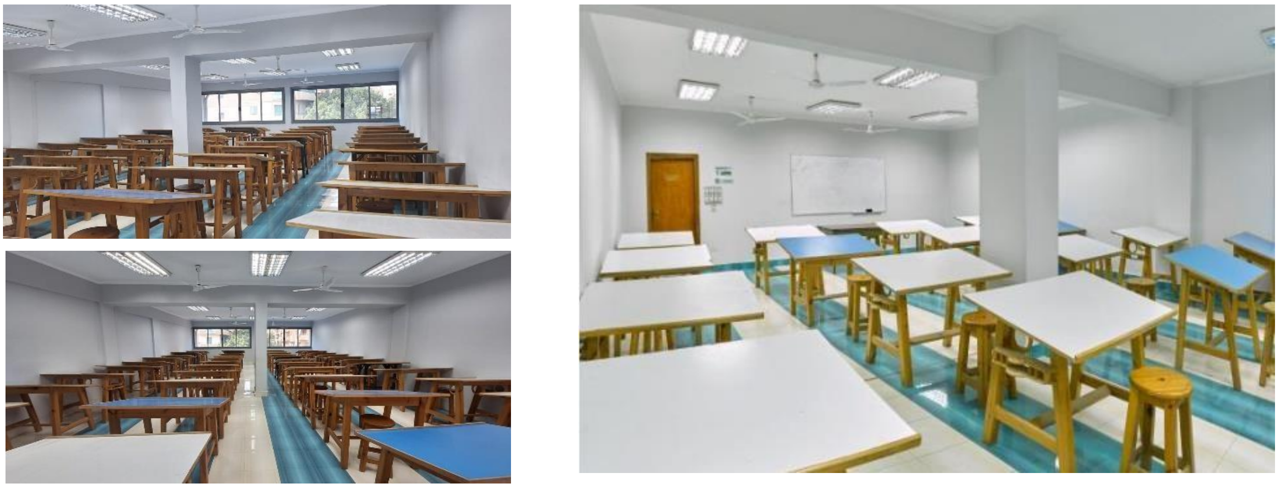


Fig (5) shows the building under study inside the October High Institute for Engineering and Technology.

C. Baseline Evaluation: The initial phase involved assessing classroom models in university buildings using Design Builder v7.0 software to establish a baseline for Energy consumption rates.

D. Alternative Implementation and Testing: Alternatives, including green walls and smart agriculture, were implemented and rigorously tested using simulation software to analyze their impact on the Energy consumption.

E. Result Comparison and Discussion: The study concluded with a thorough comparison and discussion of the results, focusing on the influence of green walls and smart agricultural practices on Energy consumption rates.

This approach provides a versatile platform for evaluating various alternatives and material options, enabling the selection of optimal solutions aimed at reducing Energy consumption rates. The simulation's objectives encompass studying the impact of green walls on the Energy consumption within university building classrooms, analyzing the effects of external green agriculture on the indoor environment of these classrooms, and conducting simulations to estimate savings percentages related to the Energy consumption in these educational spaces. Collectively, these objectives contribute to a comprehensive exploration of eco-friendly building practices, focusing on emissions reduction and indoor air quality enhancement.

9.5 Analysis of the Classrooms in October High Institute of Engineering and Technology Building; the analysis was conducted through:

9.5.1 Analysis of the climatic data for the study region, Greater Cairo. [42]

Climatic data for the Greater Cairo region was used using Climate Consultant 6.0 software. The psychometric chart illustrates the relationship between temperature and relative humidity on the horizontal and vertical axes, respectively. It identifies the characteristics of the climate in Greater Cairo by determining the thermal comfort zone based on temperature and humidity, as well as occupancy rate, including clothing type and activity level, as shown in Figure (6).

Psychometrics of thermal comfort

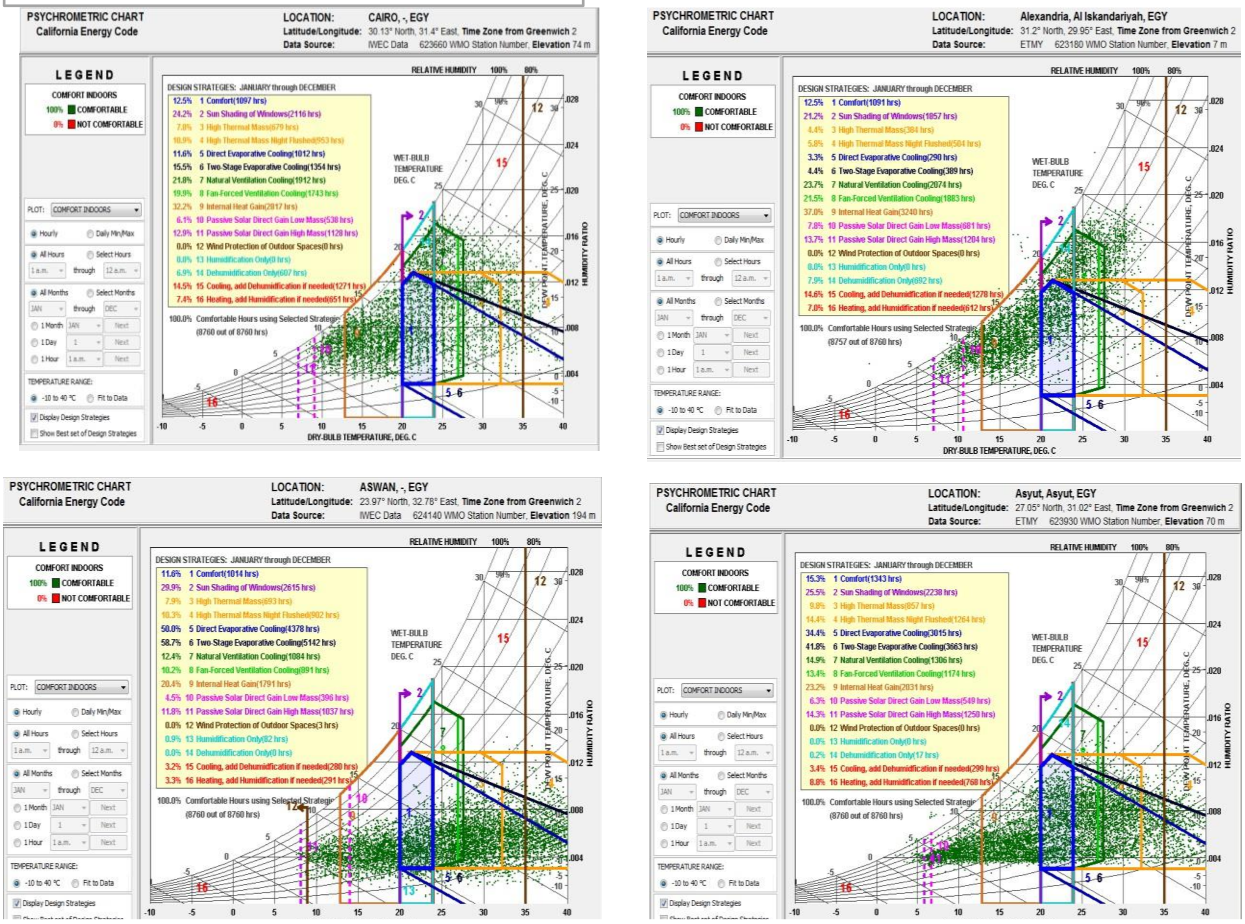


Fig (6) shows the psychometric map of thermal comfort in different climate regions for the case study in the Climate Consultant 6.0 program. Source: http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php 13-1-2024

9.5.2 Data for the Classroom Models in University Buildings:

9.5.2.1 Architectural Design Data:

The purpose of studying the classroom models in university buildings before and after implementing the modifications is to determine the impact of green walls on Energy consumption rates and the orientation and opening ratios based on different architectural dimensions of the classrooms in university buildings. A comparison will be made between the current state of the classrooms in university buildings and the modified state after implementing the alternatives. The comparison will address key design elements such as floor plans, opening ratios, walls, and orientation.

9.6 Evaluation of the Classroom Models in University Buildings Using Simulation; this is done through:

9.6.1 Simulation Methodology :[43]

The specifications and dimensions of the building are inputted into the software, and a simulation model is created to replicate the building's actual conditions. This model simulates all aspects related to Energy consumption rates in the building, as shown in the following model taken from the DesignBuilder v7.0 software. This software analyzes the input data for the entire case study, as shown in Figure (7).

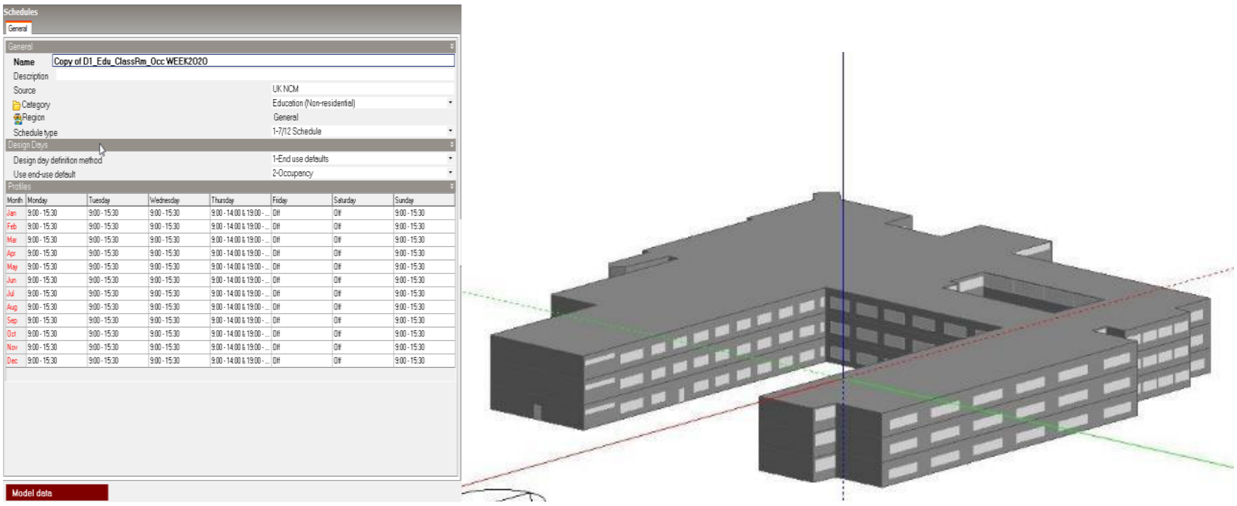


Fig (7) shows a model of the October High Institute for Engineering and Technology building, showing the classrooms' location in the university buildings under study. In Design Builder 6.0 Source: https://designbuilder.co.uk 5-3-2024/

9.6.2 Building Operation Data:

The building adheres to a defined operational schedule, conducting its activities exclusively during daytime hours, from 8:00 AM to 4:00 PM, spanning most days of the week, except for Fridays and Saturdays

Furthermore, certain crucial parameters govern the building's operation. These include an occupant density of 0.55, indicating the presence of occupants within the space. Additionally, occupant clothing insulation varies seasonally, with a value of 0.9 clo in winter and 0.49 clo in summer. The metabolic rate for occupants is set at 1.0, encompassing activities like standing, walking, and computer usage. To accommodate specific operational needs, there is a schedule adjustment from 9:00 AM to 3:00 PM, with exclusions on Fridays and Saturdays. These parameters collectively define the operational framework for the building's simulation and analysis.

10 Discussion of Results:

- The first case: Comparing the simulation results of the Energy consumption rate for the base case with different types of orientation for the model of classrooms in university buildings: in the case of a 25 cm thick red brick wall and 3 mm single glass (UV (5.894)). As Figure (8) shows:

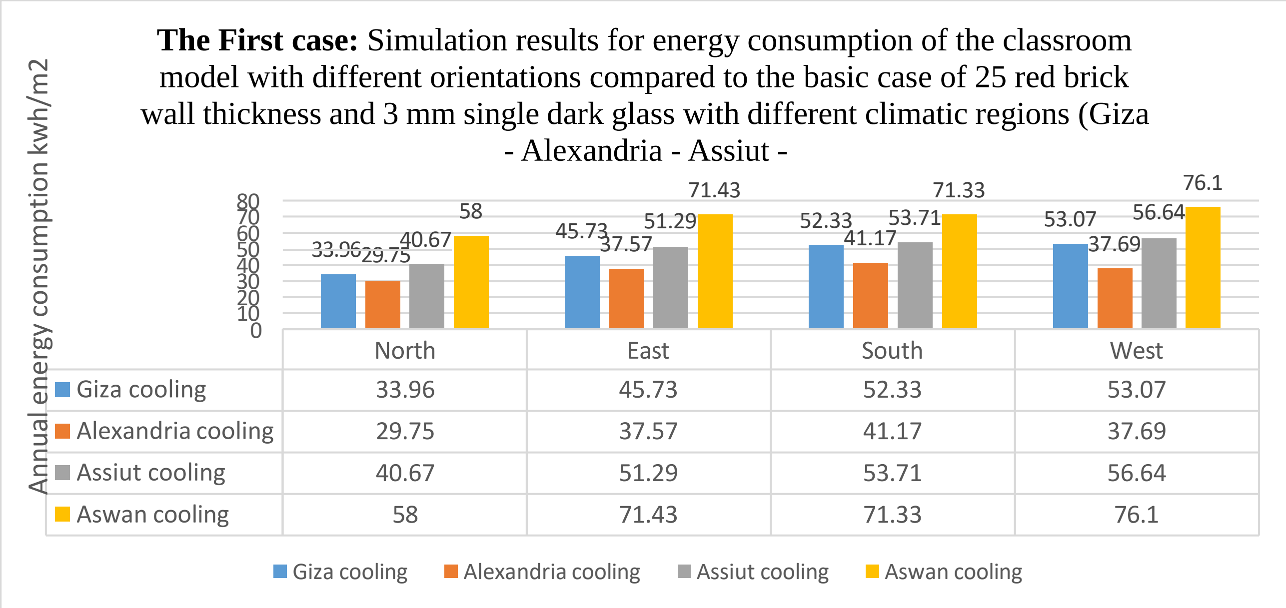


Fig 8 shows a comparison of the simulation results for the energy consumption rate of the classroom model in university buildings with different orientations compared to the baseline case with a 25 cm thick red brick wall and single 3 mm glass (UV (5.894)). The comparison is done across different climatic regions (Giza, Alexandria, Assiut, and Aswan).

From the analysis of Figure 8, it becomes evident that the energy consumption rate exhibits variations based on different orientations and distinct climatic regions. The simulation results reveal noteworthy disparities in the energy consumption for the classroom model within university buildings.

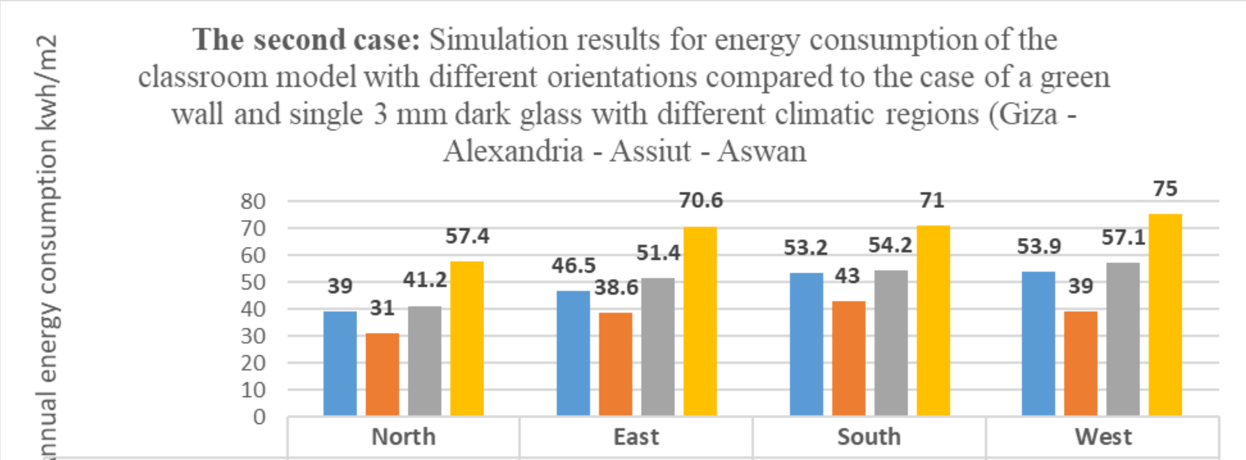
In the first scenario, with **a west orientation** and featuring a 25 cm thick red brick wall combined with a single 3 mm glass (UV(5.894)), the energy consumption rate reaches its peak at 76.1 kwh/m2 per year in Aswan Governorate, signifying the highest rate within this model. Subsequently, energy consumption rate progressively decreases to 56.64 kwh/m2 per year in Assiut Governorate, followed by 53.07 kwh/m2 per year in Giza Governorate, and 37.69 kwh/m2 per year in Alexandria Governorate.

In the case of **an East orientation**, along with the same 25 cm thick red brick wall and single 3 mm glass (UV (5.894)), Aswan Governorate once again records the highest energy consumption rate at 71.43 kwh/m2 per year. This is trailed by 51.29 kwh/m2 per year in Assiut Governorate, 45.73 kwh/m2 per year in Giza Governorate, and 37.57 kwh/m2 per year in Alexandria Governorate.

For **a south orientation**, coupled with the specified 25 cm thick red brick wall and single 3 mm glass (UV (5.894)), Aswan Governorate registers the highest energy consumption rate at 71.33 kwh/m2 per year, followed by 53.71 kwh/m2 per year in Assiut Governorate, 52.33 kwh/m2 per year in Giza Governorate, and 41.17 kwh/m2 per year in Alexandria Governorate.

Lastly, in the instance of **a north orientation**, accompanied by the same 25 cm thick red brick wall and single 3 mm glass (UV(5.894)), Aswan Governorate once again leads with the highest energy consumption rate at 58 kwh/m2 per year. This is succeeded by 40.67 kwh/m2 per year in Assiut Governorate, 33.96 kwh/m2 per year in Giza Governorate, and 29.75 kwh/m2 per year in Alexandria Governorate.

The analysis then proceeds to the second case, which involves a comparison of the simulation results for the energy consumption rate. This comparison is conducted between various orientation scenarios for the classroom model within university buildings. Specifically, it explores the impact of a green wall in combination with 3 mm single glass (UV (5.894)), as illustrated in Figure (9).



	North	East	South	West
Giza cooling	39	46.5	53.2	53.9
Alexandria cooling	31	38.6	43	39
Assiut cooling	41.2	51.4	54.2	57.1
Aswan cooling	57.4	70.6	71	75

Fig 9 shows the comparison of simulation results of energy consumption rate for classroom model in university buildings with different orientations compared to the case of green wall and single 3mm opaque glass (UV (5.894)) across different climatic zones (Giza, Alexandria, Assiut, and Aswan).

In the second case, the analysis of Figure 9 highlights the variability of Energy consumption rates across diverse orientations and different climatic regions. The results obtained from the simulations provide crucial insights into the emission patterns for the classroom model within university buildings.

For the scenario involving **a west orientation**, along with a 25 cm thick red brick wall and single 3 mm dark-tinted glass (UV (5.894)), Aswan Governorate records the highest Energy consumption rate at 75 kwh/m2 per year, representing the pinnacle within this model. This is followed by a decrease to 57.1 kwh/m2 per year in Assiut Governorate, 53.9 kwh/m2 per year in Giza Governorate, and 39 kwh/m2 per year in Alexandria Governorate.

For **the East orientation**, combined with the specified 25 cm thick red brick wall and single 3 mm dark-tinted glass (UV(5.894)), Aswan Governorate again exhibits the highest Energy consumption rate, measuring at 70.6 kwh/m2 per year. This is trailed by 54.4 kwh/m2 per year in Assiut Governorate, 46.5 kwh/m2 per year in Giza Governorate, and 38.6 kwh/m2 per year in Alexandria Governorate.

In the case of **a South orientation**, paired with the same 25 cm thick red brick wall and single 3 mm dark-tinted glass (UV(5.894)), Aswan Governorate once more leads with the highest Energy consumption rate, amounting to 71 kwh/m2 per year. This is followed by 54.2 kwh/m2 per year in Assiut Governorate, 53.2 kwh/m2 per year in Giza Governorate, and 43 kwh/m2 per year in Alexandria Governorate.

Lastly, for **the north orientation**, in conjunction with the specified 25 cm thick red brick wall and single 3 mm dark-tinted glass (UV (5.894)), Aswan Governorate maintains the highest Energy consumption rate at 57.4 kwh/m2 per year. This is succeeded by 41.2 kwh/m2 per year in Assiut Governorate, 39 kwh/m2 per year in Giza Governorate, and 57.4 kwh/m2 per year in Alexandria Governorate.

The analysis subsequently proceeds to the third case, involving a comparative examination of the simulation results for Energy consumption rates. This comparison encompasses various orientations for the classroom model within university buildings, focusing on the presence of a green wall and double dark glass (UV (1.048)), as depicted in Figure (10).

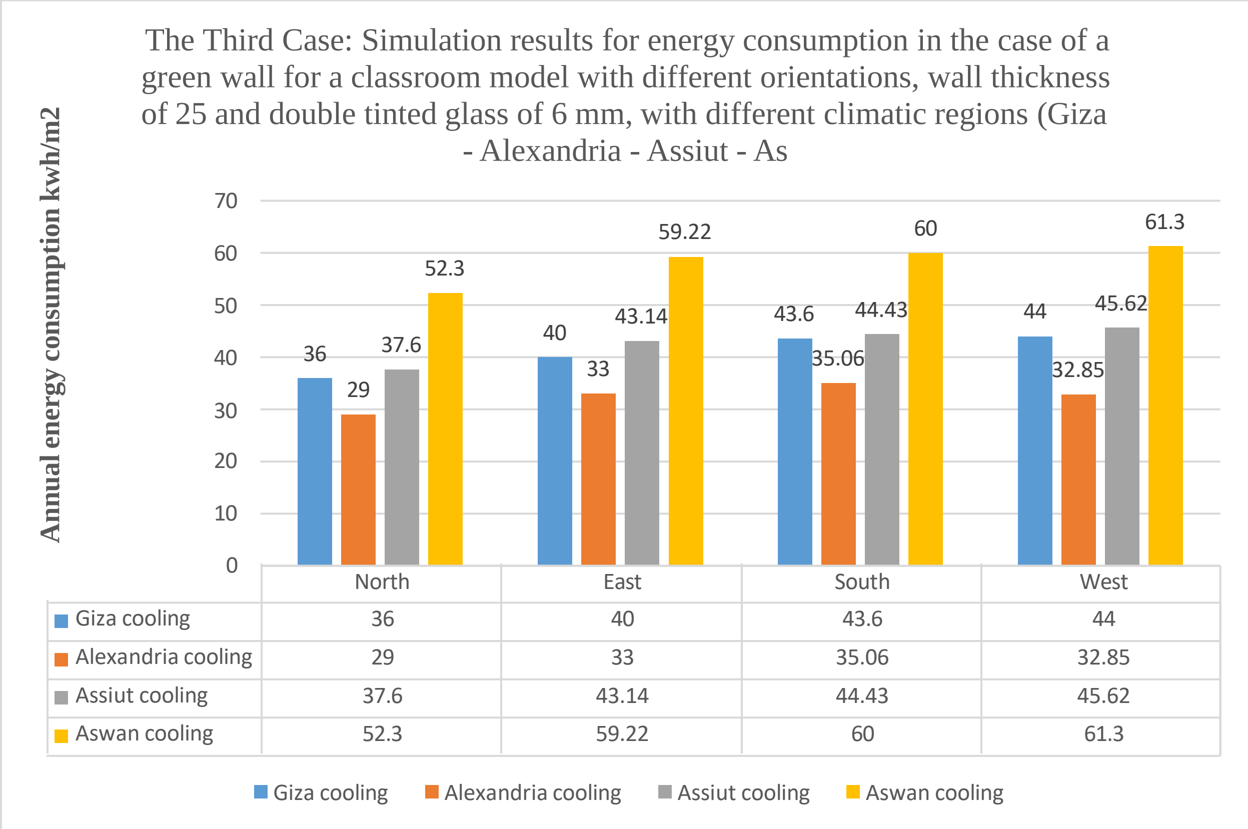


Fig (10) illustrates the comparison of simulation results for the energy consumption in the case of a green wall for the model of classrooms in university buildings, compared to the baseline case of a dark double-glazed 6mm glass, with different climatic regions (Giza - Alexandria - Assiut – Aswan)

Figure (10) presents a comprehensive analysis of Energy consumption rates within university classroom buildings, offering valuable insights into the interplay of building orientation and climatic regions on carbon emissions.

When examining **the West orientation** alongside green wall integration and dark double-glazed glass, Aswan Governorate emerges with the highest Energy consumption rate, peaking at 61.3 kwh/m2 per year. This rate steadily diminishes as we transition to less arid regions: Assiut Governorate at 45.62 kwh/m2 per year, Giza Governorate at 44 kwh/m2 per year, And Alexandria Governorate at 32.85 kwh/m2 per year.

Similarly, in the case of an **East orientation** with green walls and dark double-glazed glass, Aswan Governorate demonstrates the highest Energy consumption rate at 59.22 kwh/m2 per year. The emission rates gradually decrease: Assiut Governorate at 43.14 kwh/m2 per year, Giza Governorate at 40 kwh/m2 per year, and Alexandria Governorate at 33 kwh/m2 per year.

For **the South orientation** paired with green walls and dark double-glazed glass, Aswan Governorate again leads with the highest Energy consumption rate, registering 60 kwh/m2 per year. Subsequent emission rates follow this pattern: Assiut Governorate at 44.43 kwh/m2 per year, Giza Governorate at 43.6 kwh/m2 per year, And Alexandria Governorate at 35.06 kwh/m2 per year.

Finally, in **the north orientation** with green walls and dark double-glazed glass, Aswan Governorate exhibits the highest Energy consumption rate at 52.3 kwh/m2 per year, Followed by Assiut Governorate at 37.6 kwh/m2 per year, Giza Governorate at 36 kwh/m2 per year, And Alexandria Governorate at 29 kwh/m2 per year.

Overall, this analysis underscores the notable influence of climatic conditions and building orientation on Energy consumption, highlighting the importance of region-specific design considerations to enhance energy efficiency and reduce environmental impact. These findings equip architects and designers with essential data to inform sustainable architectural decisions and emphasize the significance of tailored design strategies for achieving environmental objectives.

11 Results:

The use of computer simulation programs during the design phase has emerged as a crucial factor in evaluating and achieving green architecture principles and achieving environmental sustainability. These programs have played a pivotal role in identifying optimal strategies for reducing energy consumption, thus contributing significantly to sustainable architectural design.

Vegetation has been identified as an indispensable component of ecosystems. Its diverse plant species harness solar energy through photosynthesis and effectively absorb carbon dioxide from the atmosphere. In addition, vegetation produces vital oxygen needed to support life on Earth and plays a vital role in mitigating the effect of global warming.

The research focused on the critical role of design decisions in determining the energy consumption rate of buildings. Specifically, three architectural dimensions were examined: orientation and incorporation of green walls. These dimensions were chosen because of their importance and potential impact on reducing energy consumption, especially in the context of university classroom buildings.

The results of the study showed that the inclusion of green walls in university classroom buildings, along with the use of dark glass, resulted in a significant reduction in the Energy consumption. This finding confirmed the effectiveness of green architectural features in achieving lower emissions in the classroom model within university buildings.

The research also explored the effect of building orientation on the energy consumption reduction rate in university classroom buildings, with a special focus on the Greater Cairo area. It was observed that building orientation played a significant role in reducing energy consumption reduction. Notably, the north orientation showed the lowest energy consumption reduction rate, showing a significant reduction of 18.2% compared to the west orientation. This result is visually represented in Figures 11, 12, 13 and 14. Collectively, these results highlight the critical role of computer simulation in promoting green architecture principles and reducing energy consumption. Furthermore, they emphasize the importance of vegetation, green architectural elements and thoughtful design decisions, such as building orientation, in achieving sustainable and environmentally responsible university classroom buildings, especially in urban areas such as Greater Cairo. These results provide valuable insights for architects, designers and policy makers working towards a greener and more sustainable built environment.

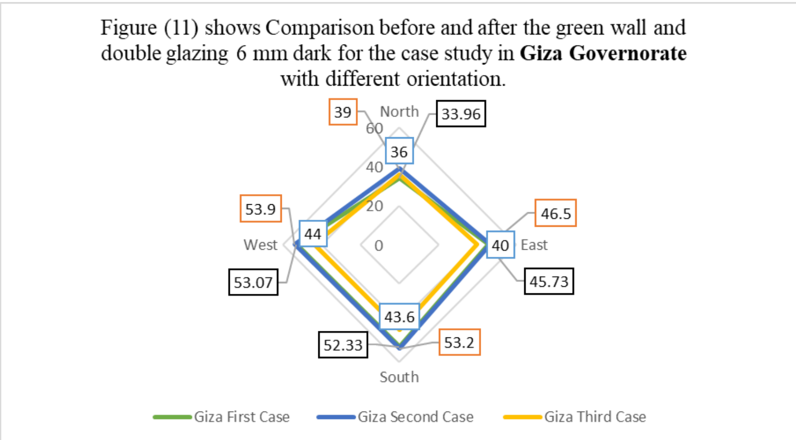


Fig (11) shows the decrease in the rate of Energy consumption s in all three study cases on the northern façade and when using a green wall with dark glass for the Giza Governorate

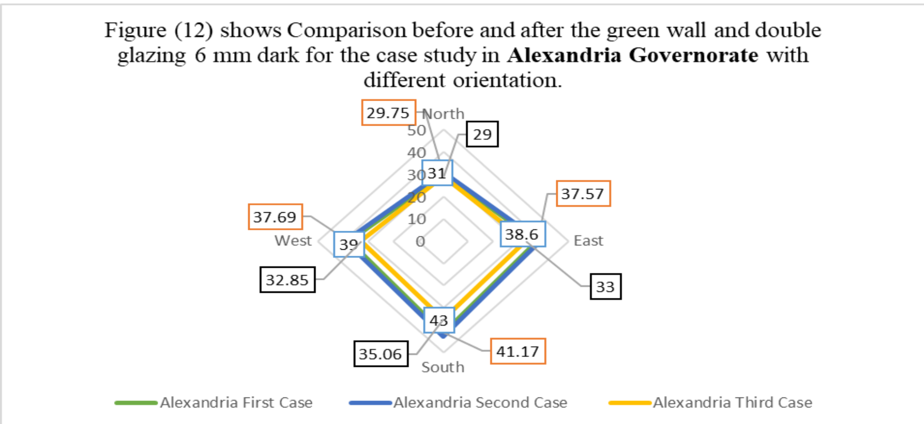


Fig (12) shows the decrease in the rate of Energy consumption s in all three study cases on the northern façade and when using a green wall with dark glass for the Alexandria Governorate.

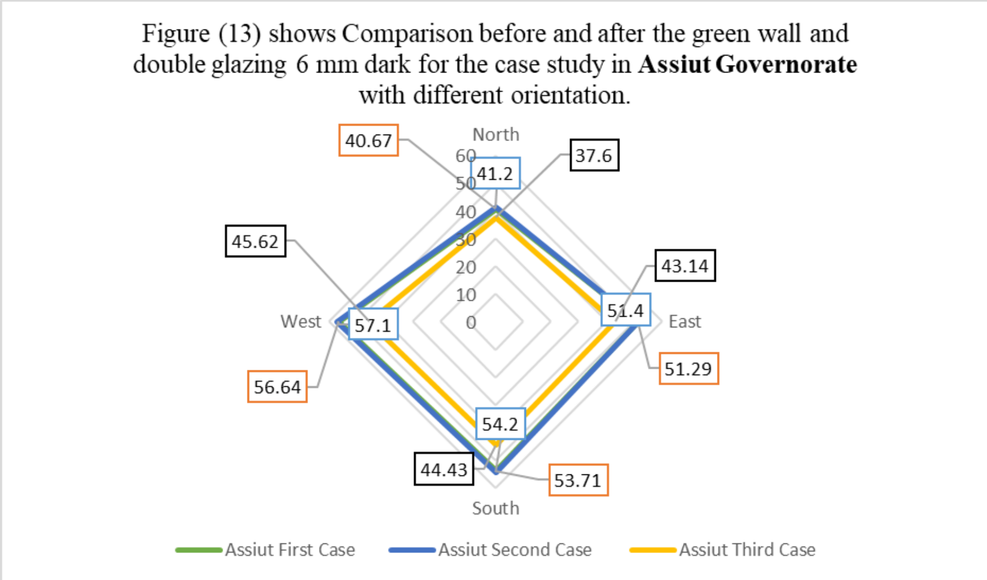


Fig (13) shows the decrease in the rate of Energy consumption s in all three study cases on the northern façade and when using a green wall with dark glass for the Assiut Governorate.

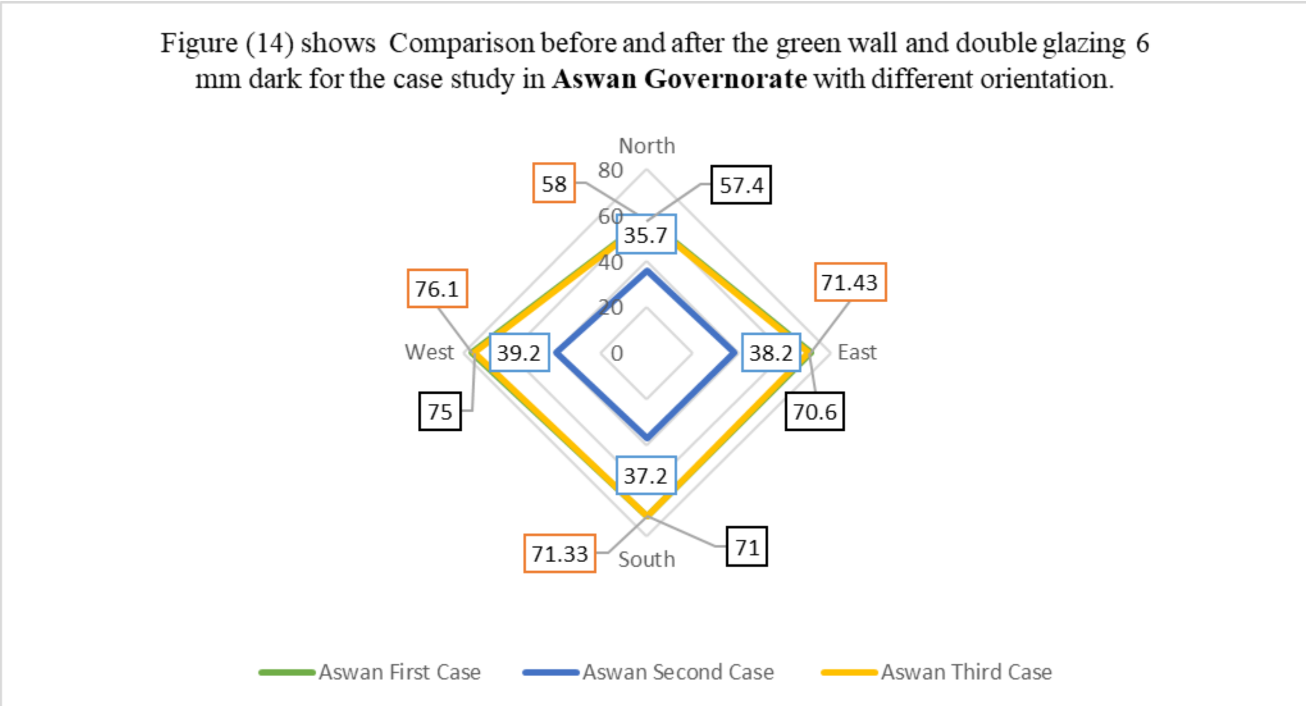


Fig (14) shows the decrease in the rate of Energy consumption s in all three study cases on the northern façade and when using a green wall with dark glass for Aswan Governorate.

Conclusion:

The results of the study confirm the crucial role that orientation plays in reducing energy consumption within classroom models in university buildings, especially in the Greater Cairo area. Notably, the north orientation appears to be a powerful strategy for significantly reducing energy consumption, with a staggering 18.2 % reduction compared to the base case of the west orientation. Furthermore, the east orientation proves to be an effective alternative, resulting in a 9 % reduction compared to the base case. These results highlight the importance of thoughtful architectural design, emphasizing the potential of green walls and specific orientations to significantly contribute to reducing energy consumption in university campus buildings.

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