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EPS Cement Sandwich Panel Walls: A Sustainable and Energy-Efficient Solution for Residential Buildings
A Simulation-Based Study of a Residential Villa in Cairo, Egypt

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Abstract: The construction industry represents a considerable portion of global energy consumption and carbon emissions, necessitating the investigation of sustainable alternatives in building materials. Expanded Polystyrene (EPS) cement sandwich panel walls have emerged as a promising energy-efficient and environmentally responsible solution, providing lightweight construction, superior thermal insulation, and diminished CO_2 emissions. This study examines the performance of EPS cement sandwich panels in a residential villa in the new administrative capital of Cairo, Egypt, an area characterized by a hot arid climate and a substantial reliance on mechanical cooling systems. Employing Design Builder and Energy Plus, the study contrasts two simulation scenarios: a baseline building model (villa type A) featuring 250 mm-thick conventional concrete block walls, and an EPS cement sandwich panels model (villa type B) that incorporates a 200 mm-thick EPS cement mix mortar core with fiber cement boards facings. Results indicate that EPS cement sandwich panels enhance thermal performance, resulting in an 81.06% reduction in yearly heat gains and losses through external walls, and a yearly 15.41% decrease in HVAC energy consumption. Consequently, yearly CO_2 emissions diminished from 45,413.18 kg to 38,414.73 kg. The EPS cement sandwich panel system attained a U-value of 0.189 W/m²K, in contrast to 1.371 W/m²K for conventional concrete block walls. These findings emphasize the effectiveness of EPS cement sandwich panels in enhancing energy efficiency and mitigating the environmental impact in hot arid climates. The study supports integrating EPS cement sandwich panels in Egypt's residential sector, aligning with national energy strategies and global sustainability goals.

1. Introduction

The construction industry significantly contributes to global energy consumption and carbon emissions, accounting for 40% of total energy use and 36% of CO_2 emissions worldwide. Among these innovations, sustainable building materials and energy-efficient design strategies have gained increasing attention as viable solutions to reduce environmental impact while maintaining structural

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integrity and occupant comfort. [11] [14]. Expanded polystyrene (EPS) cement sandwich panel walls have emerged as a promising alternative to conventional construction materials due to their lightweight nature, thermal insulation properties, and reduced carbon footprint. EPS cement sandwich panels, with their EPS cement mix core bonded between two cementitious layers, offer superior thermal resistance to conventional concrete blocks. This feature significantly reduces building heating and cooling loads, promising a substantial decrease in energy consumption. [4] [7]

Several studies have demonstrated the effectiveness of EPS cement sandwich panels in improving energy efficiency across various climates. However, their use in hot arid regions, such as Cairo, Egypt, remains underexplored, particularly in residential areas with substantial demand for heating and cooling. Cairo's climate, characterized by hot temperatures and intense solar radiation, significantly relies on mechanical cooling systems, contributing to elevated energy consumption in residential buildings. Conventional construction methods that use dense concrete or clay blocks exhibit poor thermal performance, worsening indoor heat gains and losses. Thus, integrating EPS cement sandwich panels could offer a sustainable solution to reduce energy use while preserving structural durability. [3] [18]. This study significantly contributes to the growing knowledge on sustainable construction practices in hot arid climates through simulation-based analysis. It examines the thermal and energy performance of EPS cement sandwich panel walls in a residential villa in Cairo, Egypt, the new administrative capital. Utilizing Design Builder Software Ltd (V. 7.0.0.116 – educational version) and Energy Plus (V. 9.4.0), the study evaluates the potential reduction in heating and cooling energy consumption compared to conventional construction methods in the same building model. The findings provide evidence-based recommendations for adopting EPS cement sandwich panels in Egypt's residential sector, aligning with global sustainability goals and energy efficiency initiatives.

2. Literature Review

(Horma, Charai, Mezrhab, & Karkri, 2020) Presented a new cement-based material from local products, emphasizing energy efficiency in residential buildings. An investigation on the effects of plaster and expanded polystyrene (EPS) revealed that adding 5% plaster and 40% EPS reduced thermal conductivity by about 40%, improving thermal resistance. A thermal simulation for a residence in Oujda indicated potential cooling load reductions of 40% and heating load reductions of 31%, enhancing thermal comfort. [10]. (Petrella, Di Mundo, & Notar, 2020) Analyzed the properties of cement mortars using recycled expanded polystyrene (EPS) as a sand replacement. While these EPS composites are lightweight and thermally insulating, they show lower mechanical strength compared to traditional sand mortars. However, EPS mortars offered improved thermal insulation and optimal hydrophobicity, particularly with 2–4 mm and 4–6 mm EPS beads, which prevented internal water penetration. These environmentally sustainable composites are produced without pre-treated materials and are suitable for indoor applications. [19]

(Gao, Cheng, Kang, & Ma, 2021) Developed an ultra-light insulation foamed cement composite using Portland cement, aerogel powder, graphite-modified EPS particles, a foaming agent, and additives, achieving a dry density of 120 kg/m³. The study found that a 30% volume of graphite-modified EPS particles optimally enhanced performance, yielding a compressive strength of 0.25 MPa and a thermal conductivity of 0.0326 W/m-K, effectively improving strength while lowering thermal conductivity in foamed cement-based materials. [7]. (Li, et al., 2021) Examined the bending performance and failure modes of EPS mortar-filled pultruded sandwich panels through flexural testing. Results showed that these panels have excellent thermal insulation properties. The research aimed to provide technical support for their engineering applications. [12]

(Becker, Effting, & Schackow, 2022) Analyzed lightweight coating mortars with optimized formulations that partially replaced fine aggregate with silica aerogel, expanded polystyrene (EPS), and vermiculite. Key properties assessed included consistency, air content, water retention, compressive strength, density, water absorption, void index, and thermal conductivity. A case study evaluated thermal resistance for ceramic brick masonry in Brazil's bioclimatic zones, finding that EPS reduced thermal conductivity by up to 53% and allowed for a reduction in coating thickness from 3.4 cm to 1.4 cm while maintaining thermal performance. [2]. (Horma, et al., 2022) Examined recycled EPS waste within a cement-based matrix to create a lightweight, energy-efficient composite for sustainable construction. A mixture of Portland cement with 4% gypsum and EPS aggregates demonstrated a 54% reduction in thermal conductivity, 12% in thermal diffusivity, and 36% in density, enhancing thermal resistance. Tests showed improved durability and suitability for structural and insulation applications. Numerical analyses indicated potential energy savings of up to 18%. [9]

(Mohamed & Al-Hadithi, 2022) Evaluated EPS waste as a fine aggregate substitute (50% to 60%) in lightweight cement composites. Tested eight mix designs for compressive strength, flexural strength, thermal conductivity, water absorption, and dry density. After 28 days, compressive strength reached 29.26 MPa, flexural strength 6.83 MPa, dry density 1930 kg/m³, and absorption decreased by 4.95%. Thermal conductivity reduced by 0.8291 W/m-k. [13]. (Shi, et al., 2022) Prepared non-combustible, cement-based EPS mixtures with thermal conductivity below 0.045 W/m-K and density under 140 kg/m³. The mixtures were characterized for mechanical, thermal, and flame retardant properties, examining the effects of particle size, silica coating, and EPS content. Indoor tests measured density, water absorption, compressive and tensile strength, moisture susceptibility, thermal conductivity, and combustion performance. Results indicated that smaller, graded EPS particles improved performance, while silica-coated EPS enhanced flame retardance but slightly lowered mechanical properties. These findings support material selection for better thermal insulation and flame retarding capabilities. [20]. (Alhems, Ahmad, Ibrahim, Ali, & Al-Shugaa , 2024) Evaluated the thermal performance of twin-wall panel systems in hot, arid Arabian countries. One system had a 5.0 cm extruded polystyrene (XPS) board, while the other featured a 5.0 cm foam-mortar layer with expanded polystyrene (EPS) beads between two 7.5 cm concrete layers. U-values were measured at 1.143 W/m²K for the XPS wall and 0.293 W/m²K for the EPS wall. The EPS foam-mortar system demonstrated better thermal efficiency, with a time lag of about 4.5 hours between external and internal temperature changes. [1]

(Moura, da Silva, Soares, & Monteiro, 2025) Evaluated the eco-efficiency of four insulation materials: lightweight concrete, cork, glass wool, and EPS. Using life cycle assessment and costing established eco-efficiency indicators for better decision-making. Optimal scenarios differed by impact category, highlighting the need for multiple indicators to prevent problem shifting. Cork panels were the most expensive, while the others were similarly priced. Findings showed that cork excelled in carbon footprint, but recycled EPS had the highest overall eco-efficiency. [17]

3. Expanded Polystyrene (EPS) Cement Sandwich Panels.

The EPS cement sandwich panels represent a highly innovative, user-friendly, lightweight wall panelling system utilised in internal and external applications, delivering optimal efficiency and comfort. [7] [12] [17]. As shown in Figure 1, it comprises a lightweight EPS cement mix mortar core positioned between two layers of fibre cement boards. Each panel offers thermal, acoustic, and fire resistance and exceptional water protection. [3] [5] [8]

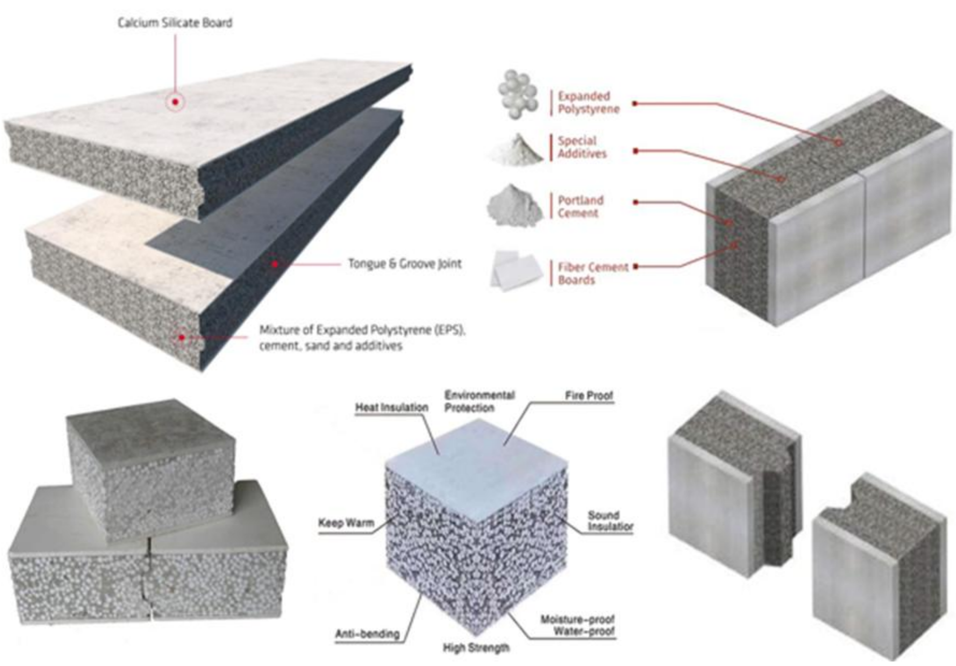


Figure (1) EPS Cement Sandwich Panels [3] [5] [8]

This amalgamation of materials provides rigidity, strength, and superior insulation for buildings. Moreover, these panels were specifically engineered to enhance the construction process while ensuring superior finishing quality and to be used for all types of buildings. [4] [18] [1]. Following the panel specifications and thickness parameters, the thickness varies from 75 mm to 200 mm. The weight calculations are approximately 725 Kg/m³ with a tolerance of +/-5%. The density ranges from 400 to 1000 Kg/m³. These panels achieve U-values of up to 0.2 W/m²-K, thereby stabilising indoor temperatures by reducing heat gains and losses. This contributes to decreased associated heating and cooling energy consumption and related CO_2 emissions. Furthermore, it offers superior sound insulation, with sound reduction capabilities reaching 60 dB. [4] [5] [10] [17] [21]

EPS cement sandwich panel walls offer advantages over conventional systems, including improved thermal insulation, lighter weight, and faster construction. The heat-resistant EPS core lowers energy consumption for heating and cooling, while cement facings increase durability and fire resistance. These lightweight panels lessen foundation loads and transport costs while maintaining high strength. Their modular design speeds up installation, reducing labour needs and construction time. EPS cement sandwich panels are also more cost-effective and eco-friendly due to lower material usage. They provide excellent acoustic insulation, thus making them a sustainable choice for modern construction. [1] [2] [3] [18] [20]. The economic feasibility of expanded polystyrene (EPS) cement sandwich panels in construction is supported by cost-benefit analyses and lifecycle assessments. These lightweight panels offer significant savings in material and labour costs due to their ease of installation and modular design, which speeds up construction and reduces workforce needs. Their thermal insulation also leads to long-term energy savings, enhancing overall cost-efficiency. While initial material costs may be slightly higher than conventional bricks and blocks, overall project expenses are typically lower due to faster completion and reduced structural load. Thus, EPS cement sandwich panels are a financially viable alternative, especially for large or time-sensitive projects. [4] [7] [9] [18]

4. Methodology.

This study employs a simulation-based methodology to analyze the thermal and energy performance of expanded polystyrene (EPS) cement sandwich panel walls in a residential villa building proposed for the new administrative capital of Cairo, Egypt. A representative villa model was developed through Design Builder Software Ltd (V. 7.0.0.116 – educational version) as shown in Figure 2, which integrates local construction methodologies and climatic data of Cairo's hot arid climate. This software is highly esteemed for its intuitive interface, enabling efficient evaluations of the environmental performance of both newly constructed and existing buildings. It minimizes modeling duration and enhances productivity using Energy Plus (Version 9.4.0) as a simulation engine. This engine is instrumental in calculating energy consumption across various parameters, including cooling, heating, ventilation, lighting, process loads, and other critical variables essential for fulfilling the analysis objectives. The baseline model (villa type A) employed conventional 250 mm-thick concrete blocks in the external walls, while the experimental model (villa type B) incorporated EPS cement sandwich panels in the external walls. These panels were characterized by a 200 mm-thick EPS cement mix core complemented by 50 mm fibre cement boards facing on either side.

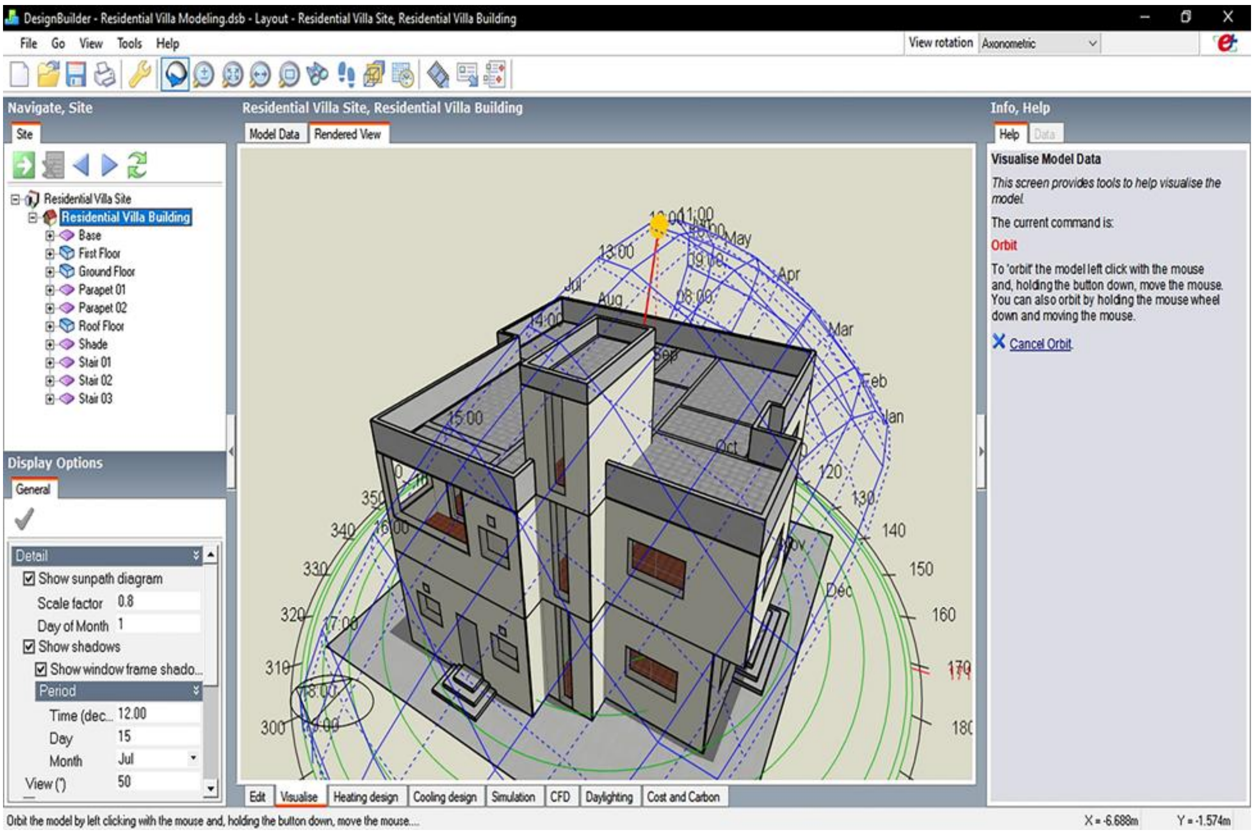


Figure (2) Design Builder Software Interface [6]

Figure 3 shows the study strategy, which compares two villa building scenarios: the baseline conventional external walls scenario (villa type A) and a scenario incorporating EPS cement sandwich panels in its external walls (villa type B). This study employs performance simulation software to comprehensively analyze multiple factors, notably the design of heating and cooling systems and energy consumption metrics. This comparison aims to assess the implications of utilizing EPS cement sandwich panels in external wall construction, focusing on their capacity to improve energy efficiency, decrease operational costs, and promote sustainable practices.

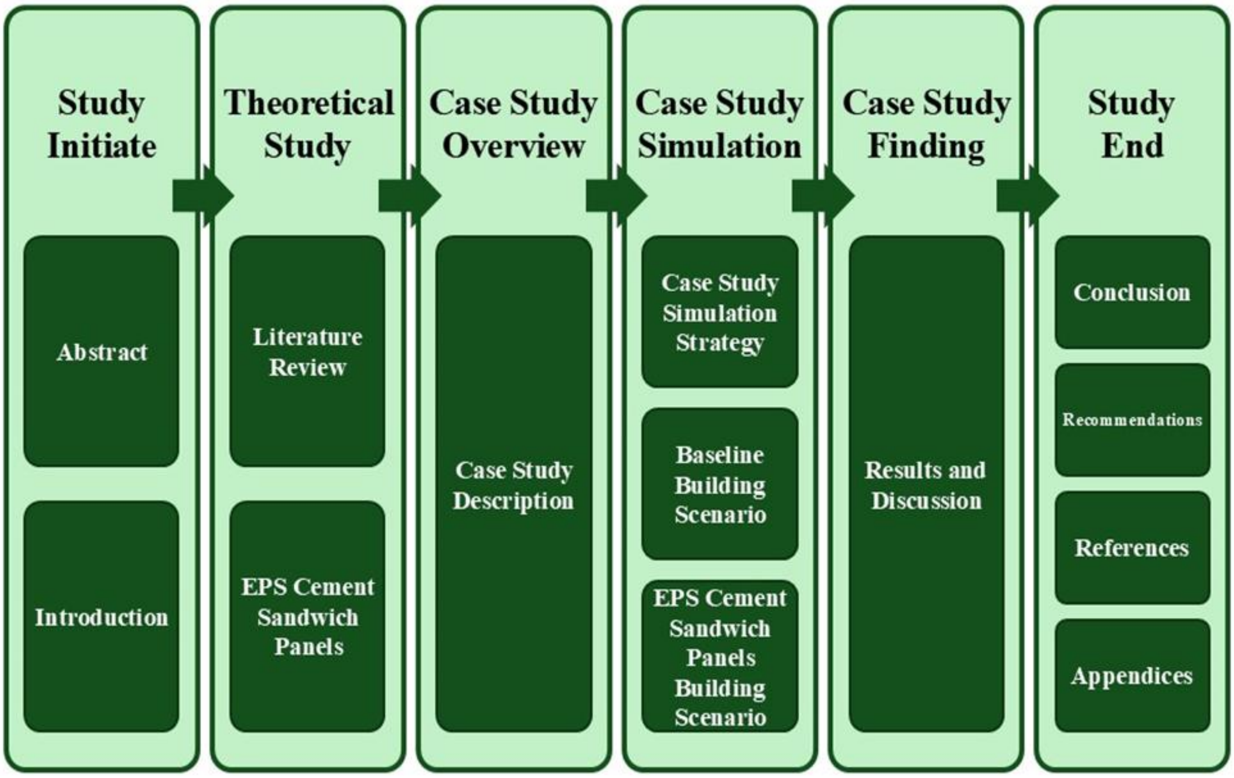


Figure (3)Study Methodology Workflow Diagram

5. Residential Villa Building Case Study Analysis.

The study aims to simulate a proposed residential villa building in Cairo's new administrative capital, utilizing conventional local materials and systems as a benchmark for comparison. The primary objective is to evaluate the impact of incorporating EPS cement sandwich panels for the external walls on the overall performance of the building.

5.1. Case Study Description.

The proposed design for the residential villa, as illustrated in Figure 4, features a thoughtfully planned layout. The ground floor encompasses an entrance, reception area, dining space, office, kitchen, toilet, a staircase, and lobbies. The first floor is designed to include a living area with a terrace, a master bedroom complete with a dressing area and toilet, two additional bedrooms, a buffet area, a toilet, a staircase, and a lobby. The rooftop will consist of a staircase leading to an open roof space. The building will have a footprint area of 163.06 m² and a total area of 329.20 m², with a ceiling height of 3.50 meters. It has been designed to accommodate an occupancy density of 0.033 people per m². The HVAC system will be carefully calibrated with separate split units to maintain a comfortable temperature of 24 °C during summer and 22 °C during winter.

Construction will utilize conventional local techniques, ensuring durable materials and a thoughtfully arranged internal layout. The villa's energy sources will comprise natural gas for water heating and electricity for various other devices and systems. The simulation model does not incorporate any surrounding elements, allowing for a concentrated evaluation of the performance of the external wall construction materials without external influences.

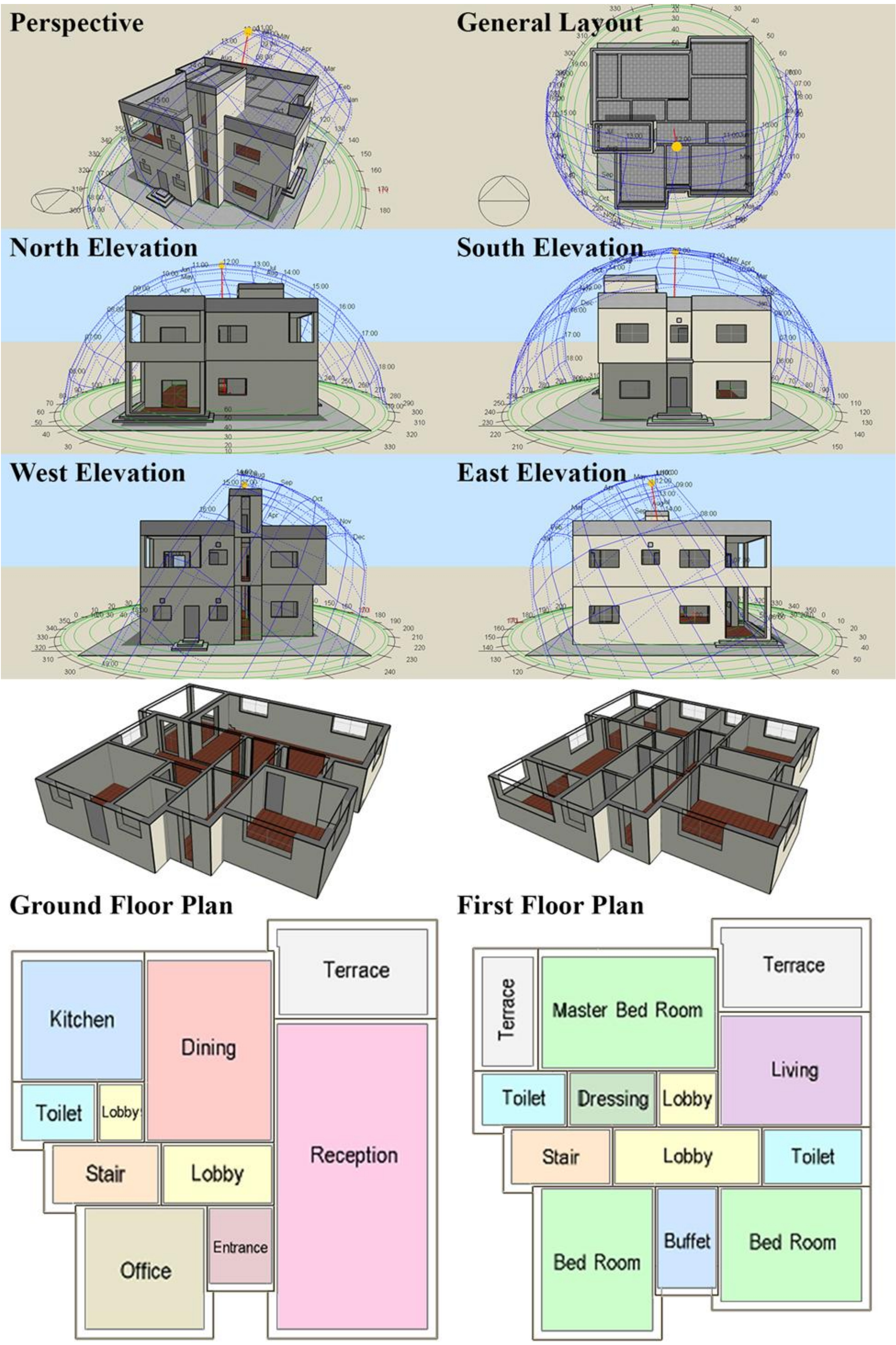


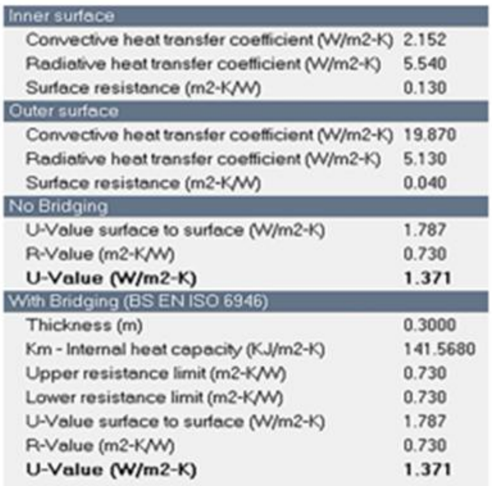
Figure (4) Proposed Villa Building Model Overview [6]

5.2. Case Study Simulation Strategy.

The proposed simulation strategy involves a comparative analysis of two distinct building scenarios. The first scenario is represented by a baseline building (villa type A), which incorporates conventional external walls made of 250 mm-thick concrete blocks, finished with 30 mm-thick external sand-cement plaster and 20 mm-thick internal sand-cement plaster. The second scenario, which utilizes EPS cement sandwich panels for external walls (villa type B), consists of a 200 mm-thick EPS cement mix mortar core adorned with a 5 mm-thick fiber cement board on both outer surfaces. Both scenarios employ the same building materials and systems for all remaining components to ensure a consistent comparison. The building performance simulation software, specifically Design Builder Software Ltd (version 7.0.0.116) and Energy Plus (version 9.4.0), will be utilized to demonstrate the impact of using EPS cement sandwich panels as an alternative to conventional external wall materials. This approach aims to enhance overall building performance in the specific environmental conditions of the new administrative capital of Cairo, Egypt. The simulation will thoroughly evaluate various factors, including analyzing cooling and heating designs, site data, comfort levels, internal gains, solar influences, and fabric and ventilation assessments. Additionally, it will cover fuel breakdown and total analysis, CO_2 production evaluation, system load analysis, and an assessment of carbon.

5.3. Baseline Building Model (Villa Type A) Scenario.

A detailed simulation analysis was conducted on the baseline building model (villa type A), utilizing conventional building materials and systems. As depicted in Figure 5, the external walls of the building are composed of 250 mm-thick concrete blocks, which are further finished by a 30 mm-thick layer of external sand-cement plaster and a 20 mm-thick layer of internal sand-cement plaster, a total weight estimated at 2000 Kg/m^3. The overall thermal transmittance (U-value) for these conventional external walls is recorded at 1.371 W/m²K. [6]. The analysis outlined in Table 1 examined the building's thermal performance during peak summer and winter day conditions, focusing on cooling and heating design, respectively. The findings indicate that the conventional external walls transfer heat to and from the building's interior spaces, resulting in considerable heat gains and losses. This assessment provides a comprehensive overview of the building's performance under baseline conditions. Enhancing the building's energy efficiency necessitates a detailed evaluation of its thermal performance. [6] (Appendix 1)



Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	1.787
R-Value (m2-K/W)	0.730
U-Value (W/m2-K)	**1.371**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.3000
Km - Internal heat capacity (KJ/m2-K)	141.5680
Upper resistance limit (m2-K/W)	0.730
Lower resistance limit (m2-K/W)	0.730
U-Value surface to surface (W/m2-K)	1.787
R-Value (m2-K/W)	0.730
U-Value (W/m2-K)	**1.371**

Figure (5) Baseline Building (Villa Type A) External Walls [6]

Table (1) Baseline Building (Villa Type A) Cooling and Heating Design Analysis [6]

	Glazing	Walls	Ground Floor	Roof Floor	Cooling Load	Heating Load
Peak Summer Day Total Heat Balance (W/m^2)	32.42	131.81	114.72	42.78	488.02	-----
Peak Winter Day Total Heat Balance (W/m^2)	08.01	19.32	00.44	05.04	-----	40.50

The existing conditions negatively affect the building's thermal performance and energy efficiency. Implementing suitable measures to resolve this issue and enhance the building's thermal performance is imperative, leading to improved energy efficiency. Following a comprehensive analysis of the heat gains and losses simulation for the baseline building model (villa type A), Figure 6 shows that the heat gains through the external walls reached 4,961.52 Wh/m² during the peak summer month. In contrast, the heat losses recorded during the winter peak month amounted to 6,234.57 Wh/m². The total heat gains and losses through the external walls for the entire year were determined to be 40,438.09 Wh/m². [6] (Appendix 2). The data presented in Figure 7 indicates that the thermal gains and losses through the building's exterior walls influence the heating, ventilating, and air conditioning (HVAC) system. Over the years, the total energy consumption for HVAC cooling was approximately 69,838.23 Wh/m², while the total energy consumption for HVAC heating was around 5,101.08 Wh/m². The related building's total carbon dioxide (CO_2) emissions for the year amounted to 45,413.18 kg. [6] (Appendix 3)

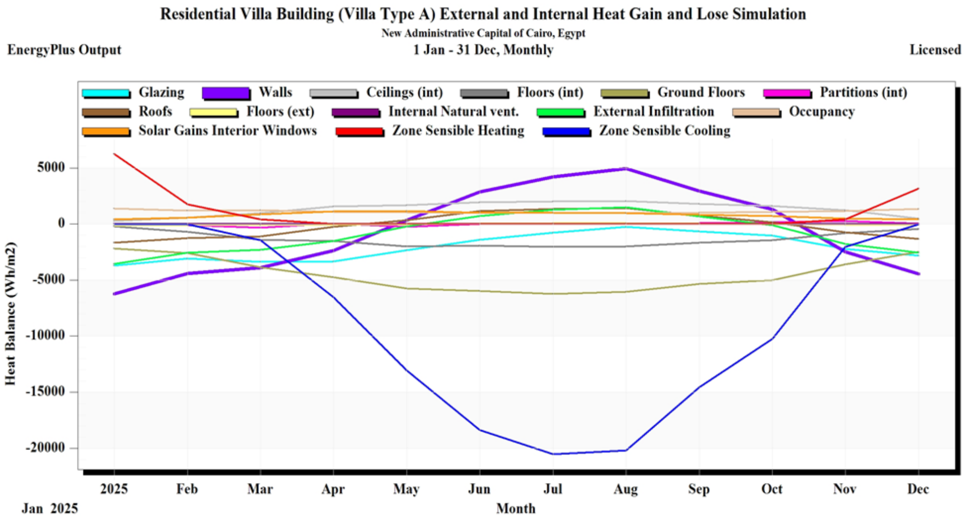


Figure (6) Baseline Building (Villa Type A) Heat Gains and Loses Analysis [6]

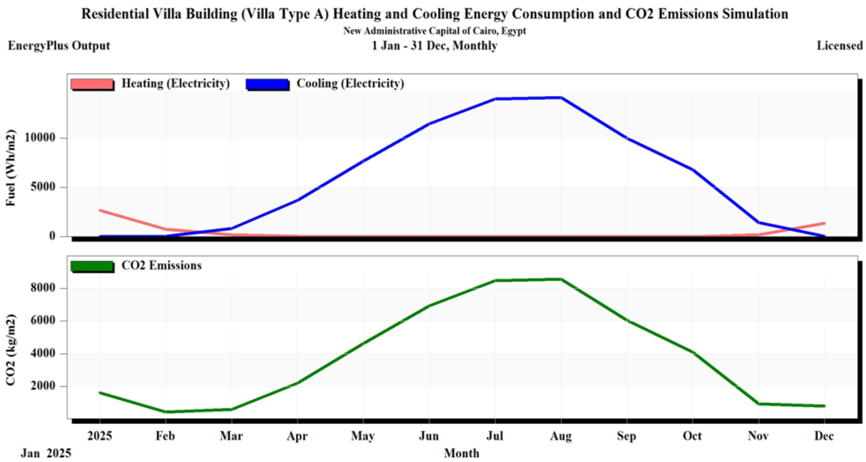


Figure (7) Baseline Building (Villa Type A) Heating and Cooling Energy Consumption and CO_2 Emissions [6]

5.4. EPS Cement Sandwich Panels Building Model (Villa Type B) Scenario.

A detailed simulation analysis was conducted on the EPS cement sandwich panels building model (villa type B), utilizing conventional building materials and systems.

As depicted in Figure 8, the external walls of the EPS cement sandwich panels of the building are composed of a 200 mm-thick EPS cement mix mortar core, adorned with a 5 mm-thick fiber cement board on both outer surfaces. The overall thermal transmittance (U-value) for these EPS cement

sandwich panels' external walls is recorded at 0.189 W/m²K. [6]. The EPS cement mix mortar core is a specialized blend featuring 10-15% cement for binding, 15-20% water to facilitate solidification, 50-70% lightweight EPS beads for insulation and reduced weight, and 10-20% fine sand to enhance texture and structural integrity. This combination results in a robust and efficient mortar suitable for diverse construction applications. Weight calculations are based on a core density of 725 Kg/m^3 +/- 5%. [4] [5] .The analysis outlined in Table 2 examined the building's thermal performance during peak summer and winter day conditions, focusing on cooling and heating design, respectively.
The findings indicate that the EPS cement sandwich panels' external walls reduce the heat transfer to and from the building's interior spaces, resulting in a considerable reduction of heat gains and losses compared to baseline building conventional external walls in both summer and winter months, which results in reduced cooling and heating loads. [6] (Appendix 4)

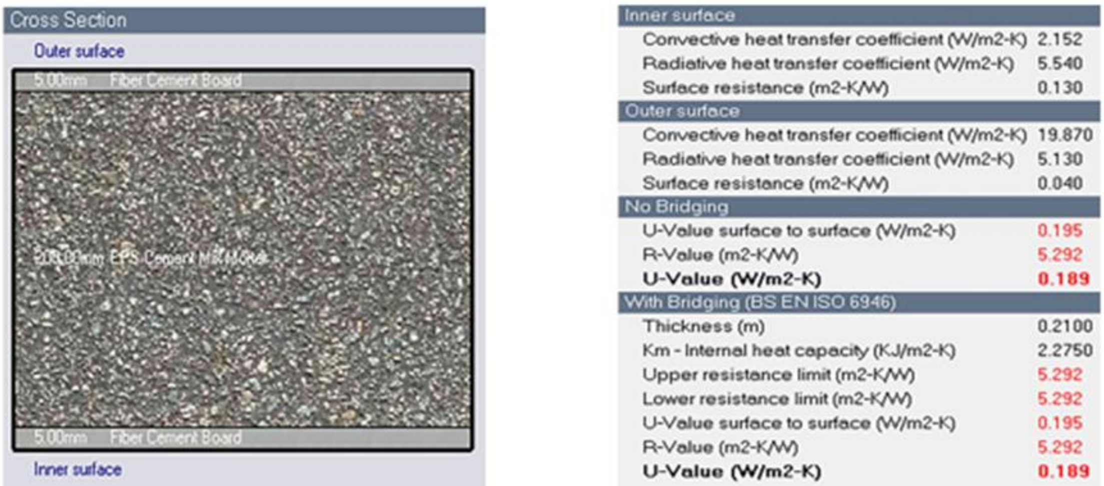


Figure (8) EPS Cement Sandwich Panels Building (Villa Type B) External Walls [6]

Table (2) EPS Cement Sandwich Panels Building (Villa Type B) Cooling and Heating Design Analysis [6]

	Glazing	**Walls**	**Ground Floor**	**Roof Floor**	**Cooling Load**	**Heating Load**
Peak Summer Day Total Heat Balance (W/m^2)	27.66	30.57	104.36	51.32	373.12	-----
Peak Winter Day Total Heat Balance (W/m^2)	08.19	03.44	01.47	05.20	-----	26.30

Following a comprehensive analysis of the heat gains and losses simulation for the EPS cement sandwich panels building model (villa type B), Figure 9 shows that the heat gains through the external walls reduced to 802.35 Wh/m² during the peak summer month. In contrast, the heat losses reduced during the winter peak month to 1,284.76 Wh/m². Cumulatively, the total heat gains and losses through the external walls for the entire year were determined to be 7,660.29 Wh/m². [6] (Appendix 5). The data presented in Figure 10 indicates that the thermal gains and losses through the building's exterior walls influence the heating, ventilating, and air conditioning (HVAC) system.
Yearly, the total energy consumption for HVAC cooling was approximately 61,279.80 Wh/m², while the total energy consumption for HVAC heating was around 2,110.88 Wh/m². The related building's total carbon dioxide (CO_2) emissions for the year amounted to 38,414.73 kg. [6] (Appendix 6)

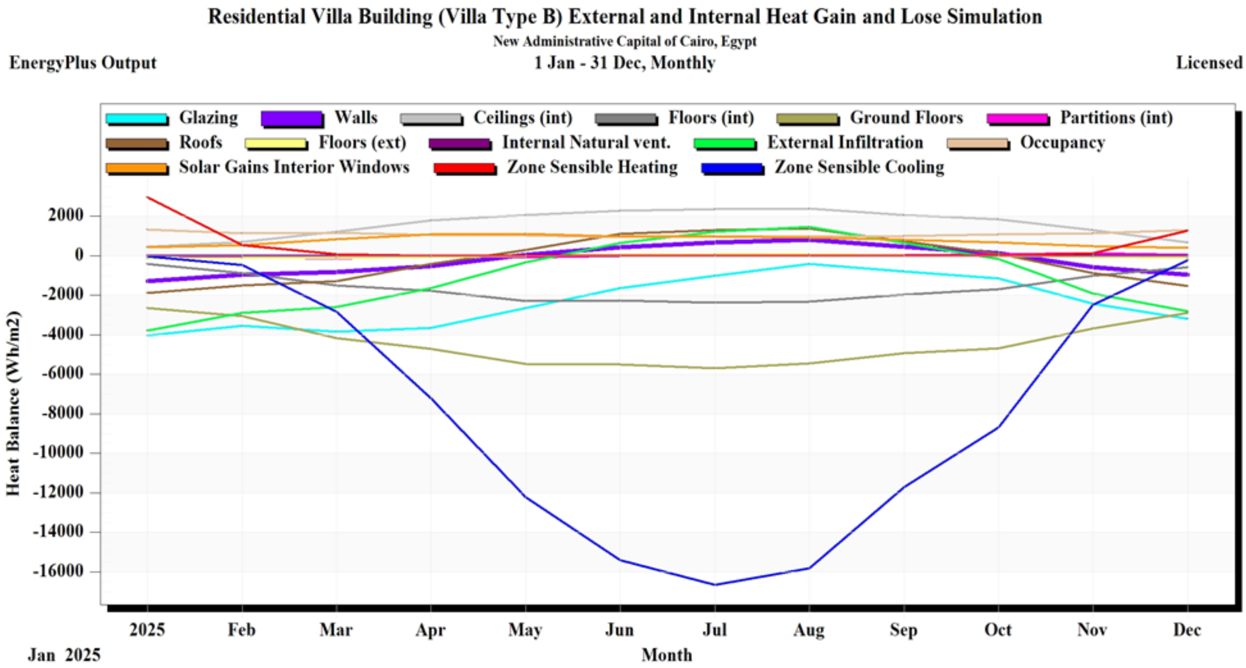


Figure (9) EPS Cement Sandwich Panels Building (Villa Type B) Heat Gains and Loses Analysis [6]

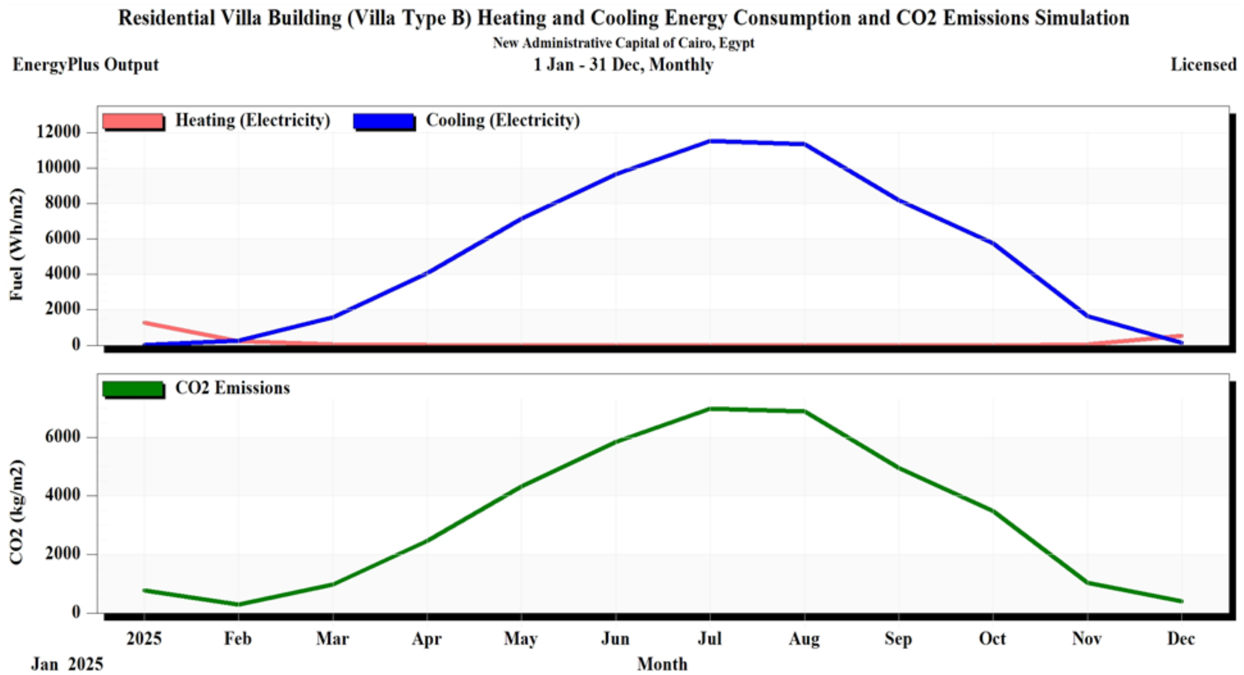


Figure (10) EPS Cement Sandwich Panels Building (Villa Type B) Heating and Cooling Energy Consumption and CO_2 Emissions [6]

6. Results and Discussion.

This study explores the thermal performance and energy consumption of a proposed residential villa in the new administrative capital of Cairo, Egypt. Building performance simulation software was employed to conduct this research, specifically Design Builder Software Ltd (Version 7.0.0.116) and Energy Plus (Version 9.4.0). The analysis compared two distinct villa scenarios: a baseline model (villa type A), which utilizes conventional external wall materials, and an alternative model (villa type B), constructed with EPS cement sandwich panels for its external walls. The objective of this investigation was to evaluate the effects of employing EPS cement sandwich panels on the overall performance of the building. The proposed villa is designed as a two-story building, encompassing a footprint area of 163.06 m² and an overall area of 329.20 m², with a ceiling height of 3.50 meters. The building's energy systems include individual water heaters powered by natural gas, while electricity will supply other appliances. The villa is designed to accommodate an occupancy density of 0.033 persons per square meter. The HVAC system will consist of separate split units, carefully calibrated to maintain temperatures of 24 °C during summer and 22 °C in winter. [6]

The baseline model, referred to as villa type A, incorporates conventional external walls of 250 mm-thick concrete blocks, completed with a 30 mm-thick external sand-cement plaster and a 20 mm-thick internal sand-cement plaster. This assembly results in an overall thermal transmittance (U-value) of 1.371 W/m²K for these external walls. In comparison, the EPS cement sandwich panels building, referred to as villa type B, features a 200 mm thick EPS cement mix mortar core, enhanced by 5 mm thick fiber cement boards on both outer surfaces of its external walls. This configuration achieves a significantly improved overall thermal transmittance (U-value) of 0.189 W/m²K for the external walls. Both scenarios utilize conventional building materials and systems for the remaining components, ensuring a consistent basis for comparison. [6]. The analysis presented in Figures 11 and 13 from the simulation study reveals a significant reduction in heat gains and losses from external walls when comparing the two building scenarios. The baseline building scenario (villa type A) exhibits yearly external wall heat gains and losses totaling 40,438.09 Wh/m². In contrast, the building constructed with EPS cement sandwich panels (villa type B) demonstrates considerably lower yearly external wall heat gains and losses, amounting to 7,660.29 Wh/m². [6]

The variation in heat gains and losses through the external walls of the two building scenarios significantly impacts the load requirements of the HVAC systems, which in turn affects overall energy consumption. Analysis presented in Figures 12 and 13 highlights the yearly HVAC energy consumption for the baseline building (villa type A), which utilizes conventional external walls and results in an energy usage of 74,939.31 Wh/m². In contrast, the building constructed with EPS cement sandwich panels (villa type B) demonstrates a reduced energy consumption of 63,390.68 Wh/m². [6] This decrease in HVAC energy demand consequently reduces CO_2 emissions, with the baseline building generating 45,413.18 kg of emissions compared to 38,414.73 kg from the EPS cement sandwich panel building. [6]

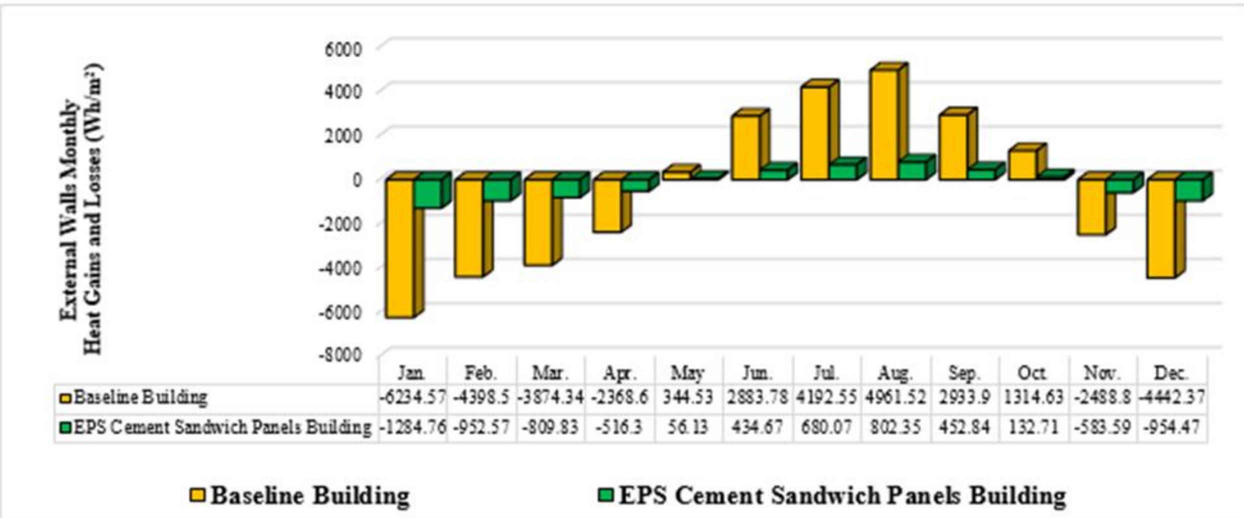


Figure (11) Building External Walls Monthly Heat Gains and losses Analysis [6]

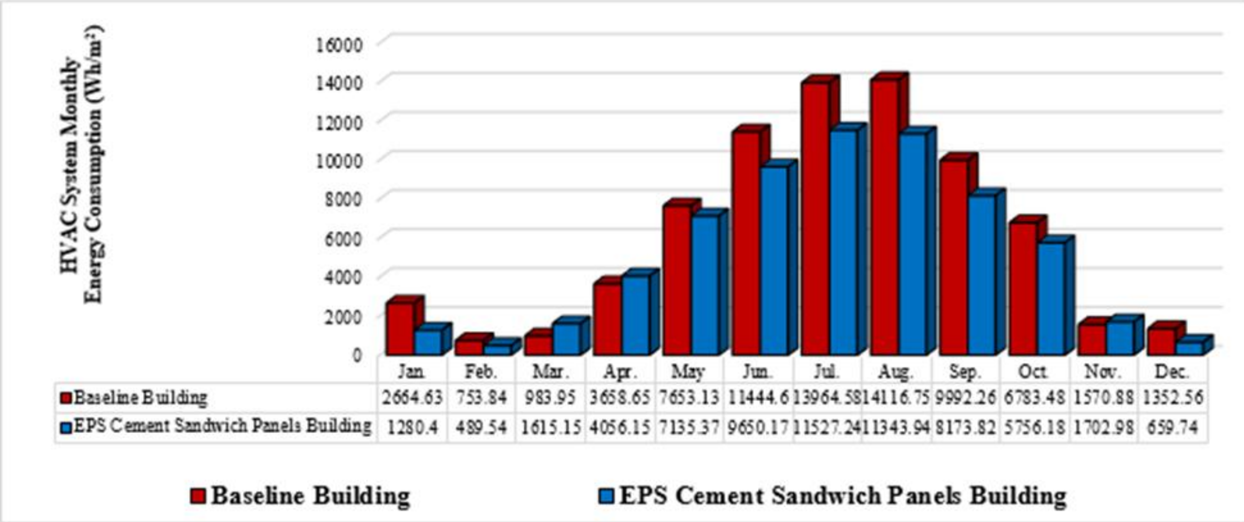


Figure (12) Building HVAC System Monthly Energy Consumption Analysis [6]

The findings suggest that implementing EPS cement sandwich panels for the external walls of a proposed residential villa in the new administrative capital of Cairo, Egypt, presents a viable alternative to conventional wall materials. This approach has the potential to achieve a remarkable reduction of up to 81.06% in heat gains and losses through the building's external walls. As a result, this integration can significantly alleviate the demand for HVAC systems, reducing energy consumption by approximately 15.41% compared to conventional external wall materials used in similar buildings, as shown in Figure 13. Furthermore, this method contributes to decreased associated CO_2 emissions by the same margin of 15.41%. This study underscores a significant improvement in energy efficiency and overall building performance, brought about by adopting EPS cement sandwich panels. These panels present a modern and efficient alternative to conventional external wall materials, effectively addressing the diverse needs of occupants while offering superior thermal insulation and durability.

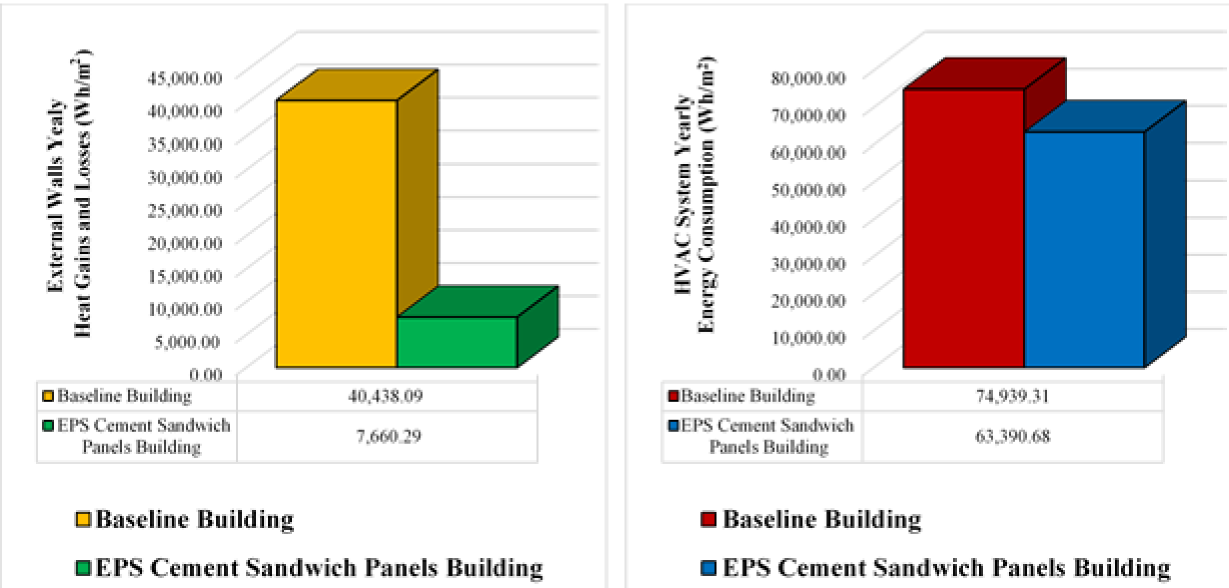


Figure (13) Building Yearly External Walls Heat Gains and Losses and HVAC System Energy Consumption Analysis

By integrating these innovative panels, buildings can substantially reduce energy consumption for heating and cooling. This improves comfort and contributes to a reduction in greenhouse gas emissions. Moreover, this approach emphasizes the conservation of natural resources by utilizing materials that require less energy in their production and provide long-lasting performance. The use of EPS cement sandwich panels minimizes the environmental footprint of construction, positively impacting the natural world, supporting local economies, and enhancing community well-being. In doing so, it actively progresses toward sustainability goals, fostering a harmonious relationship between built environments and the ecosystem.

7. Conclusions

This study demonstrates the effectiveness and sustainability of expanded polystyrene (EPS) cement sandwich panel walls for residential buildings in hot arid climates. A case study of a residential villa building in the new administrative capital of Cairo, Egypt, supports this claim. Using a simulation-based methodology with Design Builder and Energy Plus, the study evaluated the thermal and energy performance of a conventional villa with 250 mm-thick concrete block walls (villa type A) against EPS cement sandwich panels (villa type B), which have superior insulation properties.

Simulation results show that EPS cement sandwich panels achieve an 86.97% reduction in yearly heat gains and losses through external walls compared to the conventional model, with yearly heat gains and losses of 40,438.09 Wh/m² for (villa type A) compared to 7,660.29 Wh/m² for (villa type B).

This significant thermal resistance correlates with a 15.41% drop in yearly energy consumption for cooling and heating from 74,939.31 Wh/m² in the conventional model to 63,390.68 Wh/m² in the EPS cement sandwich panels model. This improves indoor thermal comfort and supports economic and environmental benefits by reducing operational costs and reliance on non-renewable energy sources.

Additionally, total yearly CO_2 emissions decreased from 45,413.18 kg in (villa type A) to 38,414.73 kg in (villa type B), aligning with global and national sustainability goals as Egypt develops its new administrative capital with a focus on green building and energy efficiency.

The lightweight nature of EPS cement sandwich panels enhances their practicality in urban developments. Their modular design simplifies installation, reduces labor needs, and minimizes material waste, lowering construction and maintenance costs. Fiber cement boards improve the panels' durability, fire resistance, and acoustic performance, making them suitable for various residential and commercial applications. This study provides compelling evidence that EPS cement sandwich panels can advance sustainable construction practices in hot arid climates. While traditional materials like concrete blocks dominate Egypt, they are less thermally efficient and environmentally friendly. EPS cement sandwich panels offer a modern solution that meets thermal comfort criteria and provides significant energy savings and reduced carbon footprints.

The findings promote broader implementation of EPS cement sandwich panels in Egypt's construction industry, especially in the evolving residential sector. Policymakers, developers, and architects must incorporate these insights into building codes and construction guidelines in extreme climatic regions. Future studies could expand this analysis to validate EPS cement sandwich panels' adaptability and scalability. In conclusion, EPS cement sandwich panels present a transformative opportunity for energy-efficient and environmentally responsible building practices in Egypt and other hot arid regions. They enhance thermal performance, reduce energy loads, and contribute to a more sustainable built environment.

8. Recommendations.

This study provides recommendations for policymakers, developers, architects, and engineers in the building construction sector.

8.1. Recommendations for Policymakers.

- Revise national and regional building codes to formally recognize EPS cement sandwich panels as an approved construction material.
- Introduce financial incentives, such as tax rebates, reduced permit fees, or subsidies, for developers and homeowners who implement energy-efficient building materials, including EPS cement sandwich panels.
- Allocate funding for research initiatives to optimize EPS cement sandwich panels specifically for Egypt's climatic conditions and promote investments in local manufacturing to enhance cost-effectiveness and accessibility.

8.2. Recommendations for Developers, Architects, and Engineers.

- Consider EPS cement sandwich panels as a viable alternative to conventional blocks or concrete walls to improve energy efficiency, decrease operational costs, and promote sustainable practices.
- Invest in research to make EPS cement sandwich panels more efficient, affordable, and scalable.
- Conduct a life cycle assessment using EPS cement sandwich panels to evaluate long-term energy savings versus initial material costs.
- Invest in local production of EPS cement sandwich panels to support Egypt's sustainable construction goals.

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10. Appendices.

10.1. Appendix (1): Baseline Building (Villa Type A) Cooling and Heating Design Analysis. [6]

Residential Villa Building (Villa Type A) Cooling Design

New Administrative Capital of Cairo, Egypt

EnergyPlus Output | 15 Jun, Sub-hourly | Licensed

Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Glazing (W/m2)	-1.95	-2.29	-6.52	-3.17	0.96	3.88	6.13	3.93	2.38	0.83	-0.38
Walls (W/m2)	20.14	18.61	8.67	7.78	7.50	8.41	6.75	5.12	9.53	19.01	20.29
Ceilings (int) (W/m2)	5.88	5.95	1.47	0.16	0.71	2.35	2.13	1.55	3.39	6.31	6.52
Floors (int) (W/m2)	1.55	1.60	-2.47	-14.28	-8.19	-1.82	-13.07	-11.07	-2.95	1.02	0.93
Ground Floors (W/m2)	-6.27	-6.16	-12.53	-24.45	-15.91	-7.01	-11.39	-14.45	-6.95	-4.61	-4.99
Partitions (int) (W/m2)	7.05	6.95	-13.29	-4.56	-3.75	-1.00	-5.01	-13.23	-4.64	9.11	7.78
Roofs (W/m2)	7.65	7.90	4.46	2.09	2.05	2.91	1.37	-0.50	1.54	5.86	6.45
Floors (ext) (W/m2)	0.26	0.28	0.27	0.24	0.21	0.15	0.17	0.14	0.18	0.25	0.25
Internal Natural vent. (W/m2)	0.00	0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00
External Infiltration (W/m2)	0.57	0.11	0.06	2.05	4.88	6.84	7.75	7.21	5.82	3.94	2.55
Occupancy (W/m2)	0.84	0.85	0.85	1.33	1.31	1.31	1.30	1.28	1.27	1.32	1.33
Solar Gains Interior Windows (W/m2)	0.00	0.00	8.27	2.79	1.94	1.15	1.31	7.76	3.88	0.00	0.00
Zone Sensible Cooling (W/m2)	-36.44	-34.49	-35.68	-45.72	-48.86	-48.56	-50.01	-51.82	-50.91	-44.10	-41.43

Residential Villa Building (Villa Type A) Heating Design

New Administrative Capital of Cairo, Egypt

EnergyPlus Output | Licensed

Glazing (W/m2)	-8.01
Walls (W/m2)	-19.32
Ceilings (int) (W/m2)	-1.81
Floors (int) (W/m2)	1.95
Ground Floors (W/m2)	-0.44
Partitions (int) (W/m2)	0.09
Roofs (W/m2)	-5.04
Floors (ext) (W/m2)	-0.28
Internal Natural vent. (W/m2)	0.00
External Infiltration (W/m2)	-7.66
Zone Sensible Heating (W/m2)	40.50

10.2. Appendix (2): Baseline Building (Villa Type A) Heat Gains and Loses Analysis. [6]

Residential Villa Building (Villa Type A) External and Internal Heat Gain and Lose Simulation

New Administrative Capital of Cairo, Egypt

EnergyPlus Output | 1 Jan - 31 Dec, Monthly | Licensed

Month												
Glazing (Wh/m2)	-3689.51	-3074.45	-3369.07	-3353.28	-2346.27	-1392.67	-790.69	-266.63	-648.30	-1018.66	-2217.79	-2822.50
Walls (Wh/m2)	-6234.57	-4398.50	-3874.34	-2368.60	344.53	2883.78	4192.55	4961.52	2933.90	1314.63	-2488.80	-4442.37
Ceilings (int) (Wh/m2)	262.76	546.14	960.06	1562.97	1665.83	1943.48	2011.62	2060.19	1803.64	1620.04	1214.85	484.90
Floors (int) (Wh/m2)	-198.95	-692.68	-1392.17	-1511.79	-2008.56	-1921.19	-2019.67	-1986.45	-1681.79	-1433.18	-820.01	-421.31
Ground Floors (Wh/m2)	-2167.94	-2597.16	-3868.15	-4751.81	-5758.07	-5964.11	-6225.37	-6041.03	-5354.53	-5009.32	-3580.57	-2491.95
Partitions (int) (Wh/m2)	42.47	-97.36	-316.25	28.48	-244.95	19.89	-4.47	56.19	87.96	137.77	275.51	50.47
Roofs (Wh/m2)	-1671.01	-1268.72	-1124.11	-271.04	349.08	1171.93	1327.69	1405.41	763.27	147.92	-725.97	-1346.09
Floors (ext) (Wh/m2)	-132.42	-105.71	-110.10	-68.98	-13.28	51.06	70.41	76.29	27.51	1.23	-66.10	-103.00
Internal Natural vent. (Wh/m2)	0.00	0.00	0.00	-0.00	-0.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00	-0.00
External Infiltration (Wh/m2)	-3548.92	-2556.79	-2303.46	-1505.88	-223.66	706.17	1270.32	1495.16	674.21	-122.76	-1771.34	-2553.15
Occupancy (Wh/m2)	1372.10	1189.43	1223.82	1076.55	1045.71	957.43	976.34	979.30	997.86	1079.89	1164.79	1338.51
Solar Gains Interior Windows (Wh/m2)	433.50	565.48	865.97	1134.28	1166.90	1026.85	1017.17	957.09	836.69	705.67	497.55	410.37
Zone Sensible Heating (Wh/m2)	6261.89	1745.89	414.10	0.45	0.00	0.00	0.00	0.00	0.00	0.00	409.15	3156.08
Zone Sensible Cooling (Wh/m2)	0.00	-19.63	-1443.20	-6514.12	-13082.17	-18387.99	-20546.35	-20196.00	-14541.03	-10260.58	-2038.38	-17.20

10.3. Appendix (3): Baseline Building (Villa Type A) Heating and Cooling Energy Consumption and CO_2 Emissions Analysis. [6]

Residential Villa Building (Villa Type A) Heating and Cooling Energy Consumption and CO2 Emissions Simulation

New Administrative Capital of Cairo, Egypt

EnergyPlus Output | 1 Jan - 31 Dec, Monthly | Licensed

Month												
Heating (Electricity) (Wh/m2)	2664.63	742.93	176.21	0.19	0.00	0.00	0.00	0.00	0.00	0.00	174.11	1343.01
Cooling (Electricity) (Wh/m2)	0.00	10.91	807.74	3658.46	7653.13	11444.60	13964.58	14116.75	9992.26	6783.48	1396.77	9.55
CO2 Emissions (kg)	1614.77	456.83	596.27	2217.14	4637.79	6935.42	8462.53	8554.74	6055.30	4110.78	951.95	819.66

10.4. Appendix (4): EPS Cement Sandwich Panels Building (Villa Type B) Cooling and Heating Design Analysis. [6]

Residential Villa Building (Villa Type B) Cooling Design
New Administrative Capital of Cairo, Egypt
EnergyPlus Output — 15 Jun, Sub-hourly — Licensed

Time	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
Glazing (W/m2)	-1.47	-1.77	-6.18	-3.37	0.68	3.55	5.59	2.82	1.24	0.91	-0.08
Walls (W/m2)	-0.94	-1.14	-0.32	3.23	4.29	4.47	5.42	5.41	4.46	0.84	-0.05
Ceilings (int) (W/m2)	7.51	7.47	-0.20	-0.55	0.09	2.12	1.80	0.94	3.61	8.08	8.50
Floors (int) (W/m2)	3.71	3.41	-3.18	-15.82	-9.88	-3.35	-15.44	-15.44	-6.20	2.67	2.77
Ground Floors (W/m2)	-4.20	-4.11	-13.74	-24.12	-15.72	-6.52	-10.83	-14.25	-6.05	-2.26	-2.56
Partitions (int) (W/m2)	3.97	3.71	-4.80	-1.51	-2.02	-1.53	-4.46	-7.72	-2.84	4.94	4.46
Roofs (W/m2)	10.23	10.21	4.46	0.93	0.83	1.91	-0.58	-4.55	-1.29	7.73	8.60
Floors (ext) (W/m2)	0.30	0.31	0.29	0.25	0.21	0.14	0.14	0.12	0.17	0.28	0.28
Internal Natural vent. (W/m2)	0.00	-0.00	0.00	0.00	0.00	-0.00	-0.00	0.00	0.00	-0.00	0.00
External Infiltration (W/m2)	0.76	0.32	0.00	2.04	4.86	6.81	7.67	6.99	5.63	4.02	2.68
Occupancy (W/m2)	0.87	0.88	0.85	1.33	1.32	1.33	1.31	1.28	1.27	1.36	1.38
Solar Gains Interior Windows (W/m2)	0.00	0.00	7.93	2.68	1.87	1.10	1.26	7.47	3.72	0.00	0.00
Zone Sensible Cooling (W/m2)	-21.49	-19.98	-24.87	-39.06	-41.73	-40.31	-41.95	-44.54	-42.12	-30.20	-26.87

Residential Villa Building (Villa Type B) Heating Design
New Administrative Capital of Cairo, Egypt
EnergyPlus Output — Licensed

Glazing (W/m2)	-8.19
Walls (W/m2)	-3.44
Ceilings (int) (W/m2)	-1.52
Floors (int) (W/m2)	1.66
Ground Floors (W/m2)	-1.47
Partitions (int) (W/m2)	0.07
Roofs (W/m2)	-5.20
Floors (ext) (W/m2)	-0.30
Internal Natural vent. (W/m2)	0.00
External Infiltration (W/m2)	-7.92
Zone Sensible Heating (W/m2)	26.30

10.5. Appendix (5): EPS Cement Sandwich Panels Building (Villa Type B) Heat Gains and Loses Analysis. [6]

Residential Villa Building (Villa Type B) External and Internal Heat Gain and Lose Simulation
New Administrative Capital of Cairo, Egypt
EnergyPlus Output — 1 Jan - 31 Dec, Monthly — Licensed

Month												
Glazing (Wh/m2)	-4044.75	-3547.76	-3835.80	-3660.70	-2654.92	-1626.23	-1003.81	-422.70	-788.11	-1149.87	-2433.89	-3187.68
Walls (Wh/m2)	-1284.76	-952.57	-809.83	-516.30	56.13	434.67	680.07	802.35	452.84	132.71	-583.59	-954.47
Ceilings (int) (Wh/m2)	453.76	715.77	1215.65	1786.69	2054.22	2290.95	2372.76	2381.72	2055.32	1838.55	1287.79	662.49
Floors (int) (Wh/m2)	-408.82	-881.12	-1509.68	-1783.04	-2295.64	-2267.65	-2365.52	-2312.63	-1963.11	-1682.81	-1019.69	-578.22
Ground Floors (Wh/m2)	-2640.09	-3063.27	-4160.27	-4719.05	-5470.33	-5511.41	-5685.87	-5460.12	-4918.52	-4680.35	-3671.73	-2888.80
Partitions (int) (Wh/m2)	25.04	-65.49	-137.74	10.30	-99.61	7.10	-5.39	23.89	33.90	64.40	125.44	40.48
Roofs (Wh/m2)	-1878.73	-1509.61	-1280.18	-422.10	280.65	1106.83	1288.12	1385.11	725.40	111.56	-885.51	-1525.36
Floors (ext) (Wh/m2)	-146.48	-119.59	-117.94	-69.35	-8.80	56.79	77.72	84.79	34.69	6.85	-69.77	-115.57
Internal Natural vent. (Wh/m2)	0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	0.00	-0.00	0.00
External Infiltration (Wh/m2)	-3775.96	-2884.97	-2591.19	-1624.53	-322.73	649.92	1229.11	1477.13	645.20	-157.84	-1904.38	-2811.39
Occupancy (Wh/m2)	1327.26	1127.96	1166.80	1047.73	1023.64	948.50	972.32	981.74	993.96	1071.19	1135.04	1289.00
Solar Gains Interior Windows (Wh/m2)	419.47	547.04	834.65	1090.40	1121.52	987.51	978.01	919.84	805.36	681.44	482.03	396.85
Zone Sensible Heating (Wh/m2)	2971.71	527.24	78.45	0.01	0.00	0.00	0.00	0.00	0.00	0.00	122.32	1260.85
Zone Sensible Cooling (Wh/m2)	-28.52	-477.36	-2830.31	-7222.08	-12218.00	-15395.09	-16668.59	-15820.16	-11713.40	-8687.72	-2494.00	-220.02

10.6. Appendix (6): EPS Cement Sandwich Panels Building (Villa Type B) Heating and Cooling Energy Consumption and CO_2 Emissions Analysis. [6]

Residential Villa Building (Villa Type B) Heating and Cooling Energy Consumption and CO2 Emissions Simulation
New Administrative Capital of Cairo, Egypt
EnergyPlus Output — 1 Jan - 31 Dec, Monthly — Licensed

Month												
Heating (Electricity) (Wh/m2)	1264.56	224.36	33.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	52.05	536.53
Cooling (Electricity) (Wh/m2)	15.84	265.18	1581.77	4056.15	7135.37	9650.17	11527.24	11343.94	8173.82	5756.18	1650.93	123.21
CO2 Emissions (kg)	775.92	296.66	978.78	2458.03	4324.03	5848.00	6985.50	6874.42	4953.33	3488.24	1032.01	399.81