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Thermochromic Glass Facades: A Sustainable Solution for Improving Buildings Energy Efficiency A Simulation-Based Study of an Office Building in Cairo, Egypt

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Keywords
Sustainable Buildings.
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Smart Glass.
Dynamic Glass.
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Abstract: The built environment enhances human life, prompting architects and engineers to adopt innovative technologies for better building performance. Thermochromic glass has gained attention as a sustainable solution for improving energy efficiency by adjusting solar heat gains based on external temperatures. This study examines the energy performance of thermochromic glass in an office building in Cairo's new administrative capital, known for its hot-arid climate, using advanced simulation tools to compare its thermal and optical properties to conventional glazing systems including Design Builder Software Ltd. and Energy Plus, to analyze two distinct building scenarios: one with conventional glazing and the other using thermochromic glass technology. Both scenarios incorporated typical occupancy patterns, heating, ventilating, and air conditioning systems, to evaluate energy consumption, thermal comfort, and daylight performance. Study findings indicate that thermochromic glass significantly reduces cooling energy demand by limiting solar heat gain during peak temperatures while maintaining adequate daylight levels. It recorded remarkable reductions in solar heat gain through the building's external glazing system, achieving reductions of up to 90.18 % compared to buildings with conventional glazing. This translates to annual energy savings of up to 51.16 % compared to conventional glazing, highlighting its potential to decrease energy loads in areas with extreme heat. Additionally, this system enhances indoor thermal comfort by minimizing overheating and decreasing reliance on artificial cooling systems. The findings highlight the viability of thermochromic glass as a cost-effective and environmentally friendly technology for sustainable building design in hot-arid climates.

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Abbreviations.

CO_2:	Carbon Dioxide.
HVAC:	Heating, Ventilation, and Air Conditioning.
LX:	Unit of Illuminance (Lux).
M:	Unit of Distance (Meter).
m^2:	Unit of Area (Square Meter).
M2K/W:	Unit of R-Value (Meters Squared Kelvin per Watt).
m^3:	Unit of Volume (Cubic Meter).
PCM:	Phase Change Material.
People/m^2:	Unit of People Density (People per Square Meter).
R-Value:	Thermal Resistance.
SHGC:	Solar Heat Gain Coefficient.
TC:	Thermochromic.
U-Value:	Thermal Transmittance.
UDI:	Useful Daylight Index.
V.:	Version.
VO_2:	Vanadium Dioxide.
Wh/m^2:	Unit of Irradiance (Watt Hour per Square Meter).
WO_3:	Tungsten Trioxide.
W/m-K:	Unit of Thermal Conductivity (Watts per Meter Kelvin).
W/m^2:	Unit of Power per Area (Watts per Square Meter).
W/m^2K:	Unit of U-Value (Watts per Square Meter Kelvin).
°C:	Unit of Temperature (Celsius Degree).

1. Introduction.

The increasing global demand for energy and the environmental challenges associated with its consumption have elevated sustainable building solutions to a top priority. Buildings, particularly in urban areas, are major contributors to energy consumption with heating, ventilation, and air conditioning (HVAC) systems accounting for the largest share. In hot-arid climates regions such as Cairo, Egypt, cooling loads dominate energy use, resulting in higher operating costs, and added strain on the energy infrastructure. As cities like Cairo continue to grow and confront escalating environmental pressures, the need for innovative strategies to enhance building energy efficiency has never been more critical. [2] [3] [21]. Smart materials and technologies offer promising avenues for reducing energy consumption while maintaining occupant comfort. Among these innovations, thermochromic glass has emerged as a leading option in sustainable architectural design. This glazing dynamically adjusts its optical properties - such as transparency and solar heat gain coefficient - in response to temperature changes. Such passive modulation optimizes indoor conditions by reducing solar heat gain during warmer periods while allowing natural light. Unlike other adaptive systems, thermochromic glass operates without energy inputs or control mechanisms, making it an appealing and low-maintenance solution for energy-efficient buildings. [2] [3] [15] [21]

The role of building envelopes is crucial in enhancing the energy efficiency and occupant comfort of structures. Traditional building materials frequently fail to effectively respond to varying external conditions, resulting in an increased reliance on mechanical systems for heating, cooling, and lighting. This underscores the need for materials and designs that can better accommodate dynamic environmental factors. [2] [21]. The importance of thermochromic glass extends beyond its energy-saving benefits. By enhancing thermal comfort and reducing reliance on mechanical cooling systems, thermochromic glazing contributes to broader sustainability goals, such as minimizing greenhouse gas emissions and fostering the integration of renewable energy. Furthermore, its capacity to adjust to changing environmental conditions positions it as a progressive solution for buildings in rapidly urbanizing and climate-vulnerable regions like Cairo. [2] [3] [21]

This study examines the potential of thermochromic glass facades to enhance the whole performance of an office building in the new administration capital of Cairo, Egypt a city renowned for its hot desert climate and significant solar radiation. By employing advanced simulation tools, the study compares the performance of thermochromic glazing with that of conventional glazing regarding heat gain and losses, thermal comfort, and energy consumption. The study focuses on a prototype office building, investigating how this innovative material can seamlessly integrate into Cairo’s architectural landscape to meet the region's distinct climatic and economic challenges. This paper expands the existing knowledge of adaptive building materials by providing simulation-based insights into the practical use of thermochromic glass. The findings are intended to inform policymakers, developers, architects, and engineers about the benefits and feasibility of this material, underscoring its role in fostering more sustainable urban environments. By focusing on key performance metrics - such as energy savings, occupant comfort, and economic viability - this study demonstrates the potential of thermochromic glass to innovate building design and operations in Cairo, Egypt, which is known for its hot-arid climate and has not been studied before using building performance simulation software to deeply analyze the key performance metrics. The results are not only applicable to Cairo but also offer valuable insights for other regions grappling with comparable energy challenges.

2. Literature Review

The use of thermochromics glass in building facades has attracted growing interest in architectural and engineering research because of its potential to improve energy efficiency, thermal comfort, and design versatility. This review summarizes some existing literature on the material properties, its performance, and the challenges involved in its implementation. (Kokogiannakis, Darkwa, & Aloisio, 2014), Proved that thermochromic glazing can significantly lower cooling loads by about 30 % in hot climates. In cold climates, it may reduce energy efficiency compared to heat mirror glazing systems, which offer better savings than triple-glazed windows. In seasonally varying climates and highly glazed office buildings, TC glass is an effective choice for conserving energy and improving thermal comfort.

(Costanzo, Evola, & Marletta, 2016), Examined the use of thermochromic windows in an office building through dynamic simulations, focusing on annual energy savings, daylighting effects, and thermal comfort. It highlights daylight availability using illuminance maps and the daylight factor, which varies by country. The study compared a commercially available thermochromic pane with theoretical glazing options such as static clear and reflective glass units. Simulations showed energy savings ranging from 5 % in colder climates to 20 % in warmer ones, without compromising daylight. It also identified an optimal transition temperature for the thermochromic pane that is effective across various climates. (Giovannini, et al., 2019), Assessed ligand exchange thermochromic glazing, which varies in optical properties and shows hysteresis in temperature changes. They present a simulation strategy that combines dynamic thermal and daylight analysis to evaluate energy use and visual comfort in offices using thermochromic glazing across different climates. Results indicate thermochromic glazing can reduce energy use by 3 % to 10 % and improve daylight availability by up to 20 % compared to static options. Increasing hysteresis further enhances daylight and reduces glare.

(Aburas, et al., 2021), Explored the effects of thermochromic glazing on building performance through simulations in desert, Mediterranean, and temperate climates. Results showed that thermochromic glazing could save between 7.1 % and 46.4 % in annual energy compared to conventional uncoated double-glazed windows. It also balanced energy savings with a useful daylight index (UDI) of 500 – 2000 lx, reducing visual discomfort by 1.2 to 3.2 meters indoors. (Teixeira, Gomes, Rodrigues, & Aelenei, 2022), Compare the annual performance of thermochromic and conventional clear glazing in an office setting, with and without a reflective solar control film, across various European climates. Findings show thermochromic glazing offers better illuminance (80 % - 88 %) and thermal comfort (20 % - 48 % of hours) than conventional glazing (64 % - 74 % and 1 % - 42 %, respectively). It also results in significant energy savings, especially in Lisbon, where savings can reach up to 50 %.

(Jin, Long, & Liang, 2022), Developed computational fluid dynamic models to evaluate the thermal performance of adaptive glazing systems made from two materials. Validated against two experimental studies, the analysis focused on a south-facing office building in Shanghai during summer and winter. Results showed that PCM-integrated thermochromic triple-glazing units reduced heat gain by up to 32 % on sunny days and 40 % on cloudy days in summer, outperforming standard double-glazing. In winter, they block beneficial solar radiation, making them less effective than traditional double-glazing. (Liu, Liu, Wang, Ding, & Meng, 2023), Examined how material colour affects their optical properties at 25 °C and 33 °C. A measurement system was developed to assess the reflectivity spectra and solar reflectivity in coloured and colourless phases. Their findings demonstrated a notable increase in reflectivity when transitioning from the coloured to colourless phase, especially in the 1300 – 1600 nm and 1900 – 2100 nm wavelengths. Reflectivity improved by 3.17 %

to 10.68 % at 25 °C and 7.22 % to 18.23 % at 33 °C. Purple-blue and dark green colours emerged as the most effective choices for thermochromic coatings, providing a valuable reference for their use in architectural design.

(Wu, et al., 2024), Examined a three-story office building model in Energy Plus to assess how thermochromic windows impact energy efficiency, lighting, and comfort across various orientations. It proposes a human-centred evaluation system and explores the integration of these windows with renewable photovoltaics, offering insights for smart window applications. (Li, Tao, Xu, & Chen, 2024), Evaluated the thermal performance of thermochromic windows in various conditions using a 3D computational fluid dynamics model. Thermochromic windows can reduce temperature differences and improve uniformity, lowering the upper-lower window temperature difference from 3.13 °C to 2.48 °C without air conditioning. Indoor air temperature and uniformity also affect the thermochromic window's surface temperature and phase transition time.

(Wang, et al., 2024), Investigated hydrogel-based thermochromic windows, focusing on their structural performance in an office building. The optimal extinction coefficients were 55 - 105 m^{-1} for visible light and 155 - 255 m^{-1} for near-infrared light. Thermochromic windows reduced electricity consumption by 33 % to 53 % and improved thermal and visual comfort. The findings aim to guide the application of thermochromic glass technology in window design. This literature presents the significant potential of thermochromic glass to transform building facades into dynamic systems that enhance energy efficiency. This study examines the energy performance of thermochromic glazing technology in an office building situated in the new administrative capital of Cairo, Egypt, known for its hot-arid climate and has not been studied before using deep building performance simulation software analysis. Advanced simulation tools are utilized to evaluate the thermal and optical properties of thermochromic glass in comparison to traditional glazing systems. Future research should study the optimization of material properties, the improvement of cost-effectiveness, and the exploration of innovative integrations with smart building technologies.

3. Thermochromic Materials and Thermochromic Dynamic Glass.

In the quest for energy-efficient and sustainable building designs, thermochromic technology has emerged as an innovative material that redefines how buildings interact with their environments. This advanced technology dynamically adjusts its properties in response to temperature variations, providing substantial benefits in energy savings, occupant comfort, and environmental impact. By integrating thermochromic into buildings, architects and engineers can significantly enhance the performance of structures, lessen dependence on artificial climate control systems, and foster greater sustainability in building design. [14] Thermochromic materials exhibit a change in colour in response to fluctuations in temperature, transitioning between opaque and transparent states when heated or cooled.

These materials can be precisely engineered to alter their colour at specific transition temperatures which can be adjusted by incorporating various compounds. [10] [13]. In building applications, thermochromic windows play a significant role in optimizing energy consumption. This technology commonly employs metallic oxide coatings, such as vanadium dioxide (VO_2) and tungsten trioxide (WO_3). Alternatively, a gel layer can be placed between two sheets of glass or plastic films. [2] [3] [6]

These windows automatically adjust their transparency according to the temperature of their external surface. Initially clear, they become opaque when the temperature surpasses a certain threshold, ranging from 10 to 90 °C. When the temperature drops below this critical point, it reverts to a transparent state. Thermochromic windows are particularly well-suited for use in skylights, sloped glazing, and upper windows where maintaining a view is less of a priority. They operate passively responding to changes in ambient temperature to manage solar heat efficiently. [17] [20] [21]

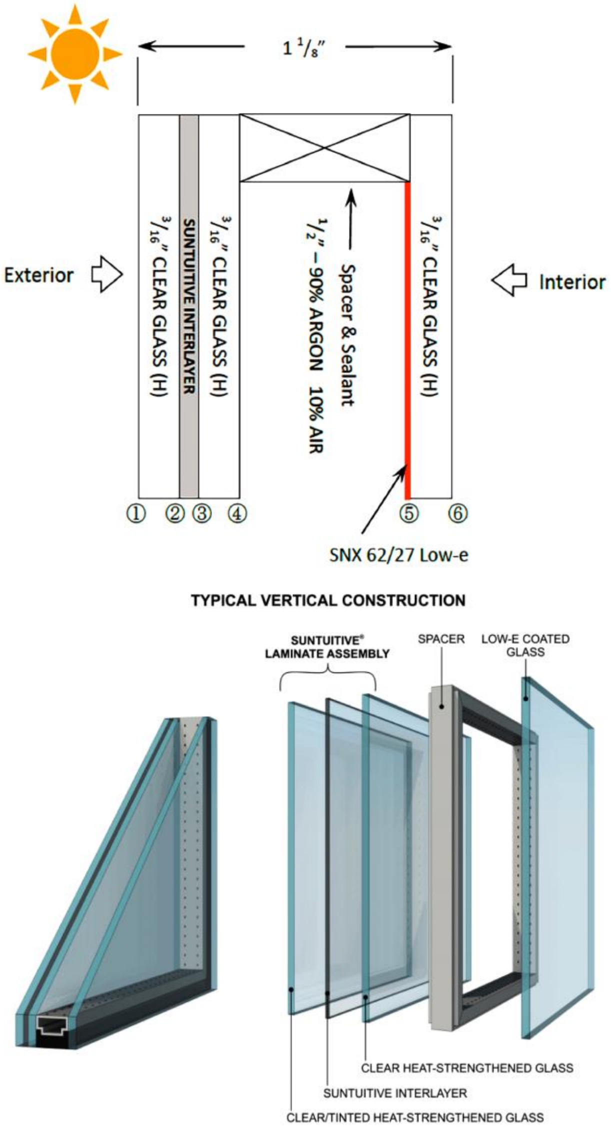


Figure (1) Thermochromic Glass Mechanism [17]

3.1. Thermochromic Glass Mechanism and Functionality.

Thermochromic glass functions by adjusting its light transmittance in response to temperature changes. Figure 1 shows it incorporates a specialized layer of thermochromic materials, such as vanadium dioxide, which react to heat by altering their molecular structure. When temperatures rise, the glass transitions from a transparent state to a tinted or opaque form. This change effectively reduces solar heat gain while permitting natural light to enter. This innovative characteristic allows buildings to passively manage indoor temperatures and ensure thermal comfort without a reliance on air conditioning or heating systems. [2] [3] [13] [17]

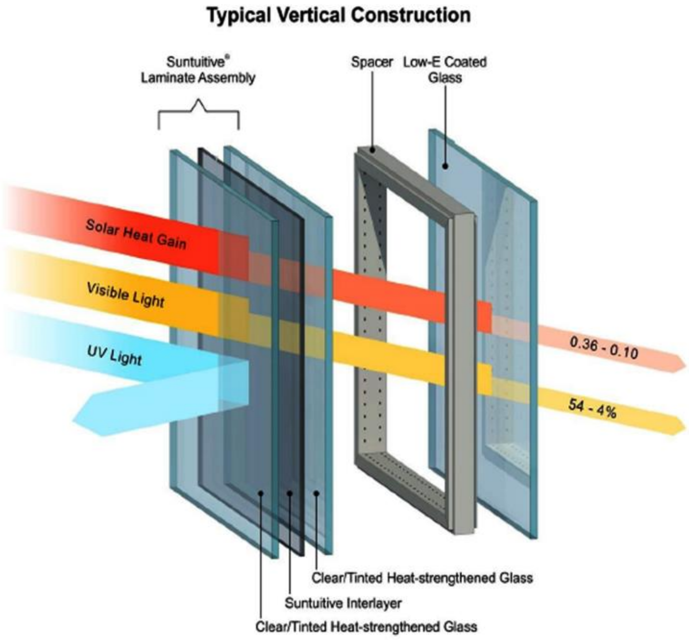


Figure (2) Thermochromic Glass Technology [17]

3.2. Thermochromic Glass and Energy Efficiency.

One of the key benefits of thermochromic glass is its significant contribution to energy efficiency. Traditional building designs often rely on fixed glazing systems that maximize natural light or block solar heat, but these systems cannot adapt to fluctuating climatic conditions. In contrast, Figure 2 shows that thermochromic glass dynamically adjusts to modulate solar heat gain. This adaptability reduces cooling loads during warmer periods while allowing heat entry in colder seasons, minimizing the energy consumption associated with HVAC systems, which typically represent a considerable portion of a building's operational energy usage. For instance, in summer, the glass darkens as temperatures rise effectively preventing excessive solar radiation from entering the building. This helps mitigate indoor overheating and lowers the reliance on air conditioning. Conversely, in winter, the glass remains transparent allowing sunlight to naturally warm the interior spaces. Studies indicate that buildings outfitted with thermochromic glass can achieve energy savings compared to conventional glass. [3] [17] [21]

3.3. Thermochromic Glass and Occupant Comfort.

Thermochromic glass significantly enhances the comfort and well-being of building occupants by effectively managing solar heat gain and glare. This innovative technology contributes to a stable and pleasant indoor environment. In modern glass-clad buildings, excessive heat and glare from sunlight can present challenges that lead to discomfort and reduced productivity. Thermochromic glass mitigates these issues by automatically adjusting to external temperatures and ensuring optimal lighting and thermal conditions throughout the day. Moreover, implementing thermochromic glass diminishes the need for blinds, curtains, or other shading devices, allowing for unobstructed views and providing a stronger connection between indoor and outdoor spaces. This approach not only enhances the aesthetic and functional appeal of the building but also supports biophilic design principles, which positively impact human mental health and productivity. [2] [17] [19] [21]

3.4. Thermochromic Glass and Environmental Sustainability.

The environmental advantages of thermochromic glass extend well beyond mere energy savings. By reducing electricity demand, particularly during peak cooling periods, buildings can significantly decrease their carbon footprint. This impact is especially critical in urban areas where energy consumption heavily contributes to greenhouse gas emissions. Furthermore, thermochromic glass can be integrated with other sustainable technologies, such as photovoltaic systems to create buildings that are both energy-efficient and self-sustaining. In addition, thermochromic glass aligns seamlessly with the principles of passive design which emphasize the use of natural processes to enhance building performance. By leveraging the inherent properties of materials and the surrounding environmental conditions, architects can create structures that rely less on mechanical interventions. This approach not only results in long-term cost savings but also helps to reduce resource depletion. [3] [6] [17] [19] [21]

3.5. Thermochromic Glass Challenges and Future Prospects.

Despite its advantages, the widespread adoption of thermochromic glass encounters challenges. A primary obstacle is the initial installation cost, which is higher than conventional glazing systems and may deter developers. Nevertheless, this expense is often offset by long-term energy savings and reduced operational costs. Furthermore, advancements in manufacturing processes are anticipated to lower production costs, making thermochromic glass increasingly accessible in the future. Another challenge involves optimizing the performance of thermochromic materials across various climatic conditions. Researchers are actively developing new formulations to enhance the durability, responsiveness, and temperature thresholds of these materials. In addition, emerging technologies such as electrochromic and photochromic glass complement thermochromic systems, paving the way for integrated smart glass solutions that offer enhanced adaptability and functionality. [2] [3] [6] [17] [21]

Figure 3 shows that thermochromic glass signifies a remarkable advancement in building facade design offering an intelligent and sustainable solution to the challenges of energy efficiency and occupant comfort. Its ability to respond to fluctuations in temperature makes it an exceptional choice for modern architecture where sustainability and performance are crucial. As technological innovations continue to enhance its functionality and lower costs, thermochromic glass is set to become a staple in high-performance buildings, contributing to a sustainable and eco-friendly built environment. By embracing such innovative solutions, the construction industry can further its efforts to meet global energy and climate goals while improving the quality of life for building occupants. [2] [3] [17] [21]

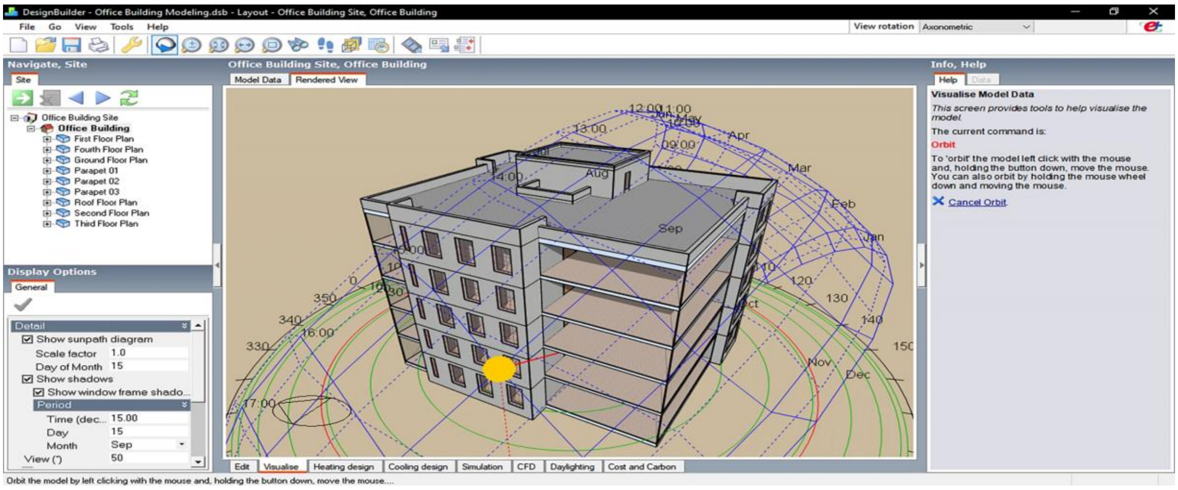
Figure (3) Thermochromic Glass Technology Case Study [17]

4. Methodology

This study investigates the effectiveness of thermochromic glass technology in building facades to enhance thermal performance, increase energy efficiency, and reduce operational costs specifically in Cairo, Egypt, which is known for its hot-arid climate and has not been studied before using deep building performance simulation software analysis. It employs building performance simulation software, specifically Design Builder Software Ltd (V. 7.0.0.116 – educational version) as shown in Figure 4. This software is well-regarded for its user-friendly interface and its ability to rapidly assess the environmental performance of both new and existing buildings while minimizing modelling time and maximizing productivity and using Energy Plus (V. 9.4.0) as a simulation engine to calculate energy consumption for cooling, heating, ventilation, lighting, process loads, and other variables necessary for achieving the analysis objectives.

This study seeks to perform a detailed comparative analysis of a proposed office building located in the newly established administrative capital of Cairo, Egypt. The analysis will explore two distinct building scenarios: the first scenario will employ a conventional glazing system, equipped with standard glass materials that provide basic aesthetic and thermal performance. In contrast, the second scenario will integrate advanced thermochromic glass technology into the building's facades. This innovative glazing option reacts to temperature changes, adjusting its tint to regulate internal temperatures and enhance energy efficiency, contributing to a more sustainable environment.

The proposed office building will proudly stand six stories tall, covering an impressive total area of 2,634.86 m² and featuring a footprint of 513.36 m². Designed with functionality in mind, the office spaces will accommodate an occupancy density of 0.1110 people per m², ensuring a comfortable and efficient work environment. Other areas within the building will adhere to standard occupancy density guidelines, promoting optimal use of space. The HVAC system will use a water chiller, meticulously set to maintain 24 °C during summer and 22 °C in winter. Furthermore, the building will be constructed using traditional local construction techniques, incorporating durable materials, thoughtfully designed internal layouts, and well-planned operating schedules to ensure a harmonious workplace for all occupants.


DesignBuilder - Office Building Modeling.dsb - Layout - Office Building Site, Office Building

View rotation: Axonometric

Display Options – General – Detail
☑ Show sunpath diagram
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Info, Help
Visualise Model Data
This screen provides tools to help visualise the model.
The current command is:
Orbit
To 'orbit' the model left click with the mouse and, holding the button down, move the mouse. You can also orbit by holding the mouse wheel down and moving the mouse.
✕ Cancel Orbit.

Orbit the model by left clicking with the mouse and, holding the button down, move the mouse....

Figure (4) Design Builder Software Ltd Interface

Figure 5 shows the simulation strategy that entails a comparison of two scenarios of the office building, the baseline building scenario (building type A) and a scenario that incorporates thermochromic glass technology in its façade (building type B).

Using software for building performance simulation, the analysis will comprehensively assess several factors, including cooling and heating design and energy consumption. This comparison aims to evaluate the impact of integrating thermochromic glass technology in building façades and its potential to enhance energy efficiency.

5. Case Study Analysis.

This study explores the potential of thermochromic glass technology to adjust a building's glazing system tint in response to external environmental conditions. It emphasizes how this innovative technology can enhance sustainability and improve the comfort of residents of the building. Furthermore, the study analyzes the impacts of this technology on thermal comfort, daylighting, and energy efficiency, making it an essential resource for architects, engineers, and building owners considering the integration of this innovative solution. The study will simulate a proposed office building in Cairo's new administrative capital, using conventional local materials and systems as a baseline for comparison. By employing building performance simulation software (Design Builder Software Ltd - V. 7.0.0.116 and Energy Plus – V. 9.4.0) alongside weather data from Cairo, Egypt, the study will analyze and assess the differences between conventional glass curtain walls and windows and thermochromic glass technology. The objective is to determine the impact of thermochromic glass on the overall performance of the building.

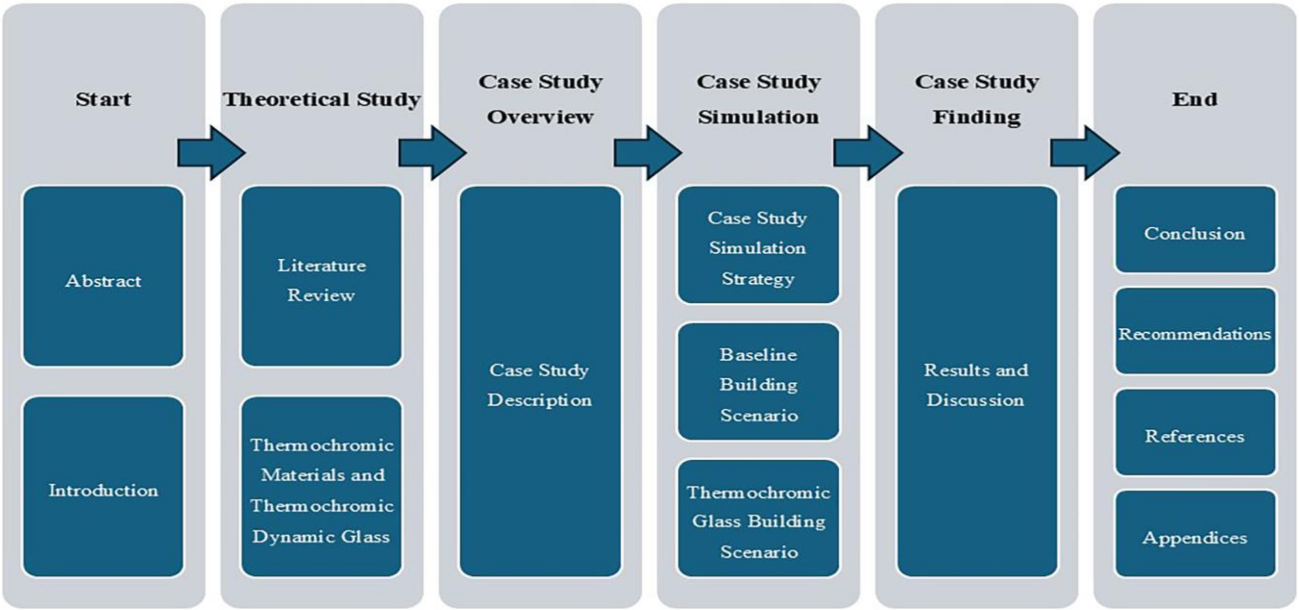


Figure (5) Methodology Workflow Diagram

5.1. Case Study Description.

Figure 6 shows that the proposed office building is designed to incorporate a ground floor with four typical upper floors. Each floor will feature a combination of closed offices, open-plan office spaces, circulation areas, and service facilities. The roof floor will include an electromechanical room with further circulation spaces and service areas, facilitating operational efficiency and accessibility. The office areas will have an occupancy density of 0.1110 people/m^2, while other spaces will adhere to a standard occupancy density. The building will have a footprint area of 513.36 m^2 and a total building area of 2,634.86 m^2. The ceiling height is 4.0 m resulting in an internal volume of 8,636 m^3. The energy sources will consist of natural gas for water heaters and electricity for other devices and systems. The HVAC system will use a water chiller, with a set point temperature of 24 °C in the summer and 22 °C in the winter.

The building will be constructed using conventional local office construction systems, materials, and internal zones, and will operate from 9:00 AM to 6:00 PM, five days a week.

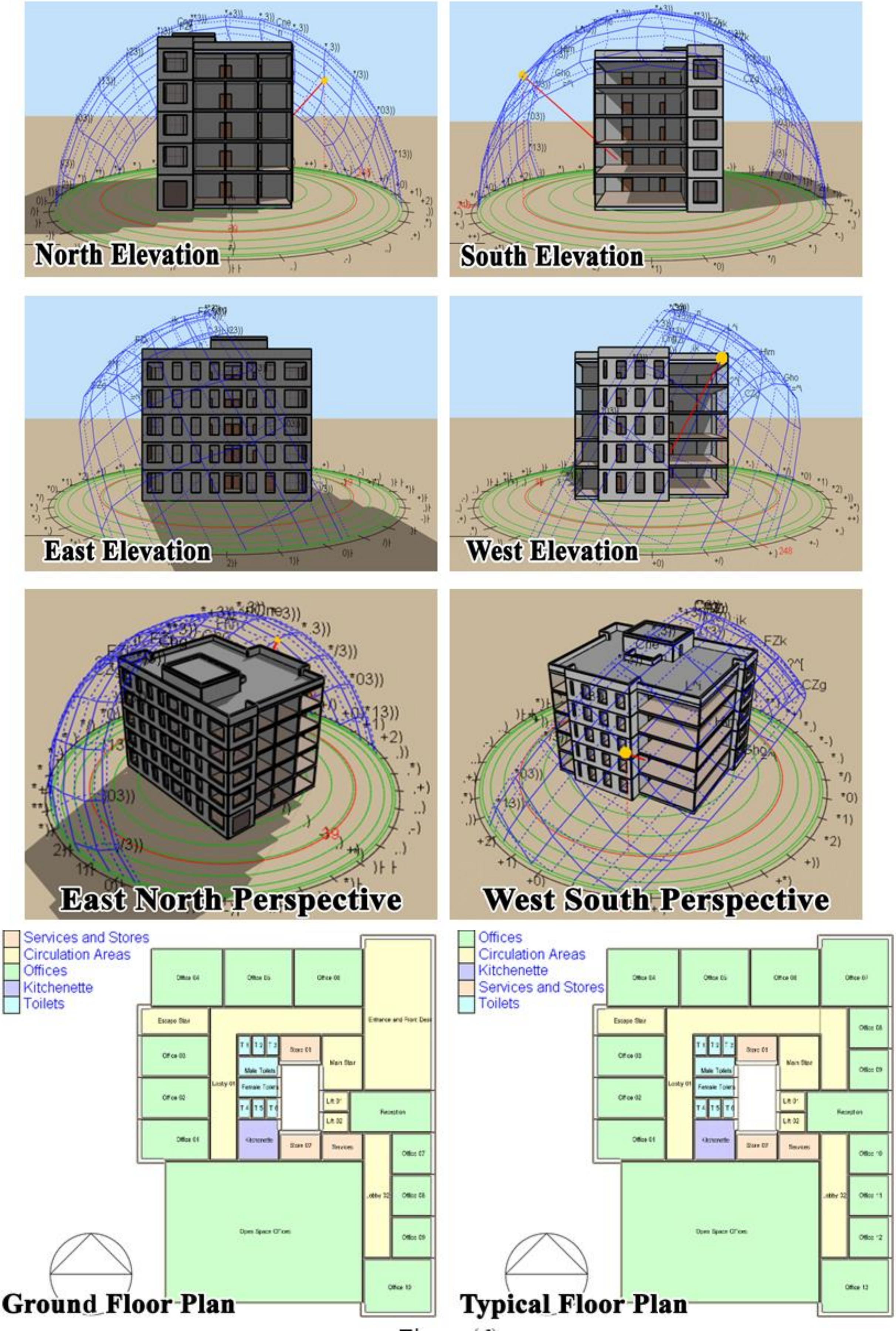


Figure (6) Proposed Office Building Model [5]

5.2. Case Study Simulation Strategy.

The simulation strategy entails a comparison between the simulation results of a baseline office building (building type A) and the same building using thermochromic glass technology integrated into the building facade (building type B). Building performance simulation software (Design Builder Software Ltd - V. 7.0.0.116 and Energy Plus – V. 9.4.0) will be used to show the effects of using thermochromic glass technology to improve overall building performance in specific environments of the new administration capital of Cairo, Egypt. The simulation process will comprehensively evaluate several factors, including cooling and heating design analysis, site data analysis, comfort analysis, internal gains and solar analysis, fabric and ventilation analysis, fuel breakdown analysis, fuel totals analysis, CO_2 production analysis, system loads analysis, and embodied and equivalent Carbon analysis.

5.3. Baseline Building Scenario.

A detailed simulation analysis was conducted on the baseline office building model (building type A), using conventional building materials and systems. Figure 7 shows that the building's curtain walls and windows were installed with a standard glazing system, consisting of double transparent glass panels, each 0.06 m thick, and an air gap of 0.17 m between them with a total U-value of 2.69 W/m^2K. The solar transmission (SHGC) is estimated to be 0.743, the direct solar transmission is 0.67, and the visible transmission is 0.801. [5]

The analysis was conducted to evaluate the overall performance of the building in the baseline scenario. Improving a building's energy efficiency requires a thorough assessment of its thermal performance. Figure 8 and 9 analyzing the building's thermal performance during peak summer days (cooling design) and peak winter days (heating design), it was discovered that the external conventional curtain walls and windows contribute significantly to heat transfer to and from the building’s interior spaces causing a huge amount of heat gain and lose in the building.


Outer surface
6.00mm Clear Glass
17.00mm Air Gap 17 mm
6.00mm Clear Glass
Inner surface

Figure (7) Baseline Building (Building Type A) Glazing System [5]

During peak summer days, the solar heat absorbed by the curtain walls and windows is projected to reach 212.33 kWh during the peak hour and a cumulative total of 1,756.40 kWh for the entire day. This additional heat puts a strain on the HVAC system, leading to increased energy consumption. [5] (Appendix 1) (Appendix 2)

The current situation is negatively affecting the building's thermal performance and energy efficiency. It is crucial to take appropriate actions to address this issue and improve the building's thermal performance for better energy efficiency. Upon conducting a thorough analysis of the heat gains and losses simulation for the baseline office building model (building type A), Figure 10 shows it was found that the solar heat gains through the external curtain walls and windows ranged from 50,419.44 kWh during the peak month and 37,679.47 kWh during the off-peak month. The total solar heat gains over the year were determined to be 545,941.23 kWh. [5] (Appendix 3)

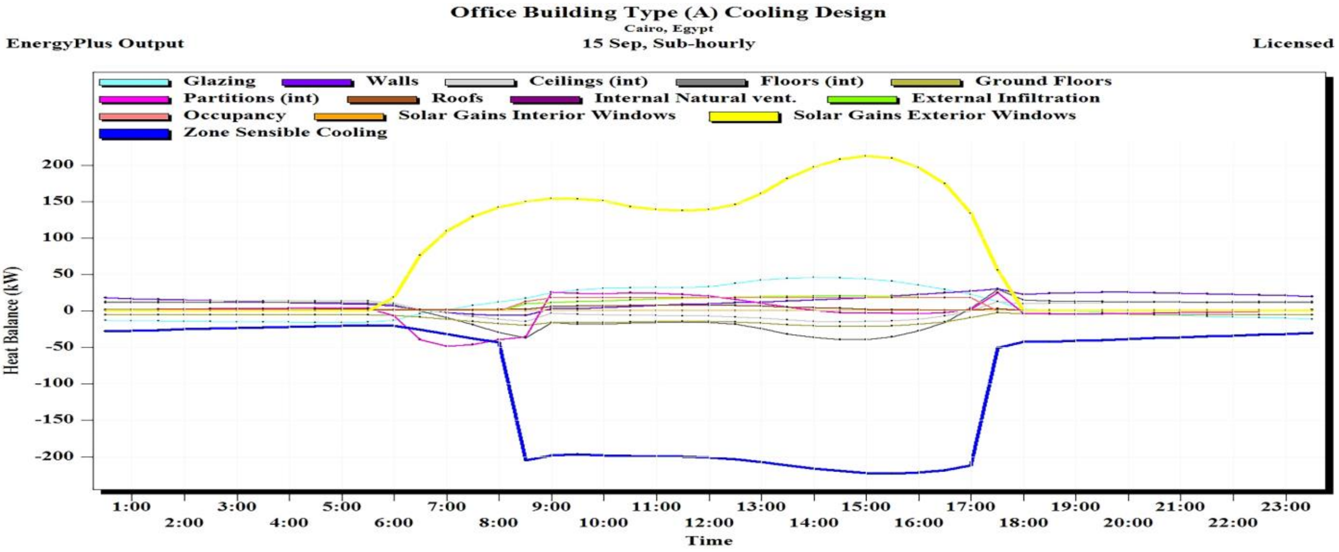


Figure (8) Baseline Building (Building Type A) Cooling Design Analysis [5]

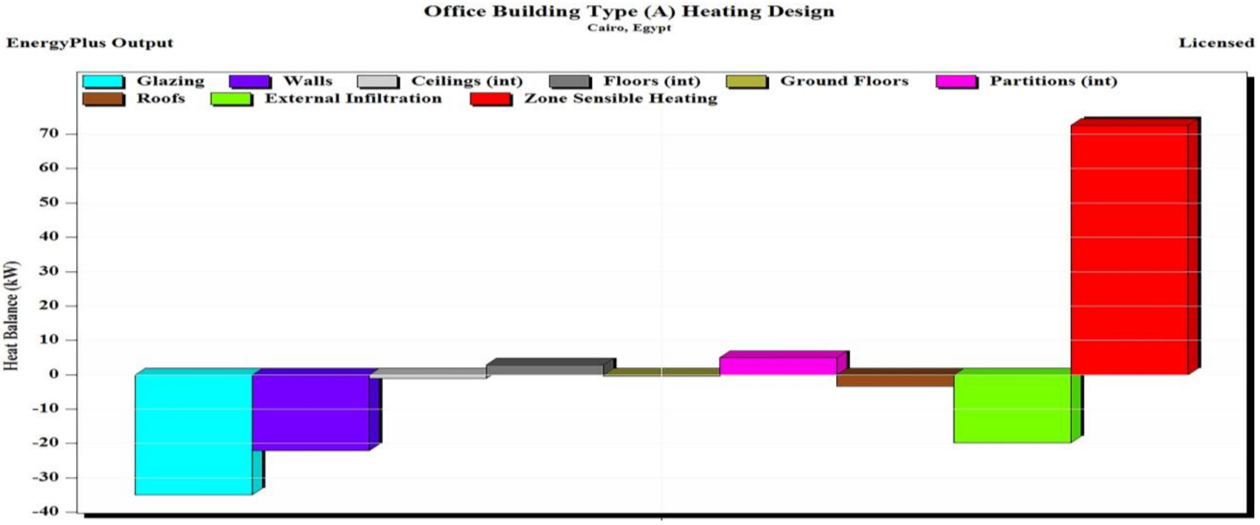


Figure (9) Baseline Building (Building Type A) Heating Design Analysis [5]

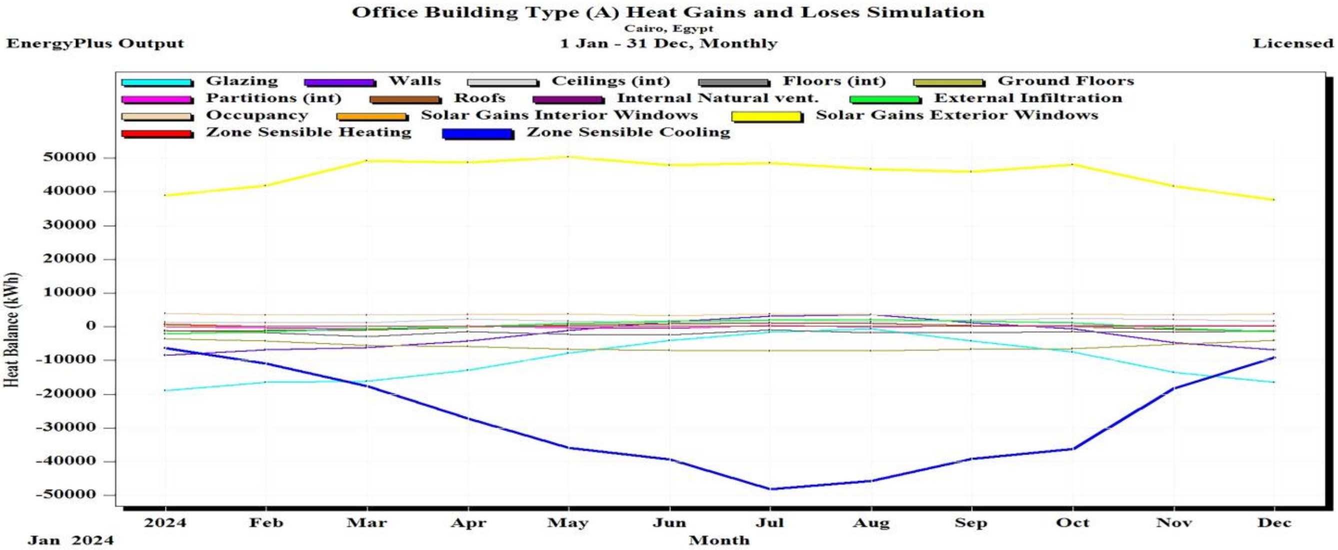


Figure (10) Baseline Building (Building Type A) Heat Gains and Loses Analysis [5]

The building's heating, ventilating, and air conditioning (HVAC) system relies on the solar heat gained through its exterior walls and windows. In the peak month, Figure 11 shows that the HVAC system consumed 30,620.98 kWh, in the off-peak month, it is estimated to be 4,819.95 kWh. The total HVAC system energy consumption for the entire year was approximately 209,518.10 kWh. [5] (Appendix 4)

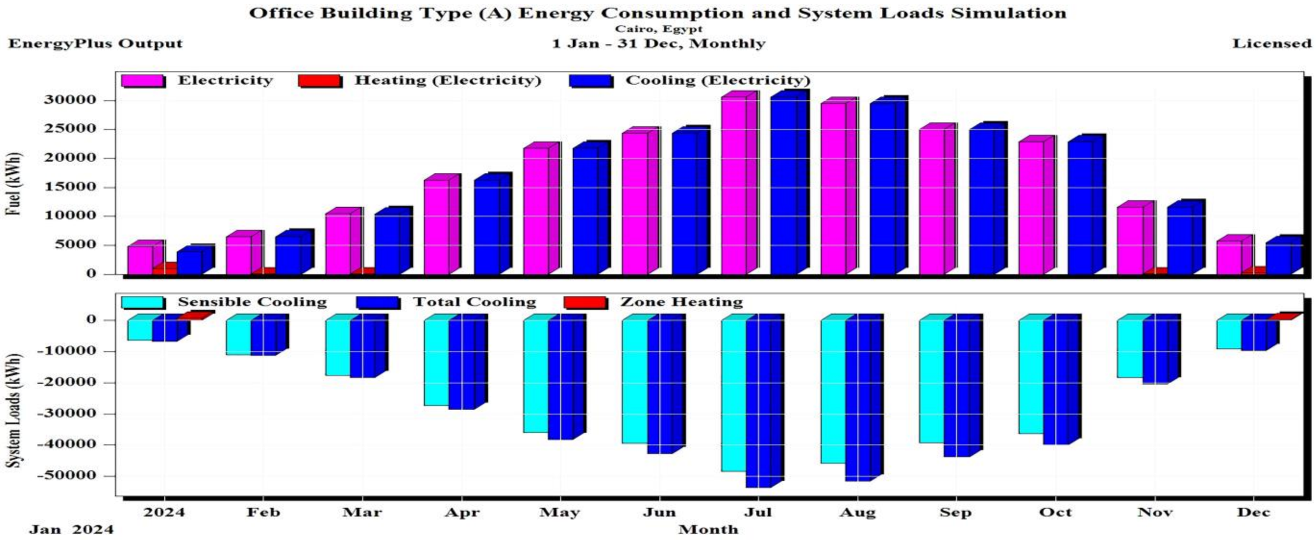


Figure (11) Baseline Building (Type A) Energy Consumption and System Loads Analysis [5]

5.4. Thermochromic Glass Building Scenario.

A detailed simulation analysis was conducted on the thermochromic glass office building model (building type B), using the same conventional building materials and systems focusing on the glazing system by replacing the conventional glazing system.

Figure 12 shows the building's curtain walls and windows were outfitted with a thermochromic glazing system, which comprised triple clear glass panels, each 0.06 m thick, with an air gap of 0.07 m between two panels and a 0.0122 m thick thermochromic interlayer between the other two panels with a thermochromic glazing system with a total U-value of 2.718 W/m²K. The estimated solar heat gain coefficient (SHGC) is 0.215, with solar transmission of 0.112 and visible transmission of 0.36. [5]. The thermochromic glazing system's innovative technology allowed the glass tinting to be adjusted to seven different states, in response to outdoor solar heat gain conditions, and without any control system.

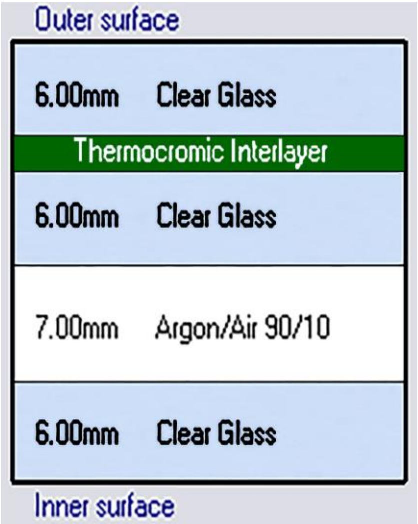


Figure (12) Thermochromic Glass Building (Building Type B) Glazing System [5]

The analysis was conducted to evaluate the overall performance of the building in the thermochromic glazing scenario as shown in Table 1.

Table (1) Thermochromic Glass Building (Building Type B) Glass States Properties [5] [19]

Thermochromic Glass States	Temperature (°C)	Solar Transmittance	Outside Solar Reflectance	Inside Solar Reflectance	Visible Transmittance	Outside Visible Reflectance	Inside Visible Reflectance	Infra-Red Transmittance	Outside Emissivity	Inside Emissivity
Clear State	5	0.19	0.36	0.38	0.49	0.09	0.10	0.01	0.33	0.12
Intermediate State 01	15	0.18	0.35	0.38	0.47	0.08	0.09	0.01	0.35	0.12
Intermediate State 02	25	0.17	0.33	0.38	0.43	0.08	0.09	0.01	0.39	0.11
Intermediate State 03	45	0.10	0.28	0.37	0.23	0.05	0.09	0.00	0.55	0.07
Intermediate State 04	65	0.03	0.21	0.37	0.06	0.04	0.08	0.00	0.72	0.04
Intermediate State 05	85	0.01	0.19	0.37	0.01	0.04	0.08	0.00	0.77	0.02
Fully Tinted State	95	0.01	0.18	0.37	0.01	0.04	0.08	0.00	0.80	0.02

Figures 13 and 14 show that upon analyzing the building's thermal performance during peak summer days (cooling design) and peak winter days (heating design), it was discovered that implementing thermochromic glass technology resulted in a notable decrease in heat transfer across the building's external curtain walls and windows. During peak summer days, the solar heat absorbed by the curtain walls and windows is projected to reach 10.80 kWh during the peak hour and a cumulative total of 103.64 kWh for the entire day. The reduction of the solar heat gained from external curtain walls and windows caused a reduction in HVAC system loads, leading to decreased energy consumption. [5] (Appendix 5) (Appendix 6)

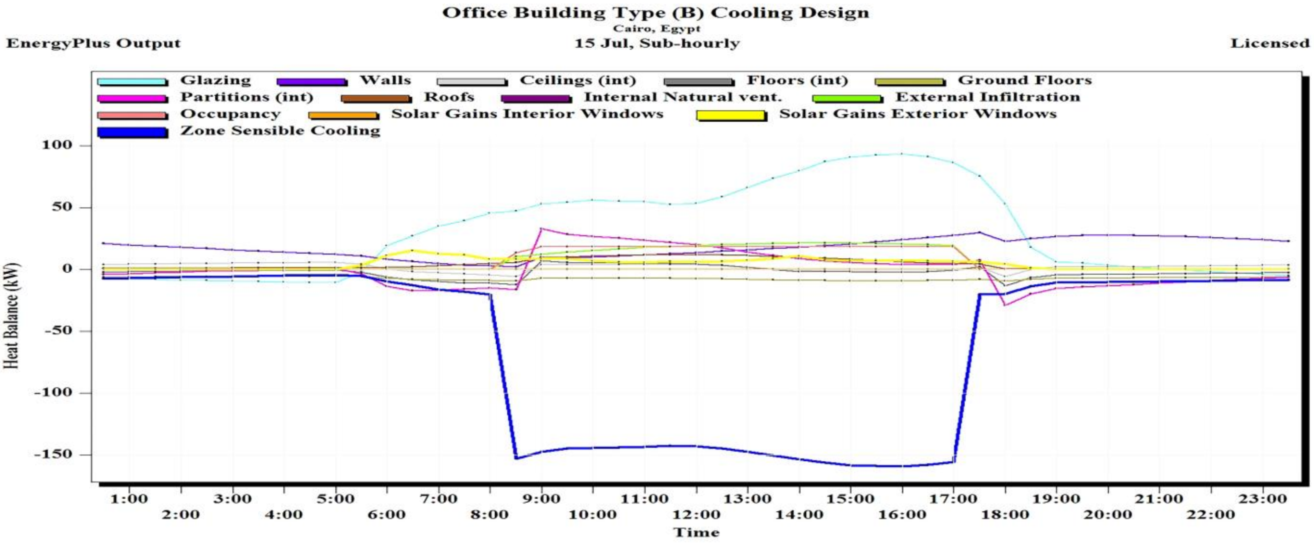


Figure (13) Thermochromic Glass Building (Building Type B) Cooling Design Analysis [5]

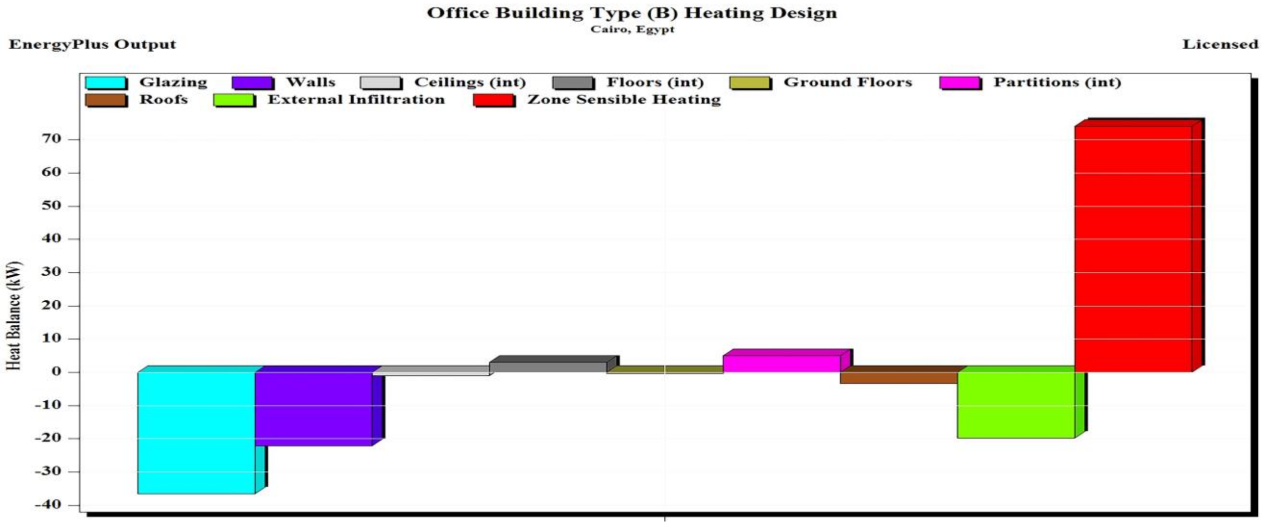


Figure (14) Thermochromic Glass Building (Building Type B) Heating Design Analysis [5]

Figure 15 shows that upon conducting a thorough analysis of the heat gains and losses simulation for the thermochromic glass office building model (building type B), it was found that the solar heat gains through the external curtain walls and windows ranged from 5,138.20 kWh during the peak month and 4,074.55 kWh during the off-peak month.

The total solar heat gains over the year were determined to be 53,639.29 kWh. [5] (Appendix 7). Figure 16 shows that in the peak month, the HVAC system consumed 16,830.15 kWh, in the off-peak month, it is estimated to be 1,756.98 kWh. The total HVAC system energy consumption for the entire year was approximately 102,337.62 kWh. [5] (Appendix 8)

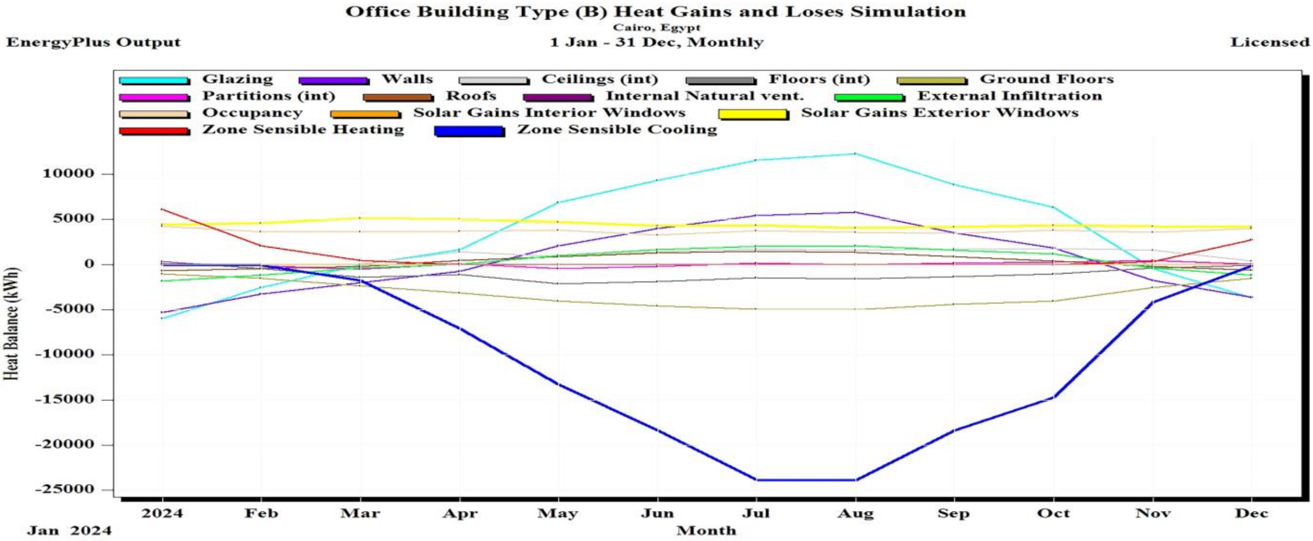


Figure (15) Thermochromic Glass Building (Building Type B) Heat Gains and Loses Analysis [5]

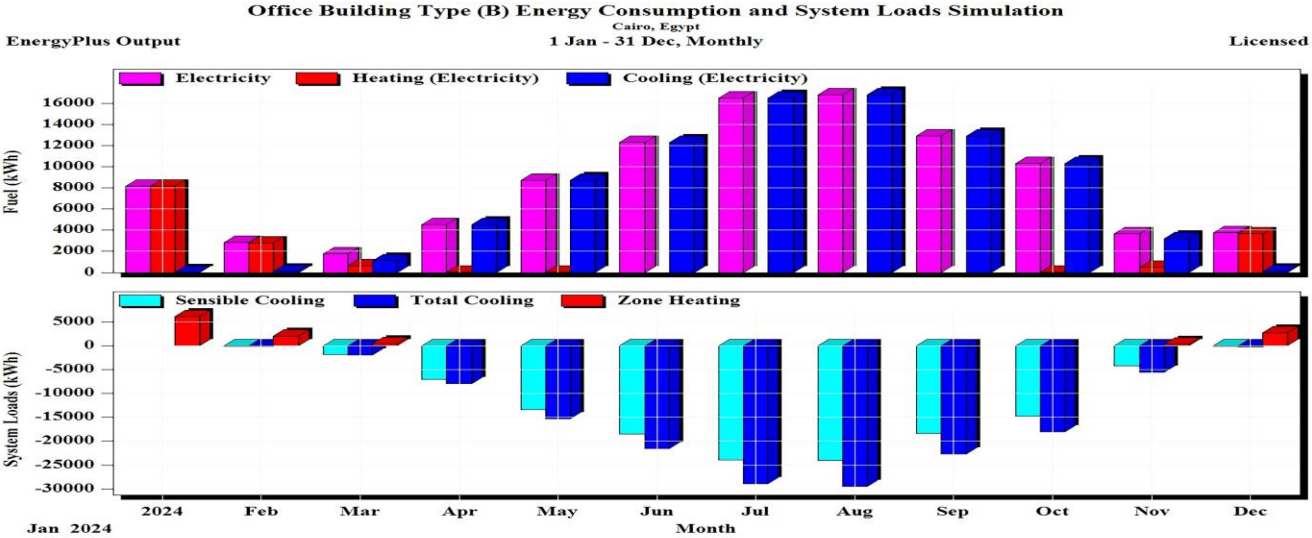


Figure (16) Thermochromic Glass Building (Building Type B) Energy Consumption and System Loads Analysis [5]

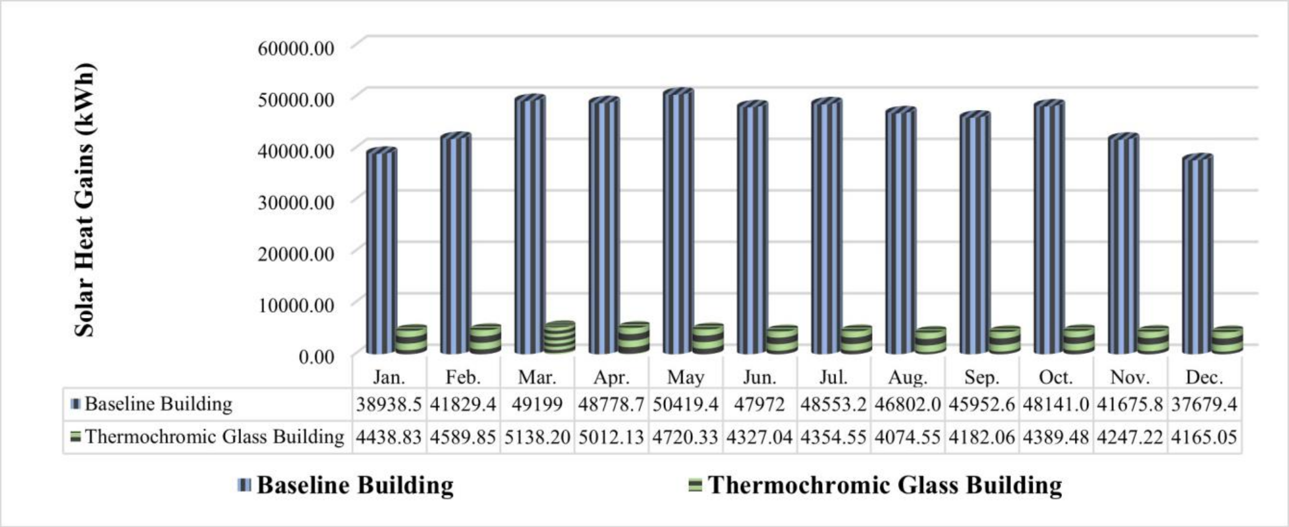
6. Results and Discussion.

This study investigates the thermal performance and energy consumption of a proposed office building in the new administrative capital of Cairo, Egypt. Building performance simulation software was utilized to conduct this study, specifically Design Builder Software Ltd (Version 7.0.0.116) and Energy Plus (Version 9.4.0). The study compared two distinct office building scenarios, a baseline office building (Building Type A) with a conventional glazing system and a thermochromic glass office building (Building Type B) that incorporates thermochromic glass technology in the building curtain walls and windows. The objective was to assess the impact of using thermochromic glass technology on the building's overall performance.

The baseline building (building type A), comprises six floors, featuring a footprint area of 513.36 m² and a total area of 2,634.86 m^2. With a ceiling height of 4.0 m, it offers an internal volume of 8,636 m^3. The building is powered by natural gas for water heaters and electricity for other appliances. Office spaces are designed with an occupancy density of 0.1110 people/m^2. Heating, ventilation, and air conditioning (HVAC), the building utilizes a water chiller system, maintaining set point temperatures of 24 °C during the summer and 22 °C in winter.

The building operates from 9:00 AM to 6:00 PM, five days a week. It boasts double transparent glass panels in the building's curtain walls and windows with a total U-value of 2.69 W/m^2K. The estimated solar heat gain coefficient (SHGC) is 0.743, with direct solar transmission of 0.67 and visible transmission of 0.801. [5]. The thermochromic glass building (building type B), has undergone an upgrade to its glazing system, incorporating thermochromic glass in its curtain walls and windows. This system comprises triple transparent glass panels, each with a thickness of 0.06 m. between the two panels, there is an air gap of 0.07 m, and while a 0.0122 m thick thermochromic interlayer is positioned between the remaining two panels. This design achieves a total U-value of 2.718 W/m^2K. The estimated solar heat gain coefficient (SHGC) is 0.215, with a direct solar transmission of 0.112 and a visible transmission of 0.36. [5]

Figures 17 and 19 analyzed the findings from the simulation study indicating a notable decrease in solar heat gains from external curtain walls and windows between the two building types. The baseline office building (building type A) experiences yearly solar heat gains of 545,941.23 kWh, whereas the thermochromic glass office building (building type B) registers yearly solar heat gains of 53,639.29 kWh. [5]



	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
▮ Baseline Building	38938.5	41829.4	49199	48778.7	50419.4	47972	48553.2	46802.0	45952.6	48141.0	41675.8	37679.4
🟩 Thermochromic Glass Building	4438.83	4589.85	5138.20	5012.13	4720.33	4327.04	4354.55	4074.55	4182.06	4389.48	4247.22	4165.05

Figure (17) Building External Curtain Walls and Windows Monthly Solar Heat Gains Analysis

The disparity in solar heat gains between the two building types directly influences the HVAC system loads, subsequently affecting energy consumption. Figures 18 and 19 analyzed the annual HVAC energy consumption that was calculated differently for the baseline office building (building type A), which employs a conventional glazing system and consumes 209,518.10 kWh, compared to the thermochromic office building (building type B), which uses thermochromic glazing technology and consumes 102,337.62 kWh. [5]

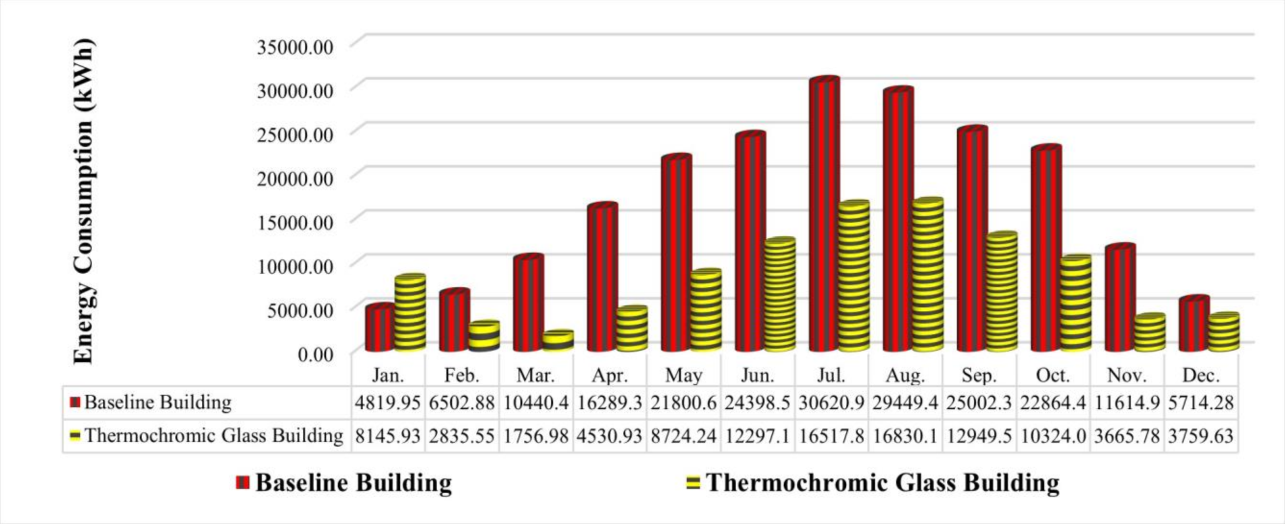


Figure (18) Building Monthly Energy Consumption Analysis

The findings indicate that integrating thermochromic glass technology into the external curtain walls and windows of a proposed office building in the new administrative capital of Cairo, Egypt, can achieve a reduction of up to 90.18 % in solar heat gains through the building's glazing system. Consequently, this integration can significantly lessen the load on HVAC systems and reduce overall energy consumption by around 51.16 % compared to traditional glazing systems in the same building as shown in Figure 19.

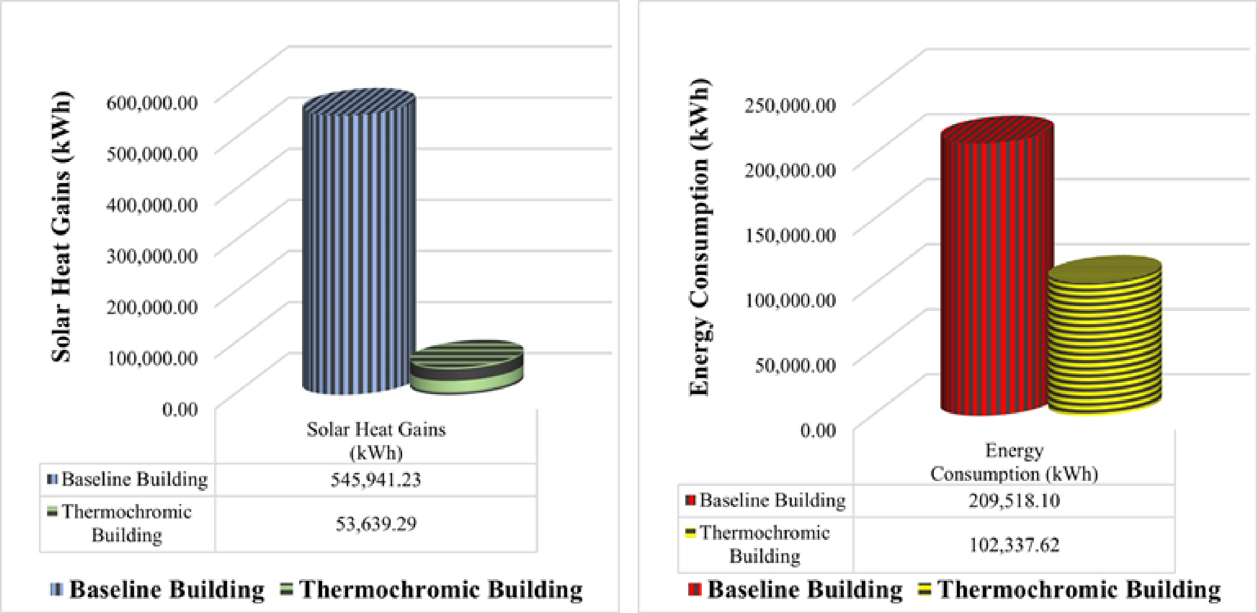


Figure (19) Office Building Yearly Solar Heat Gains and HVAC System Energy Consumption Analysis

Based on these findings, this study highlights a significant enhancement in energy efficiency and overall building performance using thermochromic glass technology in an office building facade planned for the new administrative capital of Cairo, Egypt. This innovative glazing system adjusts its tint in response to temperature changes, effectively regulating the amount of solar heat and light entering the building. During the summer, the glass darkens reducing solar heat gain and consequently the reliance on HVAC systems, which reduces energy consumption. In contrast, during the winter, the glass allows more sunlight to enter, decreasing the necessity for artificial lighting. This dynamic modulation of heat and light not only minimizes reliance on HVAC systems but also reduces energy consumption and the overall carbon footprint. Moreover, the technology enhances occupant comfort by minimizing glare and maintaining a stable indoor temperature, which can lead to increased productivity and improved building performance. By incorporating thermochromic glass into building facades, office buildings can achieve superior thermal control, optimize energy use, and support sustainable architectural practices.

7. Conclusions

This study highlights the potential of thermochromic glass facades to significantly improve energy efficiency and thermal comfort in hot climates, focusing on the new administrative capital of Cairo, Egypt. Through comprehensive simulation-based analysis, the study confirms that thermochromic glazing can effectively reduce cooling loads, easing the burden on heating, ventilating, and air conditioning systems (HVAC) and leading to lower energy consumption. The responsive nature of thermochromic glass to temperature fluctuations enhances indoor environmental quality through optimized daylighting and reduced solar heat gain and produces considerable energy savings compared to conventional glazing systems. The findings of the simulation-based study indicated significant enhancements in whole-building performance metrics when thermochromic glass technology was incorporated into the building facade, as opposed to traditional glazing systems. Notably, the study revealed an impressive reduction in solar heat gain across the building's external curtain walls and windows, achieving reductions of up to 90.18 % compared to conventional glazing buildings.

Furthermore, the analysis highlighted a substantial decrease in HVAC system energy consumption in buildings equipped with thermochromic glass technology. Over a year, HVAC energy consumption was reduced by approximately 51.16 % compared to buildings with conventional glazing. This reduction not only leads to considerable cost savings but also emphasizes the potential of this technology to advance energy efficiency goals and lessen environmental impact. The findings emphasize the necessity of incorporating innovative materials like thermochromic glass into the architectural fabric of rapidly urbanizing areas facing unique climatic challenges. This technology aligns with broader sustainability goals by diminishing reliance on mechanical cooling and decreasing greenhouse gas emissions. The insights derived from this study provide a durable foundation for policymakers, developers, architects, and engineers to advocate for the adoption of thermochromic glass in new construction projects.

As cities like Cairo continue to expand and grapple with the impacts of climate change, it is essential to implement responsive architectural solutions. This study opens the door for further investigation into lifecycle impacts, economic viability, and long-term performance of thermochromic glass in diverse environments. The successful integration of such adaptive materials could catalyst transformative building designs, promote energy-efficient practices, and support sustainable urban development on a global scale.

8. Recommendations.

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

8.1. Recommendations for Policymakers.

- Implement tax incentives for projects using thermochromic glass to encourage adoption and lower initial costs.
- Include smart glazing in building codes and require thermochromic glass for high-performance buildings in areas with high heating or cooling needs.
- Invest in research to make thermochromic glass technologies more efficient, affordable, and scalable.

8.2. Recommendations for Developers, Architects, and Engineers.

- Utilize thermochromic glass for facades exposed to sunlight to improve energy efficiency and reduce costs significantly.
- Use thermochromic glass in offices and atriums to enhance comfort and reduce glare.
- Evaluate the lifecycle costs of thermochromic glass to identify long-term energy savings and sustainability benefits that validate the investment.
- Use digital tools to model thermochromic glass performance and predict energy efficiency and comfort.
- Train users and managers in smart glass operation and maintenance to ensure long-term success.

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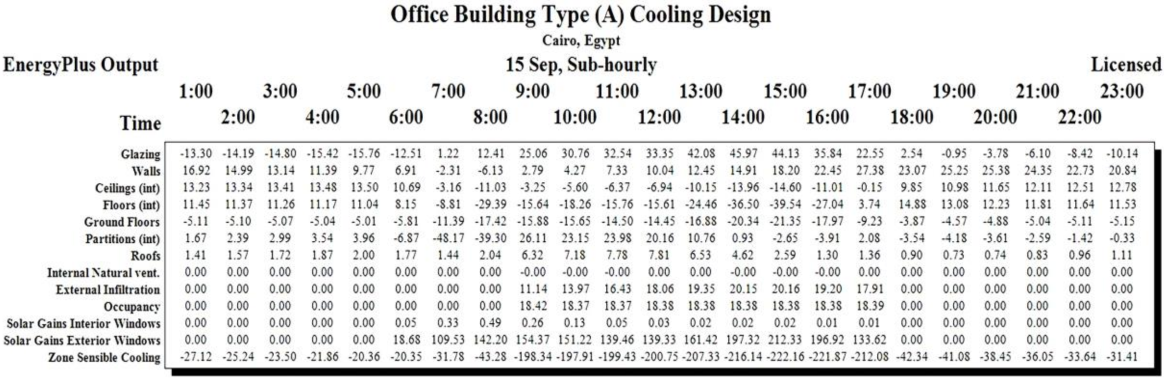
10. Appendices.

10.1. Appendix (1): Baseline Building (Type A) Cooling Design Analysis. [5]



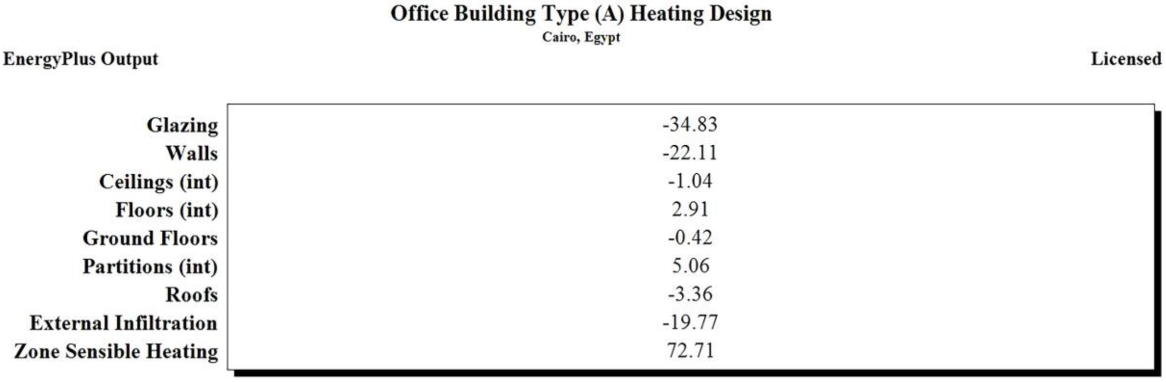
Office Building Type (A) Cooling Design

Cairo, Egypt

EnergyPlus Output **15 Sep, Sub-hourly** **Licensed**

Time	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Glazing	-13.30	-14.19	-14.80	-15.42	-15.76	-12.51	1.22	12.41	25.06	30.76	32.54	33.35	42.08	45.97	44.13	35.84	22.55	2.54	-0.95	-3.78	-6.10	-8.42	-10.14
Walls	16.92	14.99	13.14	11.39	9.77	6.91	-2.31	-6.13	2.79	4.27	7.33	10.04	12.45	14.91	18.20	22.45	27.38	23.07	25.25	25.38	24.35	22.73	20.84
Ceilings (int)	13.23	13.34	13.41	13.48	13.50	10.69	-3.16	-11.03	-3.25	-5.60	-6.37	-6.94	-10.15	-13.96	-14.60	-11.01	-0.15	9.85	10.98	11.65	12.11	12.51	12.78
Floors (int)	11.45	11.37	11.26	11.17	11.04	8.15	-8.81	-29.39	-15.64	-18.26	-15.76	-15.61	-24.46	-36.50	-39.54	-27.04	3.74	14.88	13.08	12.23	11.81	11.64	11.53
Ground Floors	-5.11	-5.10	-5.07	-5.04	-5.01	-5.81	-11.39	-17.42	-15.88	-15.65	-14.50	-14.45	-16.88	-20.34	-21.35	-17.97	-9.23	-3.87	-4.57	-4.88	-5.04	-5.11	-5.15
Partitions (int)	1.67	2.39	2.99	3.54	3.96	-6.87	-48.17	-39.30	26.11	23.15	23.98	20.16	10.76	0.93	-2.65	-3.91	2.08	-3.54	-4.18	-3.61	-2.59	-1.42	-0.33
Roofs	1.41	1.57	1.72	1.87	2.00	1.77	1.44	2.04	6.32	7.18	7.78	7.81	6.53	4.62	2.59	1.30	1.36	0.90	0.73	0.74	0.83	0.96	1.11
Internal Natural vent.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	-0.00	-0.00	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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.14	13.97	16.43	18.06	19.35	20.15	20.16	19.20	17.91	0.00	0.00	0.00	0.00	0.00	0.00
Occupancy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.42	18.37	18.37	18.38	18.38	18.38	18.38	18.38	18.39	0.00	0.00	0.00	0.00	0.00	0.00
Solar Gains Interior Windows	0.00	0.00	0.00	0.00	0.00	0.05	0.33	0.49	0.26	0.13	0.05	0.03	0.02	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Solar Gains Exterior Windows	0.00	0.00	0.00	0.00	0.00	18.68	109.53	142.20	154.37	151.22	139.46	139.33	161.42	197.32	212.33	196.92	133.62	0.00	0.00	0.00	0.00	0.00	0.00
Zone Sensible Cooling	-27.12	-25.24	-23.50	-21.86	-20.36	-20.35	-31.78	-43.28	-198.34	-197.91	-199.43	-200.75	-207.33	-216.14	-222.16	-221.87	-212.08	-42.34	-41.08	-38.45	-36.05	-33.64	-31.41

10.2. Appendix (2): Baseline Building (Type A) Heating Design Analysis. [5]



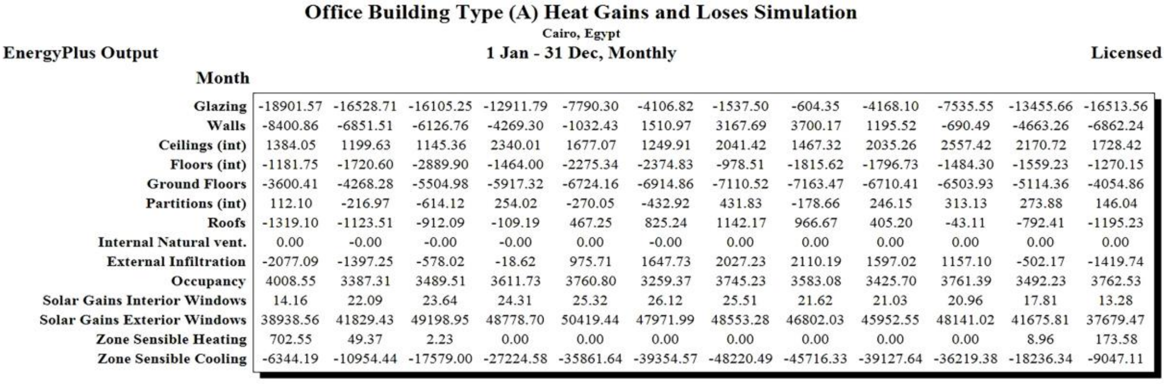
Office Building Type (A) Heating Design

Cairo, Egypt

EnergyPlus Output **Licensed**

Glazing	-34.83
Walls	-22.11
Ceilings (int)	-1.04
Floors (int)	2.91
Ground Floors	-0.42
Partitions (int)	5.06
Roofs	-3.36
External Infiltration	-19.77
Zone Sensible Heating	72.71

10.3. Appendix (3): Baseline Building (Type A) Heat Gains and Loses Analysis. [5]



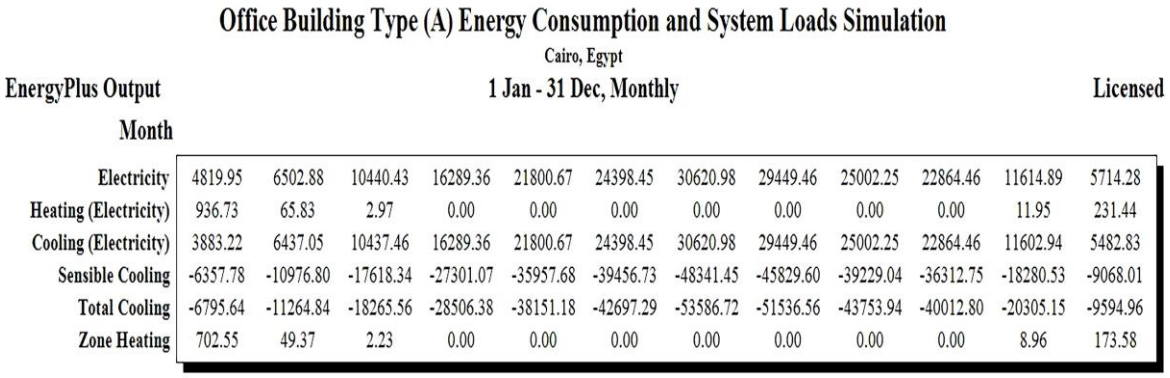
Office Building Type (A) Heat Gains and Loses Simulation

Cairo, Egypt

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

Month												
Glazing	-18901.57	-16528.71	-16105.25	-12911.79	-7790.30	-4106.82	-1537.50	-604.35	-4168.10	-7535.55	-13455.66	-16513.56
Walls	-8400.86	-6851.51	-6126.76	-4269.30	-1032.43	1510.97	3167.69	3700.17	1195.52	-690.49	-4663.26	-6862.24
Ceilings (int)	1384.05	1199.63	1145.36	2340.01	1677.07	1249.91	2041.42	1467.32	2035.26	2557.42	2170.72	1728.42
Floors (int)	-1181.75	-1720.60	-2889.90	-1464.00	-2275.34	-2374.83	-978.51	-1815.62	-1796.73	-1484.30	-1559.23	-1270.15
Ground Floors	-3600.41	-4268.28	-5504.98	-5917.32	-6724.16	-6914.86	-7110.52	-7163.47	-6710.41	-6503.93	-5114.36	-4054.86
Partitions (int)	112.10	-216.97	-614.12	254.02	-270.05	-432.92	431.83	-178.66	246.15	313.13	273.88	146.04
Roofs	-1319.10	-1123.51	-912.09	-109.19	467.25	825.24	1142.17	966.67	405.20	-43.11	-792.41	-1195.23
Internal Natural vent.	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	-2077.09	-1397.25	-578.02	-18.62	975.71	1647.73	2027.23	2110.19	1597.02	1157.10	-502.17	-1419.74
Occupancy	4008.55	3387.31	3489.51	3611.73	3760.80	3259.37	3745.23	3583.08	3425.70	3761.39	3492.23	3762.53
Solar Gains Interior Windows	14.16	22.09	23.64	24.31	25.32	26.12	25.51	21.62	21.03	20.96	17.81	13.28
Solar Gains Exterior Windows	38938.56	41829.43	49198.95	48778.70	50419.44	47971.99	48553.28	46802.03	45952.55	48141.02	41675.81	37679.47
Zone Sensible Heating	702.55	49.37	2.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.96	173.58
Zone Sensible Cooling	-6344.19	-10954.44	-17579.00	-27224.58	-35861.64	-39354.57	-48220.49	-45716.33	-39127.64	-36219.38	-18236.34	-9047.11

10.4. Appendix (4): Baseline Building (Type A) Energy Consumption and System Loads Analysis. [5]



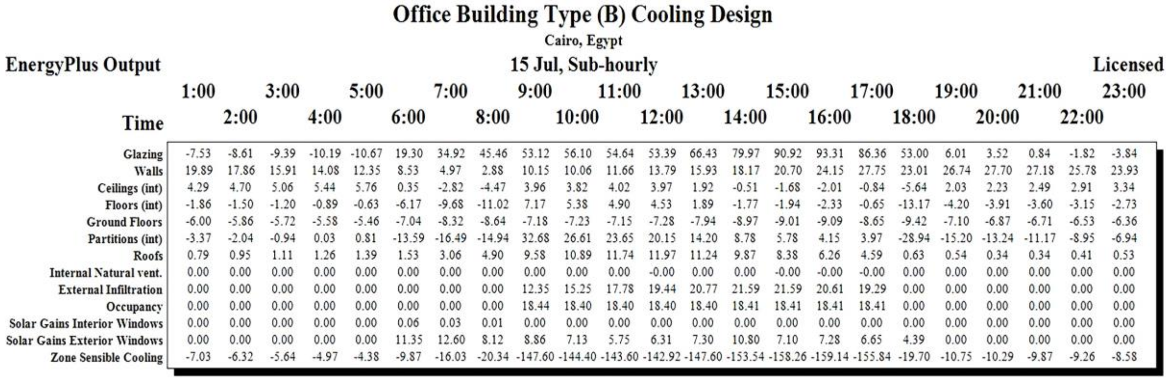
Office Building Type (A) Energy Consumption and System Loads Simulation

Cairo, Egypt

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

Month												
Electricity	4819.95	6502.88	10440.43	16289.36	21800.67	24398.45	30620.98	29449.46	25002.25	22864.46	11614.89	5714.28
Heating (Electricity)	936.73	65.83	2.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.95	231.44
Cooling (Electricity)	3883.22	6437.05	10437.46	16289.36	21800.67	24398.45	30620.98	29449.46	25002.25	22864.46	11602.94	5482.83
Sensible Cooling	-6357.78	-10976.80	-17618.34	-27301.07	-35957.68	-39456.73	-48341.45	-45829.60	-39229.04	-36312.75	-18280.53	-9068.01
Total Cooling	-6795.64	-11264.84	-18265.56	-28506.38	-38151.18	-42697.29	-53586.72	-51536.56	-43753.94	-40012.80	-20305.15	-9594.96
Zone Heating	702.55	49.37	2.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.96	173.58

10.5. Appendix (5): Thermochromic Glass Building (Type B) Cooling Design Analysis. [5]



Office Building Type (B) Cooling Design

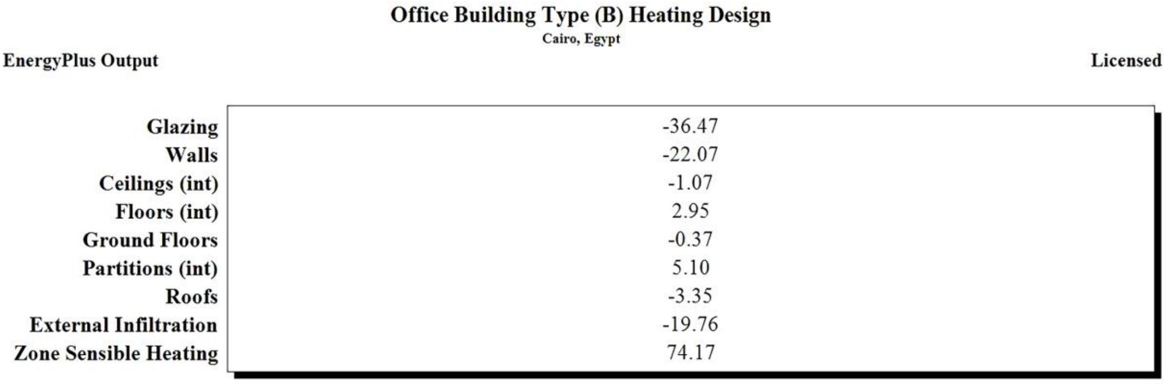
Cairo, Egypt

EnergyPlus Output — 15 Jul, Sub-hourly — Licensed

Time	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
Glazing	-7.53	-8.61	-9.39	-10.19	-10.67	19.30	34.92	45.46	53.12	56.10	54.64	53.39
Walls	19.89	17.86	15.91	14.08	12.35	8.53	4.97	2.88	10.15	10.06	11.66	13.79
Ceilings (int)	4.29	4.70	5.06	5.44	5.76	0.35	-2.82	-4.47	3.96	3.82	4.02	3.97
Floors (int)	-1.86	-1.50	-1.20	-0.89	-0.63	-6.17	-9.68	-11.02	7.17	5.38	4.90	4.53
Ground Floors	-6.00	-5.86	-5.72	-5.58	-5.46	-7.04	-8.32	-8.64	-7.18	-7.23	-7.15	-7.28
Partitions (int)	-3.37	-2.04	-0.94	0.03	0.81	-13.59	-16.49	-14.94	32.68	26.61	23.65	20.15
Roofs	0.79	0.95	1.11	1.26	1.39	1.53	3.06	4.90	9.58	10.89	11.74	11.97
Internal Natural vent.	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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.35	15.25	17.78	19.44
Occupancy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.44	18.40	18.40	18.40
Solar Gains Interior Windows	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.01	0.00	0.00	0.00	0.00
Solar Gains Exterior Windows	0.00	0.00	0.00	0.00	0.00	11.35	12.60	8.12	8.86	7.13	5.75	6.31
Zone Sensible Cooling	-7.03	-6.32	-5.64	-4.97	-4.38	-9.87	-16.03	-20.34	-147.60	-144.40	-143.60	-142.92

Time	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Glazing	66.43	79.97	90.92	93.31	86.36	53.00	6.01	3.52	0.84	-1.82	-3.84
Walls	15.93	18.17	20.70	24.15	27.75	23.01	26.74	27.70	27.18	25.78	23.93
Ceilings (int)	1.92	-0.51	-1.68	-2.01	-0.84	-5.64	2.03	2.23	2.49	2.91	3.34
Floors (int)	1.89	-1.77	-1.94	-2.33	-0.65	-13.17	-4.20	-3.91	-3.60	-3.15	-2.73
Ground Floors	-7.94	-8.97	-9.01	-9.09	-8.65	-9.42	-7.10	-6.87	-6.71	-6.53	-6.36
Partitions (int)	14.20	8.78	5.78	4.15	3.97	-28.94	-15.20	-13.24	-11.17	-8.95	-6.94
Roofs	11.24	9.87	8.38	6.26	4.59	0.63	0.54	0.34	0.34	0.41	0.53
Internal Natural vent.	0.00	0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00
External Infiltration	20.77	21.59	21.59	20.61	19.29	0.00	0.00	0.00	0.00	0.00	0.00
Occupancy	18.40	18.41	18.41	18.41	18.41	0.00	0.00	0.00	0.00	0.00	0.00
Solar Gains Interior Windows	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Solar Gains Exterior Windows	7.30	10.80	7.10	7.28	6.65	4.39	0.00	0.00	0.00	0.00	0.00
Zone Sensible Cooling	-147.60	-153.54	-158.26	-159.14	-155.84	-19.70	-10.75	-10.29	-9.87	-9.26	-8.58

10.6. Appendix (6): Thermochromic Glass Building (Type B) Heating Design Analysis. [5]



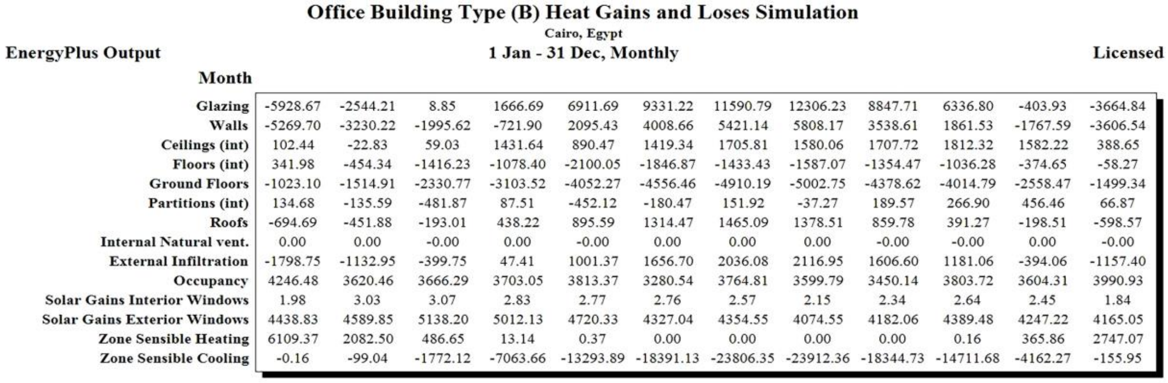
Office Building Type (B) Heating Design

Cairo, Egypt

EnergyPlus Output — Licensed

Glazing	-36.47
Walls	-22.07
Ceilings (int)	-1.07
Floors (int)	2.95
Ground Floors	-0.37
Partitions (int)	5.10
Roofs	-3.35
External Infiltration	-19.76
Zone Sensible Heating	74.17

10.7. Appendix (7): Thermochromic Glass Building (Type B) Heat Gains and Loses Analysis. [5]



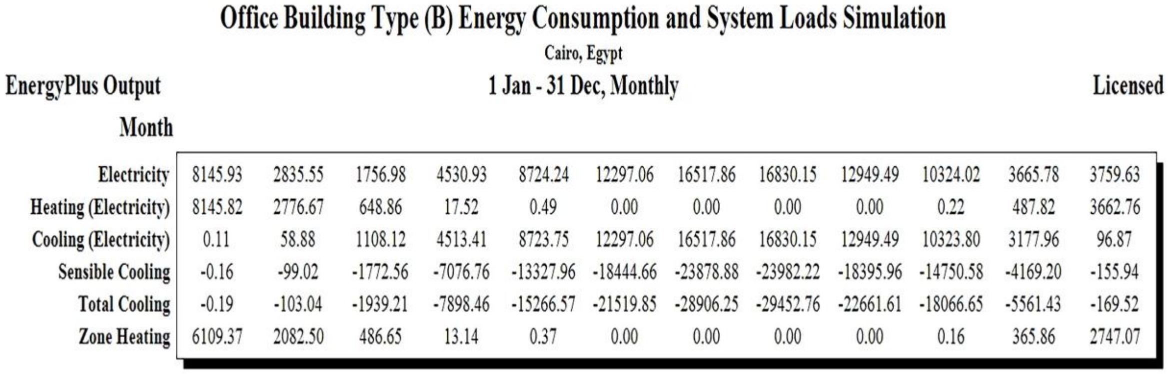
Office Building Type (B) Heat Gains and Loses Simulation

Cairo, Egypt

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

Month												
Glazing	-5928.67	-2544.21	8.85	1666.69	6911.69	9331.22	11590.79	12306.23	8847.71	6336.80	-403.93	-3664.84
Walls	-5269.70	-3230.22	-1995.62	-721.90	2095.43	4008.66	5421.14	5808.17	3538.61	1861.53	-1767.59	-3606.54
Ceilings (int)	102.44	-22.83	59.03	1431.64	890.47	1419.34	1705.81	1580.06	1707.72	1812.32	1582.22	388.65
Floors (int)	341.98	-454.34	-1416.23	-1078.40	-2100.05	-1846.87	-1433.43	-1587.07	-1354.47	-1036.28	-374.65	-58.27
Ground Floors	-1023.10	-1514.91	-2330.77	-3103.52	-4052.27	-4556.46	-4910.19	-5002.75	-4378.62	-4014.79	-2558.47	-1499.34
Partitions (int)	134.68	-135.59	-481.87	87.51	-452.12	-180.47	151.92	-37.27	189.57	266.90	456.46	66.87
Roofs	-694.69	-451.88	-193.01	438.22	895.59	1314.47	1465.09	1378.51	859.78	391.27	-198.51	-598.57
Internal Natural vent.	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	-1798.75	-1132.95	-399.75	47.41	1001.37	1656.70	2036.08	2116.95	1606.60	1181.06	-394.06	-1157.40
Occupancy	4246.48	3620.46	3666.29	3703.05	3813.37	3280.54	3764.81	3599.79	3450.14	3803.72	3604.31	3990.93
Solar Gains Interior Windows	1.98	3.03	3.07	2.83	2.77	2.76	2.57	2.15	2.34	2.64	2.45	1.84
Solar Gains Exterior Windows	4438.83	4589.85	5138.20	5012.13	4720.33	4327.04	4354.55	4074.55	4182.06	4389.48	4247.22	4165.05
Zone Sensible Heating	6109.37	2082.50	486.65	13.14	0.37	0.00	0.00	0.00	0.00	0.16	365.86	2747.07
Zone Sensible Cooling	-0.16	-99.04	-1772.12	-7063.66	-13293.89	-18391.13	-23806.35	-23912.36	-18344.73	-14711.68	-4162.27	-155.95

10.8. Appendix (8): Thermochromic Glass Building (Type B) Energy Consumption and System Loads Analysis. [5]



Office Building Type (B) Energy Consumption and System Loads Simulation

Cairo, Egypt

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

Month												
Electricity	8145.93	2835.55	1756.98	4530.93	8724.24	12297.06	16517.86	16830.15	12949.49	10324.02	3665.78	3759.63
Heating (Electricity)	8145.82	2776.67	648.86	17.52	0.49	0.00	0.00	0.00	0.00	0.22	487.82	3662.76
Cooling (Electricity)	0.11	58.88	1108.12	4513.41	8723.75	12297.06	16517.86	16830.15	12949.49	10323.80	3177.96	96.87
Sensible Cooling	-0.16	-99.02	-1772.56	-7076.76	-13327.96	-18444.66	-23878.88	-23982.22	-18395.96	-14750.58	-4169.20	-155.94
Total Cooling	-0.19	-103.04	-1939.21	-7898.46	-15266.57	-21519.85	-28906.25	-29452.76	-22661.61	-18066.65	-5561.43	-169.52
Zone Heating	6109.37	2082.50	486.65	13.14	0.37	0.00	0.00	0.00	0.00	0.16	365.86	2747.07