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The Impact of Building Facades on Energy Efficiency in Hot Climates

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ABSTRACT

The significance of sustainable buildings has grown lately due to the imperative to conserve energy. Buildings consume a substantial portion, approximately 40%, of total energy usage. The surface area of the building facade plays a crucial role in achieving energy efficiency. Particularly in hot climates, the building envelope operates as an obstacle to external climate fluctuations. This study focuses on the impact of the building facade components on the energy and thermal performance of buildings in hot climates. Based on prior studies, it investigates the effect of external wall materials, glazing layers, and insulation materials on buildings energy consumption. The study reviews innovative design approaches and technologies that improve environmental conditions, providing modern and effective solutions to optimize building envelope performance in hot climates. The research utilized DesignBuilder simulation program to assess the influence of façade wall materials and glazing on energy consumption. Findings demonstrate that selecting appropriate materials and adjusting glazing types significantly impact energy usage. Enhancing thermal properties, u-value and SHGC, can improve the performance of facade materials. Additionally, glazing areas exert substantial influence accounting for approximately 80% of the façade's impact on energy consumption. The results indicate that energy savings are up to 78.4% compared to the base-case.

1. Introduction

Over the last several decades, various studies have focused on growing worries about climate change. Overheating and solar gain pose challenges, especially in hot climates . The built environment consumes around 40% of global energy use [3]. The significance of energy-efficient building design has been emphasized by rising global temperatures and energy use, especially in areas with hot climates [4]. Of the total HVAC load, 26% is attributed to heat gain through the building envelope [5].

The building envelope influences energy consumption for heating and cooling while providing thermal comfort and sufficient daylight for building occupants [6]. According to studies, the building envelope generates 73% of total heat or gain loss [7]. Heat flow through the building envelope, comprising walls, and fenestrations (windows and doors), is influenced by their resistance, thermal capacity, absorption, transmission, and emission properties [8]. Careful consideration of specific requirements is essential when selecting materials for these components. Designing the building envelope following the local climate is crucial for achieving energy efficiency [5]. Particular design techniques should be used based on climatic zone circumstances [9].In hot climates, the maximum cooling load primarily occurs through the following building components, ranked in order of significance:

- Windows: Windows are a major source of heat gain due to solar radiation.
- Walls: Heat transfer through walls contributes significantly to cooling demands. Insulation, material choice, and wall thickness impact their thermal performance.

From the previous arrangement and Figure 1, the roofs of buildings have the least impact on energy consumption so this research will focus on building facades, including walls and fenestrations. Optimizing these elements is essential for energy-efficient building design in hot climates.

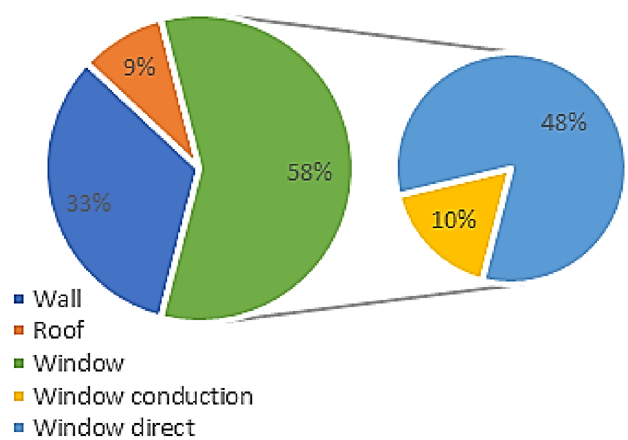


Figure 1: Heat Gain through various Building Envelope components [8]

Recent studies have focused on building facades because of their crucial role in regulating indoor temperatures, reducing energy consumption, and mitigating the environmental effects of buildings [10], [11]. An adequate building facade can contribute to reducing harmful environmental impacts by about 80% [12]. The primary determinant of building energy consumption is the balance between energy gain and loss through the building facades. Reducing the U-value of the external wall positively affected annual energy savings in heating and cooling.

The following section discusses different building facade parameters and their impact on thermal transfer within buildings. Additionally, recommendations are provided for each parameter to optimize energy efficiency.

2. Literature Review

The literature review examines previous studies on building facade performance in hot climates, focusing on the effects of wall materials, and glazing types. Key findings from existing research provide insights into the role of each component in mitigating heat gain, reducing cooling loads, and enhancing thermal comfort. These findings are separated into two parts. The first part is about the factors affecting the energy-saving performance of the wall. The second is the Factors influencing the energy-saving efficiency of the glazing:

2.1. Factors affecting the energy-saving performance of the wall

Walls play an essential role in providing thermal and acoustic comfort. Walls form a significant portion of the building envelope and are exposed to substantial direct solar radiation. A wall's thermal resistance (R-value) significantly affects building energy usage. Given the significance of implementing energy conservation measures, the impact of thermal resistance or thermal transmittance (U-value) of the building façade system can be analyzed. The U-value determines the rate of heat loss through a building material, indicating the energy conservation efficiency for a specific room or building. Thermal transmittance, or U-value, is a critical indication of a building's energy performance [13]. Enhancing these two aspects can achieve energy savings for lighting, heating, and cooling. Various techniques can improve the resistance to heat transfer through the exposed walls. The following section covers the systems and technologies that have recently been applied in building facades.

a. Wall Insulation

The thermal insulation of building envelopes is crucial for energy conservation, as it adds a high-resistance layer between the interior and exterior environments, thus reducing heat loss. Employing static or dynamic insulation materials helps mitigate heat transfer from building facades caused by temperature differentials between the interior and exterior [14]. The traditional approach argues that maintaining a continuously high thermal resistance for the building exterior will automatically reduce energy consumption and operational expenses [15].

An Guo, Z.L. stated that improving thermal insulation may improve interior comfort and reduce air conditioning energy usage by 15-20% [15]. Nevertheless, increasing thermal thickness and resistance might result in higher overall annual energy consumption [16]. There is a need for advanced technologies in the building insulation sector to address the drawbacks associated with traditional static insulation materials. As a result, the tendency of dynamic isolation began.

b. Dynamic insulation:

It can be defined in a single statement: Dynamic insulation = conventional insulation + dynamic heat exchange within the building envelope.

Dynamic insulation can adjust the thermal transmittance of the building envelope by utilizing a circulating fluid [17]. When compared to building envelopes with identical static insulation, energy savings might be greater than 40% [17]. Figure 4 indicates Available dynamic insulating systems according to fluid type. Active insulation with air likely represents the most widespread use of dynamic thermal insulation in the building field. The exploration of dynamic insulation is constrained due to its absence from widely used building design tools like DesignBuilder, Esp-r, EnergyPlus, and TRNSYS [18].

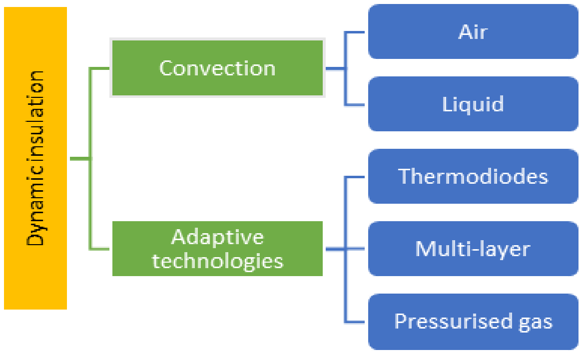


Figure 2: Available dynamic insulation systems based on fluid type/circulation [18]

Many researchers have investigated the effect of dynamic insulation on energy consumption. Samuel [19] demonstrated that using dynamic insulation reduces energy consumption by up to 9% and improves thermal comfort. another study by Fantucci [20]achieved a 42% daily thermal energy savings as a result of using dynamic insulation while the thermal performance efficiency increased between 9% and 20% and the heat loss was decreased by up to 68%. It also reduced cooling load by 12% and 4% reduction in total energy consumption and carbon emissions in the research by Elsarrag and Alhorr [21]. Ascione et al. [22] showed that Dynamic insulation caused a 29.6% decrease in cooling demand and considerable raise in summer indoor comfort. It has also been proven that total energy consumption may be decreased by roughly 30% and 50% in the research by Pflug et al. [23] and Favoino et al. [24] respectively.

Phase change material (PCM) is one of the types of dynamic thermal insulation that uses a flowing fluid: air, water, or refrigerant. PCMs are compounds that absorb and release thermal energy when they melt and freeze. When a PCM melts, it absorbs a significant quantity of heat from its surroundings, storing energy. When it solidifies, it releases the stored energy, providing heat. This property makes PCMs effective for thermal management applications in buildings, electronics, and textiles [25]. There are many types of PCMs [26]:

- Organic PCMs: Paraffin and fatty acids. Advantages include chemical stability, non-corrosiveness, and a wide range of melting points.
- Inorganic PCMs: Salt hydrates and metals. They typically have higher thermal conductivity and volumetric latent heat storage capacity but can be corrosive and suffer from supercooling.

- Eutectic PCMs: Combinations of organic and inorganic materials to optimize properties like melting point and heat storage capacity.

Abbas et al. mentioned that the use of PCM achieved the lowest energy consumption, as the percentage of energy consumption savings ranged between 11% and 6.8%, but its cost is relatively high compared to traditional materials, about 36% [27]. Another study by Sadineni demonstrated that PCM showed maximum energy savings of about 30% and a maximum expense savings of about 30% over traditional non-PCM base-case [28]. PCMs offer a promising solution for enhancing energy efficiency and thermal management across various sectors.

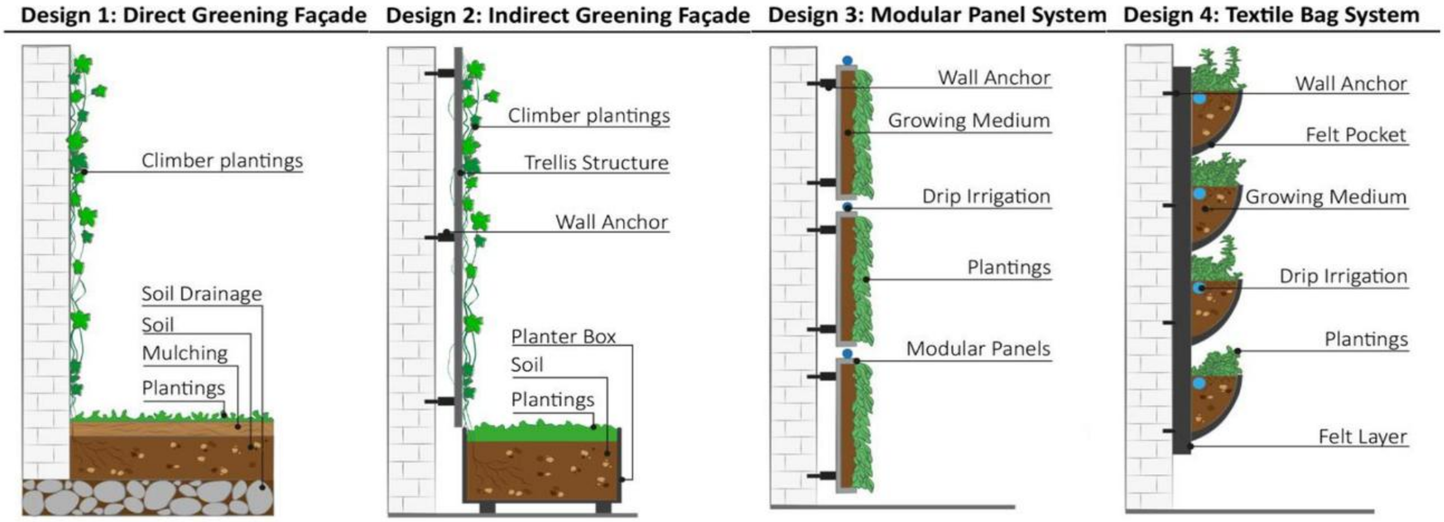


Figure 3: Classification of VGS [29]

c. Green facades (Vertical greening)

Green facades are an effective way to improve buildings by incorporating living plants into the design. The literature on green infrastructure uses many definitions, categorization systems, and typologies, but green walls can generally be separated into two categories: green façades (GFs) and living walls (LWs), Figure 3 [29]. Green facades, like other green infrastructure, help lower the internal temperature of buildings, thereby reducing energy consumption. These vertical systems offer a range of environmental, economic, and social advantages [30]. Incorporating green vegetated facades into building exteriors creates an insulating air layer [31].

According to Mahmoud et al., [32] annual energy usage can be decreased by up to 8% when using green vegetated facades that shade the walls and windows thus reducing the air conditioning load by reducing cooling load by up to 23%. The study of the thermal effectiveness of vertical greenery vegetation systems decreased indoor temperature by up to 4.0 °C- 3.0 °C [33]. Ramadhan et al, [34] mentioned that the effect of applying VGS on reducing Energy consumption with a 2.0-m air cavity width reached 59% to 78%. Using these systems will reduce annual cooling demands and CO2 emissions by about 78% [34]. Another study [35] found that green vegetated facades minimize energy demand in air conditioning units, from 13.4% to 37.6% for cooling and from 18.3% to 100% for heating, except in some orientations, while also lowering annual energy usage from 18% to 51.4% depending on building orientation and location.

2.2. Factors affecting the energy-saving performance of the glazing

The glazed openings have a considerable impact on building energy usage. During the summer, 87% of unwanted heat enters a building via windows and doors [36]. Glazing accounts for approximately 50% of building energy loss [5]. Glass transmittance significantly impacts daylight efficiency, leading to energy savings. Reducing glass transmittance of external glazing leads to increased lighting energy while it can help decrease solar gain from 55% to 40% [1].

Additionally, the U factor (U-value) and the Solar Heat Gain Coefficient (SHGC) are significant in the glazing thermal performance. Understanding the U-value measures how effective a material is at retaining heat. Lower U values indicate better insulation and energy efficiency. Lower U-values can be achieved through various methods, including adding extra glazing layers, applying special coatings to restrict solar radiation, and filling gaps between layers with low thermal conductivity gases such as air, argon, or krypton [37]. The SHGC represents how much solar heat enters a building through the glass [38]. Increasing the SHGC has a negative effect on heating and a favourable effect on energy savings for cooling[39].

The number and kind of glass layers are important to be considered when designing windows. This can affect the amount of light transmitted into the building and solar heat gain [40]. Using multiple glass layers with air space in between reduces direct solar radiation transmission [5]. Laminated glass consists of two or more layers of glass linked together by polymer sheets. The glass and interlayers come in various colors and thicknesses. It offers improved security, acoustic insulation, and UV protection [41].

2.3. Double-skin façade (DSF)

It consists of three distinct layers: an exterior surface placed at some distance from the interior glazed wall system, forming a

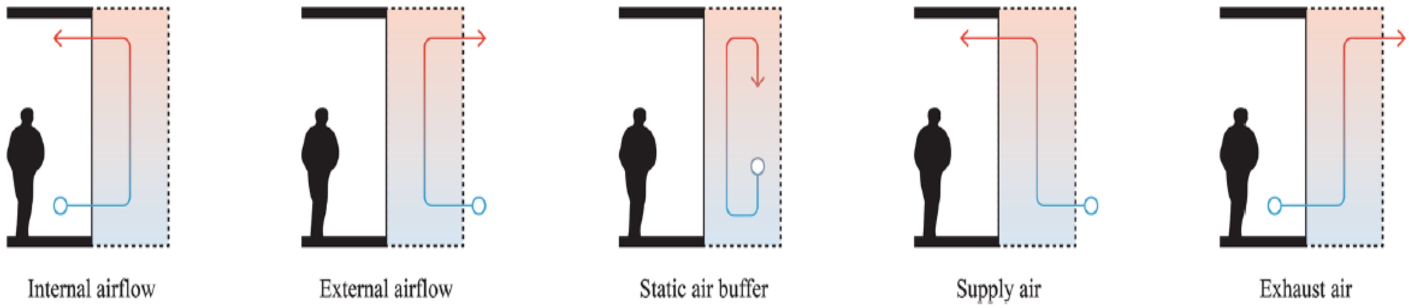


Figure 4: DSF configuration and ventilation modes with relation to envelope layers [11]

cavity (air gap) of varying size, allowing air to circulate between them [42]. This air gap is crucial for the optimal performance of both layers, offering insulation and protection against high temperatures, winds, and noise. Figure 4 shows DSF configuration and ventilation modes concerning envelope layers. The airflow within the double skin cavity is a critical aspect of the system, as the heat transferred through the facade directly impacts the energy consumption of the building [43]. DSF requires roughly 600 mm between glass skins for maintenance [44]. Al Radh et al. stated that a cavity width of 0.7–1.2 m can balance solar gain and heat transfer[45]. The stack effect, driven by differences in air density, pushes excess heat outward, effectively releasing hotter air, Figure 5. As a result, the DSF's inner layer's temperature decreases, reducing the quantity of heat transferred into the interior space.

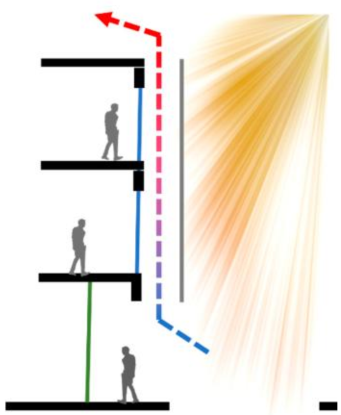


Figure 5: The operating modes of DSFs in hot climates

Another study [11], In hot and humid climates, concluded that a DSF can potentially achieve a 22% reduction in annual cooling energy consumption. When a DSF configuration was implemented into the building design, it reduced yearly cooling demand by 9% to 16%. The building's annual cooling energy usage might be reduced by 32% just by adding mechanical ventilation to the air cavity [11]. Research by Krishnan H, H., et al proved that CCF designs improved energy consumption by 22-41% compared to standard double-glazed units (DGUs) (21-37%) [46]. In another research by Al-Tamimi [47], the CCF operating temperatures were reduced by 33.5% to 68.75% monthly and 27.5% to 80.25% annually compared to single-glazed units. It can be seen that a double facade has a good potential to reduce energy consumption [48].

In light of the above background, choosing appropriate facade systems can dramatically decrease the energy consumption of the buildings. The impact of fenestration exceeds that of walls by a large margin. This study aims to assess the performance of various facade components on energy efficiency and environmental performance in buildings. The research adopted the systems formulated in the previous review that can be examined by the simulation programs to study their efficiency in saving energy. What distinguishes this research from previous studies is that it tests a combination of different walls and glass types, rather than studying only walls or glazing types.

3. Methodology

To fulfill the research objective, The methodology described below illustrates the approach employed to assess the building envelope effects on energy performance in hot climates. The procedure consists of two major aspects. These parts can be summarized as follows:

1) The first section is a theoretical investigation. The topic of this section is based on a theoretical review to determine the chosen facades and fenestration types, and the base-case description that will be simulated.
2) The second section is based on a simulation study for the suggested case studies.

3.1. The theoretical investigation

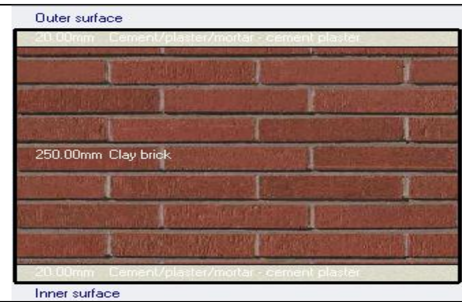
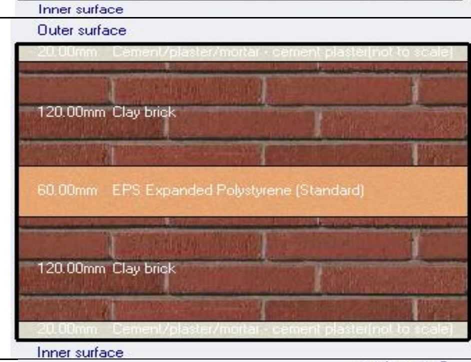
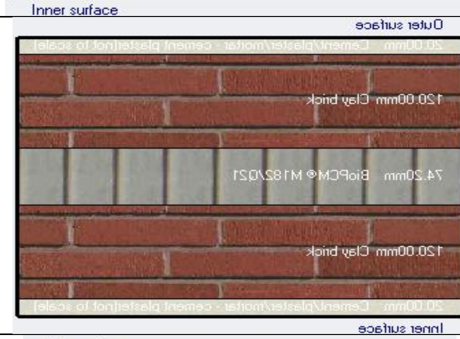
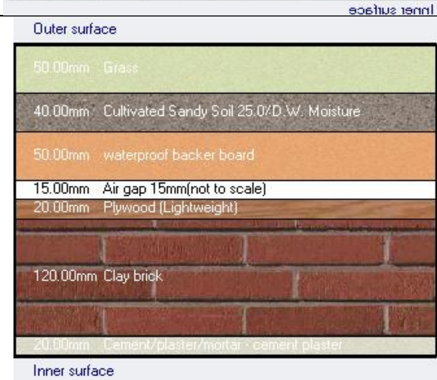
This research investigated how the parameters of walls and glazing, discussed in the theoretical section, affect energy consumption. Table 1 and Table 2 illustrate the types of walls and glazing to be studied and their thermal properties.

The study focused on studying 5 types of walls previously mentioned in the theoretical background, representing integrated facades. The components of the composite section of every wall studied were extracted from the literature review. The air cavity of DSF is 0.6m, as is the ratio mentioned in previous studies. Additionally, 3 types of glass were studied, including single and double layers, to understand the impact of layering and glass type on energy consumption.

3.2. Simulation as a method for predicting the performance of the building envelope

This study relied on simulation as the best method to predict the building envelope's performance on energy consumption during the design phase. Simulation provides savings in time, effort, and

Table 1: The studied wall types and specifications

Sample number	Wall type	Wall section (from outer surface to inner surface)		U-value
1	**Generic wall**	• Cement mortar (2cm) • Clay brick (25 cm) • Cement mortar (2cm)		**1.557**
2	**Insulated wall**	• Cement mortar (2cm) • Clay brick (12 cm) • Polystyrene insulation (6cm) • Clay brick (12 cm) • Cement v (2cm)		**0.47**
3	**PCM wall**	• Cement mortar (2cm) • Clay brick (12 cm) • BioPCM® M182/Q21 • Clay brick (12 cm) • Cement mortar (2cm)		**0.40**
4	**Green wall**	• Grass • Sandy soil • waterproof backer board (5cm) • Air gap (1.5cm) • Plywood (2cm) • Clay brick (12cm) • Cement mortar (2cm)		**0.36**
5	**DSF**	• Single clear 6mm glass • Air gap 0.6m • Double clear 6mm glass		

costs. DesignBuilder with its EnergyPlus simulation tool used for simulation. DesignBuilder is the most established and advanced user interface for EnergyPlus. The study was conducted in a security room in Cairo city with a 36m2 (6m * 6m) footprint and 3.5m height on the ground floor. The location has been ignored because all facades are identical. Through the simulation, the changes were made only to the wall and glazing types to compare these variables exclusively while keeping other variables such as the room shape, size, and usage constant.

Egypt's climate is generally categorized as hot and dry according to the Köppen climate classification [49]. Consequently, the study utilized Cairo's climatic data for the simulation program. According to Egypt [50]. It is common in Egypt for building envelopes to be constructed of bricks with internal and external cement mortar layers and a 30% opening ratio. These characteristics were considered the base case, against which results would be compared.

Table 2: The studied glazing types and specifications

Sample number	Glazing type	U-value	SHGC
A	Single clear 6mm	5.778	0.819
B	Double reflective bleached 6mm with 6mm air gap	2.429	0.636
C	Double low-e 6mm with 6mm air gap	2.334	0.426

4. Results and discussion

The results section presents findings from analyzing building envelope performance in hot climate. It discusses the impact of envelope materials and glazing properties on energy consumption. Table 3 and Figure 6 illustrate the cases studied, the total energy consumption, and the percentage of saved energy for these cases.

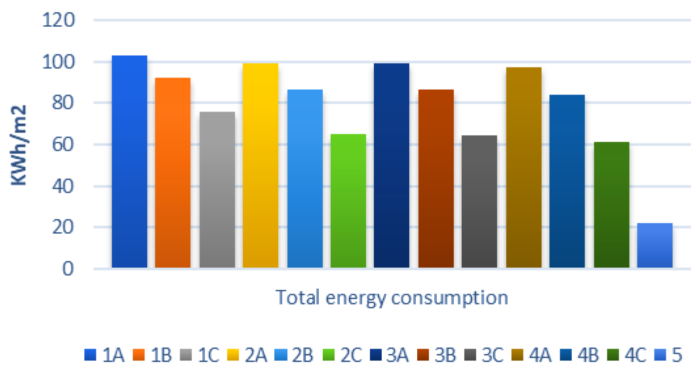


Figure 6: Total energy consumption for the cases

The results indicate that case 12 (double skin façade) is the optimal case with 78.4% saving energy compared to the base-case. Cases 2A, 3A, and 4A, had the lowest energy efficiency with saving percentages of 3.6%, 3.5%, and 5.5% respectively. These cases share the common feature of having single glazing but vary in the wall materials. This indicates that using single glazing is insufficient in energy performance. Figure 8 shows that cases (1C, 2C, 3C, and 4C) with low-e glazing are the second optimal cases. The low-e glass experiences the least amount of solar gains, unlike the single clear glass, as is clear in Figure 7.

Also, it has found a minimal difference in total energy consumption among 1A, 2A, and 3A, for example, which all use the same Glazing. This reveals that wall materials have a significantly smaller impact on facade energy performance than glazing. When comparing the sections composed of green walls, we find they have lower energy consumption than other sections, excluding the double-skin façade. Referring to Table 1, we find this logical because the U-value of green walls is lower than other types of walls. The same applies to glass, where low-e glass has a lower U-value and a higher SHGC than other glass types, making it more insulating and less heat-absorptive. Consequently, it reduces cooling energy consumption, which is predominant in hot climates.

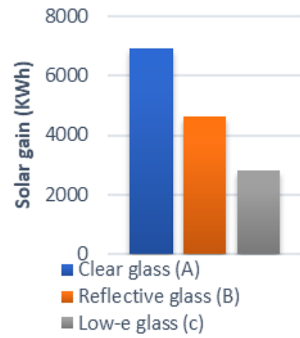


Figure 7: Solar gain exterior windows

For cooling loads, in Figure 8, case 12 (DSF) consumed the minimum cooling loads, as this type of facade insulates the interior spaces due to the large air gap that prevents thermal exchange between the inside and outside of the building. Comparing with the total energy consumption results, we find that cooling energy consumption closely aligns with them. This is because the Cooling energy consumption represents the dominant consumption in hot climates, as mentioned earlier. The base case has the largest energy consumption because it has the highest U-value for wall materials and glazing. This means that its thermal resistance capability is inferior.

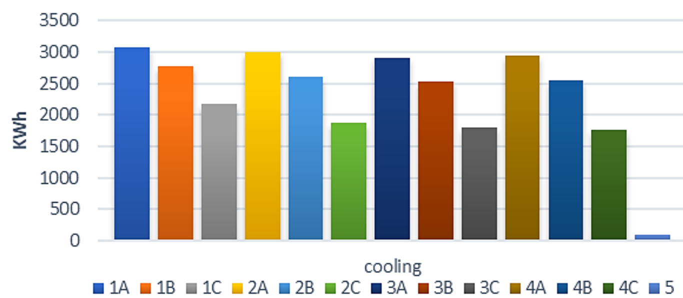


Figure 8: Cooling energy consumption

Regarding heating energy consumption in Figure 9, we observe that wall material types have a significantly greater impact than their effect on cooling energy. This is evident, for example, in cases 1C, 2C, 3C, and 4C although they have the same type of glass and differ only in the kind of wall materials there is

Table 1*:* **Case studies and their total energy consumption**

Cases	Base case	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12
Code	1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C	5
Total energy consumption (KWh/m^2)	102.97	91.95	75.79	99.23	86.4	65.16	99.32	86.16	64.62	97.29	84.03	61.11	22.28
Percentage of energy reduction relative to the base-case (%)	-	10.7	26.4	3.6	16.1	36.7	3.5	16.3	37.2	5.5	18.4	40.7	78.4
The number is wall type – The letter is glazing type (According to table and table)													

a clear difference in their heating energy consumption. Another observation is that heating energy consumption in case 3C, with PCM and low-e glass, is more than 2C with wall insulation and low-e glass. This indicates that the bio PCM with low-e glass highly insulates the room, preventing it from receiving solar radiation. The heating loads of case 3B are almost zero although the wall material and glazing do not have the best thermal performance. For wall material, the PCM is efficient in insulation as it can protect the room from cold weather. For glazing, reflective glass absorbs solar heat during the day and PCM retains it at night reducing heating energy consumption. Contrary to expectations, cases with clear glass (high U-value) consume more heating energy than those with reflective glass (low U-value). This is because clear and reflective glass absorbs solar radiation during the day, but clear glass loses it at night.

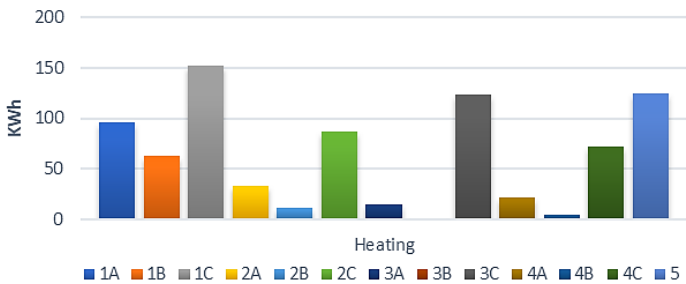


Figure 9: Heating energy consumption

Previous results indicate that a lower U-value does not always directly correlate with reduced energy consumption. This was demonstrated in case 3B which involved PCM and reflective glass. Despite green walls and low-emissivity glass having lower U-values compared to PCM and reflective glass, the first scenario achieved better heating energy performance. The glazing type is the most effective factor in energy efficiency compared to wall materials. The ratio between the effect of wall materials and the effect of the glass type is approximately 20% to 80%. The DSF is the optimal solution to overcome the high cooling loads in hot regions, as the cavity provides highly efficient insulation against external environmental conditions. The performance of conventional insulation in total energy consumption is comparable to the bio PCM in hot climates.

5. Conclusion

This study investigated the impact of façade components on energy efficiency. It aimed to identify the optimal solution that offers reduced heating and cooling loads. 12 scenarios with 5 different wall sections and 3 types of glazing have been studied and compared with the base-case in terms of energy efficiency. DesignBuilder simulation results showed the benefits of using a double skin façade (DSF) in hot climates. The research reached the fact that enhancing the building façade dramatically affects the total energy consumption by up to 80%. The lowest U-value does not always achieve the best performance. Overall, this paper emphasizes the critical role of adopting an integrated design approach that comprehensively considers all envelope components. This research provides insights for architects, engineers, and policymakers seeking to mitigate the environmental impact of buildings and promote sustainable development in hot climate regions.

References

1. Ahriz, A., et al., The Use of Double-Skin Façades to Improve the Energy Consumption of High-Rise Office Buildings in a Mediterranean Climate (Csa). Sustainability, 2022. 14.
2. Smith, J., Johnson, A., & Brown, K., Overheating in Buildings: Challenges and Solutions for Hot Climates. International Journal of Sustainable Building Technology and Urban Development, 2020. 15(3): p. 217-230.
3. Mahmoud, R., J. Kamara, and N. Burford, Opportunities and Limitations of Building Energy Performance Simulation Tools in the Early Stages of Building Design in the UK. Sustainability, 2020. 12.
4. Pacheco, R., J. Ordóñez, and G. Martínez, Energy efficient design of building: A review. Renewable and Sustainable Energy Reviews, 2012. 16(6): p. 3559-3573.
5. Bano, F. and M.A. Kamal, Examining the Role of Building Envelope for Energy Efficiency in Office Buildings in India. Architecture Research, 2016. 2016: p. 107-115.
6. Azima, M. and S. Seyis, Designing façade and envelope for a high-rise residential building using energy-efficient materials: A case in Istanbul, Turkey, in CIB, World Building Congress. 2022: Melbourne, Australia.
7. Mayernik, J., O.o.E. Efficiency, and E. Renewable, Buildings Energy Data Book. 2015, National Renewable Energy Laboratory.
8. Sozer, H., Improving energy efficiency through the design of the building envelope. Building and Environment, 2010. 45(12): p. 2581-2593.
9. Kamal, M.A., Technological Interventions in Building Facade System: Energy Efficiency and Environmental Sustainability. Architecture Research, 2020. 10: p. 45-53.
10. Mirrahimi, S., et al., The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate. Renewable and Sustainable Energy Reviews, 2016. 53: p. 1508-1519.
11. Naddaf, M.S., & Baper, S. Y, The role of double-skin facade configurations in optimizing building energy performance in Erbil city. Scientific reports, 2023. 13(1), 8394.
12. Chi, D., D. Moreno Rangel, and J. Navarro, Design optimisation of perforated solar façades in order to balance daylighting with thermal performance. Building and Environment, 2017. 125.
13. Sheng, W., B. Wen, and L. Zhang, Envelope performance of residential building in cool, warm and hot climatic zones: Results from self-designed in-situ monitoring campaigns. Energy and Buildings, 2021. 232: p. 110655.
14. Budaiwi, I., A. Abdou, and M. Al-Homoud, Variations of Thermal Conductivity of Insulation Materials Under Different Operating Temperatures: Impact on Envelope-Induced Cooling Load. Journal of Architectural Engineering, 2002. 8.
15. An Guo, Z.L., A New Method for Energy Efficiency Design of Building Facade and Its Thermodynamic Evaluation. International Journal of Heat and Technology, 2020. 38(4): p. 903-913.
16. Masoso, O.T. and L.J. Grobler, A new and innovative look at anti-insulation behaviour in building energy consumption. Energy and Buildings, 2008. 40(10): p. 1889-1894.
17. Hawkins, E., et al., Estimating Changes in Global Temperature since the Preindustrial Period. Bulletin of the American Meteorological Society, 2017. 98.
18. Fawaier, M. and B. Bokor, Dynamic Insulation Systems of Building Envelopes: A Review. Energy and Buildings, 2022. 270: p. 112268.
19. Samuel, A., SIMULATION MODELLING OF DYNAMIC INSULATION AS A MEANS FOR ENERGY SAVING AND HUMAN COMFORT.
20. Fantucci, S., V. Serra, and M. Perino, Experimental assessment of the energy performance of an advanced ventilated clay bricks façade. 2015.
21. Elsarrag, E. and Y. Alhorr, A Novel Integrated Building Energy System for High Performance Façade. Energy Procedia, 2016. 91: p. 938-944.

22. Pflug, T., et al., Closed translucent façade elements with switchable U-value—A novel option for energy management via the facade. Energy and Buildings, 2015. 86.

23. Pflug, T., B. Bueno, M. Siroux, and T.E. Kuhn, Potential analysis of a new removable insulation system. Energy and Buildings, 2017. 154: p. 391-403.

24. Favoino, F., Q. Jin, and M. Overend, Design and control optimisation of adaptive insulation systems for office buildings. Part 1: Adaptive technologies and simulation framework. Energy, 2017. 127: p. 301-309.

25. Rupp, S. and M. Krarti, Analysis of multi-step control strategies for dynamic insulation systems. Energy and Buildings, 2019. 204: p. 109459.

26. Matos, R. and N. Pala, A Review of Phase-Change Materials and Their Potential for Reconfigurable Intelligent Surfaces. 2023. 14(6): p. 1259.

27. Abbas, M., M. El-razik, and H. Gaber, A Proposed Methodology for retrofit the Efficiency of Facades of High Educational Buildings in Egypt. International Design Journal, 2022. 12: p. 271-284.

28. Sadineni, S.B., S. Madala, and R.F. Boehm, Passive building energy savings: A review of building envelope components. Renewable and Sustainable Energy Reviews, 2011. 15(8): p. 3617-3631.

29. Irga, P.J., F.R. Torpy, D. Griffin, and S.J. Wilkinson, Vertical Greening Systems: A Perspective on Existing Technologies and New Design Recommendation. 2023. 15(7): p. 6014.

30. Yin, H., et al., Cooling effect of direct green façades during hot summer days: An observational study in Nanjing, China using TIR and 3DPC data. Building and Environment, 2017. 116.

31. Davis, M.M., F. Ramirez Cevallos, and M.E. Pérez, More than just a Green Façade: Vertical Gardens as Active Air Conditioning Units. Procedia Engineering, 2016. 145: p. 1250-1257.

32. Mahmoud, A., A. Abdin, and R. Alothman, THE IMPACT OF GREEN VEGETATED FACADES ON ENERGY EFFICIENCY FOR MULTISTORY RESIDENTIAL BUILDINGS. JOURNAL OF ENGINEERING AND APPLIED SCIENCE, 2020. VOL. 67, NO. 6: p. PP.1475-1494.

33. Perini, K., et al., Vertical greening systems and the effect on air flow and temperature on the building envelope. Building and Environment, 2011. 46(11): p. 2287-2294.

34. Ramadhan, A. and A. Mahmoud, Evaluating the efficiency of a living wall facade as a sustainable energy-saving alternative in hot arid regions. Journal of Engineering and Applied Science, 2023. 70.

35. Medl, A., R. Stangl, and F. Florineth, Vertical greening systems – A review on recent technologies and research advancement. Building and Environment, 2017. 125.

36. Al-Qahtani, L. and L. Elgizawi, Building envelope and energy saving case study: a residential building in Al-Riyadh, Saudi Arabia. International Journal of Low-Carbon Technologies, 2020. 15.

37. Carmody, J. Window Systems for High-Performance Buildings. 2004.

38. Rezaei, S.D., S. Shannigrahi, and S. Ramakrishna, A review of conventional, advanced, and smart glazing technologies and materials for improving indoor environment. Solar Energy Materials and Solar Cells, 2017. 159: p. 26-51.

39. Ali, H. and R. Al-Hashlamun, Building Envelope Thermal Upgrade for School Buildings in Jordan. IOP Conference Series: Earth and Environmental Science, 2019. 290: p. 012068.

40. Hassan, A. and N. Al-Ashwal, Impact of Building Envelope Modification on Energy Performance of High-Rise Apartments in Kuala Lumpur, Malaysia. 2015.

41. Vedrtnam, A. and S. Pawar, LAMINATED GLASS:CLASSIFICATION, CHARACTERIZATION, AND FUTURE PERSPECTIVES. Journal of Materials Education, 2020. 42: p. 51-61.

42. Aksamija, A. Energy Performance of Different Types of Double Skin Facades in Various Climates. 2017.

43. Sharma, R.K. and D.D.G.M. Purohit. Energy efficient facades for Hot and Dry climate in India.

44. Zani A, G.C.a.R.L., Thermal Performance of Closed Cavity Facades. Proceedings of Façade Tectonics 2020 World Congress, Los Angeles, 2020.

45. Al Radhi, H., S. Sharples, and F. Fikiry, Will multi-facade systems reduce cooling energy in fully glazed buildings? A scoping study of UAE buildings. Energy and Buildings, 2013. 56: p. 179–188.

46. Krishnan H, H., et al., Effect of solar shading device inside the cavity of double skin facade for increasing energy efficiency: An experimental study. 2022. 2520.

47. Al-Tamimi, N., A.F. Al Kahlout, A.M. Qahtan, and A.A.M. Alqanoo, Innovative Closed Cavity Façades (CCF) with Inner Shading and Advanced Coatings for Enhancing Thermal Performance in the Tropics. 2024. 14(3): p. 603.

48. Salles, T. and D. Mela, Double Skin Facade Buildings: Configurations and Technologies in Brazil. IOP Conference Series: Earth and Environmental Science, 2020. 503: p. 012081.

49. Kottek, M., et al., World Map of the Köppen-Geiger Climate Classification Updated. Meteorologische Zeitschrift, 2006. 15: p. 259-263.

50. (HBRC), N.H.a.B.R.C., RESIDENTIAL ENERGY CODE FOR NEW BUILDINGS IN EGYPT. 2006: The Egyptian Ministry of Housing, Utilities & Urban Communities: Cairo, Egypt.