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Evaluating the use of aluminum composite panel types on thermal performance in office building in hot climate

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Abstract: This study examines the thermal efficiency of Aluminum Composite Panels (ACP) in office buildings situated in hot climates, with the goal of satisfying the increasing need for energy-efficient building materials in places with high temperatures. ACPs provide favorable options because of their exceptional insulation and long-lasting quality. Analyzed using modeling software (DesignBuilder), several ACP types were assessed to determine their effects on energy consumption and interior thermal comfort. The research primarily examines important measures such as the decrease in cooling load and the temperatures experienced within buildings with varied façade orientations (north, south, east, west) and window-to-wall ratios (20% and 50%). The findings demonstrate that Aluminum Composite Panels with Polyurethane Board (ACP-PUB) as a core material exhibit significant efficacy, resulting in a reduction in cooling loads by 7.2% for west-facing units, 8.2% for north-facing units, 6.2% for east-facing units, and 5.6% for south-facing units as compared to the base scenario when WWR was 20%. with a 50% window-to-wall ratio, comparing the effectiveness of aluminum composite panels (ACP) show that ACP-PUB insulation consistently provides the greatest reduction in cooling energy consumption across all orientations. Specifically, it reduces cooling demand by 5.4% for north-facing units, 2.8% for east-facing units, 2% for south-facing units, and 3.3% for west-facing units. Overall, ACP-PUB demonstrates superior performance in enhancing energy efficiency in hot climates, making it the most effective choice for minimizing cooling demands. In addition, the operation temperatures saw a reduction of up to 0.5°C in August for all the different options. The findings underscore the notable enhancement in thermal efficiency attained by ACP systems in hot climes, stressing their capacity to augment energy-efficient building design. The study provides useful information for architects, engineers, and legislators who seek to advance sustainability and enhance thermal comfort in places with hot climates.

Keywords: Aluminum Composite Panels (ACP) – indoor thermal comfort – energy efficiency – thermal performance - Building Energy Consumption.

Table of symbols:

Symbol	Meaning
ACP	Aluminum Composite Panels
WWR	window-to-wall ratios
ACP-EPS	Aluminum Composite Panel with Expanded Polystyrene
ACP-PF	Aluminum Composite Panel with Phenolic Foam
ACP-MFS	Aluminum Composite Panel with Mineral Fiber
ACP-PUB	Aluminum Composite Panel with Polyurethane Board (PUB)

1. Introduction

The need for environmentally friendly and efficient building materials has increased due to the continued growth of construction projects and the urgent need for sustainability. Buildings have a significant impact on energy demand and greenhouse gas emissions, accounting for approximately 40% of global energy use. This emphasizes how crucial it is to use building materials and methods that reduce their negative effects on the environment while increasing efficiency.[1] The increasing energy demand, primarily driven by the use of fossil fuels, presents a significant environmental risk, intensifying global warming and climate change. A highly effective passive design strategy to address these challenges involves carefully selecting building envelope materials.[2] The building envelope, particularly its exterior walls or façade, plays a crucial role in regulating the heat exchange between indoor and outdoor areas. The thermal conductivity of façades contributes to around 20% to 30% of a building's total energy consumption. As a result, contemporary construction regulations emphasize the importance of reducing energy requirements for heating and cooling by enhancing the thermal insulation properties of facade materials.[3]

Optimizing the design and material choice for office building façades is essential to monitoring thermal performance and energy efficiency in areas with a hot climate. [4] Aluminum Composite Panels (ACP) are considered one of the most promising materials in this particular application. ACP, or Aluminum Composite Panels, have become increasingly popular in contemporary architecture design because to their renowned durability, aesthetic adaptability, and exceptional insulating characteristics.[5]

Aluminum Composite Panels (ACPs) are composed of two aluminum sheets that are adhered to a core material. .[6] The outer aluminum sheet is frequently coated with Polyvinylidene Fluoride (PVDF) to improve its longevity and resilience to weather conditions. [7] The core material offers thermal insulation and decreases the total weight, while high-performance adhesives guarantee a robust connection between the layers.[8] Aluminum composite panels (ACPs) are available in several thicknesses, often ranging from 3mm to 6mm as shown in figure 1. They are commonly utilized in building facades due to their robustness, longevity, and capacity to be visually adaptable. Modern architecture greatly benefits from the inclusion of these materials, since they provide notable advantages such as enhanced thermal performance and increased fire safety. [9] ACPs have the ability to improve the thermal insulation of buildings. By minimizing heat transmission over the building envelope, they contribute to the regulation of inside temperatures, so decreasing the need on air conditioning and heating systems.[10] This can result in substantial energy conservation. Aluminum Composite Panels (ACPs) are available in several varieties and are considered a unique material that lacks a globally accepted classification system. [12] ACP (Aluminum Composite Panels) are commonly classified according to their use, functional purpose, and the impacts of surface ornamentation. This categorization enables a customized approach in choosing the suitable kind of ACP for certain applications, guaranteeing the best possible functionality and visual attractiveness in both indoor and outdoor architectural designs. As depicted in figure 2.

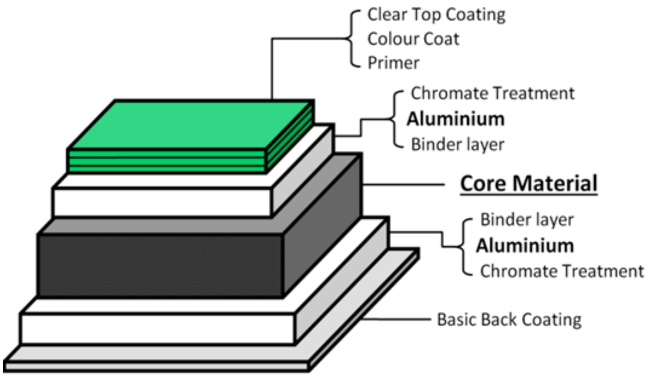

Figure 1 Common layers in an Aluminium Composite Panel (ACP) George, L., Wuhrer, R., Fanna, D. J., Rhodes, C., & Huang, Q. (2019)[8]

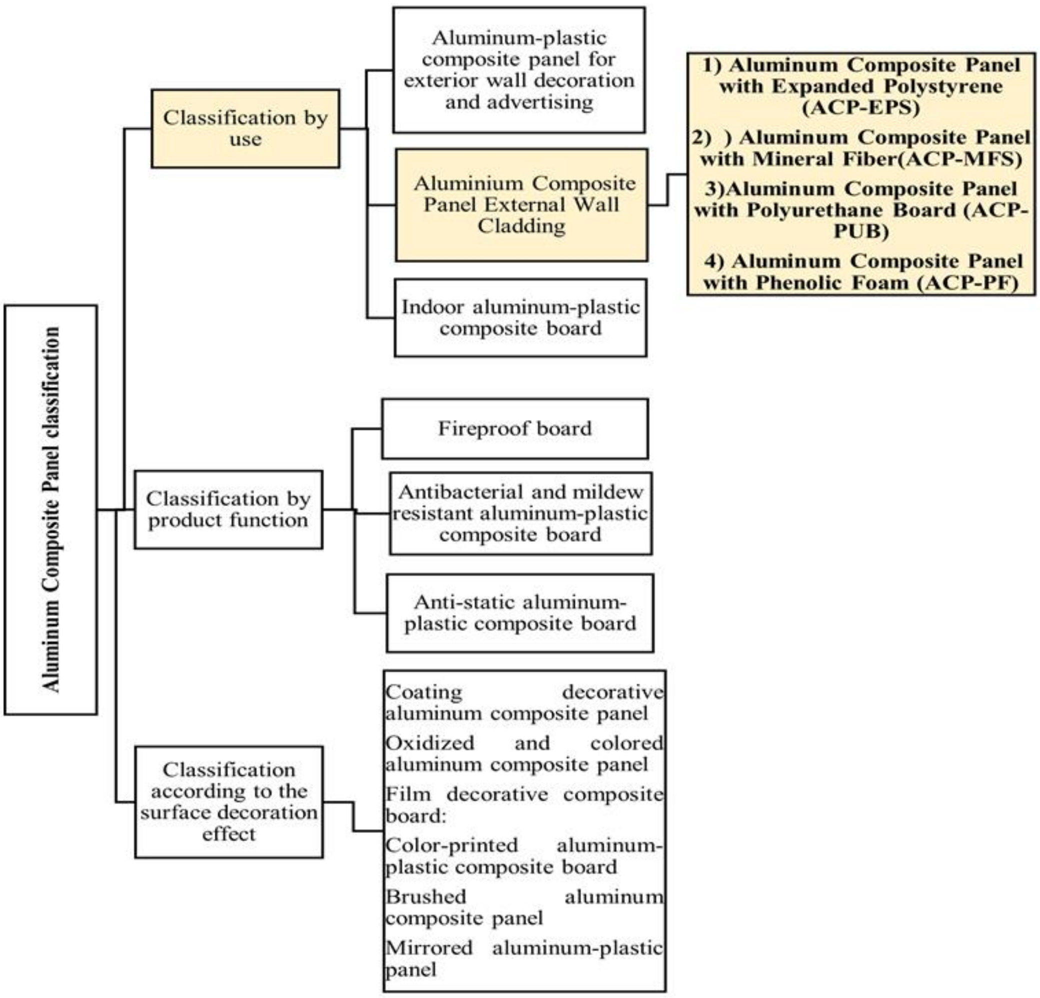

Figure 2 Aluminium Composite Panels classification source: the researcher

Aluminum Composite Panels (ACPs) have evolved significantly from their initial combustible designs, with variations primarily arising from the core material and lamination process. These factors impact the panel's fire resistance, structural integrity, durability, and thermal performance, making the selection of the core material crucial for ensuring optimal mechanical properties, safety, and regulatory compliance. Here are some common types of ACPs used for exterior cladding:[13]

1. **Aluminum Composite Panel with Expanded Polystyrene (ACP-EPS) Core**: These ACPs feature two aluminum sheets bonded to an EPS foam core. EPS is prized for its lightweight, cost-effectiveness, and superior thermal and acoustic insulation. With an R-value up to 2.78 and thermal conductivity of 0.038 W/(m·K), EPS panels significantly enhance energy efficiency and comfort in building applications.[14]
2. **Aluminum Composite Panel with Mineral Fiber Core (ACP-MFS)**: Incorporating non-combustible minerals like magnesium oxide or aluminum hydroxide, these panels offer outstanding fire resistance and thermal insulation. The core is bonded to the aluminum sheets with a high-temperature adhesive. With thermal conductivity ranging from 0.030 to 0.046 W/(m·K), these panels are ideal for fire-resistant applications such as façade cladding, tunnels, and airports, ensuring both safety and durability.[15]
3. **Aluminum Composite Panel with Polyurethane (ACP-PUB) Foam Core**: These panels consist of a PU foam core sandwiched between two metal or nonmetal skins. PU foam is lightweight and low-density, used primarily for thermal insulation in buildings and cold storage. Though not inherently decorative, it can be combined with various surface materials to enhance aesthetics while providing excellent thermal insulation with a thermal conductivity of 0.017 to 0.022 W/(m·K).[16]
4. **Aluminum Composite Panel with Phenolic Foam Core (ACP-PF)**: Made from phenolic resin and additives, phenolic foam is a rigid, closed-cell material known for its low thermal conductivity (0.021 to 0.030 W/(m·K)), exceptional heat preservation, and superior fire resistance. Valued for its thermal insulation, flame retardancy, minimal smoke emission, and durability, phenolic foam is used in various construction applications including wall panels, ceilings, and sound-absorbing panels, offering robust weather resistance and mechanical strength.[17]

The objective of this study is to assess the thermal efficiency of several types of ACPs in office buildings located in hot regions. The research utilizes simulation software, DesignBuilder, to examine the effects of various types of ACP on energy consumption and indoor thermal comfort. The analysis focuses on key elements such as reducing cooling load, optimizing operative temperatures, and studying the impact of different façade orientations and window-to-wall ratios (WWR20% and 50%) to gain a thorough understanding of the effectiveness of ACP. The study focused on the Kingdom of Saudi Arabia (KSA) as a representative case study for regions with hot climates. The study's scope encompassed the following:

- **Material Analysis:** Investigation of several varieties of ACP (Aluminum Composite Panel), with a specific emphasis on their thermophysical characteristics and their potential to enhance thermal efficiency.
- **The Building Simulation**: stage use the DesignBuilder program to simulate the thermal performance of office buildings using several types of Aluminum Composite Panels (ACP). The simulations are performed on buildings with window-to-wall ratios (WWR) of 20% and 50% to evaluate the effects on energy usage and indoor thermal comfort in hot climes. This approach aims to identify the optimal ACP configurations that can effectively reduce cooling loads and enhance thermal efficiency.
- **Energy Consumption**: Evaluation of the decrease in cooling load achieved by utilizing different types of ACP.
- **Thermal Comfort:** Assessing indoor operative temperatures to gauge the efficacy of ACPs in sustaining pleasant indoor conditions.

2. literature review

In hot climate regions like Saudi Arabia, particularly in Jeddah, the interplay between thermal comfort and energy performance in office buildings is critical .Kiki et al. (2021) demonstrated a potential 20% reduction in energy consumption by implementing a specific thermal comfort model tailored for hot climates. Their findings underline the importance of adaptive comfort models in enhancing energy efficiency without compromising occupant comfort.[18] Howarth et al. (2020) further emphasized the importance of efficient building envelopes, noting that improved insulation and energy efficiency measures have been crucial in managing the energy demands for air conditioning in Saudi Arabia [19]. Additionally, Alayed et al. (2022) highlighted the benefits of using thermal mass in building constructions to stabilize indoor temperatures, reducing the need for mechanical cooling.[20] Abden et al. (2022) also emphasized the combined use of PCMs and thermal insulation to enhance energy efficiency in residential buildings. Their study provided further evidence of the benefits of integrating advanced insulation materials and PCMs to achieve optimal energy performance.[21]

The design and material selection for office building envelopes in hot climates are pivotal in enhancing energy efficiency and occupant comfort. Qahtan (2023) explored the effectiveness of reversible smart insulated window glazing, finding that such systems can significantly improve building thermal performance in Saudi Arabia's extreme climates. This study highlights the role of advanced glazing technologies in reducing cooling loads and enhancing indoor comfort.[22] Alaidroos et al. (2022) focused on the impact of building envelope characteristics, such as thermal insulation and air leakage, on the effectiveness of PMV-based controls in schools. Their findings are directly applicable to office buildings, suggesting that well-insulated envelopes with minimal air leakage can optimize thermal comfort and energy efficiency [23]. Salih, Weli, and Abdulkader (2023) investigated the thermal performance of integrated PCMs in building structures, finding that such systems can reduce peak interior temperatures by up to 4.5°C, with a time lag of approximately 120 minutes and a decrement factor of about 0.34. These results indicate that PCMs can significantly enhance the thermal inertia of building envelopes, leading to improved energy performance and occupant comfort.[24] Hassan et al. (2022) reviewed recent advancements in latent heat PCMs and their applications for thermal energy storage and buildings, highlighting their suitability for use in building air-conditioning systems in Jeddah.[25] Alghamdi (2019) compared external and internal insulation options for non-insulated buildings in Saudi Arabia. The study found that external insulation is 50% more efficient than internal insulation, despite higher upfront costs. This suggests that investing in high-quality external insulation can yield significant long-term energy savings.[26] Their study emphasizes the importance of advanced insulation materials in achieving thermal comfort and energy efficiency in office buildings. Together, these studies underscore the critical role of advanced building materials and design strategies in creating energy-efficient and comfortable office environments in hot climates. During a thorough examination of existing literature on methods to enhance energy efficiency in office buildings located in hot climates, a significant deficiency was observed: there is a dearth of research specifically investigating the influence of Aluminum Composite Panels (ACP) on energy efficiency and thermal comfort. Although ACPs are often used in modern construction, their impact on energy usage and occupant comfort in hot regions has not been well studied. This omission is especially noteworthy for multiple reasons. ACPs are becoming more commonly utilized in contemporary building because of its attractive appearance, long-lasting nature, and adaptability. They provide a durable and lightweight choice for outside cladding, which can have a considerable impact on a building's thermal efficiency. Furthermore, structures located in hot regions encounter distinct obstacles associated with elevated ambient temperatures, strong solar radiation, and the resulting need for cooling. The selection of facade materials can significantly influence the total energy consumption of these structures by influencing the transfer of heat into and out of the building envelope. This research seeks to fill the current knowledge gap by examining the impact of ACPs on energy efficiency and thermal comfort, providing crucial data and insights. This involves assessing the impact of different varieties of ACPs, which have varying core materials and insulating qualities, on the cooling load of buildings, operative temperatures, and overall energy efficiency. Comprehending these impacts is essential for architects, engineers, and legislators who are working towards creating and executing environmentally friendly and energy-efficient structures in hot regions.

3. Methodology

This study utilizes a thorough methodology to assess the thermal efficiency of several types of Aluminum Composite Panels (ACPs) in office buildings situated in hot regions. The process comprises various essential steps, such as selecting materials, constructing models, setting up simulations, and analyzing the outcomes. Every stage is meticulously crafted to guarantee a comprehensive and precise evaluation of the influence of ACPs on energy usage and the comfort level of interior thermal conditions.

1. **Selection of Materials**: Perform an extensive literature review to identify frequently utilized varieties of Aluminum Composite Panels (ACPs) and evaluate their thermal characteristics.
2. **Building Modeling and Simulation Setup**: Create two office building models as a starting point, each with a different window-to-wall ratio (WWR). One model will have a 20% WWR, while the other will have a 50% WWR. These models will be designed in accordance with KSA codes and design principles. Utilize the DesignBuilder software to simulate these models, taking into consideration various façade orientations (north, east, south, west) in order to evaluate their thermal performance.
3. **Execute simulations** for the basecase models without ACPs to construct a control scenario. Perform individual simulations for each type (ACP) applied to both building models with 20% and 50% window-to-wall ratio (WWR).
4. **Conduct data analysis on the simulation findings**, specifically focusing on the cooling load, operative temperature, and energy usage. Conduct a comparative analysis of the thermal efficiency of various ACP types in relation to the baseline models. Analyze the influence of the direction of the building's exterior and the ratio of window-to-wall area on the effectiveness of Aluminum Composite Panels (ACPs). Determine the specific type of ACP that offers the highest thermal performance and energy efficiency for each window-to-wall area scenario.
5. **In conclusion**, based on the findings, recommendations are suggested: Determine the optimal ACP (Advanced Cooling Systems) variants for minimizing cooling demands and enhancing thermal satisfaction in hot regions. Examine the impact of façade orientation and window-to-wall ratio (WWR) on the thermal efficiency of ACPs. Provide concrete guidelines for architects, engineers, and policymakers about the utilization of ACPs in the context of sustainable building design.

This methodology seeks to offer a thorough assessment of the thermal efficiency of Aluminum Composite Panels in office buildings, thereby giving useful insights to sustainable architecture and energy-efficient building design.

4. Case Study Analysis

4.1 The Climate Analysis

The case study is situated in Jeddah, Kingdom of Saudi Arabia (KSA). Jeddah experiences a hot and dry climate, specifically classified as a maritime desert subzone.[27] The city experiences a temperature range of 48 ◦C at its highest and 13 ◦C at its lowest, along by fluctuating degrees of relative humidity.[28] Further information can be found in Table(1).

varying relative humidity levels, as explained in more detail in Table (1).

Jeddah experiences the highest number of Cooling Degree Days (CDDs) per year compared to other cities in Saudi Arabia, totaling 6587 CDDs,[26] as shown in Table(2)

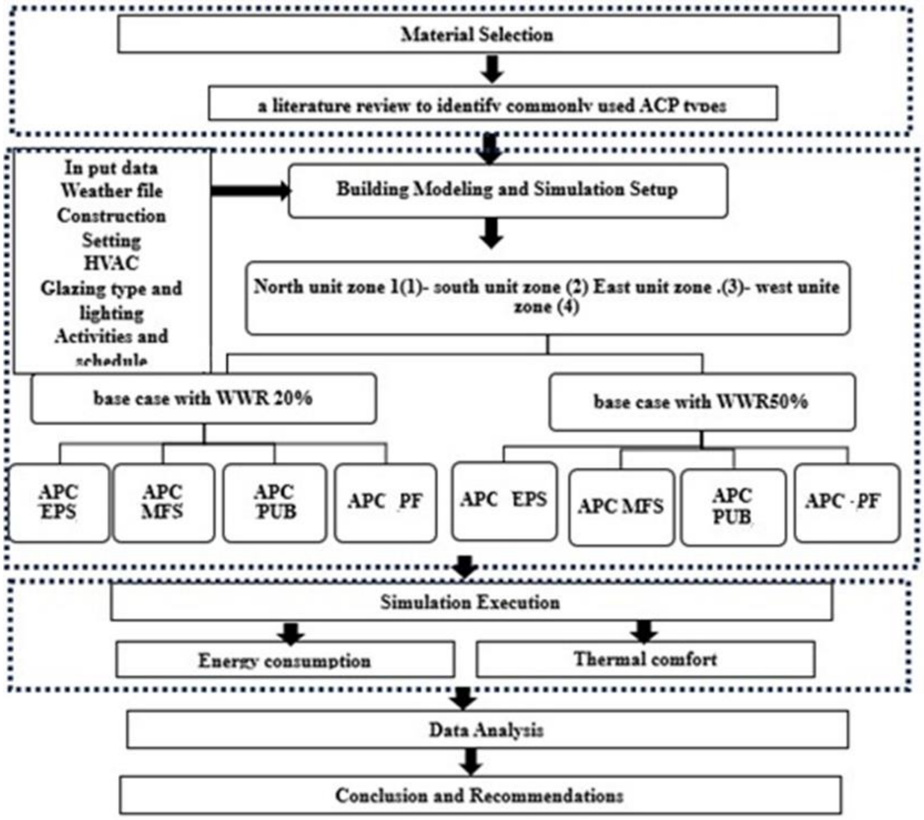

Figure 3 the research methodology source: the researcher

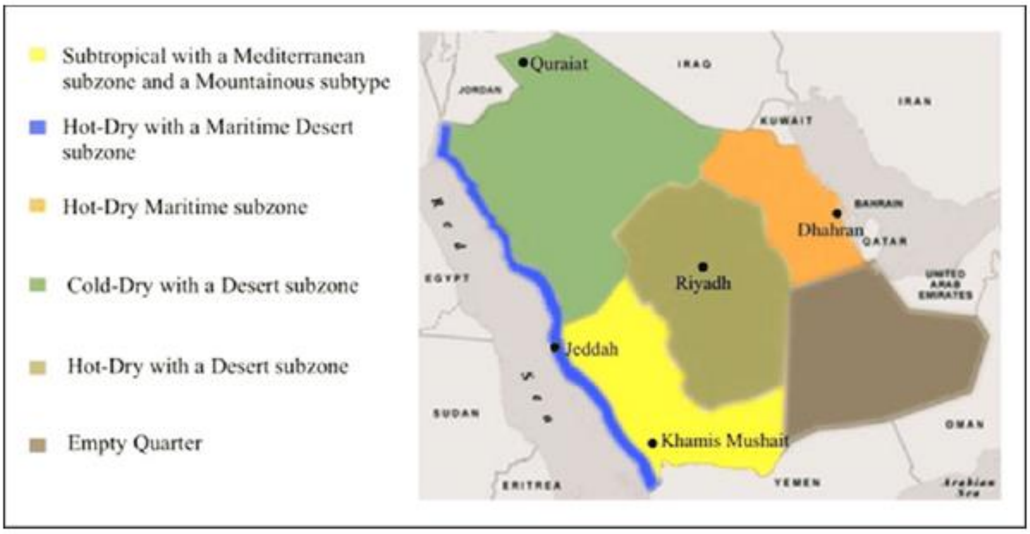

Figure 4 Climatic classification of Saudi Arabia source:[24]

Table 1 Temperatures and humidity levels in Jeddah city, KSA. [24]

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Max. Temperature	32	35	39	42	42	48	45	41.5	42	43	38	36.5
Min. Temperature	13	15.4	18	19	20	23.4	24.8	25	23.8	20	20	17
Relative Humidity	59	56	60	58	56	58	49	52	66	61	65	51

Table 2 Cooling and heating degree-days for five cities in KSA.[25]

City	Cooling Degree Days (CDDs) (°C-Days)	Heating Degree Days (HDDs) (°C-Days)
Jeddah	6587	0
Dhahran	5953	142
Riyadh	5688	291
Tabuk	4359	571
Abha	3132	486

4.2 Building modeling and simulation setup

The basecase model of the office building in this study is a standard office building with a floor space of 400 square meters. The building has been constructed with measurements of 20 *20 meters and features an enclosed inner courtyard. The building's height is roughly 10 meters. This model was chosen in accordance with the regulatory norms set by the Kingdom of Saudi Arabia. Two alternative versions of the base case model were examined to assess the energy efficiency of the building. The initial variant has a Window-to-Wall Ratio (WWR) of 20%, whereas the subsequent variant has a greater WWR of 50%. The building maintained same features and qualities in both forms. These two iterations of the fundamental model will enable a thorough assessment of the energy efficiency and possible compromises linked to various Window-to-Wall Ratios (WWRs) in office building.
For this research , we are using DesignBuilder simulation software to assess the thermal efficiency of different options for ACP (Aluminum Composite Panel) cladding systems. The selection of these alternatives was based on the findings of the literature review.

DesignBuilder is a commonly utilized software that models various construction materials, such as façade and insulation components, to simulate and forecast the thermal performance of buildings.The simulation will be performed twice, with two distinct Window-to-Wall Ratios (WWR) of 20% and 50% as shown in figure 5 and figure 6. The researcher will evaluate different types of ACP cladding systems for each WWR, as shown in Figure (8). The goal is to get a thorough comprehension of the impact of various ACP cladding systems on energy usage for cooling reasons. DesignBuilder's modeling technique provides flexibility in creating construction files that detail the various materials utilized in the façade cladding systems and specify their thermal qualities and specifications. Each of the four available possibilities for ACP façade cladding systems will be simulated for each WWR (Window-to-Wall Ratio) in order to evaluate and assess the thermal performance of each system. The performance of each system differs depending on its composition and the characteristics of the materials employed. The simulated options and the comprehensive breakdown of each scenario are displayed in Table (4). This comprehensive analysis will offer valuable insights into the most efficient ACP cladding systems for maximizing energy efficiency and ensuring optimal thermal comfort in office buildings in hot climate

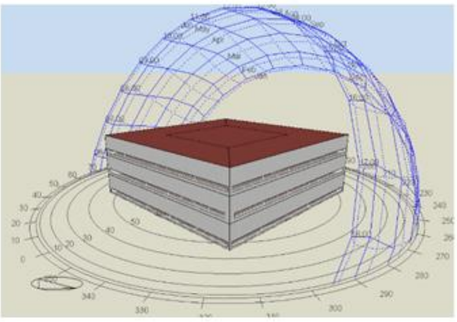

Figure 5 shows the DesignBuilder modeling WWR20%

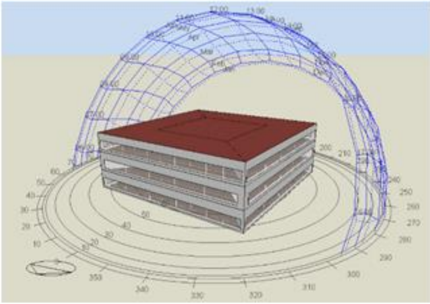

Figure 6 shows the DesignBuilder modeling WWR 50%

In order to carry out experiments and assess the thermal efficiency of the office building, the research suggests utilizing a representative 4-office unit as shown in figure (7). Each office unit will have a distinct orientation, with one positioned towards the west, one towards the east, one towards the south, and one towards the north. The office units will be situated on a standard floor of the building, facilitating concentrated investigation of individual office spaces. The subsequent sections discuss the characteristics of the model, table(3) such as its geographical location, meteorological data, scale, properties, and occupancy schedule for the base scenario

Step No.	Process Step	Details
1	Prepare Simulation Model	- **Location:** Jeddah, KSA - **Floor Space:** 400 m² - **Dimensions:** 20m x 20m per level - **Height:** 3.3m per level, total 9.9m - **Walls:** U-value = 5.11 W/m².K, R-value = 1.8 - **Glass:** U-value = 2.89 W/m².K, R-value = 0.25 - **Lighting:** 45.5 W/m² - **WWR:** 20% and 50%
2	Set Technical Parameters	- **HVAC:** As per Saudi Building Code 4 t/n - **Lighting:** 45.5 W/m²
3	Run Simulation Scenarios	- **Energy Consumption:** For WWR 20% and 50% - **Thermal Comfort Assessment**
4	Data Collection and Analysis	- **Collect:** Energy and thermal comfort data
5	Evaluate Outcomes	- **Analyze:** Energy consumption and thermal comfort for different WWRs
6	Reporting	- **Prepare Reports:** On energy performance and thermal comfort
7	Recommendations	- **Provide:** Design optimization recommendations based on simulation results

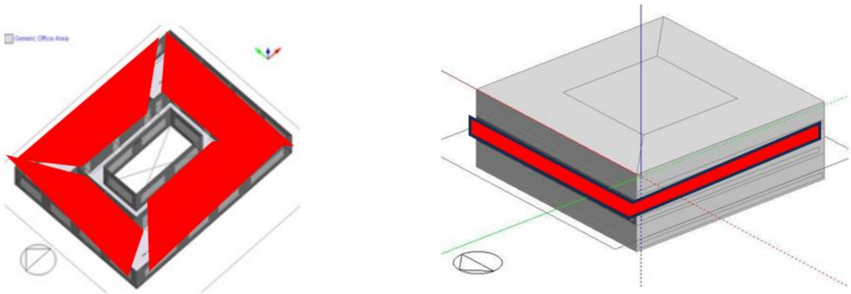

Figure 7 illustrates the different units with various orientations used in the simulation process. The simulation was conducted on a typical floor of the building

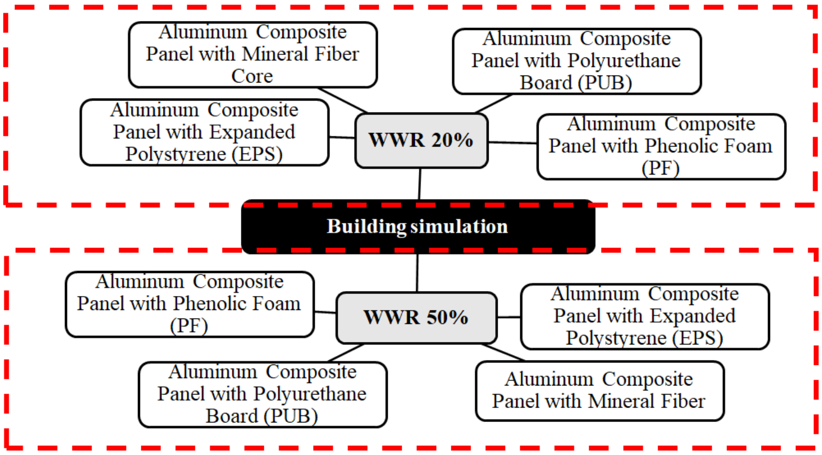

Figure8 simulated alternatives and the scenarios source: the researcher

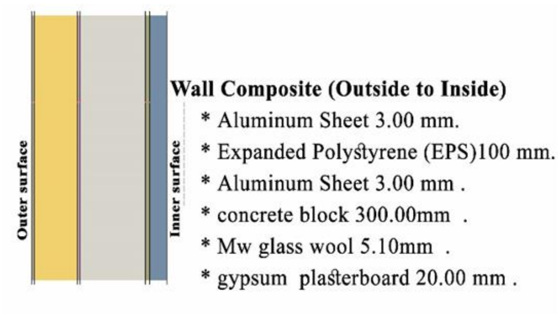

Figure (9) shows the cross section for ACP-EPS source the researchers

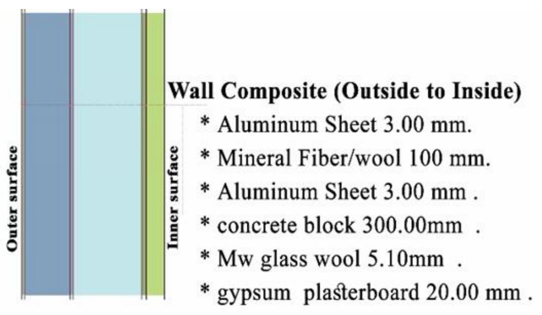

Figure (10) shows the cross section for ACP-MFS source the researchers

Table (4) simulated alternatives and the scenarios' composition details for each alternative and their properties . **source:** the researcher

	External Wall Composite (Outside to Inside)	U value (W/ m2 ·K)	Density kg/m3	Conductivity W/m.K	Heat Capacity (J/ (kg·K))	Wall U Value
External wall for base case without Aluminum Composite Panel (base case)	30cm concrete block					5.11
	5.1mm glass wool	0.3555	200.0	0.040	670.00	
	2 cm gypsum board					
External wall with Aluminum Composite Panel with Expanded Polystyrene (ACP-EPS)	Aluminum Sheet 3 mm	5.8817	2800.0	160.00	896.00	0.224
	Expanded Polystyrene (EPS)100 mm	0.3303	25.0	0.0350	1400.0	
	Aluminum Sheet 3 mm	5.8817	2800.0	160.00	896.00	
	30cm concrete block					
	5.1 mm glass wool	0.3555	200.0	0.040	670.00	
	2 cm gypsum board					
Aluminum Composite Panel with Mineral Fiber (ACP-MFS)	Aluminum Sheet 3 mm	5.8817	2800.0	160.00	896.00	0.21
	Mineral Fiber 100 mm,	0.3303	30.0	0.0350	1000.0	
	Aluminum Sheet 3 mm	5.8817	2800.0	160.00	896.00	
	30cm concrete block					
	5.1 mm glass wool	0.3555	200.0	0.040	670.00	
	2 cm gypsum board					
Aluminum Composite Panel (ACP) with Phenolic Foam (ACP-PF)	Aluminum Sheet 3 mm	5.8817	2800.0	160.00	896.00	0.224
	Phenolic Foam 100 mm	0.2	35.0	0.020	n/a	
	Aluminum Sheet 3 mm	5.8817	2800.0	160.00	896.00	
	30cm concrete block					
	5.1 mm glass wool	0.3555	200.0	0.040	670.00	
	2 cm gypsum board					
Aluminum Composite Panel with Polyurethan Board (ACP-PUB)	Aluminum Sheet 3 mm	5.8817	2800.0	160.00	896.00	0.17
	Polyurethane Board 100 mm	0.2398	30.0	0.0250	1400	
	Aluminum Sheet 3 mm	5.8817	2800.0	160.00	896.00	
	30cm concrete block					
	5.1 mm glass wool	0.3555	200.0	0.040	670.00	
	2 cm gypsum board					

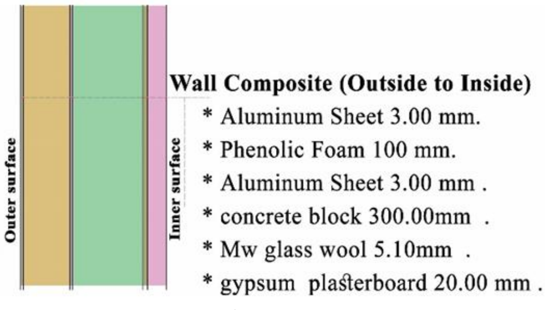

Figure (11) shows the cross section for ACP-PF source the researchers

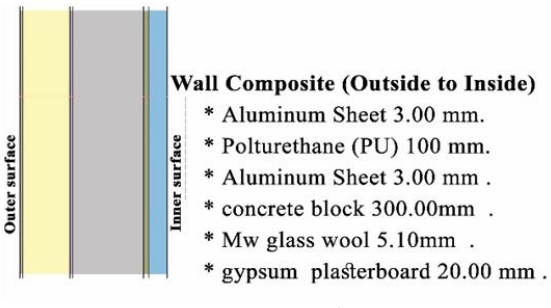

Figure (12) shows the cross section for ACP-PUB source the researchers

5. Results

Thermal Performance Analysis of Simulated Alternatives

Evaluating the thermal performance of alternatives to aluminum composite panels (ACP) is one of the study's goals. It is clear that in hot regions, thermal load has a major influence on energy usage. DesignBuilder software was used to simulate the listed alternatives and determine the cooling demand for each scenario. These situations were chosen in accordance with the literature review's discussion of their use in external facades. The outcomes of the simulations run under various ACP situations are instructive.

5.1 Evaluating Cooling Energy

In july, the case study region saw the largest cooling load, with the east and south-facing units displaying the highest energy usage for cooling Figure (9) and figure 10. To find each composite's thermal performance, four simulated compositions of ACP with various insulation core materials were examined. In case WWR was 20% The findings demonstrate that the performance of ACP using (EPS) insulating material is substantially similar to that of ACP using Polyurethane Foam (PF). In contrast to the other panel compositions, the ACP with Mineral Fiber (MFS) insulating material displayed a marginally reduced cooling load. the east unit's annual cooling load was 6787.7kWh, the south unit's 6321.48 kWh, the west unit's 6392.38kWh, and the north unit's 5397.7 kWh as shown in figure 13. This minimum cooling load was achieved with (ACP PUB) . For the east, west, south, and north façade units, the cooling energy consumption was lower than the base scenario by 6.2%, 7.2%, 5.6%, and 8.2%, respectively. This shows that the cooling electricity use is highest in the east and west units as shown in figure 13. After this performance, compared to the basic scenario, ACP MFS demonstrated a cooling load decrease of 5.7%, 6.6%, 5.1%, and 7.3% for the east, west, south, and north façade units, respectively.

The study examines the cooling requirements of office buildings, specifically focusing on the base situation when the window-to-wall ratio is 50%. The study assesses the efficacy of aluminum composite panels in comparison to different insulating materials in order to identify the most efficient material. The analysis revealed that ACP-EPS insulation resulted in a 2% decrease in the cooling demand of the base scenario, amounting to 6312.17 kWh. Similarly, ACP-MFS and ACP-PF exhibited reductions of 3.7% and 4.9%, respectively. ACP-PUB successfully achieved a reduction of 5.4%, resulting in a decrease in demand to 6082.82 kWh. The initial cooling demand reduced by 1.4% to 9764.09 kWh. Among the options, ACP-PUB had the most effective performance, reducing the demand by 2.8% to 9620 kWh. The initial cooling energy consumption was reduced by 1.5% to 8743.33 kWh, with ACP-MFS and ACP-PF reaching a 2% decrease as shown in figure 14. The most significant decrease was accomplished using ACP-PUB, resulting in a 3.3% reduction in cooling demand to 8506.9 kWh. ACP-PUB insulation exhibited the highest level of effectiveness in reducing cooling energy usage in all orientations, indicating its exceptional performance in improving energy efficiency in office buildings located in hot climates.

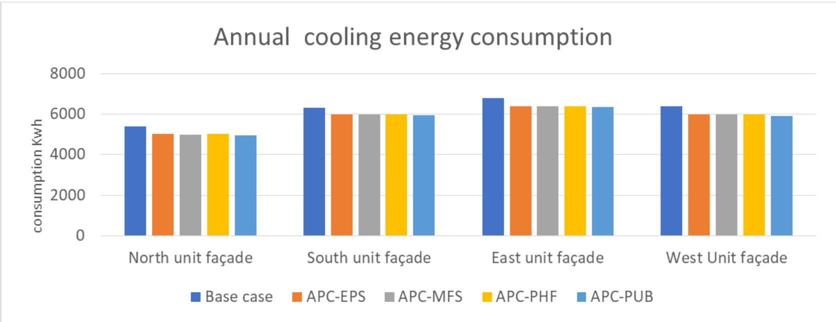

Figure 13 displays the annual cooling energy consumption for units with different orientations and ACP alternatives in case WWR 20% source :the researcher

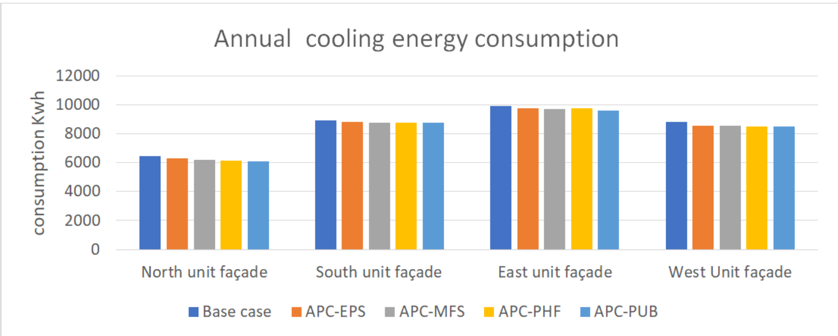

Figure 14 displays the annual cooling energy consumption for units with different orientations and ACP alternatives in case WWR 50% source: the researcher

5.2 Operative Temperature Analysis for Thermal Comfort Evaluation

The study evaluates the operative temperatures in two directions (East and South) both before and after the installation of aluminum composite panels (ACP) with several types of insulation materials (EPS, MFS, PF, and PUB)in two cases when WWR 20% and WWR 50%.

According to the study, office units that face east when WWR was 20% experience a maximum operative temperature of 30.69°C in July , mostly because of the sunlight in the morning. Enhancing thermal performance can be achieved by utilizing diverse aluminum composite panels (ACPs) that incorporate a range of insulating materials. EPS insulation decreases temperatures to 30.16°C, MFS insulation decreases them to 30.14°C, PHF insulation decreases them to 30.51°C, and PUB insulation achieves the most substantial reduction to 30.08°C. The base case operative temperature in July for south-facing units, which consistently receive sunlight, is 29.52°C. The EPS insulation decreases the temperature to 29.06°C, the MFS insulation to 29.05°C, the PF insulation preserves it at 29.06°C, and the PUB insulation leads to the lowest temperature of 28.98°C as shown in figure 15. In general, PUB insulation is the most efficient in lowering temperatures and minimizing the need for cooling energy, hence improving thermal comfort during the hottest months of summer.

In the case the WWR 50%, the east-facing unit had a peak operative temperature of 32.86°C, In July suggesting that it was exposed to morning sunlight. Various varieties of aluminum composite panels were employed in order to mitigate heat. (ACP-EPS) decreased temperatures to 32.55°C, while (ACP-MFS) and (ACP-PF) decreased temperatures to 32.54°C and 32.55°C, respectively. (ACP-PUB), the most efficient material, achieved a temperature reduction to 30.08°C, showcasing its remarkable thermal efficiency and capacity to minimize cooling energy requirements. Also In July, the south-facing unit, benefiting from continuous exposure to sunlight, maintained an operational temperature of 30.34°C. The ACP-EPS decreased temperatures to 30°C, but the ACP-MFS decreased temperatures to 29.99°C. The use of ACP-PUB insulation resulted in the most substantial reduction in temperature, reaching a low of 28.98°C as shown in figure 16. The study indicates that various types of ACP are successful in improving thermal comfort and reducing the need for cooling.

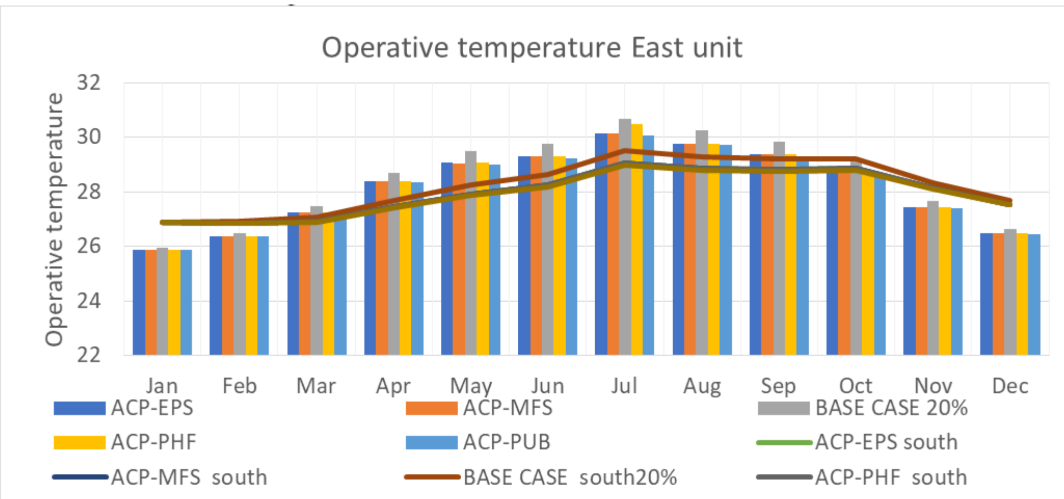

Figure 15 Comparative analysis for the operative temperature before and after using APC for east and south façade unit With WWR 20% source the researcher

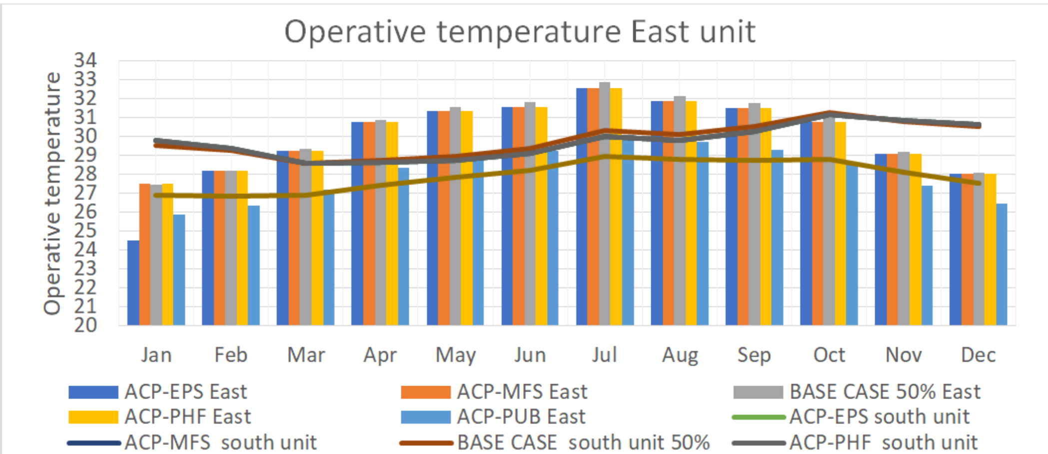

Figure 16 Comparative analysis for the operative temperature before and after using APC for east and south façade unit With WWR 50% source the researcher

5.3 Relative Humidity Analysis for Thermal Comfort Evaluation

This study investigates the influence of various aluminum composite panels (ACP) with insulation on the levels of relative humidity in office buildings. The study specifically focuses on units that are oriented towards the east and south directions. Regarding units that face east, the base case with WWR 20% data indicates that the highest relative humidity reaches 59.81% in September, while the lowest relative humidity drops to 51.38% in April. The introduction of ACP results in a minor rise in these values: ACP-EPS reaches 61.2% and 52.01%, ACP-MFS reaches 61.23% and 52.02%, ACP-PF reaches 61.21% and 52.01%, and ACP-PUB reaches 61.42% and 52.01%. The peak solar radiation for south-facing units is 61.93% in September and 50.36% in January. The levels of ACP insulation increase somewhat as follows: ACP-EPS to 63.23% and 50.33%, ACP-MFS to 63.25% and 50.33%, ACP-PF to 63.23% and 50.33%, and ACP-PUB to 63.46% and 50.30% as shown in figure 17.

The minimum and maximum relative humidity for the east-facing units which have WWR 50% are 46.79% in April and 54.67% in September, respectively. The introduction of different insulating materials in various aluminum composite panels (ACP) results in slight elevations in humidity levels. ACP EPS exhibits a variation from 55.29% in September to 46.89% in April. The ACP MFS achieved a 55.3% record in September and a 46.9% record in April. Similarly, the ACP PF. The ACP PUB has the most significant rise, reaching a peak of 55.36% in September and a minimum of 46.88% in April. The south-facing units experience a maximum relative humidity of 57.95% in September and a minimum of 45.14% in January, according to the base scenario. ACPs with varying insulations marginally increase humidity levels, with ACP-MFS reaching 58.64% in September and 44.59% in January, while ACP-EPS exhibits comparable patterns. ACP-PF and ACP-PUB display marginal differences, with PUB reaching a peak of 58.73% in September and a low of 44.48% in January as shown in figure 18. The minor increases in thermal regulation indicate that ACPs have a substantial impact on improving temperature control, while also causing a slight increase in indoor humidity. Efficient dehumidification methods are essential for controlling this rise, guaranteeing that the advantages of energy efficiency and thermal comfort are not negated by the disadvantages of elevated indoor humidity levels.

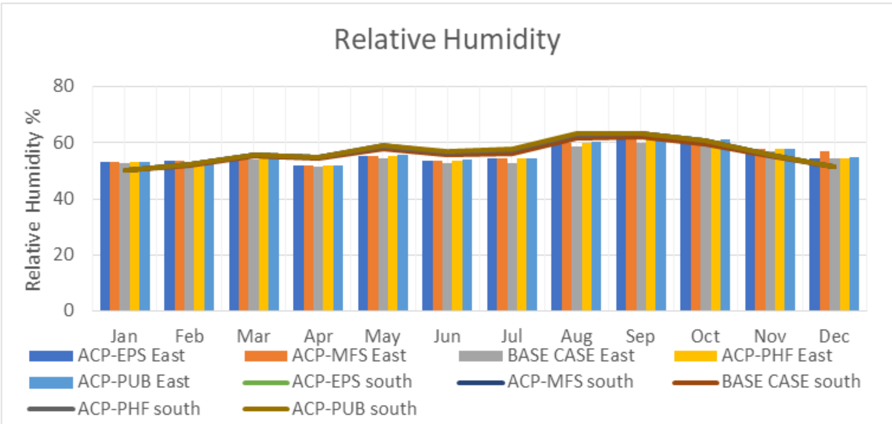

Figure 17 Comparative analysis for the Relative humidity before and after using APC unit in east and south façade With WWR 20% source the researcher

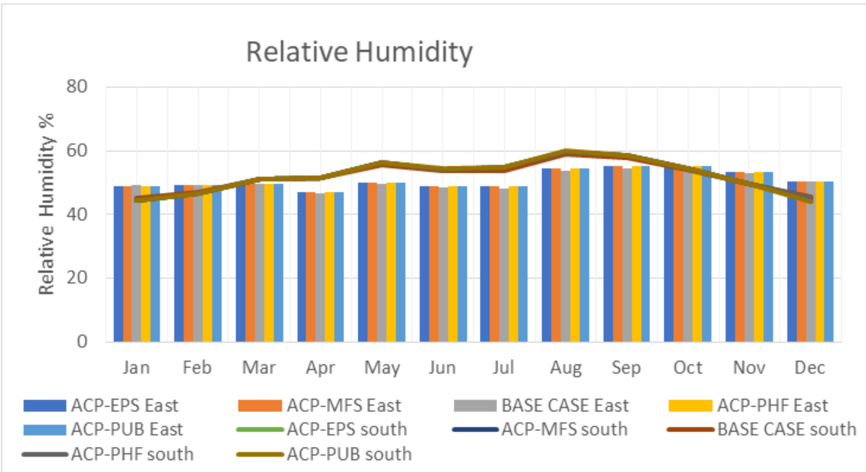

Figure18 Comparative analysis for the Relative humidity before and after using APC unit in east and south façade With WWR 50% source the researcher

6. Discussion of results

In hot climate where thermal efficiency is crucial, the selection of façade material is of utmost importance in determining a building's performance. The aim of this research is to assess the efficacy of Aluminium Composite Panels (ACPs) in office buildings to improve energy efficiency. (ACPs) are highly esteemed for their exceptional insulating characteristics. In this research, the impact of different types of ACPs on energy consumption and indoor thermal comfort was investigated using DesignBuilder modeling software. Research findings indicate that (ACP-PUB) is highly efficient in decreasing cooling loads. In particular, these panels demonstrated significant cooling reductions of 7.2% for units facing west, 8.2% for units facing north, 6.2% for units facing east, and 5.6% for units facing south, in comparison to the base case scenario WWR 20%. Notwithstanding the increased cooling requirements for southern and eastern units caused by prolonged sun exposure, ACPs successfully alleviate this issue by improving the thermal resistance of the exterior walls. This decrease in heat conduction results in reduced operative temperatures, therefore greatly enhancing overall thermal comfort.

Furthermore, ACP-PUB insulation invariably surpasses other materials in decreasing cooling energy consumption in all orientations. Under conditions where (WWR) is 50%, the cooling requirements for north-facing units reduced by 5.4%, east-facing units decreased by 2.8%, south-facing units decreased by 2%, and west-facing units decreased by 3.3%. An analysis of the WWR 20% and WWR 50% scenarios reveals that a reduced WWR improves energy efficiency when employing ACPs. The enhanced performance can be ascribed to the panels' capacity to more effectively impede heat transmission from the outside, thereby decreasing the cooling energy needed. These findings emphasize the need of choosing suitable façade materials and improving wind-water ratio (WWR) to achieve substantial savings in cooling energy consumption and improve building comfort in hot climate.

Following the introduction of the four distinct alternatives of aluminum composite panels (ACP), the operational temperature decreased by approximately 0.5°C during the summer months in all units. The observed reduction indicates an improvement in the capacity of a system to control temperature, leading to enhanced comfort for occupants and the potential for energy conservation in cooling. The decrease in operational temperature demonstrates the effectiveness of ACP in minimizing heat absorption and improving the overall thermal efficiency of the structures.

The analysis demonstrates that (ACPs) enhance insulation and energy efficiency, but they also raise relative humidity slightly. The observed phenomenon can be attributed to the decreased air exchange and enhanced thermal efficiency, resulting in increased moisture retention within the structure. Despite the slight rise in relative humidity, it has the potential to impact indoor comfort, particularly in hot climate. In spite of the energy savings obtained from improved insulation, higher humidity levels can cause interiors to seem warmer and may impact occupant comfort. Minimal differences exist in the effects of several types of ACP (EPS, MFS, PF, PUB) on relative humidity. The findings indicate that the selection of core material in ACPs has a notable impact on thermal performance, while its effect on humidity levels is comparatively less prominent. The analysis emphasizes that the fluctuations in relative humidity are more pronounced during periods of highest solar radiation, especially in September for units facing south. These findings indicate that ACPs may have greater efficacy in regulating temperature rather than humidity, and it may be necessary to employ supplementary techniques such as dehumidification to adequately control moisture levels.

7. Conclusion and recommendations

Optimizing energy efficiency in office buildings, particularly in hot regions, requires careful selection of the appropriate façade material. This study aims to fill the existing research gap on Aluminum Composite Panels (ACP) by utilizing the Design Builder application to carry out comprehensive thermal performance simulations. The objective was to assess several types of ACP (Advanced Cooling Panels) in order to determine their efficacy in reducing cooling loads and enhancing overall energy efficiency. The analysis evaluated the performance of several ACP materials in terms of thermal insulation, heat retention, and decrease of cooling load. The results indicated that ACP-PUB (Polyurethane Board) exhibited the maximum thermal efficiency compared to the other choices examined in both the base scenario. The exceptional performance of ACP-PUB can be attributable to its excellent thermal insulation qualities, which effectively restrict heat gain and minimize the energy needed for cooling. Therefore, it is the optimal selection for improving energy efficiency in office buildings situated in warm climates. Based on the simulations and research, ACP-PUB is recommended as the best choice for the façade material in hot conditions. It can significantly reduce cooling energy consumption and improve thermal comfort. Although (ACPs) provide evident advantages in decreasing energy usage and improving thermal comfort, it is important to take into account their little effect on raising relative humidity, especially in regions where humidity regulation is of priority. The optimization of building comfort and energy efficiency will depend on effectively balancing thermal insulation with humidity control.

REFERENCES

[1] Mohamed Abdelsalam, G., Razzaz, M. E., & Elnekhaily, F. (2020). Effectiveness of High Energy Efficiency to Minimize Energy Consumption for Residential Buildings in Egypt. Engineering Research Journal, 165, 78-95.

[2] Yang, T., Ding, Y., Li, B., & Athienitis, A. K. (2023). A review of climate adaptation of phase change material incorporated in building envelopes for passive energy conservation. Building and Environment, 110711.

[3] Dabous, S. A., Ibrahim, T., Shareef, S., Mushtaha, E., & Alsyouf, I. (2022). Sustainable façade cladding selection for buildings in hot climates based on thermal performance and energy consumption. Results in Engineering, 16, 100643.

[4] Sadafi, N., Jamshidi, N., & Zahedian, M. (2021). Energy efficient design optimization of a building envelope in a temperate and humid climate. Iranica Journal of Energy & Environment, 12(3), 255-263.

[5] Almarzooqi, A., Alzubaidi, A., & Alkatheeri, S. (2022, July). Fire hazards by aluminum composite cladding in high-rise buildings. In Proceedings of the 5th European International Conference on Industrial Engineering and Operations Management, Rome, Italy (pp. 26-28).

[6] Mohaney, P., & Soni, E. G. (2018). Aluminium composite panel as a facade material. Internationa jurnal of enginering trends and technology (IJETT)–Volume, 55.

[7] Dréan, V., Girardin, B., Guillaume, E., & Fateh, T. (2019). Numerical simulation of the fire behaviour of facade equipped with aluminium composite material-based claddings-Model validation at large scale. Fire and Materials, 43(8), 981-1002.

[8] George, L., Wuhrer, R., Fanna, D. J., Rhodes, C., & Huang, Q. (2019, November). Characterisation Techniques for the Identification of Composite Cladding Materials and their Thermal Properties. In 1st International Conference on Mechanical and Manufacturing Engineering Research and Practice (iCMMERP-2019).

[9] Guillaume, E., Fateh, T., Schillinger, R., Chiv, A., Ukleja, S. (2018). Study of fire behavior of façade mock-up equipped with aluminum composite material-based claddings, using intermediate–scale test method. Fire and Materials, 442(5): 5ss61-577. https://doi.org/10.1002/fam.2635

[10] Ablaoui, E. M., Malendowski, M., Szymkuc, W., & Pozorski, Z. (2023). Determination of thermal properties of mineral wool required for the safety analysis of sandwich panels subjected to fire loads. Materials, 16(17), 5852.

[11] Khan, T., Acar, V., Aydin, M. R., Hülagü, B., Akbulut, H., & Seydibeyoğlu, M. Ö. (2020). A review on recent advances in sandwich structures based on polyurethane foam cores. Polymer Composites, 41(6), 2355-2400.

[12] Yuen, A. C. Y., Chen, T. B. Y., Li, A., De Cachinho Cordeiro, I. M., Liu, L., Liu, H., ... & Yeoh, G. H. (2021). Evaluating the fire risk associated with cladding panels: An overview of fire incidents, policies, and future perspective in fire standards. Fire and materials, 45(5), 663-689.

[13] Dabous, S. A., Ibrahim, T., Shareef, S., Mushtaha, E., & Alsyouf, I. (2022). Sustainable façade cladding selection for buildings in hot climates based on thermal performance and energy consumption. Results in Engineering, 16, 100643.

[14] Zhang, Y., Zhou, R., Wu, T., Huang, C., Chen, Z., & Jiang, J. (2023). Experimental and simulation study on the combustion fire spreading characteristics of aluminum composite panels with different thicknesses. Fire and Materials, 47(5), 651-664.

[15] Ablaoui, E. M., Malendowski, M., Szymkuc, W., & Pozorski, Z. (2023). Determination of thermal properties of mineral wool required for the safety analysis of sandwich panels subjected to fire loads. Materials, 16(17), 5852.

[16] Khan, T., Acar, V., Aydin, M. R., Hülagü, B., Akbulut, H., & Seydibeyoğlu, M. Ö. (2020). A review on recent advances in sandwich structures based on polyurethane foam cores. Polymer Composites, 41(6), 2355-2400.

[17] Song, F., Li, Z., Jia, P., Bo, C., Zhang, M., Hu, L., & Zhou, Y. (2020). Phosphorus-containing tung oil-based siloxane toughened phenolic foam with good mechanical properties, fire performance and low thermal conductivity. Materials & Design, 192, 108668.

[18] Kiki, G., André, P., Houngan, A., & Kouchadé, C. (2021, November). Improving the energy efficiency of an office building by applying a thermal comfort model. In Journal of Physics: Conference Series (Vol. 2069, No. 1, p. 012172). IOP Publishing.

[19] Howarth, N., Odnoletkova, N., Alshehri, T., Almadani, A., Lanza, A., & Patzek, T. (2020). Staying cool in A warming climate: temperature, electricity and air conditioning in Saudi Arabia. Climate, 8(1), 4.

[20] Alayed, E., Bensaid, D., O'Hegarty, R., & Kinnane, O. (2022). Thermal mass impact on energy consumption for buildings in hot climates: A novel finite element modelling study comparing building constructions for arid climates in Saudi Arabia. Energy and Buildings, 271, 112324.

[21] Abden, M. J., Tao, Z., Alim, M. A., Pan, Z., George, L., & Wuhrer, R. (2022). Combined use of phase change material and thermal insulation to improve energy efficiency of residential buildings. Journal of Energy Storage, 56, 105880.

[22] Qahtan, A. M. (2023). Enhancing building thermal performance in Saudi's extreme climates through reversible smart insulated window glazing: Laboratory-scale experiments. Energy for Sustainable Development, 76, 101279.

[23] Alaidroos, A., Almaimani, A., Krarti, M., Qurnfulah, E., & Tiwari, A. (2022). Influence of building envelope characteristics on the effectiveness of PMV-based controls for schools located in Saudi Arabia. Indoor and Built Environment, 31(10), 2411-2429.

[24] Salih, S. O., Weli, R. B., & Abdulkader, A. A. (2023). Investigation of Thermal Performance of Integrated Phase Change Materials in Building Structure. Al-Rafidain Engineering Journal (AREJ), 28(1), 249-255.

[25] Hassan, F., Jamil, F., Hussain, A., Ali, H. M., Janjua, M. M., Khushnood, S., ... & Li, C. (2022). Recent advancements in latent heat phase change materials and their applications for thermal energy storage and buildings: A state of the art review. Sustainable Energy Technologies and Assessments, 49, 101646.

[26] Alghamdi, A. A. (2021). Numerical investigation of thermal insulation options for non-insulated buildings in Saudi Arabia. International Journal of Ambient Energy, 42(12), 1428-1434.

[27] Alrashed, F.; Asif, M. Climatic Classifications of Saudi Arabia for Building Energy Modelling. Energy Procedia 2015, 75, 1425–1430.

[28] Aldossary, N.A.; Rezgui, Y.; Kwan, A. Domestic energy consumption patterns in a hot and humid climate: A multiple-case study analysis. Appl. Energy 2014, 114, 353–365.

[29] Indraganti, M., & Boussaa, D. (2016). Occupant's thermal comfort in Qatari offices–Need for the new adaptive standard. QScience Proceedings, 2016(3), 23.

[30] Krarti, M., Dubey, K., & Howarth, N. (2017). Evaluation of building energy efficiency investment options for the Kingdom of Saudi Arabia. Energy, 134, 595-610.