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Enhancing Energy Efficiency in Higher Educational Buildings: Guidelines for Façade Techniques in Hot Arid Regions

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ABSTRACT

The use of air conditioning systems to cool buildings has a drastic increase worldwide, leading to an energy crisis particularly in hot arid climate regions, during the summer season. Therefore, building facades play a crucial role in indoor thermal comfort. To address these issues, adopting passive solutions in wall construction techniques in building facades can simultaneously reduce energy consumption and improve the indoor environmental quality.

This research focuses on the limited existing literature that specifically examines the challenges and opportunities related to building facades in educational buildings within hot arid climates. The novelty of this research lies in its in-depth exploration of materiality, techniques and design considerations tailored to educational buildings, offering valuable insights into effective strategies for improving energy efficiency and thermal comfort in these settings. The real results of this work encompass actionable recommendations and guidelines for the implementation of sustainable and energy-efficient building facade systems in educational buildings.

Keywords: climate change - educational buildings - energy efficiency- facade - passive techniques- thermal comfort

1 INTRODUCTION

Building façades play an important role in regulating the thermal performance of buildings, particularly in hot arid regions where extreme heat and solar radiation present massive challenges. The design and construction technique of façades directly impact the factors of indoor thermal comfort of buildings such as temperature control, natural ventilation and daylight utilization. Furthermore, energy efficiency in buildings is significantly influenced by the performance of façades, as they serve as the primary interface between the interior and exterior environments[1].

It is crucial to optimize façades for energy efficiency and thermal comfort particularly in hot zones, where there is a great need for ventilation and air conditioning. The need for air conditioning systems in buildings increases as temperatures rise, particularly during hot summer months. In particular, artificial lighting and air conditioning system are used in higher education services to regulate the temperature and light study areas, to reach the thermal comfort for students to be more productive[2].

Buildings on university campuses are increasingly being viewed as sustainable initiatives in the context of energy conservation and environmental quality because of their impact as medium- to large-sized townships with a variety of large-scale facilities, including lecture halls, research centers, laboratories, administrative offices and conference rooms, among other large-scale facilities[3].

Facades of educational buildings particularly universities in hot arid climate regions face challenges leading designers to giving aesthetics and philosophical forms over environmental aspects. This prioritizes technological advancements and practical impact on building performance and energy consumption rates. This negligence by the designers of the environmental aspects led to the negative performance of the building facade and high energy consumption in educational buildings. Poor façades of educational buildings contributed to severe problems and led to the decrease of student's performance inside these building[4].

The study highlights the importance of sustainable and energy-efficient building facade systems in educational buildings within hot arid climates. It does not only address the crucial need for optimizing energy consumption and enhancing indoor thermal comfort, but also aligns with several Sustainable Development Goals (SDGs) set by the United Nations. By adopting passive design strategies and integrating renewable energy sources in buildings and particularly in facades, this leads to enhancing the sustainability concept and the resilience of educational buildings. This approach improves energy efficiency and thermal comfort and mitigates the environmental impact associated with air conditioning systems, thereby contributing to SDG 13 (Climate Action). Moreover, the study supports the development of educational facades that integrate with the surrounding environment, promoting sustainable cities and communities as outlined in SDG 11. By addressing these SDGs, the research aims to drive positive changes, foster sustainable development and contribute to a more inclusive and environmentally conscious future[5].

The paper will address two phases: the literature review phase and the analytical phase. Phase one deals with different techniques for walls and highlight the main passive systems. Phase two is a comparative analysis between different facades techniques and materially to optimize energy efficiency in hot arid climate regions which seeks to provide a comprehensive result. The conclusion comes along with guidelines for façade a critical area as hot arid climate region must have effective façade design, insulation, shading systems and material selection are essential components in mitigating heat gain and reducing energy consumption for cooling and enhancing the overall building performance.

2. BUILDING FAÇADE AND ENERGY EFFICIENCY

The façade of a building serves as the first line of defense against external elements including heat, cold and noise. An energy-efficient façade plays a crucial role in reducing energy consumption and promoting sustainability. By incorporating proper insulation, high-performance windows and efficient shading systems, the façade can minimize heat loss during winter and prevent heat gain during summer resulting in significant energy savings for heating and cooling purposes. Additionally, an effectively designed façade can maximize natural light penetration, reduce the need for artificial lighting and enhance occupant comfort. The choice of materials, such as reflective coatings enhance the energy performance of the façade.

2.1 Façade of Educational Building

Energy-efficient buildings has historically focused more on office buildings, there is a growing recognition of the importance of energy efficiency in educational buildings. As educational institutions strive to reduce their carbon footprint and create healthier learning environments, research efforts are expanding to address the unique requirements and challenges of educational buildings.

The facade of an educational building is a critical element in achieving optimal energy efficiency, given its role as the interface between the interior and the external environment. This is particularly important for schools and universities, which often have high occupancy rates and extended operational hours, leading to significant energy consumption. The building envelope, encompassing the facade, roof and windows, serves as a protective layer against harsh weather conditions. By enhancing the facade's design it's the most important element in building envelope, educational buildings can reduce energy losses related to heating, cooling and lighting. The facade's insulation, airtightness and solar shading properties are key factors in minimizing energy use for temperature control figure 1.[1]

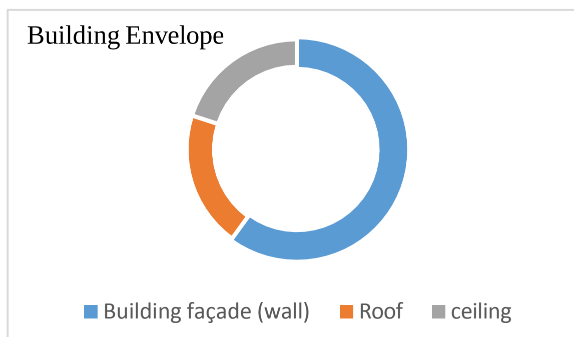


Figure 1: Components of building envelope
Source: [1]

The passive cooling of the building and the integration of renewable energy sources, into the facade design are important considerations for maximizing energy efficiency. These strategies not only reduce energy consumption but also promote sustainability[4].

2.2 Types of Building Façade

The building façade, like a skin, encases the building and effectively shields it from external influences such as rain, sound, temperature and wind. It also serves as the main contact between the outside and inside, allowing air and sunlight to circulate[6].Façade protects structures, extends building life and regulates energy consumption. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) classifies facades into exterior and semi-exterior parts. Advancements in technology have led to intelligent, responsive, sustainable and interactive facades that respond to the environment [7] .

A. Passive Façade

Passive cooling systems use natural processes like radiation, conduction, or convection to maintain comfortable indoor temperatures, reducing peak cooling loads and air conditioning equipment’s, promoting energy conservation and thermal comfort [8]. Traditionally, facades are static, unable to adapt to changing environmental conditions. The paper seeks to contribute to the understanding of passive design principles and their application in improving energy efficiency and comfort in buildings [9].

B. Active Façade

Active building parts require pushbutton innovation for occupant control, while frame innovation like engine frameworks interprets activity. Recent facade systems improve energy efficiency. Dynamic facades enhance energy efficiency in buildings by adapting to changing environmental conditions and performance requirements, thereby enhancing overall the environmental quality [10].

2.3 Impact of Climatic Change on Building Façade

This section discusses the impact of climatic change on thermal comfort on facades. Climate change is a significant global issue, posing a threat to Earth's ecosystem and society's survival. Its impacts are the increase of greenhouse gases and carbon dioxide, with anthropogenic activities being the largest contributor [11]

Hot arid climates are characterized by extreme dry heat, short winters and low precipitation. The Köppen climate classification defines arid climates as prevailing weather conditions that sustain little or no vegetation due to extremely low precipitation levels. Desert climates have two main variations: hot desert climate (BWh) and cold desert climate (BWk). Hot desert climates fig (1). experience peak heat periods, with maximum temperatures reaching over 40^{o}C-45 ^{o}C degrees Celsius during summer and a minimum of 35 at night. These regions have average temperatures well above the world average due to minimal winter periods and prolonged summers figure 2 [12].

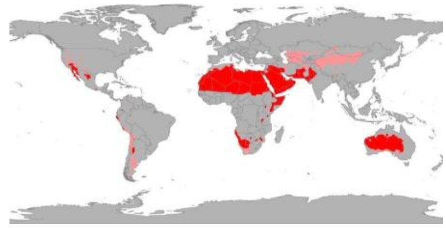


Figure 2: Classification of KOOPEN for hot arid climate. Source: [12]

2.4 Energy Consumption in Buildings

Buildings account for 40% of global energy use and carbon emissions, with cooling consumption varying based on design quality and climatic conditions. In hot climates, buildings with suitable heat and solar protection can reduce cooling loads to 5 kWh/m2/year, while low-quality environmental design can cause loads up to 450 kWh/m2/year[13].

Egypt accounts for 20% of petroleum and 40% of dry natural gas consumption in 2013. The country faces a challenge in meeting oil demand, which has increased by 3% annually over the past decade [2]. Energy consumption per capita stands at 0.88 toe in 2022, including 1 509 kWh of electricity. Total energy consumption increased slightly in 2022 after a strong rebound in 2021 (+7%). Previously, it had remained roughly stable over 2017-2020 and increased by around 4%year between 2013 and 2017.To be energy-efficient, buildings should control energy input through regulation systems or passive techniques figure 3[14].

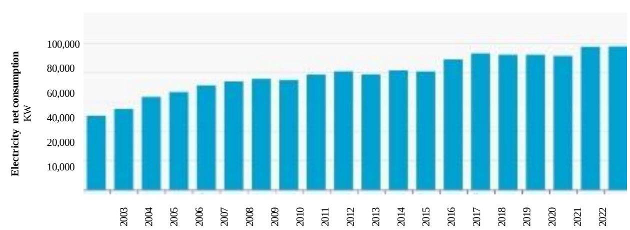


Figure 3: Total electricity net consumption in Egypt till 2022. Source: [15]

2.5 Building Façade Performance and Energy Efficiency in Facades

Energy efficiency in a building refers to the energy consumption per square meter of floor area, which is measured against established benchmarks for that building type under certain climatic conditions. Building energy consumption benchmarks are representative values for common building types [16] Energy efficiency in facades involves designing products and systems that use less energy while delivering higher performance, aiming to reduce fossil fuel use and climate change. This is crucial due to resource depletion and pollution. Techniques include shading devices, windows, glazing, insulation, passive techniques, renewable energy and low-energy materials. [17].

The thermal performance of a facade is crucial in hot arid climates, where the building envelope can contribute up to 30% to the heat load. Improving the facade's thermal performance can reduce the size of HVAC (Heating, ventilation and air conditioning) systems and lower energy costs [13] .Heat energy is transferred through conduction, convection and radiation. conduction occur through opaque facade assemblies; convection is caused by wind or pressure-driven air movement and radiant heat transfer from the sun through fenestrations. The building façade is influenced by energy usage, living quality and environmental factors, serves as the transition plane between microclimates.as shown in figure 4 [a,b] [18].

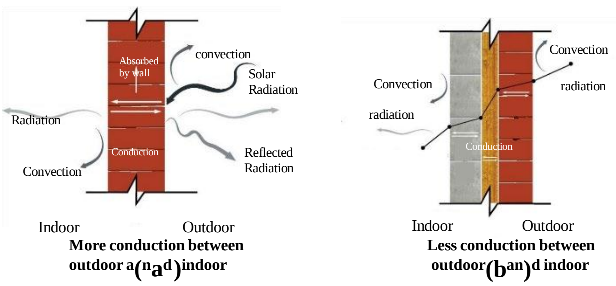


Figure 4: Heat transfer; (a) solid wall, and (b)composite wall.
Source: [12]

2.6 Enhancing Energy Efficiency in LEED

Energy efficiency in building design, particularly in the facade, plays a crucial role in achieving sustainable and environmentally friendly structures. The Leadership in Energy and Environmental Design (LEED) certification is a widely recognized standard that promotes sustainable building practices and recognizes buildings that meet specific criteria for energy efficiency, resource conservation and environmental responsibility. Energy efficiency is a key component of LEED certification, as it directly impacts the overall performance and sustainability of a building.

The relationship between energy efficiency in building facades and LEED certification is significant. Building facades are not only essential for the aesthetic appeal of a structure but also play a vital role in regulating energy consumption and enhancing indoor environmental quality. The design and materials used in building facades can have a substantial impact on the energy performance of a building, influencing factors such as heating, cooling and lighting requirements[19].

LEED certification places a strong emphasis on energy efficiency, with specific criteria and credits dedicated to promoting sustainable building practices. While LEED certification does not have a specific section solely focused on building facades, facade design is integrated into various aspects of the certification process. Credits related to energy performance, daylighting, thermal comfort and material selection all contribute to the overall energy efficiency of a building, with facade design playing a significant role in meeting these criteria.

The integration of facade design into the LEED certification process underscores the importance of considering energy efficiency in building design. Sustainable facade design can help reduce energy consumption, lower operating costs and minimize environmental impact, all of which are key objectives of LEED certification. By incorporating energy-efficient facade solutions, such as high-performance glazing, shading devices and insulation, buildings can improve their energy performance and qualify for higher levels of LEED certification.

3. PASSIVE COOLING SYSTEMS THAT ENHANCE FACADES' ENERGY EFFICIENCY

Incorporating passive cooling systems into building facades is a strategic approach to reduce energy consumption and enhance occupant comfort particularly in hot arid climates. These systems enhance processes like orientation, shading and ventilation, to mitigate heat gain and create a cooler indoor environment.

3.1 Orientation

Building orientation represents the relation between its elevations and the original geographical direction. In the design process, it is important to consider the actual quantity of solar radiation on the facades of a building as a whole, as it affects the thermal load of the building and controls the thermal behavior and the amount of thermal comfort [20]. In addition, it affects the quantity of ventilation crossing inside the building which in turn has a direct impact on the quantity of energy consumed in it to achieve thermal and life requirements [21].

Since the sun is the source of natural light and temperature, the building should be designed in such a way that consider the sunset and sunrise directions. Building orientation is crucial for passive thermal and visual comfort and should be decided early in the design process. Successful orientation minimizes energy loads and maximizes free energy from the sun and wind. Different orientation patterns impact energy consumption, with studies often choosing the East-West direction figure5 [20].

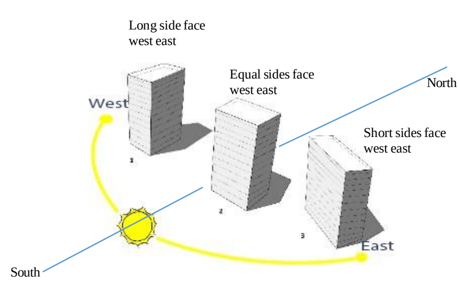


Figure 5: The best orientation of the building with the sun.
Source: Adapted by the authors

3.2 Windows

A. Openings

Windows in buildings provide daylight access, enhancing aesthetics, comfort and energy efficiency. Proper design minimizes artificial lighting and heat transfer, while strategic positioning ensures visual comfort and avoids direct sunlight access, reducing cooling demand [2].

B. Transparency and Window to wall ratio

Window design ensures optimal daylight and minimal cooling in a building envelope, balancing sufficient daylight with minimal heat transfer with the window to wall ratio (WWR) indicating optimal balance. Window size and orientation significantly impact internal conditions, with key design issues including maximum WWR (18%), glazed areas (10%). As for large glazed areas and large window areas it used solar shading devices, to ensure optimal day light and thermal comfort figure 6 [20].

Figure 6: Different WWR impact on optimal comfort. Source: [20]

The window to wall ratio significantly influences energy saving in buildings. The glazing system in buildings significantly impacts energy consumption, as it is responsible for heat loss and gains. Depending on the outside temperature and window size, windows can cause between 10 and 25 percent of heat loss and excessive heat absorption [22].

3.3 Shading Devices

Window shading is an effective method to protect the facade from excessive solar heat gain. Which can cause high interior temperatures and increase cooling loads for air conditioning systems. Proper design of shading devices can block sun in summer, while in winter, solar heat can warm the interior space and reduce heating loads. The type and angle of shading depend on the sun's orientation and position. The device should reflect sun radiations, prevent reflection and avoid hot air locking[2].

A. Fixed Shading devices

Fixed shading design is influenced by the sun's height and azimuth, with horizontal shadows having the most impact on the south side and ridge length estimated by the vertical louvers shading is crucial on the east or west side where solar height is low. However, the horizonal louver is located in north-south especially the north façade. Vertical fins can increase protection speed and shorten protrusion length. Eggcrate-shaped shadows combine vertically and horizontally, considering both solar and azimuth heights. As for geometrical or double skin it combines different geomatical shape that make the direct light pretend very difficult. for However, Figure7 illustrates different types of external fixed shading[23]

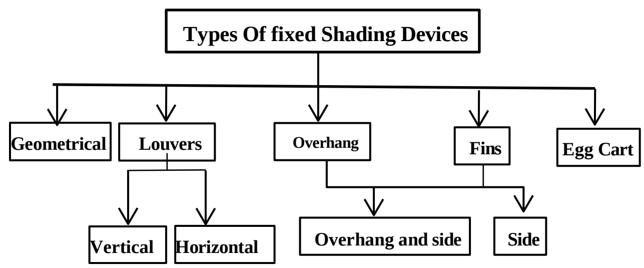


Figure 7: Types of fixed shading devices. Source: By the authors

Solar shading is a cost-effective, easy-to-implement solar passive cooling technique for thermal cooling in developing countries through utilizing overhangs, louvers and awnings to reduce peak heat gain and improve interior lightings figure8 [8].

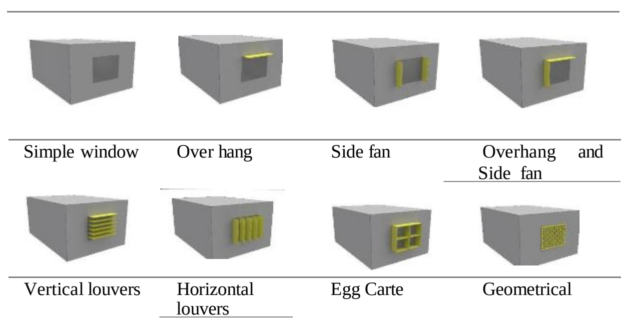


Figure 8: Shapes of fixed shading devices. Source: [20]

B. Movable Shading devices

Active or responsive shading systems, also known as dynamic or kinetic shading systems, are designed to respond to various environmental situations, such as daylighting control, solar thermal control, ventilation control and energy generation. These systems help buildings adapt to evolving external conditions and allow or block solar radiation access into interior spaces figure9.

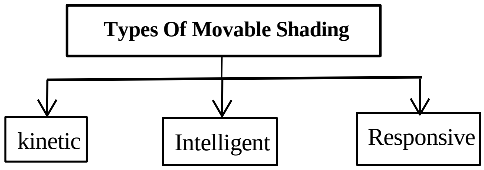


Figure 9: Types of Movable shading.
Source: By the authors

Active shading systems can be categorized into smart glazing, kinetic external shading devices and integrated renewable energy shading systems. Smart glazing devices include suspended particle devices, while kinetic systems, like rotating and folding ones, can be integrated with renewable energy [24].

The most optimal shades for movable shading in hot climates are overhang and horizontal louvers, which reduce energy consumption by 33% for cooling and 30% for heating, using folding movement technologies in kinetic architecture [25].

3.4 Natural Ventilation

Wind orientation enhances natural ventilation, reducing cooling energy demand and improving indoor climate comfort. Preventing dust infiltration requires air inlet options on the prevailing wind side [2].

A natural ventilation system consists of three components: ventilation inlets, a flow path through the space to the exhaust point and an outlet. Natural ventilation restricts the facade of the building, allowing natural light into much of the space and contributing to occupant satisfaction [26].

A. Single sided ventilation

Single sided ventilation strategy is applicable when a space has only one side along the elevation. Key considerations include: building orientation towards the prevailing wind direction, location of openings and windows towards the prevailing wind direction and elevation features to create the required negative pressure zone figure10.

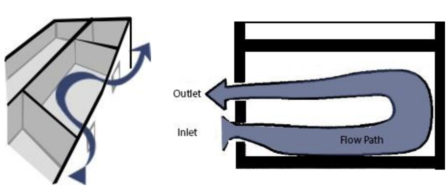


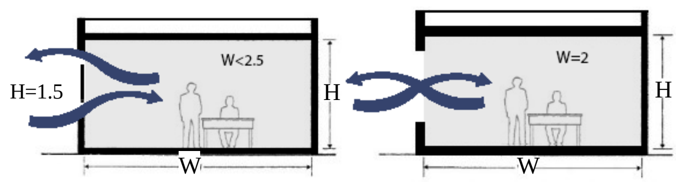
Figure 10: Single sided ventilation.
Source: By the authors

Single-sided natural ventilation relies on pressure differences across openings, with complex physical processes, especially wind-driven flow, influenced by outdoor wind conditions and turbulent motion. To optimize natural ventilation potential, buildings must be designed to maximize available airflow and have their main facades facing north and south figure10 [26].

The depth of a space is crucial for allowing fresh air into a building, with higher spaces promoting better air quality and thermal comfort. The effective depth of fresh air is essential in natural ventilation design [26].

Compared with an upper and lower opening geometry, a single large opening generates lower ventilation rates and the ventilated air does not penetrate as far into the space. Single-sided ventilation is therefore effective to a depth of about figure11:

- ➔ A.2.5 times the floor to ceiling height for an upper/lower opening geometry.
- ➔ B.2 times the floor to ceiling height for a single opening geometry.



(a) **(b)**

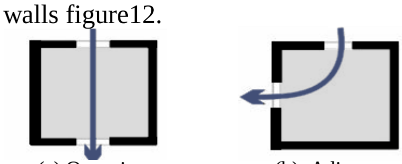
Figure 11: Effective depth for fresh air;
(a) Upper and lower, and (b) Large openings
Source: By the authors

Effective depth measures fresh outdoor air penetration into naturally ventilated buildings, ensuring thermal comfort and air quality.

B. Cross ventilation

Cross ventilation is a method for improving natural ventilation in indoor spaces by placing inlet and outlet openings at the diagonal of the space. Key considerations include building orientation, size of openings and space depth. Different cross-ventilation techniques are used to adjust wind velocity and achieve the required indoor air velocity. The presence of noticeable wind velocity and open area in urban planning are essential requirements for cross-ventilation [2].

Therefore, the ventilation flow rate of wind-driven cross-ventilation is more effective for thermal comfort than stack effect ventilation due to its ability to achieve high indoor air velocities. It can be classified into four configurations based on the number and location of wall openings. The first configuration has two openings in opposite walls and the second has two openings in adjacent walls figure12.



(a) Opposite (b) Adjacent

Figure 12: (a) Cross Ventilation, and (b)opposite and adjacent
Source: By the authors

4. MARTERIAL TECHNIQUES FOR FAÇADE ENERGY EFFICIENCY

4.1 Wall system

Walls are the construction of enclosing walls with facade systems in hot climates, considering the thermal air envelope formed at different orientations of buildings under facade insulation conditions. It reveals the importance of external walls in regulating the heat-wind regime of the air and room microclimatic layer. The analysis in paper outlines the facade systems for improving ventilation, ensuring microclimatic comfort and enhancing energy efficiency in building [27].

A. Thermal mass wall

Walls are important for building envelope and solar radiation, must have adequate heat storage and conduction properties. Careful selection of wall thickness, material, finishes and thermal insulation reduces heat transmission [28]. To achieve thermal mass, materials must have high specific heat capacity, density and moderate conductivity. Heavyweight construction materials like brick, stone and concrete have these properties, while wood has low thermal conductivity and steel has high conductivity table1.

Table 1. Building material Characteristics
Source: [29]

Building Material	Density (kg/m2)	Thermal Conductivity(W/mk)	Thermal Mass
Timber	500	0.13	Low
Steel	7800	50.0	Meduim
Precaste Concrete	2300	1.75	High
Bricks	1750	0.77	High
Sand stone	2300	1.8	High

Thermal mass indicates a material's ability to store heat fig .13, but other factors like the length of time for heat in and out, resistance to heat flow at the surface and thermal capacity, conductivity and density also play a role. Longer heating/cooling cycles lead to more heat reaching different depths within the available thermal mass. Longer-term average room temperatures define the thermal storage core temperature and heat gradient figure13[29].

Figure 13: Location of insulation to maximize thermal mass
Source: [29]

B. Glazed wall

The design of building facades, including opaque walls and translucent windows, significantly impacts energy consumption. Windows reduce heating and air conditioning, while providing light and energy savings. Traditional methods are best for improving building energy efficiency, as they provide sufficient energy savings figure 14 [30].

1. Single-pane windows

Single pane windows feature a single glass layer providing wind protection and low thermal insulation, with clear glass transmitting 70-90% of solar radiation.

2. Double-pane windows

Double-pane windows, with two glass panes separated by air or gas, reduce heat and cold transfer, while being more expensive but reducing cooling energy usage by 18% during summer.

3. Tinted glass

Tinted glass absorbs solar radiation, reducing indoor heat and light transfer. Gray, bronze, blue and green tinted windows have similar reflectance percentages, with grey offering better thermal performance.

4. Low-Emissivity (Low-E) coating

Low-E glass windows are transparent metal coatings that transmit light, minimize infrared and ultraviolet light penetration and reflect heat. They come in passive and solar control coatings for different weather conditions.

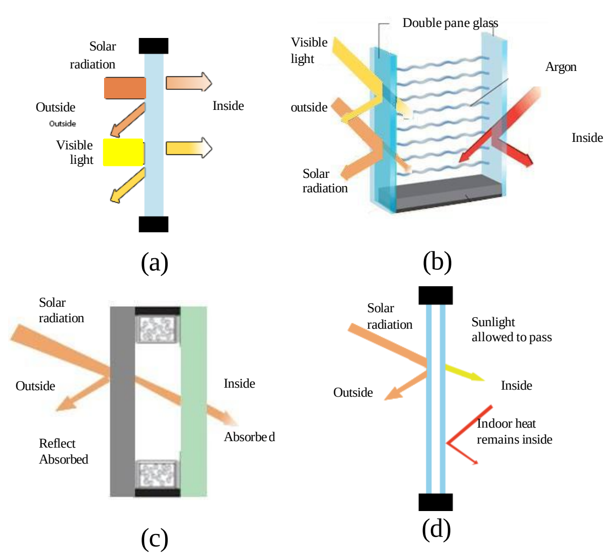


Figure 14: (a) Single pane window, (b) Double pane window, (c) Tinted glass, and (d) Low -emissivity
Source: By the authors

C. Thermal insulation wall

Insulation, placed on hotter surfaces, reduces space-conditioning loads by 15%. Optimal thickness depends on thermal performance, fire safety, moisture, condensation, air infiltration and environmental benefits [31] .Insulation materials in building facades can reduce energy consumption, increase comfort, ease installation, be lightweight and cost-effective, providing numerous benefits [32].

Traditional thermal building insulation consists of organic and inorganic. Inorganic such as mineral wool, including glass, rock and slag wool, is a fibrous material used in insulation materials, formed by mixing natural sand with recycled glass and melting stone. Organic like Polystyrene, Polyurethane, Cork and Cellulose are building materials enhanced with recycled paper, wood fiber and boric acid for improved thermal properties, resistance to pests, fire and corrosion [33].

4.2. Building Finishing Material

The choice of exterior wall finishing materials is crucial for energy efficiency in hot arid climates. Optimal finishes include insulation, reflecting solar heat and minimizing heat transfer. Light-colored or reflective finishes reduce heat absorption, while insulation prevents heat transfer, reducing air conditioning use. Proper selection enhances thermal performance, ensuring a comfortable and sustainable working environment [28].

A. Material specification

Building materials selection is crucial for passive design, considering thermal characteristics and climate responsive strategies. High thermal resistance insulation, reflective exterior finishes, high thermal mass materials and effective air and moisture barriers minimize heat transfer, stabilize indoor temperatures and prevent air leakage [2].

B. Thermal resistance and thermal conductivity of materials

Thermal resistance measures a material's ability to block heat transfer, impacting insulation effectiveness and energy efficiency in the building industry, while R-value measures global thermal conductivity and resistance [34].

In hot arid climates, reflective and low absorption/emissivity building materials are beneficial for reducing heat gain, maintaining cooler indoor temperatures and improving energy efficiency.

5. MATERIALS AND METHODS

In this section educational buildings in hot arid climate zones are analyzed and compared based on façade techniques and materials, including insulation, shading devices, ventilation strategies and material properties, with each example focusing on specific techniques. So, the comparative analysis had been done on several steps:

- General background and site information: This step involves gathering general information about the selected educational building, such as their locations and the specific climate characteristics they are situated in. Understanding the climate conditions, including temperature and solar radiation, is essential for evaluating the performance of the buildings' façades.
- Building characteristics: In this step, the analysis focuses on the buildings' material choices and construction methods. Information regarding the materials used for the building envelope, such as walls and windows. The construction techniques employed, including insulation methods and the use of shading devices, are also considered. These characteristics play a crucial role in the building's energy efficiency and thermal performance.
- Comparative analysis: The selected examples are analyzed and compared based on their façade techniques and materials. Key parameters for comparison include thermal insulation, shading devices, ventilation strategies and material properties.

Identifying the most adapted solution: Based on the comparative analysis, the building with the best outcome in terms of energy efficiency is identified. This building serves as a reference for developing the guidelines and recommendations for educational building façades in hot arid climates.

Optimizing of energy efficiency: The final objective is to establish a guideline for educational building façades in hot arid climates that aims to optimize energy efficiency. This guideline incorporates the findings from the comparative analysis and identifies the most suitable façade techniques and materials for the specific climate conditions.

5.1. Applications of Educational Buildings with Energy Efficient Facades

Here are some examples of educational buildings that have successfully implemented passive design techniques.

A. Université Mohammed VI Polytechnique (Bengari, Morocco)

Université Mohammed VI Polytechnique (UM6P) is a leading institution for higher education and research, located in Benguerir, Morocco. The university was established in 2017 with a vision to become a world-class institution entrepreneurship and sustainable development.

It is consisting of three floors. the university had used number of methods and approaches were used to maximize energy efficiency. These are a few of the main strategies for using passive design. To cut down on energy use, the institution implemented passive design ideas in its buildings. This elements like the correct orientation of the structure, the thoughtful positioning of windows to maximize natural light and ventilation and the use of insulation to reduce heat transmission[35].

B. Carnegie Mellon College (Doha, Qatar)

Carnegie Mellon College in Doha, Qatar, is a branch campus of Carnegie Mellon University (CMU) located in Education City, a hub for international universities in Qatar. The college offers undergraduate programs in Computer Science, Business Administration and Information Systems, all of which are designed to meet the needs of Qatar's growing economy and job market.

This example demanded a design for the "Green Spine" to traverse construction. The project was developed as rectangular building along the north side and as a semi-circle on the south side creating, at the center, an atrium connected to the "Green Spine". The rectangular as well as the circular part of the building were designed as a series of volumes the classrooms, the laboratories and lecture halls, each separated by courtyards. This succession of spaces creates an environment where teachers and students can interact [36].

C. Princess Nora Bint Abdulrahman University (Riyadh, Saudi Arabia)

Princess Nora bint Abdulrahman University (PNU) is a renowned women's university located in Riyadh, the capital city of Saudi Arabia. Established in 2007, it is named after Princess Nora bint Abdulrahman, a prominent member of the Saudi royal family and a champion of women's education in the country

It consists of four floors and a large courtyard. The majority of the PNU campus buildings are registered with the USGBC's LEED® rating system, with certification goals of LEED Gold and LEED Certifie To achieve LEED certification, various sustainable design and construction practices are implemented in PNU buildings. This includes incorporating energy-efficient systems, optimizing natural daylighting, utilizing renewable energy sources, implementing water conservation measures and selecting eco-friendly and locally sourced building materials [37].

D. Kuwait University College of Life Sciences (Ardia, Kuwait)

The College of Life Sciences at Kuwait University is a prestigious institution offering a comprehensive range of academic programs in various life science disciplines. Located in Ardiya, Kuwait, the college is dedicated to providing high-quality education and fostering scientific research in areas such as biology, biotechnology, biochemistry, environmental sciences and more.

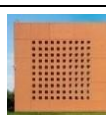
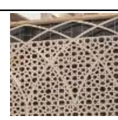
This exceptionally site-responsive building is notable for its dramatic, angular sloped façade and its cladding of striking, desert-colored, textured material. The array of diamond-shaped forms—perforated metal panels—filter natural daylight and shade the interior from the harsh sun. The color intensity of the golden structure changes with the sun’s movement throughout the day, much like the surrounding desert. The angular geometry of the panel array is echoed in the building footprint and surrounding landscape features[38].

E. Mohamed Bin Zayed university (Abu Dhabi, United Arab Emirates)

The building consists of four floors. One notable feature of the building is its emphasis on energy efficiency and sustainability. The use of thick reinforced concrete helps in maintaining a stable internal temperature by providing thermal insulation. Additionally, the building incorporates a variety of shading and cooling techniques to reduce the reliance on air conditioning and minimize energy consumption.

To mitigate the effects of solar radiation and heat, the university employs reflective materials on its exterior surfaces. These materials have the ability to reflect a significant portion of the sun's rays, reducing heat absorbed by the building[39].

Table 2. Façade techniques of educational buildings
Source: By the authors

		Name	Université Mohammed VI Polytechnique	Carnegie Mellon	Princess Nora Bint Abdulrahman University	Kuwait University College of Life Sciences	Mohamed bin Zayed university Masdar Institute / Foster	Remarks
PASSIVE COOLING SYSTEMS	Building	Image						Type of building all of them is **Educational Building**
	Characteristics	Location	Bengari	Doha	Riyadh	Ardia	Abu Dhabi	The buildings are located in the **Arab zone**, characterized by its **hot arid climate** and features various orientations. However, the majority of the buildings is oriented towards the **Northeast**, with the long façade positioned to minimize direct sunlight exposure and maximize shade from indirect sunlight. This orientation choice is driven by the objective of reducing solar heat gain and optimizing energy efficiency in response to the prevailing climatic conditions.
			Morocco	Qatar	Saudi Arabia	Kuwait	United Arab Emirates	
		Orienation						
			Northeast	East-West	Northeast	North	Northeast	
		Climate	Hot Arid Climate (Desert)	Hot Arid Climate (Desert)	Hot Arid Climate (Desert)	Hot Arid Climate (Desert)	Hot Arid Climate (Desert)	
		prevailing wind	East	Northeast	Northwest	Northwest	Northwest	
		Averge Temp.	10°C - 40°C	18°C - 45°C	14°C - 55°C	8°C - 43°C	18°C - 40°C	
	Window	Glazing Type	Single glazed	Double Glazed (low emissivity)	Double Glazed (low emissivity)	Double Glazed (low emissivity)	Double Glazed (low emissivity)	They commonly used **Double Glazing** with Low-E coating to: 1. Lower Energy consumption 2. Increased Thermal comfort
		Material characteristics	Normal glass Clear	Normal glass Clear	Normal glass Clear	Normal glass Clear	Normal glass Clear	
		Solar heat gain	Gain	Gain	Gain	Gain	Gain	
		WWR	10% void	10% void	70% void	95% void	25% void	
	Shading Devices	Shading Type	Egg carte	Louvers, Over hang	Double skin	Double skin	Double skin	Used different types of shading devises in facade orientated to direct sun light to give natural light in space without distortion
								
		Movement	Fixed	Fixed	Fixed	Fixed	Fixed	
		Material	Prefabricate concrete	Lime stone	Perforated metal	Perforated metal	Perforated metal	
		Visible tansmittance	-	-	Penetrate	Penetrate	Penetrate	
		Solar heat gain	Reduction	Reduction	Reduction And Gain	Gain	Gain	

		Name	Université Mohammed VI Polytechnique	Carnegie Mellon	Princess Nora Bint Abdulrahman University	Kuwait University College of Life Sciences	Mohamed bin Zayed university Masdar Institute / Foster	Remarks
	Ventilalation	**Type**	Single sided ventilation	Cross sided ventilation	Single sided ventilation	Single sided ventilation	Cross sided ventilation	They rely on single side ventilation due to improve thermal comfort in space.
MATERIAL TECHNIQUES	Wall Material	**Type**	Sand stone 	Lime stone 	Lime stone 	Curtain wall 	Glass fiber reinforced concrete 	In the construction of the building, materials with large thickness and low thermal conductivity were utilized.
		Thickness (mm)	50	30	40	12	40	
		Density (kg/m3)	1,800	1,600	1,600	100	2,200	
		Thermal conductivity (w/m2.k)	1.6	0.36	0.42	0.021	0.8	
		Refelction	-	-	-	Reflected	Reflected	
		Absorpation	Absorb	-	-	Absorb	Absorb	
	Insulation Material	**Type**	Expanded Polystyrene	Polyurethane	Polyurethane	Gas Filled	Expanded Polystyrene	Insulation materials with high resistance and low thermal conductivity. These materials are specifically chosen to minimize heat transfer through the building facade and maintain comfortable indoor conditions.
		Thickness (mm)	20	20	20	20	20	
		Thermal Resitance (m^2K/W)	0.76	0.94	0.94	0.24	0.76	
		Thermal conductivity (w/m2.k)	0.034	0.026	0.026	0.005	0.034	
		Refelction	-	-	-	-	-	
		Absorpation	Absorb	Absorb	Absorb	Absorb	Absorb	
	Finishing material	**Type**	Reflecting coating	Lime stone	Lime stone	Perforated metal	Local sand	Most of finishing material reflect sun rays and if it is absorbed it percentage is very low
		Refelction	Reflected	-	-	Reflected	Reflected	
		Absorpation	-	Absorb	Absorb	-	Absorb	

5.1. Findings and discussion

As shown in table the optimization of energy efficiency in educational buildings within hot arid climate regions demands careful consideration and strategic implementation. The comparison of educational buildings in various Arab countries has shed light on the diverse approaches to façade techniques and materiality of the use of insulation materials and thickness. It is evident that the selection of insulation materials and the appropriate thickness play a pivotal role in enhancing the energy performance of educational buildings in hot arid climates.

The study's examples all show that creating educational base units with their orientation toward the northeast in mind is a typical design strategy. This deliberate orientation accomplishes several goals, chief among them being ventilation optimization and maintaining the overall spatial integrity of the learning space. The base pieces are oriented in this particular way because windows have been carefully placed by the designers to allow for effective natural ventilation and airflow throughout the room.

At Université Mohammed VI Polytechnique and Carnegie Mellon have demonstrated that decreasing heat buildup within buildings can be achieved by optimizing the window-to-wall ratio (WWR) between 10% and 20%. One of the most important design factors for attaining better thermal performance and energy efficiency is the strategic control of WWR figure 15.

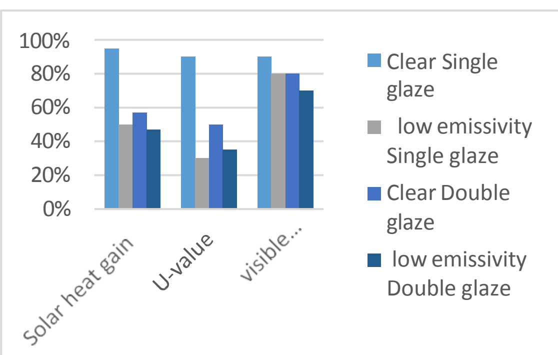


Figure 15: Comparison between the different types of glazing.
Source: By the authors

With regard to wall techniques, Carnegie Mellon and Université Mohammed VI Polytechnique serve as good illustrations of the significance of ideal wall design in hot, dry regions. effective application of ideal wall construction methods in hot, dry areas. These structures successfully handle the difficulties brought on by extremely high and low temperatures by utilizing walls that are thicker and have lower conductivity. The incorporation of these wall techniques results in increased occupant well-being, less discomfort from heat and higher energy efficiency.

The thickness of building materials significantly impacts their thermal performance, especially in hot arid climates. Increasing insulation thickness improves thermal resistance and energy efficiency. Wall thickness enhances thermal mass, absorbing and storing heat, reducing the need for cooling. Thinner walls help buffer temperature fluctuations by releasing heat gradually at night figure 16,17.

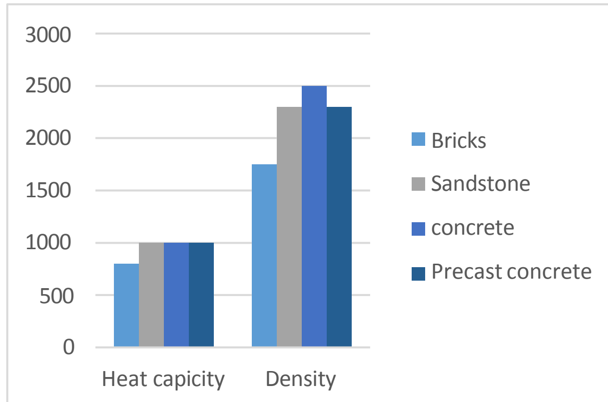


Figure 16: Comparison between heat capacity and density for construction material.
Source: By the authors

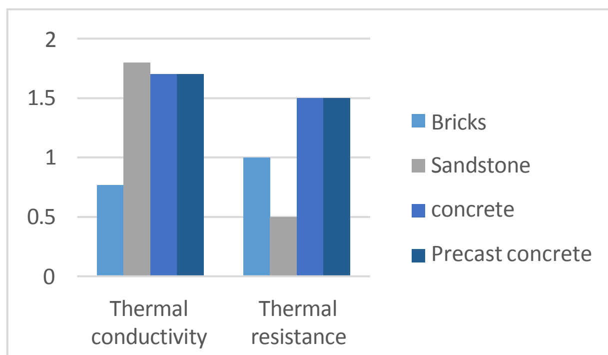


Figure 17: Comparison between insulation materials and its effect on façade.
Source: By the authors

It is generally beneficial to use building materials with high resistance and low conductivity to minimize heat transfer into the building. These materials can help reduce the reliance on mechanical cooling systems, improve energy efficiency and maintain comfortable indoor temperatures.

By incorporating materials with high resistance and low conductivity, along with effective shading and insulation measures, it is possible to create energy-efficient buildings that can withstand the challenges of hot arid climates while ensuring occupant comfort figure 18.

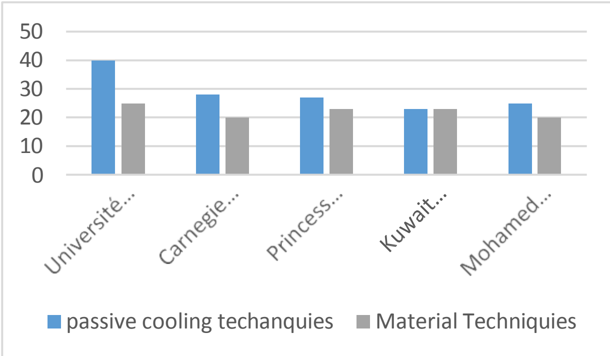


Figure 18: Comparison between university to find which one obtain higher Energy Efficiency.
Source: By the authors

University Mohammed VI Polytechnique has made significant efforts in adopting passive cooling techniques and incorporating energy-efficient materials to achieve energy efficiency in their buildings. Passive cooling techniques focus on utilizing natural ventilation, shading and thermal insulation to reduce the need for mechanical cooling systems and minimize energy consumption.

6. RESULTS: DESIGN GUIDELINES FOR EDUCATIONAL BUILDING IN HOT ARID CLIMATE

The guidelines for façades in hot arid climate regions should be tailored to address the specific challenges posed by these climates. Emphasizing the use of high thermal resistance insulation materials and integrating acceptable thickness of walls is essential to minimize heat transfer through the building facade. Therefore, the outcome of analyzing the educational buildings in the previous comparison table, are considered the design guidelines for educational building in hot arid climate figure 19:

1. Orientation:

- Considering the most effective orientation is east-west orientation as they are the most sensitive wall specially the west. So, both of them must be minimized. For effective daylighting, balanced solar gain and natural ventilation. Long side are facing north-south direction

2. Window-to-Wall Ratio (WWR):

- Optimizing the Window-to-Wall Ratio to balance daylighting and thermal performance.
- Determining north could have the maxim WWR. Although the south has low or medium WWR.
- Utilizing WWR as in east and west the opening is smaller than at north or south.

3. Shading Devices:

- Implementing appropriate shading strategies to minimize direct sunlight penetration for all sides.
- Using of shading devices such as overhangs, fins and louvers. Strategic placement and sizing of shading elements will help reduce heat gain while maintaining visual comfort.
- Applying fixed shading would be more useful if horizontal shades are placed on the south façade and vertical on east and west.
- Recording double skin one of important shading if needed to make WWR 90% or more.

4. Material Selection and finishing material:

- Choosing façade materials with low thermal conductivity and appropriate thickness.
- Determining the thickness of the materials should be based on the desired thermal performance.
- Choosing the local material as it always has the most components that resist heat.
- Using glaze type more than one layer with large thickness with low emissivity.

5. Insulation Materials:

- Utilizing insulation materials with high resistance to heat transfer.
- Using insulation options such as fiberglass, cellulose, or spray foam insulation can help reduce thermal bridging and minimize heat loss or gain through the building facade.
- Offering materials with high insulation properties, such as Polyurethane or Expanded Polystyrene.

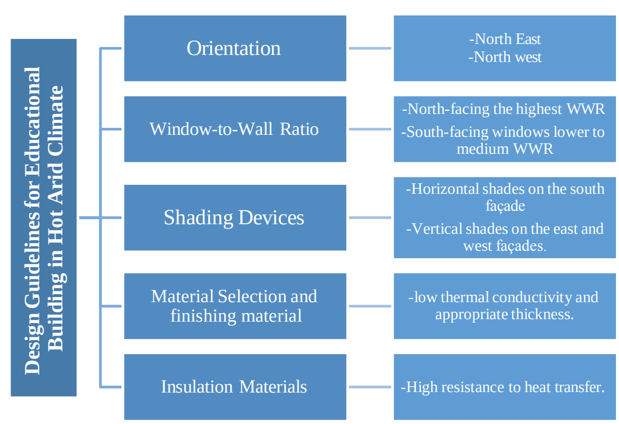


Figure 19: Guidelines to gain minimum energy efficiency in educational buildings
Source: By the authors

Implementing guidelines for façades in hot arid climate regions can maximize energy efficiency by minimizing heat transfer and optimizing natural daylighting, ventilation and thermal performance. The east-west orientation, north-south-facing long sides and balancing window-to-wall ratios help reduce heat gain. Strategic use of shading devices prevents direct sunlight penetration, reducing mechanical cooling needs.

Choosing low thermal conductivity façade materials, using glaze-type materials with multiple layers and incorporating high-resistance insulation materials further enhances thermal performance. This approach promotes sustainable practices and comfortable indoor environments, promoting sustainable practices in educational buildings

7. CONCLOUSION

Building façades are most important in controlling a building's thermal performance, especially in hot arid climates where intense heat and sun radiation pose serious problems. The elements of internal thermal comfort in buildings, such as temperature regulation, natural ventilation and daylight use are directly impacted by the design and construction methods of façades. Furthermore, because façades are the main point of contact between the interior and outside environments, façade performance has a substantial impact on building energy efficiency.

Optimizing façades for energy efficiency and thermal comfort is essential especially in hot arid climates where air conditioning and ventilation are more necessary. Higher education services, in particular, employ air conditioning and artificial lighting to control the temperature.

After what showed up in the comparative analysis these guidelines for façade design process are possible to optimize energy efficiency in educational buildings. Each of them has a unique layering of material with varying resistance and thickness by increasing one of the wall layers thickness or changing its arrangement, it gives different result. Therefore, all of them reach the optimum energy efficiency with different solutions.

The promising application is University Mohammed VI has used 90% of the passive cooling guidelines proposed to enhance energy efficiency through shading devices, optimal building orientation with long sides facing north and south, controlling the window-to-wall ratio (WWR) to maximize daylight while minimizing heat gain and using local materials with higher thickness. The use of shading devices, such as overhangs, sunshades and louvers, effectively blocks direct solar radiation, reducing heat gain and reliance on mechanical cooling systems. Building orientation minimizes direct solar exposure, improving thermal comfort and optimizing natural light and ventilation strategies. The WWR is carefully proportioned to allow sufficient daylight while minimizing heat gain, reducing the need for artificial lighting and cooling.

Therefore, educational buildings in Arab countries would improve energy efficiency by using an integration of successful design techniques. In such temperatures, the following are some perfect options for educational building facades: High-performance insulation to reduce heat transmission between the building's exterior and inside, the facade should use high-quality insulation materials. This lessens the need for very cold air conditioning and helps maintain a suitable space temperature. Through having careful considerations of orientation, shading techniques, material selection and insulation materials will contribute to reduced energy consumption, improved thermal comfort and enhanced overall building performance. To reach energy consumption for cooling and heating, ensuring a comfortable indoor environment.

Based on the literature study and analytical study. It is found that there is no specific value for minimizing energy in educational buildings particularly in hot arid region. This is due to the existence of several variables thickness of wall, insulation, WWR...etc. Which affect quantity of energy minimized.

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