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Evaluation of Mixed-Mode Strategies in Office Buildings of the Tropical Savanna Climate

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Abstract:- The interaction between architecture and the built environment has created a comfortable environmental condition free from external climatic effects with gradual changes and adaptation. This study aimed to investigate the mixed-mode strategy in office buildings of the tropical savanna climate, with a view to enhancing energy efficiency. The study was based on a qualitative method of inquiry using an observational checklist as an instrument of data collection. The key findings were; shading devices, and fenestrations were found to be very effective in the study area. While the recommended window to wall ratio for energy-efficient design was not complied with, in the design and construction of the studied building. The study concludes by recommending that architects need to be conscious in designing fenestrations in office buildings, and also window to wall ratio in their design from the initial stage so as to reduce the effects of intense solar gain into the building interior, especially in tropical climates.

Keywords:- *Architecture, Mixed-Mode Strategies, Office Building, Shading Devices, Energy-Efficiency Design.*

I. INTRODUCTION

The interaction between architecture and the built environment has created a comfortable environmental condition devoid of external climatic effects with gradual changes and adaptation. Mixed-mode buildings integrate both natural and artificial ventilation systems to provide human thermal comfort and save energy (Cheng, 2018). The quest in understanding the operation of a mixed-mode building is targeted toward maximizing comfort while minimizing energy use. Energy consumption in buildings has become a major issue of global debate (Muazu, 2012; Elijah & Abubakar, 2018; Musa & Abdullahi, 2018). A good understanding of a mixed-mode office building is essential for a successful building design especially in tropical savanna climate in a manner that, human comfort and energy needs will be envisaged, planned, and carefully incorporated in the design and operation processes.

According to Building energy efficiency guidelines for Nigeria (BEEG), globally, office buildings account for 40 – 60% of total electricity consumption (BEEG, 2017), most of which go to cooling systems (Adamu, Gillott, &Boukhanouf, 2019). This has called for the practitioners of the building industry to aggressively face the critical challenge of reducing energy usage, through a robust utilization of energy-efficient ways of designing and constructing buildings, to offset the global energy demand. The global campaign for the reduction of buildings energy consumption is largely due to the threats of climate change as contained in the 2030 agenda for sustainable development goals (United Nations, 2015). Research efforts concerning buildings energy efficiency are steadily making progress by focusing more attention on mixed-mode ventilation systems. This is a result of increased awareness of climate change and its effects (Rupp, Vasquez, & Lamberts, 2015).

Office workers spend a good number of hours daily in their offices engaging in all forms of office activities, it is important to provide an enabling environment for them so that, their productivity, efficiency, and wellbeing will be enhanced. An office building architecture has a critical effect on office activities (Habibullah et al., 2022). It is characterized by a complex socio-technical and environment system approach in which the task, employee, and the building are fundamental variables. Contemporary office design requires a more holistic person-environment system where space is considered in all its dynamic elements in which users modify their environment so that it meets their needs and expectations. Studies have also found the importance of people controlling their environment and established that in those situations, occupants became more satisfied with their thermal conditions (Brager*et al.*, 2004; Deuble*et al.*, 2010; Vischer, 2012; Alessi, 2015).

The aforementioned formed the basis for conducting a field survey in the Federal secretariat complex Bauchi (FSCB) -Nigeria, to evaluate the mixed-mode concept of the building, alongside, its compliance with the energy efficiency guidelines. The idea is to analyze the current situation and then come up with a recommendation on how the office buildings within the study area can be designed.

A. STATEMENT OF THE PROBLEM

The effects of global climate change have made the tropical savanna climatic regions difficult to improve through design due to its high outdoor thermal conditions, thereby, demanding for more energy to keep the building occupants comfortable. In Nigeria, energy consumption by offices is majorly for cooling amounting to 48-68% of total energy load (Batagarawa *et al.*, 2011; BEEG, 2017; Adamu *et al.*, 2019). These consumptions could severely increase up to 300% by 2050 if the current rate is unmanaged (Cabeza *et al.*, 2020; Fajilla*et al.*, 2020). Climate change predictions point to the chances of further increase of global temperature by 1.5^{O}C between 2030 to 2050 (IPCC, 2019). According to the National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN), between 1941 and 2000, a significant increase in temperature in Northeast-Nigeria was recorded to have risen by 1.4 – 1.9^{0}C (NASPA-CCN, 2011). Additionally, a projected increase of 0.04^{0}C per year up to 2046. This if unchecked, may result in unprecedented heat waves (Viceto*et al.*, 2019). In a tropical climate, heat waves increase morbidity, decrease productivity, and premature death (Elnabawi& Hamza, 2020). More so, the main sources of energy in Nigerian offices are either from the unreliable national grid or standby generators which are unsustainable, hence, the need to focus more on energy-efficient ways of designing and constructing buildings to avert the catastrophe that might occur. Elsharkawy (2018) established that design for human thermal comfort in mixed-mode offices has become increasingly necessary due to its direct effects on workers' health, productivity, and mental well-being.As an alternative to reduce the unnecessary use of mechanical ventilation in offices, increasing attention is being directed towards mixed-mode ventilation strategies (Luo, 2014)in workspaces.Furthermore, the current standards for human thermal comfort (ASHRAE standard 55, EN 15251, and ISO 7730) consider mainly air- conditioning and naturally ventilated spaces in their development, thereby, undermining the potentials of mixed-mode buildings which are the most dominant styles in tropical savanna climatic region. This has called for a re-evaluation of the existing models and seek for a new vocabulary that will not only consider mixed-mode building in its development but also, adequately respond to this new era of climate change.

This study attempts to fill the gap highlighted above by identifying the fenestration attributes of the study area, determining the window to wall ratio compliance of the study area, and finally, evaluating the shading elements of the study area to serve as a complementary tool to an integrated design process within the context of this study.

B. AIM AND OBJECTIVES OF THE STUDY

The study aims to investigate the mixed-mode strategy in office buildings of the tropical savanna climate with a view to enhancing energy efficiency.

a) Objectives of the study
- To identify the fenestration attributes of the FSCB building
- To determine the window to wall ratio compliance of the study area
- To evaluate the shading elements of the study area.

b) RESEARCH QUESTIONS
- What is the fenestration attributes of the FSCB building
- What is the window to wall ratio compliance of the study area
- What are the shading elements of the study area.

II. LITERATURE REVIEW

Mixed-mode buildings integrate natural and air-conditioning ventilation to provide thermal comfort and save energy (Cheng, 2018). Mixed-mode refers to a hybrid approach to the conditioning of spaces using a combination of natural ventilation from operable windows and mechanical systems that provide conditioned air distribution within the space. Ideally, a mixed-mode building should apply natural ventilation as a default ventilating strategy but use artificial cooling only when the natural ventilation becomes ineffective (Brager& Baker, 2008; Rijal, *et al.*, 2009). Designing a mixed-mode ventilated system is a complicated task, especially with the advent of global climate change, requiring thorough considerations of a range of factors such as; occupant thermal comfort, building envelope, building geometry, building orientation, surrounding environment, and, climate. A naturally ventilated building may not be capable of maintaining the indoor temperature within a narrow spectrum as an HVAC system is, this does not necessarily indicate occupants in naturally ventilated buildings would feel less thermally comfortable than those in mechanically conditioned buildings. (de Dear and Brager, 1998; Gossauer and Wagner, 2007; Manchanda, 2008). This is because people are active recipients of thermal stimuli, and therefore they would behaviourally, physiologically, and/or psychologically adapt to their environment (de Dear and Brager, 1998). The effectiveness of natural ventilation systems can be enhanced by theintroduction of courtyards, atriums, wind shafts, (Short & Lomas, 2007), double skin façade (Gratia & de Herde, 2004).The main goal of a mixed-mode ventilation strategy is to maximize occupants' thermal comfort while minimizing the energy use and operating cost of air-conditioning by providing occupants with adaptive opportunities. Previous studies revealed that in mixed-mode spaces occupants normally prefer natural ventilation as a default, eventually supplemented by cooling in the hot periods (Leaman, 2006).

The rising interest in mixed-mode ventilation systems led the International Energy Agency (IEA) to establish a project called Annex 35 "Hybrid Ventilation in a new and retrofit office buildings" to investigate the mixed-mode systems and to develop guidelines for their design. The mixed-mode system is classified into three different categories:
- Concurrent: This is the most prevalent system where air-conditioning and operable windows are in the same space at the same time. A typical example is an open-plan office space with air-conditioning and operable windows that works simultaneously to provide comfort to the occupants. This is the most common ventilation type in the study area.
- Changeover: when the building switches between mechanical cooling and natural ventilation on a seasonal or daily basis. The building automation system determines the mode of operation based on outdoor climatic conditions.
- Zoned or zone-based: when mechanical cooling and natural ventilation operate in different areas of the building (Brager, 2007).

Among the studies of Annex 35, one was conducted at Sydney University, the Wilkinson Building(Brager, 2007). It was a zoned mixed-mode ventilation environment where libraries, computer laboratories, and lecture theatreshad an artificial ventilation system while offices, teaching studios, and workshops were naturally ventilated. The study considered 25 naturally ventilated offices for staff which was provided with an occupant-controlled cooling/heating system. The design was aimed to allow occupants to exercise much flexibility in terms of controlling their office environments to provide or restore comfort to themselves. The results revealed that occupants of the naturally ventilated spaces are more satisfied with the perceived air quality than their counterparts in mechanically ventilated environments.

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Additionally, the provision of operable windows alongside mechanical cooling/ heating systems enhanced the occupant's flexibility of changing the unsatisfactory conditions to the more comfortable conditions which highlighted the friendly relationship in the application of both passive and active ventilation strategies. The study found that office occupants' comfort was best achieved in mixed-mode ventilation buildings than air-conditioned spaces(Rowe, 2003).

This research aims to focus on a mixed-mode ventilated strategy in office buildings of the tropical savanna climate with a view to enhancing energy efficiency. Previous research examined either zone-based mixed-mode environments, comparing natural ventilated with air-conditioned spaces, or analyzed mixed-mode buildings in change-over mode. The studies found that the mixed-mode space guaranteed better thermal comfort to its occupants compared to natural ventilated or air-conditioned spaces. This suggests a gap in research.

III. RESEARCH METHODOLOGY

Research Methodology systematically solves the research problem (Kothari, 2004). The purpose of research methodology is to provide a detailed explanation of the procedures used in carrying out the research. In trying to satisfy the requirements of this study, an observation checklist was used as an instrument of data collection. The data collected were analyzed using content analysis.

A. Study Area

The study was conducted in Bauchi, Bauchi State, Nigeria and it is classified as the tropical savanna climatic region based on Koppen's climate classification. Bauchi is the headquarters of the Bauchi Local Government area of Bauchi State Nigeria. It is located on latitude $10^{0}17^{1}$N and Longitude $09^{0}49^{1}$ E. Bauchi state is located in North-Eastern Nigeria, it covers an area of 45,837 square kilometers(figure 1) below. The climatic condition of Bauchi State is very hot in April and May, while December and January are the coldest months(Awolola and Olurunmaiye, 2020).

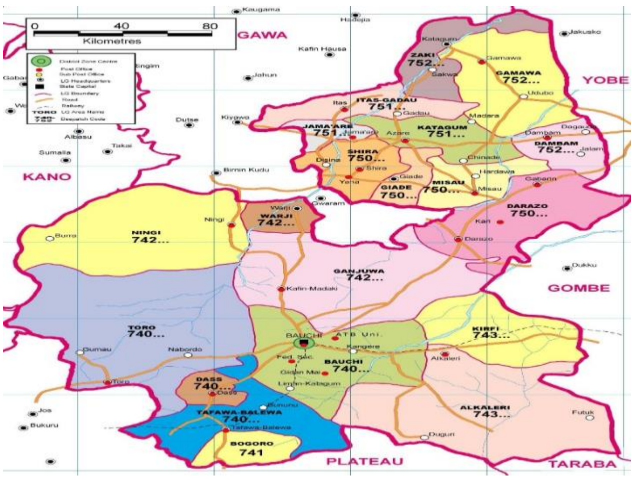

Fig. 1: Map of Bauchi State- Nigeria

Source: www.nigeriansat.gov.ng (2021)

B. Characteristics of a case study building

This segment of the research seeks to address the research aim of this study which seeks to evaluate the mixed-mode strategy of the study area. Mixed-mode (hybrid) buildings integrate both natural and artificial ventilation systems to provide thermal comfort and save energy (Cheng, 2018). The Federal secretariat complex, Bauchi is located on the Federal Secretariat Road, off Yakubun- Bauchi Road, Bauchi, Bauchi State, Nigeria. The building has a Global Positioning System (GPS) coordinate of 10^{0} 17^{I} 58.14^{II} N and 9^{0} 49^{I} 25.51^{II} E. The selection of the building for the case study was aimed at a detailed investigation of mixed-mode strategy in office buildings of the tropical savanna climate. This, therefore, necessitates the selection of a building that offers various adaptive opportunities to its occupants, which includes; operable windows, operable doors, operable blinds, and decentralized HVAC control. FSCBbuilding is a 4-story building presently accommodating 42 Federal Ministries, Departments, and Agencies, (FMOWH, 2021), with other auxiliary facilities such as; a staff canteen, Federal staff clinic, Business Centre, and 2 conference halls. The building has 3 central courtyards that aid in natural lighting and ventilation as seen in Figure 2. All offices are arranged on the verandas thereby, making it accessible to natural lighting and cross ventilation.

Fig. 2: Satellite view of the Federal secretariat complex, building

Source: goggle earth pro (2021)

IV. RESULTS AND DISCUSSIONS

The principle of a mixed-mode building is far from being a conventional air-conditioned building with operable windows. Mixed-mode buildings are intelligently designed to integrate climate-responsive design concepts ofa building envelope. In trying to satisfy the requirements of this study, an observation checklist was used as an instrument of data collection. The data collected were analyzed using content analysis.

A. *Observation Checklist*

The observation checklist was set up to guide the data collection for the assessment of the mixed-mode content of the study area. The checklist was developed through an in-depth review of relevant literature and careful selection of the most relevant variables. The building's floor plan was drafted as a requirement for the study due to the unavailability of the building's original floor plan. The building's information was sourced from the building's custodians (Federal Ministry of Works and Housing). The mixed-mode strategy of the case study building was analyzed and presented in table 1.

Ventilation type			**Window control**		
Windows	Vents	Stack	Manual window operation	Mechanical window operation	Window HVAC interlock
✓			✓		

Mixed-mode classification			**Building's floor height**			
Concurrent	Change over	Zoned	Ground	First	Second	Third
✓			3.0m	2.9m	2.9m	2.9m

Table 1: Mixed-mode Strategy of the Study Area as Observed

Source: Author's fieldwork, 2021

B. *Content Analysis for Building Envelope*

In this section, the evaluation of the mixed-mode content of the study area was discussed in conjunction with relevant studies carried out by previous researchers. The analysis was guided by the quest in answering the research questions of this study.

a) Building envelope

Building envelope simply refers to a structural barrier between the interior and exterior of a building that influences the occupant's comfort. The elements of the building envelope considered in this study are; fenestrations, window to wall ratio, glazing, and shading devices. Fenestration is an important element of the building envelope that remarkably influences building ventilation. In architecture, fenestration means opening in a building's facade, most notably, doors and windows. The current global climatic emergency makes it necessary to utilize the potentials and techniques of building design and construction to achieve the desired comfort. Fenestration offers building occupants thermal potential, visual comfort, security, and privacy.

The FSCB offices have adequately employed the concept of wind-driven cross-ventilation. The depth of all offices is 6m center to center but with varying widths, depending on the office occupancy. The air movement and sunlight through windows can reach the farthest distance of about 6m from the window (Ghassan *et al.*, 2021). This means that the FSCB offices having had windows in the opposite direction at 6m maximum distances will optimally allow more daylight and airflow into the offices which can create a balance between the consumption of energy in both cooling and lighting systems. Cross ventilation is most recommended than single-side ventilation due to air temperature distribution and thermal comfort (Reda *et al.*, 2021). Office occupants' health and productivity is a factor of sufficient ventilation and tolerable indoor air quality (Reda *et al.*, 2021).

According to BEEG (2017), cross-ventilation is more effective since the wind pressure will force the air through the building to a maximum office depth of 12m. cross ventilation provides better performance in thermal comfort, and indoor air quality than single-side ventilation (Kyritsi and Micheal, 2020; Ahmed *et al.*, 2021). The building form of the FSCB is rectangular with the longest side laying on the East-West direction (Figure 3), thereby, having more windows on the North and South facade than East and West based on its orientation. Windows are the weakest points of the building envelope, especially for cooling and heating. Therefore, the window's location, size, glazing, internal and external shading can have a significant influence on the thermal comfort and energy efficiency of a building.

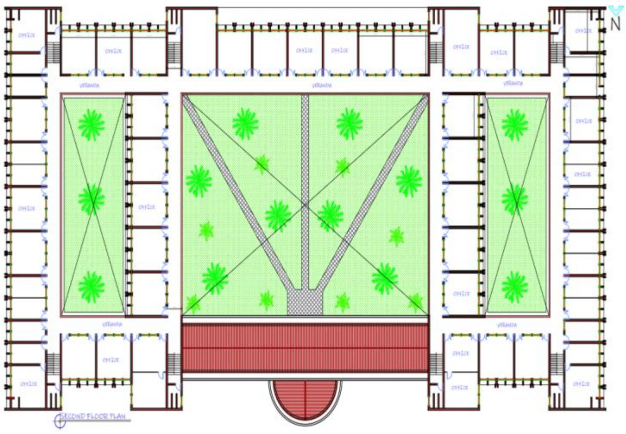

Fig. 3: Building form of the Federal secretariat complex, building

Source: Author's fieldwork, 2022

The concept of cross-ventilation in the FSCB is enhanced by three (3) central courtyards (Figure 2 &3). The office window sizes are 1200X1500mm. All external windows are awning top-hung (projected) type and all veranda windows are horizontal fin (Louver) type (Figure 4). According to Ghassan *et al.,* (2021), awning top-hung and horizontal fin windows are 75% and 90% effective respectively in terms of air admittance. Designing large windows in offices will allow for the passage of more daylight and creates a balance between the cooling systems and energy consumption for lighting (Fasi and Budaiwa, 2015) but, its location on the building has to be adequately considered due to heat gain and loss through windows. In essence, the ventilation in the FSCB building is very effective having considered the design principles of passive cooling in tropical climates.

Fig. 4: Window opening types

Source: Fieldwork, 2021

Walls are important building elements that significantly affect thermal comfort and buildings energy consumption. Energy-efficient design in tropical climates requires the knowledge and understanding of the ideal size and proportion of openings, especially on the external walls. The National Building Energy Efficiency Code (BEEC) for Nigeria (20017) recommends that the Window to Wall Ratio (WWR) for any orientation shall not exceed 20%. In situations where the design is such that this cannot be achieved, then, all glazing elements on the relevant facades are to be adequately shaded. This is because, heat gain through windows has a significant impact on office occupants' thermal comfort (Alibaba, 2016). The findings of this study revealed that the FSCB building does not comply with the National and International standards of recommended 20% WWR. This study further disclosed that 88% of the offices have a WWR of 32% which is far above the recommended percentage. Although, 7.2% of the offices have met the 20% WWR and 4.8% of the offices have just 15% WWR. Based on these findings, therefore, the design of the FSCB building does not meet the recommended threshold of WWR. The concept of WWR is to maximize the building's protection from solar radiation which gain access through the glazed areas and harvest solar heat which subsequently leads to thermal discomfort. However, BEEC (2017) suggests that, where WWR cannot be achieved practically due to design constraints, the building's glazing facade shall be adequately shaded.

A suitable window glazing selection that considers microclimate can have a significant effect on office occupants' thermal comfort and buildings energy demand. An observation survey conducted in this study has shown that single-glazed clear glass is predominantly used for window glazing in the study area (Figure 4). According to BEEG (2017), single-glazed clear glass has 88% visual light transmittance which aids in visual comfort. On the contrary, Evola*et al.,* (2017) revealed that single-glazed clear glass admits so much solar radiation into the building interior thereby, significantly contributing to the cooling load in hot seasons. Hence, appropriate management of heat gain in office buildings of the tropical savanna climatic region cannot be overemphasized. Glazed surfaces are often treated to scale back the amount of solar energy transmitted through them. Studies established that reflective coating on glasses tends to prevent a greater amount of heat gain into the building than most tinted glasses, and also increases privacy (Singh *et al*., 2019). As good as the heat gain properties of reflective glass, its major deficiency is the visual light transmittance capacity. According to BEEG (2017), singled-glazed reflective glass has the lowest light transmittance capacity of 11%. A scientific breakthrough has brought to light the use of smart dynamic glasses in offices. Smart glasses according to Baetens*et al.,* (2010) as cited by Evola*et al.,* (2017) are adaptive to climate, in that, they only admit solar energy if there is daylight or heating demand. Despite smart glasses' ability to prevent glare and thermal discomfort, their usage is highly constrained due to their high cost and low availability (Evola et al., 2017).

Nevertheless, this study has observed widespread use of window blinds in all offices of the study area. The window blinds used are predominantly Venetian blinds and fabric/ curtain blinds. The interview section of this study has found out that, the window blinds used in the study area significantly contribute to providing comfort to office occupants by preventing solar radiation and also ensuring privacy. The findings of this study have agreed with a study by Ishaq and Alibaba (2017) which indicated that internal shading devices such as Venetian blinds or curtains are often used to avert the undesired solar gains. Also, Singh *et al.,* (2016) have disclosed that internal Venetian blinds are found to be the most effective shading device that controls heat gain and daylight through office fenestrations.

In tropical savanna climates, sunlight occurs from morning to evening throughout the year (Nimet, 2022). Therefore, to reduce the need for cooling in the hot season, the use of external shading elements is the most effective strategy that protects the building from intense solar radiation before it reaches the glazed area (Singh *et al.,* 2016; Ishaq and Alibaba, 2017; Evola*et al.,* 2017; Sghiouri*et al.,* 2018; and Ghassan *et al.,* 2021). Various types of shading devices can be found in the literature review section of this study. BEEG (2017) recommends that North and South facades can be easily shaded with vertical shading elements considering the solar altitude in Nigeria. East and West facades require a combination of horizontal and vertical shading elements since the sun is very low and reaches the facades almost perpendicularly. This study observed that the FSCB, building effectively utilizes the egg-crate (combination of vertical and horizontal) shading elements in all facades (Figure 5). The depth between the horizontal and vertical shading elements from the building's external walls are 600mm and 900mm respectively. This exceeds the 500mm recommended horizontal shading for buildings in Nigeria (BEEC, 2017). Therefore, effective solar shading was achieved in the study area.

Fig. 5: Shading devices of the FSCB, building

Source: Author's Fieldwork, 2021

Freewan (2014) and Lan *et al.*, (2016) in their studies found out that, egg-crate shading devices perform excellently well yearly in tropical climates, as they continue to provide effective solar protection to the building envelope. Furthermore, the FSCB employs the use of deep verandas and balconies that has a width of 2400mm (Figure 6). These verandas and balconies provide a lot of shading to all veranda windows and dispel the direct sunlight into the offices. This approach proved effective as the office occupants irrespective of their location in the FSCB building have unanimously agreed that they don't experience direct sunlight into their offices through the verandas. Considering the importance of shading devices in buildings of the tropical savanna climates in promoting occupants' thermal comfort and energy efficiency, it has become a clarion call to Architects to investigate the impact of shading devices on occupants' comfort based on different geometrical forms.

Fig. 6: Use of Deep Verandas and Balconies as Shading Elements

Source: Fieldwork, 2021

The findings of this study revealed that the FSCB building envelope was designed and constructed based on the principles of energy consciousness typical of a tropical savanna climate.

V. CONCLUSION

Based on the findings of this study, it is evident that cross ventilation in the studied building is very effective considering the depth of the offices, positions, and sizes of the windows, as well as the provision of three strategic courtyards. However, the glazing used in the FSCB has a good visual light transmittance capacity but has a major disadvantage of contributing to excessive cooling load in hot seasons. Also, the building does not comply with the recommended window to wall ratio of 20% on all external walls. The study further revealed that effective internal and external solar shading was achieved in the study area.

VI. RECOMMENDATION

- Office window sizes and location should be given a favourable consideration during the design stage to control solar intrusion.
- For any energy-efficient design in the tropical climate, the architect needs to calculate the window to wall ratio from the initial stage and ensure compliance with the recommended national threshold.
- The use of internal shading (window blinds) shall be encouraged in offices of the tropical savanna climate.
- There is a need for studies into glazing suitable for use in officesof the tropical climate that are energy-efficient and cost-friendly.
- Design for offices in tropical climates should consider the type and effective width of external solar shading devices based on the building geometry and its cardinal orientation.

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