Investigating the Effect of Vacuum Glazing on Cooling Energy Consumption in Office Environments, Hot Humid Climate Nigeria: A Field-Based Study.

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ABSTRACT

This research aims to investigate the potential of vacuum glazing to reduce cooling energy consumption in an empirical office building models in hot humid climate of Ilorin. Two miniature models representing an office room scenario with one having a single glazed unit and the other with double glazed unit. Findings from this study indicated that during the heating period (12pm to 3pm) the temperature level in the field study increases, but it also shows a great reduction in the temperature difference of the double glazed unit compared to the single glazed unit which demonstrates consistency in the thermal overall performance of the double glazed unit. From field survey, it is affirmed that single glazed unit shows an increase in the indoor temperature than the outdoor temperature thereby making the indoor environment not conducive, but it is observed that the double glazed unit has the potential in regulating the indoor environment (by showing a great reduction in the indoor and outdoor temperature). Glazing surfaces account for 50% of heat entering buildings, influenced by type and material composition. Results show significant cooling energy savings with various glazed surfaces, especially those oriented towards the south axis. This research may serve as a benchmark for the design of office complex buildings in Nigeria for cooling energy consumption

Keywords: vacuum glazing, cooling energy consumption, office environments, hot humid climate Nigeria.

INTRODUCTION

In hot humid climates, where high temperatures and humidity levels pose significant challenges for maintaining thermal comfort in buildings, the integration of vacuum glazing presents a promising solution to minimize energy consumption for cooling while ensuring occupant comfort. Vacuum glazing, with its superior thermal insulation properties and ability to reduce heat transfer, offers potential benefits for enhancing building energy efficiency and reducing reliance on mechanical cooling systems.

The integration of vacuum glazing into office buildings in hot humid climates requires careful consideration of several factors, including climate conditions, building orientation, facade design, and HVAC (heating, ventilation, and air conditioning) systems. By adopting a comprehensive approach that combines passive design strategies with innovative technologies, Office buildings that optimize energy performance, improve indoor environmental quality, and increase occupant comfort can be designed by architects and designers.

Energy is the most important factor in any country's ability to eradicate poverty, advance economically, and maintain national security (Sunday, 2012). It is considered as the life blood of every nation's monetary development, it's also a critical component for monetary development. As each agricultural and commercial increase, the call for electricity further increases (Alawiye, 2011). Environmental concerns and global warming are constantly pushing the world to find alternative energy sources (Yaici & Eutchev, 2014). According to (Ahmed, et al., 2014) About 117 joules (EJ) of the world's final energy consumption, 32% of its total energy consumption, 19% of its energy-related carbon dioxide emissions, and 51% of its global electricity consumption are attributed to the building sector. Due to rising energy requirements for HVAC (heating, ventilation, and air conditioning) and lighting in buildings, buildings have been consuming more energy in recent years, which has led to low efficiency (Energy Information Administration, 2004). Electricity plays a very important role in the socio-economic and technological development of every nation. Electricity generation in Nigeria is characterized by excess capacity and inadequate supply. A country's ability to develop economically depends on its ability to supply electricity, which is an economic infrastructure (National Planning Committee, 2017). Nigeria's available electrical capacity ranges between 3500MW to 5000 MW for a population of 186 million people, this capacity is clearly insufficient (USAID, 2017). Nigeria uses only 7% of the per capita electricity consumed in Brazil and 3% in South Africa. This is directly related to the poverty level of the country. The economic well-being of a nation and its citizens is gauged by indicators such as GDP and per capita income. Nigeria has the 23rd largest economy in the world, with a gross domestic product of $486.793 billion (World Bank, 2017). The largest portion of energy used in buildings comes from energy losses through the building envelope as a result of the windows and other existing building elements' inadequate thermal insulation (Cuce.E., 2014). Windows are an integral part of the building structure, providing passengers with natural light, fresh air and visibility, and protecting them from dust, noise, rain, intrusion and excessive temperature. Additionally, windows provide the aesthetic and psychological dimension to the building design (BS8233, 1987). Basically, windows typically account for about 30 to 50 percent of transmission losses through building envelopes. Because windows are so important in lowering the amount of energy that buildings require for heating and cooling, there is a lot of focus on optimizing their performance on a global basis. To achieve a good overall thermal performance of the window, it is necessary to optimize the thermal performance of individual window components. These components include the glass panes, window frame, edge seal etc. (Bergh, Hart, Jelle, & Gustavsen, 2013).

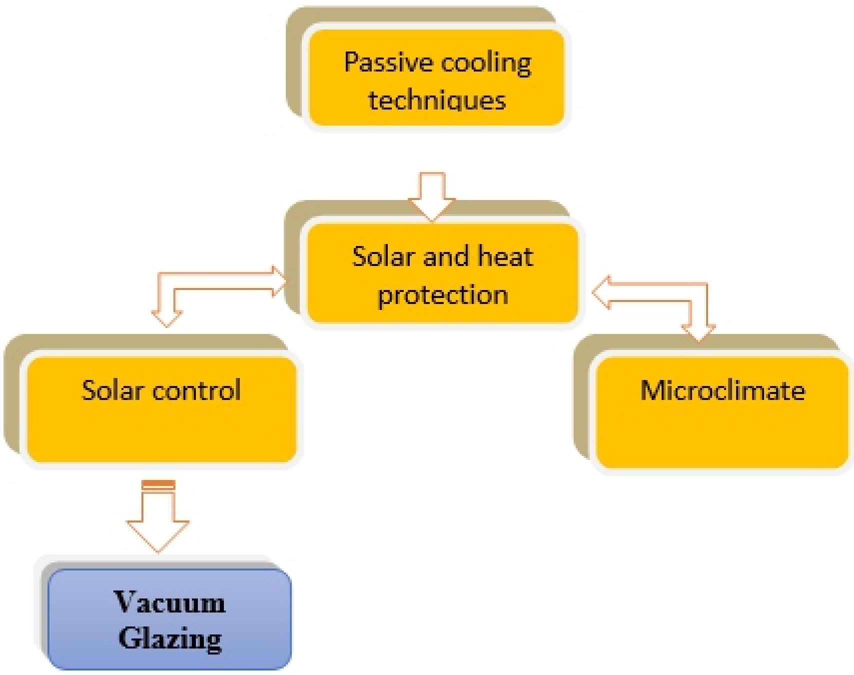
The energy and environmental performance of a building are influenced by the climate, and this has an impact on the occupants' comfort. Every climate has its own special difficulties. Hot and humid regions are one of the hardest climates to enhance through design because of its high humidity and day time temperature which results in high indoor air temperatures (Bahaj, PAB, & Jentsch., 2008). In hot and humid climates, indoor air temperature is normally higher than outdoor air temperature especially in glazed buildings because of internal heat gains and solar radiation transmitted through the building enclosure. Ilorin being the study area has its mean monthly temperature high throughout the year, most of the heat gain comes from glazed surfaces. To mitigate this effect, the concept of energy efficient glazing has emerged to resolve the thermal holes in buildings

One of the most crucial elements affecting the building's overall heat gain is the building envelope. It is an important part of any building, because the shell can protect the occupants and play an important role in regulating the indoor climate (Al-Tamimi, Fadzil, & Wan Harun , 2011). Windows are essential parts of the building envelope because they allow for passive solar gain, air ventilation, vision, daylighting, and the ability to evacuate the building in an emergency. However, because of their remarkably high U-values in comparison to other building envelope components, they account for a substantial portion of building energy use. According to Cuce (2014); The U-values of the roof, floor, external walls, and windows of a typical building are approximately 0.16, 0.25, 0.30, and 2.00 W/m2K, respectively. Due to rising heat loss and Ufactor, single-glazed windows are no longer used in many countries (Aydin, 2000).

This research sets the stage for exploring the potential of vacuum glazing to address the unique challenges of hot humid climates while meeting the energy and comfort needs of occupants in office buildings. By examining recent research, field studies, and best practices, this study aims to investigate effective strategies for integrating vacuum glazing into office buildings in hot, humid climates to reduce cooling energy use while preserving occupant thermal comfort.

LITERATURE REVIEW

In recent years, due to the increasing energy demand for cooling, heating, ventilation and air conditioning (HVAC) and lighting of buildings, building energy consumption has increased, and efforts are currently being made to lower energy consumption through energy-efficient design and construction. According to (Environmental Impact Assessment, EIA 2004), energy efficiency is energy intensity. The scarcity of conventional energy sources and rising energy costs have prompted people to rethink the overall design and application of air conditioning units, as well as develop new technologies and methods to achieve comfort in buildings in natural environments. Passive building cooling is usually divided into three parts: (i) heat avoidance/reduction (reduction of heat absorption) (ii) thermal deceleration (heat flow change) and (iii) heat removal (removal of internal heat) (M., 1990). Hence, the passive cooling technique used for research can be broken down as shown in figure 2.1 below:



As shown in Figure 2.2, Vacuum glass is composed of two flat glass plates with sealed edges, which surrounds a narrow, highly evacuated room. Because of convection and gas conduction, heat transfer between the glass plates is eliminated by the vacuum (Collins and Simko, 1997).

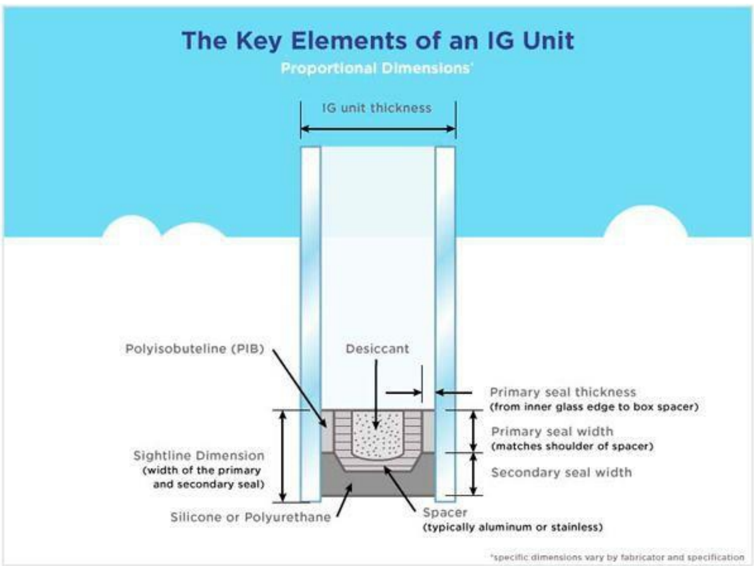


Figure 2.2: Concept of vacuum glazing

The movement of energy from one system to another as a result of temperature differences is known as heat transfer.

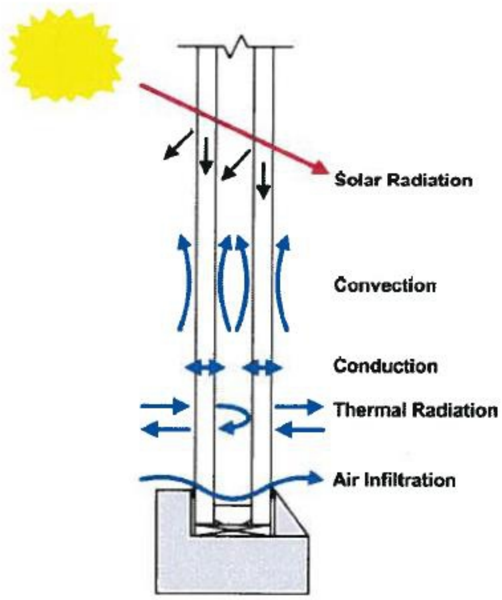


Figure 2.3: Heat transfer mechanisms

The building's energy balance is significantly impacted by the heat output of the windows. Windows allow for the extraction of a significant amount of energy from the building; therefore, in colder climates, more energy is required to offset the loss of heat. Furthermore, a lot of energy can enter buildings through windows due to solar radiation. The window components, such as glass, spacers, and frames, need to be carefully chosen in order to achieve the desired results (i.e. thermal transmittance and solar heat gain coefficient) (Gustavsen A. U., 2011).

METHODOLOGY

This research adopts an exploratory, and field measurement approach to frame the answers to its research aim and objectives. (Gliner, Morgan, & Leech, 2000))

Figure 3.1 shows the dependant and independent variables used for this research.

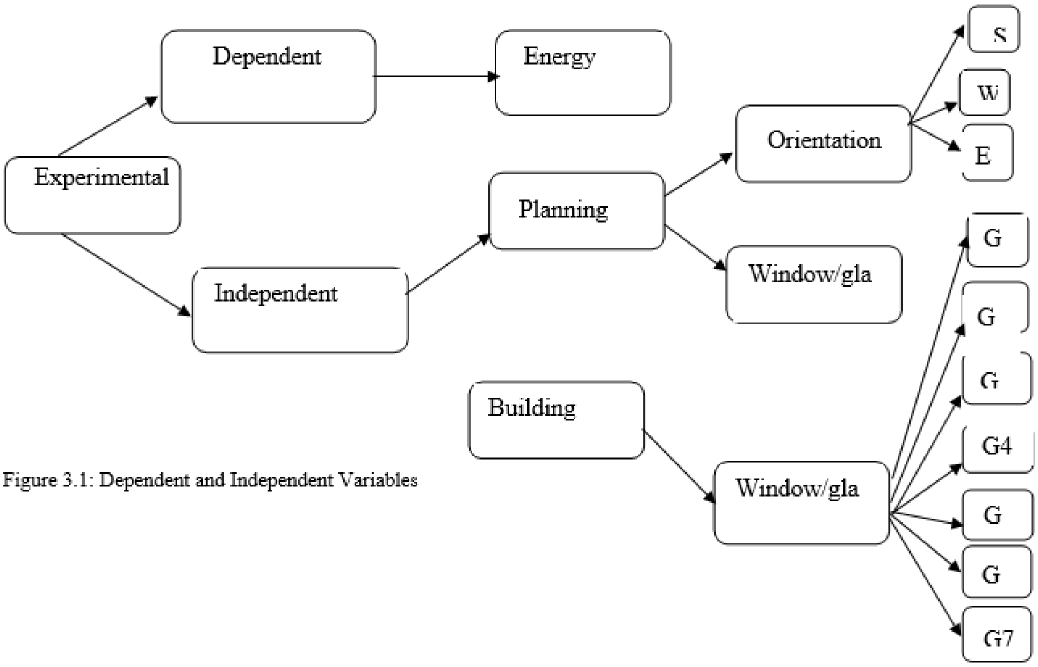


Figure 3.1: Dependent and Independent Variables

To prove the hypothesis, that the application of two layers of glass can save energy, two basic research methods were chosen. Firstly, an extensive literature review regarding the thermal efficiency and level of optimization in glazing surface is carry out as theoretical background. It depends on theoretical sources such as researches, conference papers and well documented previous studies. The cooling loads will be calculated for each model. Secondly, two block models are modelled to predicts the temperature difference in the scenarios under the appropriate condition.

The field Study

The field exercise was carried out using two miniature models, a comparative analysis was carried out to assess the proficiency of Ecotect analysis tool. The miniature models represented a room scenario with one having a single glazed unit and the other with double glazed unit.

Description and Construction of Live Model and Instrumentation

The miniature models were of $3m^3$ size as shown in figure 3.2. The walls and floor were made from 5mm plywood glued ad nailed in an airtight manner to prevent unwanted infiltrations. The callout section of the double glazed unit used in the study is shown in figure 3.3. The glazing system were a single 4mm clear glass ad also a double 4mm clear glass representing the double glazed unit (sealed in an airtight manner to prevent infiltration) as shown in figure 3.4.

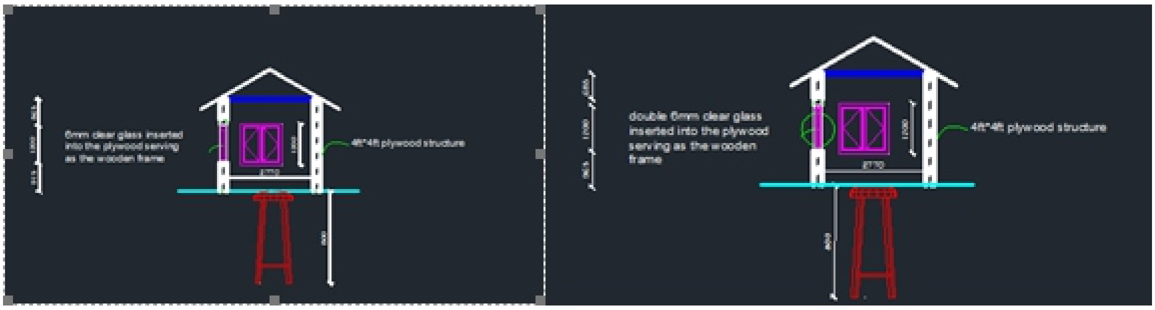


Figure 3.2: sketches of the field study for both the single glazed and the double glazed unit

Source: Researchers field study (2019).

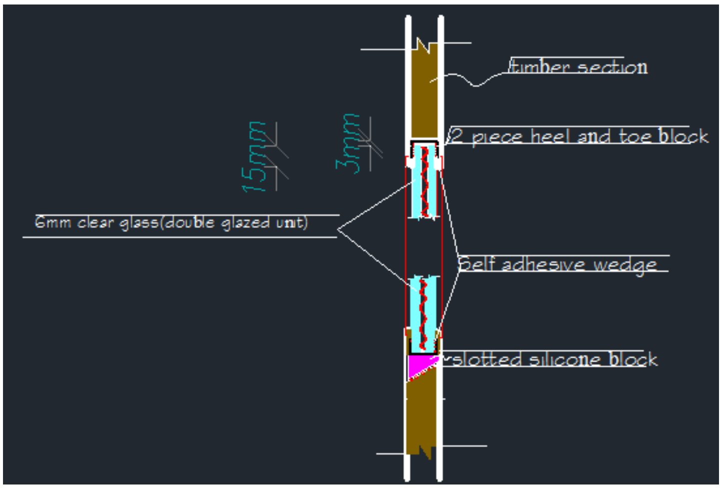


Figure 3.3: callout section of the live model

Source: Researchers field study (2019).

Figure 3.4: glazing units used for the field study.

Source: Researchers field survey (2019).

Plate I, II and III shows the miniature models and the instrument used for the assessment.

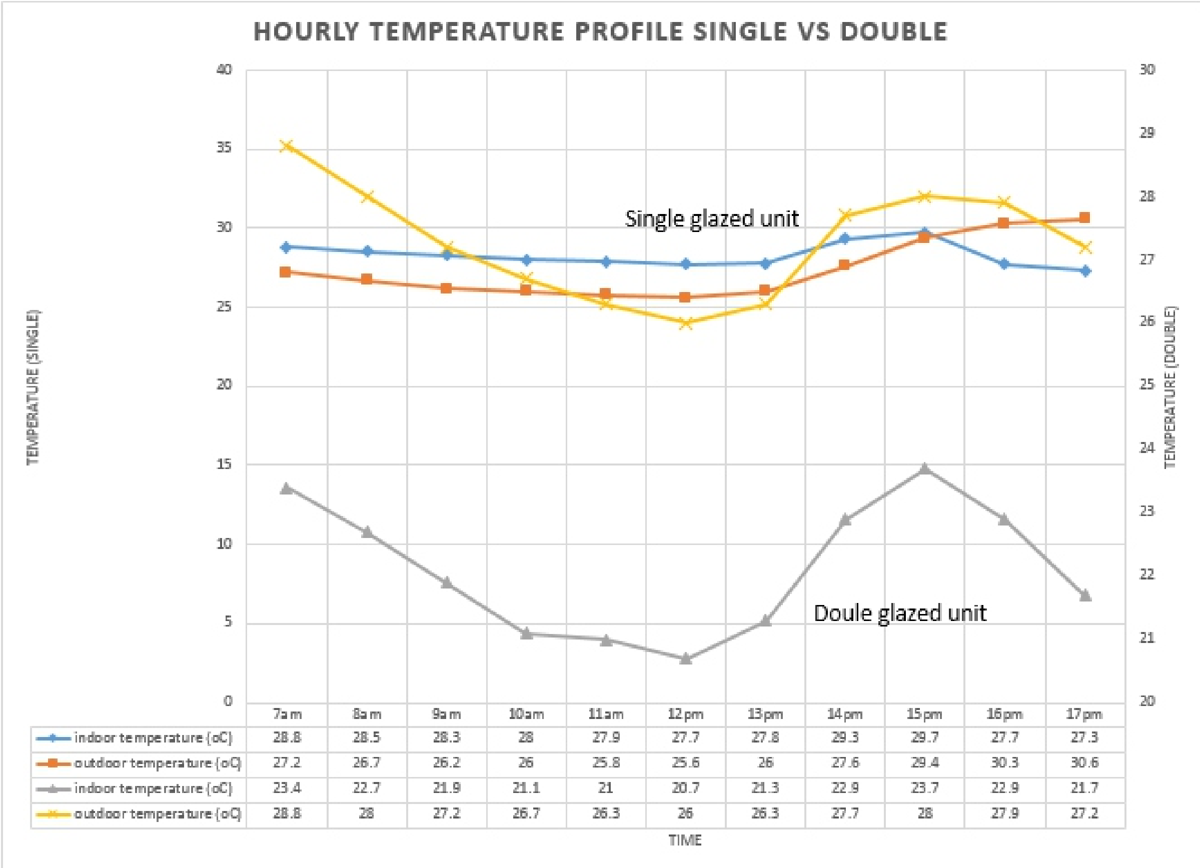
Plate I: Miniature model with single glazed unit. Source: field survey, (2019)

Plate II: Miniature model with double glazed unit. Plate III: kestrel weather meter mounted on a tripod stand.

Source: field survey, (2019)

Temperature Profiles of the Built Models

Findings of the temperature profile of both single glazed and double glazed unit are demonstrated in figure 3.5. It shows the indoor temperature (blue line) of the single glazed unit was quite high than the outdoor temperature (red line) compared to the instance of double glazed unit where the outdoor temperature (orange line) was far higher than the indoor temperature (ash line). This indicates that the single glazed poses a bigger challenge in satisfying indoor temperature than the double glazed unit. Results collected for daily averages in the field study carried out between 30th April to 4th May are shown in figure 3.6.



	7am	8am	9am	10am	11am	12pm	13pm	14pm	15pm	16pm	17pm
indoor temperature (oC)	28.8	28.5	28.3	28	27.9	27.7	27.8	29.3	29.7	27.7	27.3
outdoor temperature (oC)	27.2	26.7	26.2	26	25.8	25.6	26	27.6	29.4	30.3	30.6
indoor temperature (oC)	23.4	22.7	21.9	21.1	21	20.7	21.3	22.9	23.7	22.9	21.7
outdoor temperature (oC)	28.8	28	27.2	26.7	26.3	26	26.3	27.7	28	27.9	27.2

Figure 3.5: Difference in daily temperature profile of the single glazed unit (top) and double glazed unit (bottom) for a typical day. Source; Field study (2019).

The glazing surface is the main source of heat, accounting for nearly 50% of the heat entering the building. The heat dissipation of the glaze is also affected by the surface size and the type of glaze. There are various kinds of glazes worldwide, from single-layer glaze to multi-layer glaze or unglazed. However, in addition to the type of glaze, the materials are affected by their composition. The thermal performance of the glaze is very important. (U-value, SHGC and Visible transmittance). Single glazing with aluminium flush frame, double glazed surface were varied with different orientation to evaluate the effect of cooling energy consumption that can be achieve using each type of this glazed surface. Table 3.3 shows the energy efficiency of the cooling system for different glazing units calculated,

Table 3.3: Monthly cooling energy efficiency for different glazed surfaces.

	G1	G2	G3	G4	G5	G6	G7
Months	(kwh)	(kwh)	(kwh)	(kwh)	(kwh)	(kwh)	(kwh)
Jan	42368.99	17419.50	16276.53	18880.50	17583.75	22472.93	20640.65
Feb	40500.68	18859.60	17587.95	20171.36	18728.63	24303.84	22265.28
Mar	46134.79	22126.74	20632.82	23573.45	21878.55	28432.35	26037.48
Apr	38938.73	19639.29	18286.82	21006.56	19472.15	25606.32	23438.22
May	39229.70	19926.52	18525.35	21426.43	19836.75	26405.71	24159.52
Jun	29972.07	16922.52	15665.87	18288.29	16862.57	23133.50	21118.99
Jul	25088.69	16024.20	14813.00	17434.33	16060.15	22265.56	20323.87
Aug	26029.99	17225.59	15905.75	18702.95	17205.52	24058.19	21942.36
Sep	23028.70	14136.85	13069.03	15434.56	14223.08	19713.43	18001.62
Oct	36451.18	18403.65	17101.99	19885.25	18408.48	24603.95	22517.28
Nov	37919.40	15448.30	14442.50	16850.65	15709.53	20041.06	18428.67
Dec	36100.33	14378.63	13418.43	15723.77	14634.39	18726.69	17187.41
Total cooling load	421763.25	210511.375	195726.031	227378.109	210603.578	279763.531	256061.328
% Energy savings	0%	50.09%	53.59%	46.09%	50.06%	33.67%	39.29%

Showing various glazed area with three different orientations (S, W and E), the model on the southern axis showed great potential in cooling energy savings than the east and west side of the model. The percentage energy savings observed are 0%, 50.09%, 53.59%, 46.09%, 50.06%, 33.67% and 39.29% respectively for the different glazed surfaces.

Summary of Findings

Generally during the heating period (12pm to 3pm), the temperature level for both the simulation and the field survey rises, but these values were lower in the double glazed unit compared to the single glazed unit for both models, which demonstrates consistency in the way that the thermal performance double glazed unit.

The research findings demonstrate significant differences in the temperature profiles between single-glazed and double-glazed units, indicating that single glazing poses a greater challenge in maintaining indoor temperatures compared to double glazing. The study highlights that the glazing surface accounts for nearly 50% of the heat entering the building, with different types and compositions of glazing affecting thermal performance.

The monthly cooling energy efficiency of different glazed surfaces was analyzed, revealing varying levels of energy savings. The model with glazed surfaces oriented towards the southern axis showed the most potential for cooling energy savings compared to east and west orientations. Percentage energy savings ranged from 0% to 53.59%, based on the kind of glazing used and orientation, with double-glazed surfaces consistently outperforming single glazing. These findings underscore the importance of glazing type and orientation in minimizing cooling energy consumption in hot climates.

Conclusion and Recommendation

Building energy and environmental performance are impacted by climate. Climate has an impact on buildings, which impacts occupant comfort. Designing energy-efficient buildings is a challenge that is specific to each climate. The research field is contained in hot and humid climate areas, which are characterized by high performance from the combination of temperature and very high humidity, which can lead to serious Discomfort. The basic design principle of hot and humid climate is to reduce the heat input through the building envelope. The main tasks during design should be:

1) Reduce the external area of the building: the buildings here have been oriented so that the longest side of the building faces north and south to reduce solar radiation. The two sides along the east-west axis have been reinforced with shading devices to reduce the effects of sun exposure on the residents.

2) Use materials with longer heating periods: A strategy is used here to consider materials with high thermal physical properties, such as conductivity, transmittance, and resistance. The building improves the comfort of users due to its advantages. Within the framework of this study, vacuum glazed surfaces are used as glazing materials to prevent poor thermal insulation in single glazing systems; lightweight concrete is used as walling materials. For floors, terrazzo tile floors were used, calcium silicate tiles are used as suspended ceilings of buildings. Calcium silicate tiles are light in weight, sealed at the edges, and have high edge resistance, minimizing damage during handling, transportation, storage and installation.

3) Create a buffer space between structures: A strategy is adopted here to create spaces such as sidewalks, corridors, and lobbies around the building to increase air flow around the building, hard and soft landscapes are used.

4) Increase the number of shading devices in the building: The strategy here is to have appropriate shading devices (horizontal and vertical) to prevent direct solar emission from entering the building.

Since passive cooling methods are intended to regulate heat absorption and dissipation in buildings to enhance indoor thermal comfort, they are typically employed to stop heat from entering buildings.

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