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Thermal Performance of Residential Building Envelope in Tropical Climate of Jos, Nigeria - A Literature Review Approach

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Abstract: ***There has been a renewed conversation on thermal performance and thermal efficiency of buildings lately as a means of addressing the current energy crisis and series of environmental problems, this is because the building sector constitutes a substantial percentage of overall global consumption and demand for energy. Buildings generally, and residential buildings in particular consume a lot of energy for ventilation, heating, and air conditioning. Reducing energy consumption in buildings can help protect the environment against excessive carbon dioxide emission thereby mitigating the effects of changes in global warming and climate. The task of Architects, therefore, is to design building envelopes with high thermal performance in order to reduce the energy required to achieve thermal comfort through passive heating and cooling techniques. This paper reviews the concept of passive building design and critically analyzes the various passive design principles and techniques which adaptable to improving thermal performance in residential building envelopes in tropical climates. A detailed study of available research material on this subject matter was carried out with the purpose of providing relevant information as well as guidelines to professionals in the building sector on the most effective ways of achieving passive design techniques in residential buildings in other to reduce energy demands for thermal comfort.***

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1.0 Introduction

The primary function of all buildings is to provide an environment that is conducive to the well-being of occupants by adapting to the prevailing climatic conditions and protecting from severe outdoor climate. (Akande & Adebamowo, 2010). However, with the current challenge of climate change and global warming, buildings particularly residential buildings are unable to fulfill the function of providing comfort without consuming more and more energy from fossil fuels for heating, ventilation and air conditioning. Electricity consumption as a focal energy source in residential buildings in Nigeria is projected to be 50.4 percent (Akinbami & Lawal, 2010). The Government of Nigeria's 2009 projection of Vision 2020 report in Oyedepo, (2014) also reported that 55.3% of generated electricity were consumed by domestic loads, these figures are way above the world average of 31% as estimated by Saidur, Masjuki and Jamaliddin (2007).

According to Lapillone and Wolfgang, (2009) cited in Georgiou, (2015) approximately two third of the residential energy consumption is required for the conditioning of spaces with the remaining third utilised for cooking, lighting and other domestic needs. There is a global challenge as a result of unpredictable scenarios surrounding energy generation and the utilisation of various forms of energy, this scenario or phenomenon has brought about the condition that is now generally referred to as an energy crisis (Mbalisi & Offor, 2015). The advancement in technological development and the growth in the world economy has brought about the increasing demand for electrical power which is largely dependent on fossil fuels. It is expected to increase the demand for oil yearly. Any shortfall in the supply of energy according to Ziagos and Wedel (2007) constitutes an energy crisis. Approximately 90% of the world's consumption of energy relies on fossil fuels such as natural gas, coal, and petroleum as its primary sources (Odkmen & Gultedn, 2011). Oetinger (2010) predicts that the European Union (EU) will face a significant decline in its electricity generation capacity by 2020, losing over a third of it due to the limited lifespan of existing installations. The EU's efforts to transition towards low-carbon energy sources, particularly nuclear and hydrogen, will determine the replacement for this lost capacity. The implication of the energy crisis is the danger of not being able to sustain energy supply to the benefit of the coming generation. This is a big challenge that calls for urgent attention, hence the world must key into the sustainability principle which is the new world order. The energy crisis is exacerbated by the combustion of fossil fuels, leading to the emission of greenhouse gases. These gases are major contributors to ozone layer depletion and the subsequent challenges of changes in climate and global warming (Buba, 2004; Porbeni, 2004; Deweerdt, 2007; Odjudo, 2011). These obvious challenges associated with energy globally can only be addressed by concerted efforts by all critical stakeholders of which building designers and developers are the front liners.

According to Muhaisen (2015), the shortfall in conventional energy resources and the unfavorable conditions connected with its use on the environment, reducing energy consumption of buildings has become imperative. Similarly, the rising tendency of energy reduction and environmental problems according to Muhammad (2012), can be corrected only through the adoption of inactive cooling techniques of attaining coziness in buildings that is climate reactive design. Lawal and Ojo (2011) also opined that buildings should react to passive energy with minimum use of active energy in bringing about comfort. This was corroborated by Ajibola (2001) who emphasised the need for buildings in Nigeria to be responsive to passive energy with negligible use of active energy to ensure economic viability and minimal environmental depletion. Lawal and Ojo (2011) emphasise that constructing buildings in tropical regions, particularly in warm and humid climates, should prioritise two objectives: reducing indoor heat gain and maximizing evaporative cooling for the occupants. This approach is crucial in achieving optimal thermal comfort.

A passive building design according to Yau and Short (2013), is a building design concept that utilises the physical architectural configuration and material ensemble to provide the required insulation, natural lighting, heating, and cooling within a building, without using mechanical and electrical equipment. A "Passive House" as defined by Feist, (2016) "is a building for which thermal comfort can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to fulfill sufficient indoor air quality condition without a need for recirculated air''.

The two important mediums here as can be deduced from the above definitions are building envelope design and the thermal quality of materials used for the construction, these two components must be exploited in the application of passive design principles for the thermal efficiency of buildings.

In building envelop design therefore, the following specific elements can be exploited to achieve passive design include optimised building, orientation, appropriate window sizing and placement, appropriate shading devices for windows where necessary (to reduce summer heat gain and ensure winter heat gain) as well as proper sizing of thermal energy storage mass (Yau and Short, 2013). Also, the building's form, spacing, and configuration in a given environment affect both the solar and wind factor which play a larger role in determining the amount of solar radiation received by the surface of the building and the airflow around it (Nayak and Prajapati, 2006). Also, according to Bradshaw, (2006) "The building envelope is a device through which heat exchange between the internal and external environment is controlled. The various modes of operation of an envelope are (1) admitting heat gain, (2) excluding heat gain, (3) containing internal heat or (4) dissipating excess internal heat. The opaque portion of the envelope, once designed, is generally considered fixed control. The dynamic elements of the envelope include operable window sashes, window shading devices, and insulating shutters". Insulation and thermal mass are effective in reducing heat gain and heat loss in buildings.

From the foregoing it is established that various methods could be adopted in the design and construction of a building to improve its thermal performance, this paper gives a concise analysis of the concept of passive building design and construction techniques with emphasis on important factors that can enhance the achievement of thermal comfort in residential building envelopes in tropical climate of Nigeria which is hoped to be a guide to designers and builders alike in this era of climate change and global warming.

2.0 Methodology

The methodology includes gathering information from secondary sources. This study is a review of the literature, the primary data and material came from official documents, books, journals, bulletins, reports, conference proceedings, workshop papers, and other published sources. In order to present a clear picture of the topic at hand, the data from many sources are discussed. It is acceptable to consider the views and conclusions that resulted from this methodical approach as legitimate and trustworthy.

3.0 Discussion

Passive cooling building design or Passive building design also referred to as Climate Responsive Building Design can be described as the various design techniques which are adopted in the design of a building to ensure that the building provides the required thermal comfort to its occupants by heating up or cooling down itself naturally without resorting to the use of mechanical and electrical equipment which depends on energy (Ogunsote, Prucnal- Ogunsote, & Adagbie, 2011). A design that enables the heating and cooling of the building by itself without making use of mechanical devices (Adebisi, Ayinla, & Okeyinka, 2018). A design that can ensure the sustained comfortable temperature within the building by exploiting climate and natural elements to achieve optimum benefit and reducing or completely eliminating the use of mechanical systems for heating, cooling, and lighting (Hashim, Tabet, Mona & Akash, 2016). It is a design strategy that relies mainly on the exploitation of available microclimatic elements and materials to enhance the high performance of the building envelope thermally for the comfort of the occupants. It is obvious from the above definitions that passive building envelope design must be in line with the climatic and environmental conditions of the building site as well as the thermal quality of materials used for the construction.

Passive Cooling Building Design Techniques

Passive Design Techniques or Strategies are the design variables considered in the design of a building with the aim of harnessing the capacity of the immediate natural environment of the building site for the purpose of achieving the required indoor thermal comfort with minimum energy demand (Offor & Emenike, 2019). The choice of passive building design techniques is governed by the climate of the immediate environment in which the building is located (Hashim et al., 2016). According to Appah and Koranteng (2012), several factors which influence the building's response to its immediate external environment include shape, orientation, absorption of solar radiation, window-to-wall ratio, and material selection. As stated earlier the various modes of operation of a building envelope include the following: admitting heat gain, excluding heat gain, containing internal heat as well as dissipating excess internal heat (Bradshaw, 2006). From the foregoing the elements to be exploited in the design of the building envelope therefore include (1) optimised building envelope, (2) orientation, (3) appropriate window sizing and placement (4) appropriate shading devices (5) proper sizing of thermal energy storage mass (6) material choice based on thermal properties.

Optimised Building Envelope

Building envelope optimisation refers to the application of various design techniques or strategies in the building envelope design in order to enhance higher thermal performance. Building Envelope according to (IFMA) includes all of the exterior components of a building, such as walls, roofing, foundations, windows, and doors. It includes all components that make up the shell or skin of the building.

The building envelope includes four basic functions which are: adding structural support, controlling moisture and humidity, regulating temperature, and controlling air pressure changes (Yeatman, 2016). From the four basic functions of the building envelope, temperature regulation, moisture, and humidity control as well as air pressure control can be optimizable for the purpose of thermal efficiency.

Temperature control

Temperature is generally high in tropical climate and the building envelope serve as a medium of heat transfer, as heat goes in and out of a building through its envelope which is the roof, walls, windows, and floor(s) while doors and other fixtures as well as internal room arrangements affects the distribution of heat/temperature within the building (Akande, 2010). Envelope Design as defined by Akande, 2010 is 'the integrated design of building form and materials as a total system to achieve optimum comfort and energy savings.

Optimizing building 'Envelope Design' in the tropics particularly in warm humid climate help to regulate the rate of heat transfer by minimizing indoor heat gain and maximizing evaporative cooling of the occupants in order to achieve thermal comfort (Lawal & Ojo, 2011). Building envelope component or building façade can be grouped into opaque and transparent components, while the opaque components comprise the walls, roofs, basement walls, and fixtures like doors which have no glazing, the transparent components is comprised of windows, skylights, and ventilators which are completely glazed as well as doors that are often half glazed (Jakinder, Prabhjot & Sanjiv, 2017). The opaque components which usually form the major part of the building envelope are carefully selected mostly based on their thickness, surface area, material type, colour, and finishes for the purpose of limiting the ingress of the amount of heat gain, whereas transparent components which consist largely of windows with glazing to enhance visual connection with the outdoor and the admittance of daylight is usually vulnerable to solar heat gain hence are a medium through which huge amount of heat and solar radiation may be transmitted into the interiors if suitable thermal efficiency measures are not considered in their choice (Jakinder et al., 2017). In the choice of glazing material for a building envelope, the glazing properties must be considered, the glazing properties are described in terms of solar heat gain coefficient (SHGC) and U-value of complete fenestration systems (including frame and glass). Values for SHGC are usually taken between 0 and 1, which indicate the thermal resistance capacity of a glass. Lower SHGC and U-values are generally preferred for thermal efficiency (ECBCUG, 2009). Heat or thermal energy transfer from one region to another occurs in three modes, that is Conduction, Convection, and Radiation. Conduction is the heat transfer through solid material, Convection is by fluid motion while radiation is heat transfer by electromagnetic waves (Bradshaw, 2006). The building envelope, therefore, can be optimised against heat transfer by a combination of design configuration, choice of material, envelope insulation, the introduction of cavity wall, choice of appropriate finishes for surfaces of the envelope, vegetation cover (landscape), and shading, all of these strategies aid in reducing heat gain in building (Adebisi et al., 2018).

Temperature can be controlled by its reduction to an acceptable minimum by the use of thick walls with high thermal mass, as this helps to regulate the inflow and outflow of heat (Leo, Dharmasastha, Shiva & Maiya, 2017).

Moisture and Humidity Control

Moisture and humidity are closely related and are elements that affect the thermal comfort of occupants of a building and also affect the thermal performance of the building envelope. Moisture is defined as wetness which affects the structure of the building envelope by way of dampness penetration, it is an active water leakage that is detrimental to the building structure and its materials (Petri, Matti, Toni, Juka, Jommi & Matti, 2017). Humidity on the other hand is defined as the partial pressure of water vapor that is present in the air (Venkatesh & Sundaram, 2012). Moisture and Humidity control are essential and vital parameter in residential building design in other to achieve indoor thermal environmental comfort for humans, as heating and cooling loads requirements for air conditioning in any given indoor space is not exclusive with the sensible heating and cooling terms alone, but a combination of latent and sensible loads including the control of moisture and humidity (Mujahid, Gandhidasan, Rehman & Al-Hadhrami 2015). Moisture and Humidity problems in buildings, as defined by WHO (2009), is "any visible, measurable, or perceived outcome caused by excess moisture indication, indoor climate problems or problems of durability in building assemblies caused by various leaks of water". Dampness penetration occurs via moisture flow through the building envelope by four major means which are; bulk water movement, capillary action, air-transported moisture, and diffused airflow. Bulk moisture movement usually occurs as a result of direct water passage into the building envelope due to the presence of a water source, the presence of cracks or openings in the envelope, and a driving force like gravity or pressure. Capillary action refers to the upward movement of water into the building envelope against the pull of gravity through a porous material and is capable of accumulating much moisture in the building fabric which can negatively affect the thermal performance of the envelope, Air-transported moisture including wind or stack effect, household activities such as cooking, bathing, washing and drying of clothes, which can leak into, or out of buildings. A process known as diffused air flow is small amounts of moisture in the form of water vapor that passes directly through a building's envelope. The amount of diffused airflow (vapor) that occurs in a building is determined by two things: the driving force that pushes it and the permeability of the building material the vapor is passing through (AHL 2007).

The building envelope can be optimised in different ways to prevent moisture and humidity penetration thereby enhancing high performance, the various ways the envelope can be optimized to prevent moisture penetration according to NIBS, (2013) include:

- Choice of exterior finishing materials: material for external walls and finishes must be carefully selected to limit moisture and humidity penetration.
- Introduction of vapor retarders: retarders include plastics, aluminum, treated papers, and epoxies which can act as a sufficient barrier to moisture penetration. Low-porosity rock-like slate can also be used as a damp-proof membrane to prevent moisture penetration.
- Air infiltration and rain barriers: this plays an important role in preventing air infiltration from winds and other weather conditions.
- Insulation: insulation materials like closed cell and non-hygroscopic insulation can be used to reduce high moisture levels that can develop in walls. The insulation acts as a vapor barrier depending on its thickness.
- Choice of internal finishes: interior finishes must be selected to allow liquids and gases to pass through them as it is. In hot and humid climates, the permeability of the interior finish should be much higher than that of the exterior finish. This will allow moisture that enters the wall to migrate to the inside of the building where the moisture will be removed by the air conditioning system. The reverse is true for cold climates; the exterior finish should

Air Pressure Control

Air pressure control plays a significant role in building envelope thermal performance, hence the building envelope can therefore be optimised to ensure adequate control of air pressure. There are three primary reasons according to Straube, (2001) why air pressure control is important to building performance, these include Moisture control, Energy savings, and Comfort/Health.

- Moisture control: Moisture problems constitute one of the major issues in a building that tends to reduce the quality and performance of building components/elements. Moisture problem according to World Health Organisation [WHO] (2009), is any visible and measurable or perceived defect(s) that occur in a building as a result of excess moisture indication, indoor climate problems, or problems of durability in building assemblies caused by various leaks of water. Moisture control is necessary for buildings not only to avoid problems of structural performance and human health and durability but most importantly to improve the thermal efficiency of the building. The various means moisture can be transported include both liquid and vapor states by convection, diffusion, capillarity suction, wind pressure, and water pressure (WHO, 2009). Moisture control in buildings must be considered at the design stage by incorporating design features that can control the entry of large amounts of rainwater and groundwater from the exterior, prevent moisture seepage through capillarity action, prevent excessive water movement through air and vapour diffusion and effective discharge of rain and waste water from within the building (National Research Council (NRC) 2007). The various means by which moisture control can be optimised to prevent moisture penetration into the building envelope according to NIBS, (2013) have earlier been stated above.
- Energy saving: The exchange of air between the interior and exterior of the building as a result of constant air leakage from the building which must

be replaced requires energy. Straube (2001) revealed that approximately 30% to 50% of the energy consumed in the conditioning of space in an insulated building is a result of air leakage through the building. To ensure a reduction in the energy required operate a building, there is the need to improve the thermal insulation of the building envelope (Thormark, 2006).

- Comfort/health: One of the important parameters for measurement of building performance is Comfort and Health and air pressure control is essential in achieving comfort and good health. Comfort and health are achieved through efficient air pressure control to ensure adequate ventilation. Ventilation is a phenomenon whereby indoor (used and contaminated) air is replaced by the admission of fresh air from the outdoor space natural or mechanical means, in order to enhance the comfort and well-being of occupants (Pierre, Jean-Marc & Marion, 2007).

Air flow is driven by differences in absolute air pressure between two spaces and a continuous flow path or opening connecting the spaces, this variation in pressure results from three mechanisms which include wind pressure, stack effect or buoyancy, and mechanical air handling equipment and system (Vince & Edward, 2003). Wind pressure and stack effect are natural phenomena that can be controlled by design principles and construction methods. Wind pressure causes air infiltration into the indoor space of the envelope through cracks, holes, and gaps around doors and windows, open doors and windows, joints between walls and floor as well as through the building skin itself (Bradford, 2006). Stack effect on the other hand occurs through the building envelope as a result of variation in temperature within and without the building envelope, stack effect pressures are also generated by differences in air density with temperature, that is hot air rises and cold air sinks and can neither be prevented nor neutralised, but can be shifted and broken up to limit its effect on the building envelope.

The general approach taken to control wind pressure flow, include compartmentalizing building plans and sealing all openings at one plane in the envelope enclosure, this primary plane of airtightness is referred to as Air Barrier System (Straube, 2001). Design strategies can be employed to reduce the problems associated with the stack effect. These strategies include: limiting indoor humidity levels, improving the airtightness of the building envelope, use of revolving doors or airlocks at the entrance level, creating more airtightness compartments at different floor levels to enable floor performance as horizontal barriers to vertical airflow as well as compartmentalizing building vertically.

Orientation of Building

Orientation of a building is the placement of the building at a position in a given site in relation to the sun path, wind direction, and other environmental factors as well as view considerations. The purpose of orientation according to Akande, 2010 is to turn the building to its important side that guarantees the best living conditions for the occupants. Buildings that are properly placed in a given site with the correct orientation with reference to the sun's path will provide the best and desired thermal comfort to their occupants (Muktar & Halil-Zafar, 2017). Orientation has a direct influence on building thermal performance as it significantly influences the cooling load of the building Karasu (2010). An appropriate building orientation enhances building envelope thermal performance thereby supporting energy reduction through passive solar heating and cooling, daylighting, and natural ventilation (Ochedi & Taki, 2019). Thermal requirements are affected by the orientation of windows and other openings in the building envelope as well as the dominant wall areas (Bradshaw, 2006). It is therefore important to properly orient the building in order to take good advantage of solar radiation and the prevailing wind, hence a good understanding of the building site by designers is important as that will enable designers to achieve proper and desirable orientation (Ochedi & Taki, 2019).

The tropical geographical zone is characterised by different seasons with variation in climate within the zone, with 90% of its tropical ecosystem as hot and humid which may be permanent or seasonal, while the remaining 10% is hot and dry and include mainly desert-like ecosystem (Almeida-Val, Adalberto & David 2006). Buildings within the tropical zone are characterised by high humidity, high temperature within the envelope, low air quality for indoor spaces, and glare as a result of which much energy is required for cooling the building in order to bring about the desired thermal comfort of occupants (Shabuddin, 2012). Proper orientation can be used to achieve thermal comfort in the tropics as desired. Where comfort can be achieved through air movement, building orientation should be in line with the prevailing winds, where ambient temperature has a greater influence on comfort than ventilation, orientation with respect to the sun's path is desirable (Abed, 2012). There is therefore no single orientation that can be suitable for all buildings. The most suitable orientation must be exploited in the design of every building in order to achieve the desired thermal comfort. In a tropical climate with hot humid conditions, orientation should be such that the shorter side of the building faces east and west (FMPWH, 2016). Building orientation with a longer axis towards east and west has greater potential for winter solar heat gain than with north–south orientation, windows orientation towards the south provides the highest solar gain in winter but low solar gain in summer, and orientation of shorter side of the building toward the east and west provides a high solar gain in summer and low solar gain in winter and also maximises summer cooling loads (Bradshaw, 2006).

Appropriate Window Sizing, Placement, and Orientation

Windows according to Azmy and Ashmawy (2018) are considered the most important functional elements of the building envelope as they have a direct impact on the thermal behavior of the building and hence the amount of energy consumed within it. Window size, its placement, and its orientation in the external wall of the building envelope have major impacts on the thermal performance of the building. Window size is the specific percentage of the area of the window and that of the enclosure within the envelope which accommodates the window and will impact the envelope's heating and cooling (Eljojo, 2017). Window Placement is the position of the window aperture in the external wall of the building envelope while Window Orientation is the direction of the window opening in the outer shell of the building envelope and they all affect the amount of natural lighting and ventilation entering into the interior of the building envelope and the amount of exposure of the envelope to the sun and therefore affects its thermal performance (Azmy & Ashmawy, 2018).

Appropriate Shading Devices

Shading of the building envelope is one of the means by which the envelope's thermal performance can be enhanced. Shading is considered the most effective of all passive solar cooling strategies in tropical climates and as such should be the first line of defense in minimizing the ingress of solar gain in buildings (Adebisi, Ayinla & Okeyinka, 2018). The main principle of the shading strategy is the prevention of direct solar radiation that penetrates into the building envelope through its opening and absorbing materials (Abed, 2012). Research Carried out by Al-Tamimi, Fadzil & Sharifah (2011), established that choosing the most appropriate shading devices for a building can improve the number of comfortable hours indoors, the research stated a percentage increase in the improvement to about 4.7% and 20% for ventilated and unventilated conditions respectively in buildings in the tropics. Studies carried out by Kumar & Kaushik (2005) have shown that appropriate shading of a building can reduce its indoor temperature by about 2.5ºc to 6.8ºc much better compared to other cooling techniques. In terms of cost, shading of buildings is more economical, it is also very effective and easy to carry out than other known passive cooling techniques Mohammed (2012).

There are two main shading strategies for building envelopes which are the Self-shading and External shading strategies. Self-shading strategies are the strategies employed to ensure the reduction in the penetration of solar radiation through windows, roofs, and opaque solid exterior walls which are usually the predominant path of entry for solar energy, while External shading strategies include the use of vegetation, landscape elements, designed building elements such as overhangs, vertical fins, louvers, egg crates, pergolas, screen panels, and double roofs as well as other resources on the site in shading the building envelope from direct solar heat penetration (Bradford, 2006). Careful consideration of shading devices at the early stage of design is important, particularly for facades with a high window-to-wall ratio (Cellai, Carleti, Sciurpi & Secchi, 2014). To effectively carry out adequate shading of the building envelope, one or more shading devices can be used.

Proper Sizing of Thermal Energy Storage Mass

Thermal mass is defined as 'the material of the building which absorbs or releases heat from or to the interior space" (Shafiigh, Asadi & Mahyuddin, 2018). Thermal mass refers to materials used in solar thermal systems, commonly known as passive solar heating systems, for storing heat. These materials include water, concrete, masonry, or earthen construction. In a passive solar system, which relies on excellent insulation, solar collection, and thermal storage, thermal mass plays a crucial role. Dense building materials like stone, concrete, and brick are often referred to as thermal mass as result of their heat capacity and high density (Leckner, 1991).

The thermal mass element plays a crucial role in buildings by contributing to the decrease in heating energy consumption and cooling purposes across various climatic zones. Additionally, it has the potential to significantly mitigate the environmental consequences related to the burning of fossil fuels for energy production. By utilizing thermal mass, buildings can effectively lower costs, enhance comfort levels, and even diminish or eliminate the need for air conditioning. Essentially, thermal mass possesses the ability to store substantial amounts of thermal energy, thereby impeding the rapid transfer of heat through building components. This delayed heat transfer is advantageous as it results in a sluggish response time, which helps to moderate temperature fluctuations in the indoor environment caused by changes in outdoor temperatures. Moreover, thermal mass may be employed to utilise off-peak energy demands, as suggested by Ashrae (1997). In addition to producing a desirable heat transfer delay, thermal mass also exerts a moderation effect by retaining some absorbed heat energy instead of re-radiating it, as noted by Ogoli (2000).

Material Choice Based on Thermal Properties

Choosing materials with the appropriate thermal properties is the second crucial factor in achieving a passive building design. The characteristics of building components have a crucial impact on the regulation of heat transfer within structures. When it comes to passive building design, several key thermal properties deserve careful attention. These properties include thermal resistance, thermal conductivity, thermal transmittance (or thermal U-value), insulation, and thermal mass. The thermal transmittance or overall U-value (W/m2K) of the building envelope is the primary factor that determines the steady-state heat loss or gain. Hence reducing the thermal transmittance of the building envelope via the increased level of its insulation can bring about a reduction in heating demand thereby resulting in lower heating energy consumption, Yau and Short (2013).

Bradshaw, (2006) stated that "The building envelope is a device through which heat exchange between the internal and external environment is controlled. The various modes of operation of an envelope are (1) admitting heat gain, (2) excluding heat gain, (3) containing internal heat or (4) dissipating excess internal heat. The opaque portion of the envelope, once designed, is generally considered fixed control. The dynamic elements of the enveloped include operable window sashes, window shading devices, and insulating shutters". Insulation and thermal mass are effective in reducing heat gain and heat loss in buildings. Al-Saadi (2006) defined "Thermal insulation as "a material or assembly of materials used to provide resistance to heat transmission". Thermal insulation in buildings serves various purposes, which encompass conserving energy employed for heating and cooling, minimizing temperature variations to enhance thermal comfort within enclosed areas, safeguarding the building and structures against thermal damage, freezing damage, frost heaving, and harm caused by water vapor condensation. It also helps regulate the surface temperatures of building components, ensuring operational efficiency and occupant comfort. Additionally, it plays a role in preventing water vapor condensation and reducing the transmission of airborne sound through walls, floors, and ceilings. Thermal insulation can be classified into three main types: Capacitive, Resistive, and Reflective. Capacitive insulation materials possess a wide thickness and exhibit a high capacity to store heat, effectively limiting heat flow. Traditionally, such materials as stones and adobe have been commonly used. On the other hand, Resistive thermal insulation materials are characterised by their low density and the presence of air holes or gaps, which significantly reduce conductive heat transfer. These materials offer excellent heat resistance and provide high thermal performance, typically measured by the R-value, even with thin layers compared to capacitive insulation. Lastly, Reflective insulation materials employ two highly reflective surfaces, with low emissivity, to counteract radiant heat transfer, a feature not typically found in conventional mass insulation materials. Examples of reflected thermal insulation materials are fiberglass laminated bubble aluminum materials, woven fabric insulation, and aluminum reflective insulation materials among others. To achieve high thermal performance in buildings, any suitable insulation materials can be combined with building materials and components. The figure below shows different types of insulation materials according to their compositions.

The main purpose of insulation is to decrease the transfer of heat, both in terms of heat gain and heat loss. Consequently, having more insulation in a building's exterior envelope results in less heat being transferred into or out of the building, particularly when there are temperature differences between the interior and exterior (Bradshaw, 2006). Insulation assists in isolating interior surfaces from the exterior, thereby reducing the impact of external conditions on the Mean Radiant Temperature (MRT). Furthermore, insulation helps minimise drafts caused by temperature disparities between walls and the surrounding air.

The wide range and forms of insulating materials available enable their application to building materials and components to include the desired thermal performance of such components. Insulation materials can be incorporated into the cores of concrete masonry units (CMUs) or brick units, enhancing their thermal performance and decreasing their structural weight. This integration serves to improve the overall insulation capabilities and reduce the overall mass of the units.

Residential buildings constitute a larger percentage of the overall building population in Nigeria. Ensuring thermal comfort for occupants is of utmost significance in residential buildings due to evident factors such as the health and well-being of individuals, along with economic considerations. Building performance optimisation has been carefully reviewed in order to provide sufficient information for designers of residential buildings on the various passive design techniques and approaches that can be applied in the design of building envelopes to achieve the desired thermal comfort for occupants of homes in tropical climates. It has been established that the building envelope is the medium through which the exchange of heat between the internal and external environment can be controlled. It has been determined that the building envelope operates in several modes, which encompass the admission of heat gain, the exclusion of heat gain, the containment of internal heat, and the dissipation of excess internal heat. The envelope of the building has also been analyzed and categorised into fixed elements and dynamic elements. Once the opaque portion of the building envelope is designed, it is typically regarded as a fixed control element. The fixed elements are predominantly opaque in nature. On the other hand, the dynamic elements encompass operable components such as windows and insulating shutters.

Passive design techniques can be implemented in both the opaque and dynamic elements of the building envelope through various means. These include optimizing the building envelope, determining the building's orientation, selecting materials with suitable thermal properties, utilizing effective shading devices, choosing appropriate window sizes and placements, and ensuring the proper sizing of thermal energy storage mass.

4.0 Conclusion

The importance of the thermal performance of residential building envelope in enhancing the thermal comfort of occupants as well as trimming down to the barest minimum the amount of energy required for heating, ventilating, and air-conditioning cannot be overemphasised. Envelope design based on passive design principles can help bring about the desirable thermal comfort in residential buildings without resorting to excessive use of conventional energy hence protecting the environment against excessive carbon dioxide emission and mitigating the effects of global warming and climate change through thermal resistance, thermal conductivity, thermal transmittance or thermal U-value, insulation and thermal mass.

Building designers should utilise the necessary information regarding envelope design and the thermal quality of material based on the passive design approach which this paper has extensively discussed. A good understanding and application of passive design principles can help achieve high thermal performance and energy efficiency in our residential building envelopes.

5.0 Recommendations

There is a need for training and retraining of professionals involved in building design to equip them with the current design strategies for achieving thermal and energy-efficient building design. There is a need for more research on building materials particularly local building materials to improve their thermal properties. Improve building envelope insulation methods and materials to lessen heat transfer between indoor and outdoor spaces. To reduce thermal bridging, this can entail utilizing materials with higher R-values and making sure the installation is done correctly.

Use passive design techniques to minimise the need for mechanical cooling systems and maximise thermal comfort, such as orientation, shade, and natural ventilation. To properly regulate indoor temperatures, this may entail including elements like overhangs, cross-ventilation, and thermal mass. Investigate tropical-adapted roofing options, such cool roofs or green roofs, to lessen heat absorption and lower interior temperatures. For example, cool roofs absorb less heat and reflect more sunshine than conventional roofing materials. Optimise window design and glazing parameters to strike a balance between controlling heat gain and allowing natural light to enter. By using high-performance glazing and low-emissivity (low-e) coatings, thermal insulation can be enhanced while daylighting is maximised. Increase the effectiveness of air conditioning systems by using energy-efficient equipment, performing routine maintenance, and sizing them appropriately. In addition, to supplement mechanical cooling, think about incorporating passive cooling components like earth-air heat exchangers or evaporative cooling.

To enforce minimum thermal performance criteria for residential structures in tropical climates, strengthen construction codes and standards. This can entail imposing regulations on window U-values, insulation levels, and energy-efficient design concepts. Increase knowledge of the value of thermal comfort and energy efficiency in residential buildings among builders, architects, and homeowners. Adoption of energy-saving measures can be encouraged by offering educational materials and training courses on sustainable building techniques. Encourage more study and development of construction methods, building materials, and renewable energy solutions that are suited to tropical regions. This may result in the creation of fresh approaches to enhance thermal performance while lessening the negative effects on the environment. To encourage the use of renewable energy systems and energy-efficient building techniques, offer tax credits, subsidies, or other forms of financial assistance. Driven by government laws and initiatives, sustainable construction technology can be widely adopted. Encourage community involvement and teamwork to tackle issues related to thermal comfort in neighborhoods or communities. This could entail setting up seminars, neighborhood associations, or community initiatives with an emphasis on energy- and sustainable-building techniques.

By putting these suggestions into practice, residential structures in tropical regions like Jos, Nigeria, can perform better thermally, improving sustainability, energy efficiency, and comfort.

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