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An Overview of Implications and Suggestions for Reducing Temperature Rise in Buildings Located in the Tropics

Charles Munonye, Oluchi Ifebi, Nkechi Maduka, Michael Ngobili

Department of Architecture, Faculty of Environmental Sciences, Chukwuemeka Odumegwu Ojukwu University, Uli Campus, Nigeria

Email address:
cc.munonye@coou.edu.ng (Charles Munonye)

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Abstract: Climate models predict that greenhouse gas warming will cause temperatures to rise faster in the coming years with a serious impact on people living in the tropics. The building sector is acknowledged as one of the highest contributors to greenhouse gas emissions, and poorly designed buildings are not capable of proving thermal comfort to building occupants. This paper presents an overview of how the built environment can respond to this global threat of climate change. It observed that human behavior through adaption to changes in indoor temperatures may be one of the solutions to these rising temperatures. Furthermore, building materials that are good conductors of heat were found to be unsuitable for use in building construction. The application of passive design strategies in buildings located in tropical climates can minimize energy consumption and at the same time improve the thermal comfort of the occupants. Furthermore, an effective way to minimize energy consumption in warmer climates is to select appropriate building materials that contribute to cooling the indoor temperature. This paper recommends that properly designed naturally ventilated buildings that consider sustainable building materials can respond to the globally rising temperatures. The information gathered from the overview of this paper will serve as a guide to professionals in the built environment.

Keywords: Built Environment, Climate Models, Greenhouse Gas, Temperature, Tropics

1. Introduction

This paper highlights the energy consumption in the building sector and addresses sustainable ways to improve human adaptation to the rising temperatures in indoor spaces. Greenhouse gases are produced mainly by the burning of fossil fuels. Most of the increase in temperature has been attributed to a human-induced increase of atmospheric greenhouse gas, for which the building sector is one of the greatest contributors. Among the factors that contribute to the buildings' emissions are building envelope, air conditioning, space heating, and ventilation [1]. At the 2015 United Nations Climate Change Conference, held in Paris France (the 'Paris Agreement') a new framework convention on climate change was adopted. Mitigation and adaptation were adopted as the main objectives of the United Nations Framework on Climate Change (UNFCC) in combating climate change. Indeed, there is a growing concern that we have already passed an early 'tipping point' where the most aggressive global movements to reduce carbon emissions can do little to avoid a significant shift in the global climate system. As a result, mitigation alone cannot be a solution to climate change, and there is a need to think of adapting as the climate changes. Passive approaches designers can consider when designing buildings located in tropical climates were suggested.

2. The Building Sector

The tropical climate is an area within the Tropics of Cancer and Capricorn. The tropical climate occupies approximately 40 percent of the land surface of the earth, is home to half of the surface of the earth, and is home to half of the world's population [2]. There are two categories of tropical climate; warm and humid regions (characterized by excessive rainfall and considerable sunshine) and hot and dry regions (known for their extremely high temperatures with little precipitation). Human activities in all these climatic zones are the major causes of the release of greenhouse gas such as methane and chlorofluorocarbon (CFC's) into the atmosphere. In the last 50 years, there has been an increase in the global surface air temperature due to climate change, resulting in some catastrophic results. Between 1999 and 2018, about 495,000 people died worldwide with losses of US $3.54 trillion [3]. The author further reported that by 2050, more than 970 cities will face an average summertime temperature of about 35 degrees, with 90% of these cities located in Asia and Africa.

The building sector is one of the highest contributors to greenhouse gas emissions. One of the functions of a building is to provide the microclimate required for human habitation. Buildings have a great impact and influence on the natural environment, with approximately 90% of people spending about 90% of their daily time inside them. In the United Kingdom, for example, an increase in temperature by 1^oC causes an increase in energy consumption by about 10% [4]. On the local scene, Nigeria is the 44^{th} emitter of CO_2 in the list of over 200 countries in the world [5]. Energy is consumed and significant greenhouse gas is emitted during the building life cycle. Precisely, energy is consumed during manufacturing, transportation, construction, operation, and during the demolition of buildings. Most literature approaches embodied energy from a 'cradle-to-gate' perspective as the summation of the energy that is consumed directly or indirectly for the production of constructive materials. This is the total energy used in the entire life cycle of a building excluding the energy that is used for the operation of buildings [6]. Thus, the total life cycle energy of a building includes both embodied energy and operating energy [7]. It is important to calibrate the performance of buildings in terms of both embodied and operating energy to reduce energy consumption.

Embodied energy; This is the amount of energy required to extract, process, and transport materials to the point of use or application. Embodied energy is expended once in the initial construction stage of a building. The construction industry is one of the largest consumers of commercial energy in the form of electricity or heat by directly burning fossil fuels. Construction activities not only consume energy but also cause environmental pollution and the emission of greenhouse gases, which lead to climate change. Building materials that possess high embodied energy could result in more carbon dioxide emissions than the ones with low embodied energy. Embodied energy can be reduced by recommending low energy-intensive materials. Knowledge about the embodied energy contents of building materials could encourage the use of, not only the production, and development of low embodied energy materials but also the preference among construction design and industry to curb energy use and carbon dioxide discharge.

Operating energy: Operational energy is the total energy used to maintain the inside environment in form of heating, cooling, lighting, and operating appliances. In order words, operational energy sums up the effective life of the building. The greatest proportion of energy is used during the building's operational phase, though the usage varies from building to building and from location to location. During this stage, about 30% of the global CO_2 generated by buildings alone is primarily for thermal comfort [8], with the likely outcome of the emission rising to 60% in the future [9]. Thus, the greatest energy reduction can be targeted during the operational phase of the building by reducing the energy used in heating and cooling the indoor spaces. In tropical climates, usually associated with high temperatures, the indoor environment can be cooled by active means in the use of air conditioning systems. Another method of cooling indoor spaces is by a passive technique where appropriate design features are applied to encourage adequate ventilation in buildings. This latter option has been envisaged as a viable solution to the problems of the energy crisis and environmental pollution. To eliminate or reduce the impact of these devices that cause climate change, the United Nations Framework Convention on Climate Change (UNFCC) came out with some strategies narrowed down to two objectives: mitigation and adaptation.

3. Mitigation and Adaptation

Mitigation and adaptation are the main objectives of UNFCC in combating climate change. The mitigation approach involves a human intervention to limit the sources of gases, while adaptation is defined as 'the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' [10]. To drive a reduction in greenhouse gas emission (GHG), that causes climate change, many countries adopted benchmarking processes that require calculations of building energy demand. Measures such as the Energy Performance of Building Directive (EPBD) in Europe requires member states to develop calculation methodologies to allow building energy demand to be determined. Denmark was one of the earliest countries to adopt energy efficiency regulations in the country's building code. The United States of America (USA) pioneered energy efficiency regulations in 1975 and was followed by South Korea and Japan and later India in 2007. In Nigeria, there is a National Building Code which needs to be reviewed to capture some trends in climate change.

Solutions to climate change may not solely be technical problems requiring technical solutions; rather it is more to do with human behaviour and how building occupants respond to the larger environment. Indeed, there is a growing concern that we have already passed an early 'tipping point' where the most aggressive global movements to reduce carbon emissions can do little to avoid a significant shift in the global climate system. As a result, mitigation alone cannot be a solution, and there is a need to think of adapting as the climate changes [3]. Hence, the importance of adapting buildings and their users to climate parameters with lower energy consumption is imperative.

In tropical climates, most of the buildings are naturally ventilated, and there may be a relationship between the adaptation of the occupants to the local environment and the local temperatures they experience daily. It is important to take advantage of these naturally ventilated buildings where adaptation to wider ranges of indoor thermal conditions is possible, unlike in air-conditioned buildings where a narrow range of temperatures is obtainable.

To encourage adaptation in indoor spaces, the adaptive thermal comfort model likely fits into the adaptation strategy recommended by the United Nations Framework on Climate Change to reduce greenhouse gas emissions. An adaptive approach to thermal comfort is capable of responding to climate change, using its sustainable design approaches to achieve energy efficiency in buildings. The adaptive comfort model applies to naturally ventilated buildings predominantly found in tropical climates. This adaptive model is recognized in developed countries, leading to its inclusion in both the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) and the European Committee for Standardization. Some other countries that have developed their model for adaptive thermal comfort are China [11], and India. Other countries are also in the race to develop an adaptive thermal comfort model applicable to their locality.

4. Buildings and Thermal Comfort

Comfort is not only a function of human physiology but also involves the nature of the buildings. Because of climate change and energy consumption in buildings, the design of buildings and their services extend beyond the comfort requirements of building occupants. Buildings are not seen as a function of just the physical and physiological state of the human body. For ages, humans have been adopting different strategies to achieve the desired level of thermal comfort. Different creative ways, such as behavioural adjustment, choice of clothing, and the use of fireplaces, were adopted to achieve comfort. In later years, during the 19th century, comfort research concentrated in industrial buildings and coal mines because of health and safety issues, and vulnerable populations and hospital patients [12]. By the end of the 19th century, significant progress was made in thermal comfort research when scientists discovered the four environmental parameters (air temperature, relative humidity, air velocity and mean radiant temperature) and personal factors that can be assessed to determine thermal comfort. The foundation for the methodological approach to adaptive thermal comfort was laid by Dr. Thomas Bedford in the 1930s and Nick Baker. Considerable progress in adaptive thermal comfort was made in the 1960s when the ‘focus of research shifted away from winter heating towards modeling the dynamic response of buildings in the summertime, where highly glazed buildings were overheating on sunny days and during heating waves’ [13]. Some of the pioneer researchers who did extensive research work on adaptive thermal comfort in this regard are; Fergus Nicol, Charles Webb, Edward Danter, and Michael Humphreys.

Thermal comfort is defined by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) as the ‘condition of mind that expresses satisfaction with the thermal environment’ [14]. ASHRAE’s definition of thermal comfort is about a person’s psychological condition of mind, whether the person feels neither ‘too hot nor too cold’ or thermally neutral provided that the person is healthy and wears a normal amount of clothing at the time of assessment. A building that is ‘too warm’ or ‘too cold’ can become very uncomfortable and possibly lead to ill health. The human body reacts to heat by increasing the blood flow to the skin’s surface and by sweating. Excessive cooling affects human health directly and indirectly. If the body’s core temperature falls below 35^{o}C, the person becomes hypothermic, which may decrease mental skills and coordination. In order to maintain the ‘core’ body temperature, it is essential that the thermal condition of building occupants is maintained, by retaining the core body temperature within a very narrow range of 37^{o}C. Some actions are subconscious, like diverting blood from decentralized areas like hands and feet to keep the vital organs warm in cold environments or to start sweating in warm environments. Conscious actions include removing or adding clothes and adapting our activity level. Of all the four environmental parameters (air temperature, relative humidity, airspeed and mean radiant temperature) two key areas of thermal comfort are air temperature and air movement. Both can be controlled and improved with certain devices, such as heaters and air conditioning units, fans, or by natural ventilation techniques.

Air temperature: is ‘the temperature of the air surrounding the person’ [14]. Air temperature is the most commonly used indicator of thermal comfort and is considered the most important factor determining heat stress. Results from many researchers indicate the relationship between air temperature, indoor thermal comfort, and productivity. A thermometer that should not be affected by any radiant heat is usually the best instrument for measuring the air temperature.

Airspeed: is defined as ‘the average of the instantaneous air velocity over an interval of time’ [14]. Air movement plays an important role in the comfort of a building occupant by causing the feeling of freshness. This is achieved by increasing the rate of evaporation in a human body, especially at high humidity where evaporative cooling is the main source of heat loss from the body. Wind, therefore, reduces the adverse effects of thermal discomfort caused by high temperature and humidity. However, high air movement in a cool or cold environment may be perceived as draught, if the air temperature is less than skin temperature, it will significantly increase convective heat loss. While in colder countries, high air movement may be viewed as unwelcome by building occupants, the opposite is the case in warmer countries especially when the indoor temperature becomes unbearable. Results from many researchers have indicated the importance of air movement in an indoor environment, especially in the tropics. According to [15], inadequate ventilation is probably the most important reason for occupant discomfort in naturally ventilated buildings. Designers of buildings located in the tropics should take advantage of the recent suggestion in ASHRAE standard, for higher air velocity consideration in warmer climates, to produce sustainable designs that rely on the infiltration of more air into naturally ventilated buildings.

The emphasis on these two parameters (air temperature and airspeed) is because of the way heat is transferred. Heat is transferred through thermal conduction, where two objects come in contact, then particles collide, and energy is passed on from one to the other. Heat is also transferred through convention and radiation without the need for two objects to be in physical contact.

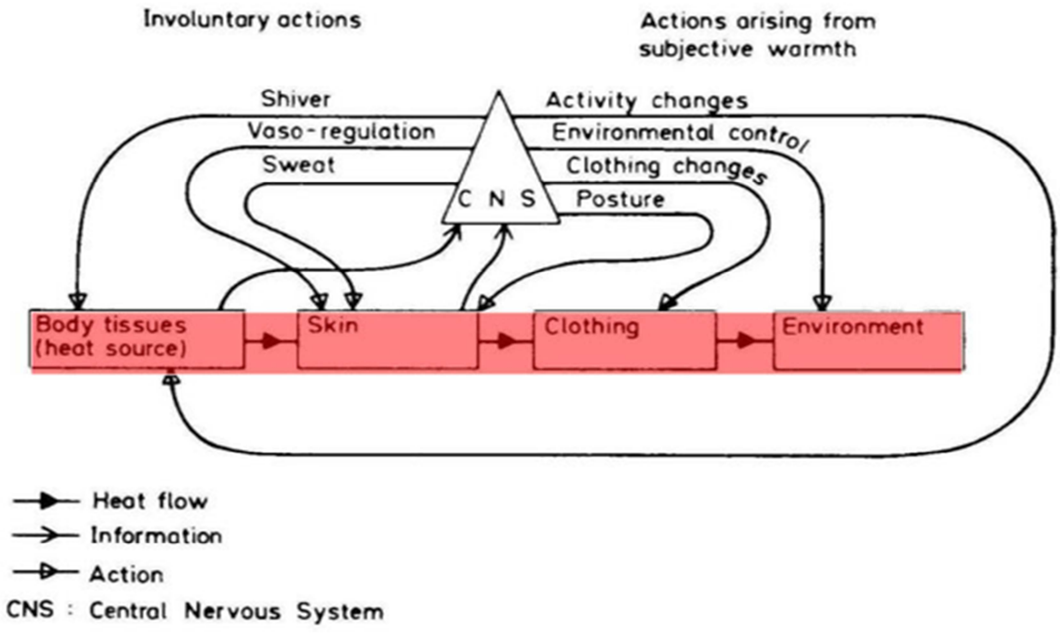
Conduction: Conduction of heat transfer from buildings mostly occurs through the building envelope, windows, and ceiling. Materials like marble, gravel, concrete, asphalt, are good conductors of heat and must be avoided in external construction. Materials that transfer minimum heat from the outside to the insides like glass and wood may be chosen for walls, ceilings, and windows for a cool interior. Windows also act as a medium of heat transfer where the glass absorbs and traps the heat within the room.

5. Adaptive Thermal Comfort

The major complaint of indoor occupants in the tropics is overheated indoor spaces. It will be difficult to specify an environment known to be acceptable to all the building occupants. This is because, people respond differently to thermal environments because of the differences in age, health status, type of clothing worn, rate of activity, and how each individual acclimatizes to the environment. Because of this unlikeliness of a given indoor environment to satisfy 100% of the people at the same time, ASHRAE Standard 55 suggested that an indoor environment can be assumed to be acceptable when 80%, or more, of the occupants, accept the indoor thermal conditions [14].

The adaptive approach to thermal comfort was considered as a result of the oil shock in the 1970s. This oil shock caused an energy crisis, resulting in the high cost of heating indoor spaces in order to provide the desired thermal comfort to building occupants. According to [13], energy is saved because the adaptive approach allows the indoor temperature to drift closely with the prevailing outdoor temperature, and the reduced difference between the two variables reduces the energy needed to heat or cool indoor environments. The adaptive approach to thermal comfort was also introduced to encourage the reduction of greenhouse gas emissions in the building sector. The adoption of the adaptive model in buildings can help to meet the goals set by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Conventions on Climate Change (UNFCC), regarding the reduction of greenhouse gas emissions in the building industry.

The journey towards the achievement of this objective (reduction in greenhouse gas emission) started on a serious note when Nicol and Humphreys hypothesized the existence of feedback between the occupants' thermal comfort and their buildings, with occupants adapting to a much larger range of temperatures than that predicted by the PMV/PPD model [11]. Adaptation refers to the initiatives and measures used as strategies to reduce the vulnerability of natural and human systems against happening or and the potential climate change effects. In order words, it can be defined as the gradual decrease of the organ's response to a stimulus, involving all the actions that make them better suited to survive in such an environment. In the context of thermal comfort, adaptation may involve all the processes that people go through to improve the fit between the environment and their requirements. The relationship between the thermal environment and the occupants' is quite complex. Occupants' adaptation and sensation of the thermal environment is the comprehensive effect of the three adaptive behaviours; behavioural (clothing and window), physiological (acclimatization) as well as psychological (expectation) [12]. These three adaptive behaviours are further discussed below and illustrated in Figure 1.



(Source: [12]).

Figure 1. *Thermal regulatory system.*

Behavioural Adaptation: includes all actions taken by a person consciously or unconsciously to maintain a comfortable thermal condition. The behavioural adaptation strategy is in form of personal, technological, and cultural adjustments. At the personal level, actions taken by people are in form of changing clothing levels, changing activity and posture, eating, drinking, and moving to different locations. At the technological level, the surrounding environments are modified by opening/closing windows, and doors, and switching on/off fans. While the cultural adjustments include activity according to the sociocultural and traditional setup, including adaptation to various clothing based on social norms.

Physiological Adaptation: This type of adaptation is present in all living organisms, including humans, birds, animals, and plants. As per its name, physiological adaptation refers to the internal organs, tissues, and cells. In this type of adaptation, the cellular features, internal organs, changes in the hormonal level, mood swings, and other features help an organism to survive, adapt and respond to the changes in its environment.

Psychological Adaptation: are the effects of cognitive and cultural variable on the thermal sensation of the individual and the extent to which one's perception and expectations are altered towards a thermal environment.

6. Suggestions to Reduction of Temperature Rise in Buildings

Temperature rise in buildings located in tropical climates can be reduced by the proper application of passive design strategies. The application of passive design strategies in buildings located in tropical climates intends to minimize energy consumption and at the same time improve the thermal comfort of the occupants. The building envelope, orientation, shading methods, and ventilation rate are important considerations in passive design.

Building envelope: The energy consumption of buildings depends on the components of the building envelope. Building fabrics consist of the roof, walls, windows, doors, floors, or any other fabric that controls the flowing energy between the interior and the exterior of a building. The building fabric can play an important role in sustainable buildings by reducing the energy consumption and maintaining the indoor thermal comfort of the occupants. The building fabric controls the flow of energy between the interior and exterior of a building. It can play an important role in sustainable buildings, by reducing the energy consumption and maintaining the indoor thermal comfort of the occupants. Low thermal conductivity and appropriate heat capacity design of the building envelope or fabric can potentially reduce the heat gain or loss through the building components. Furthermore, the building fabric must be protected from the direct impact of solar radiations, using different shading strategies.

Building materials: Construction materials such as cement, bricks, cement block, and solid masonry materials used in the tropics are considered as high mass and considered very effective against rapid heat transfer, which is due to their abilities to absorb heat from solar reduction at a much lower rate than lightweight materials. The heat absorption of a surface depends on the capacity of the building materials to reflect, absorb, and store radiation. The heat storage capacity of building materials is expressed by the thermal mass which is a function of material density and specific heat. The ambient temperature, solar access, humidity, wind patterns, and diurnal temperature variation of a location all influence the behaviour of thermal mass. An effective way to minimize energy consumption in warmer climates is to select building materials that contribute to cooling the indoor temperature. The characteristics of any building in terms of the materials used in the construction of the walls and the floors, including the type of doors, windows, ceiling, and the type of roof and the design determine the thermal condition of that building and to a large extent, the thermal perception of building occupants.

Thermal mass is the ability of a material to store energy at one point in time and release this energy later. Thermal mass depends on the relationship between the specific heat capacity, density, thickness, and conductivity of the material. The measures of the heat flow through a material, which is also the ratio of heat transmittance to heat storage (conductivity divided by density and specific heat) is referred to as diffusivity, and diffusivity is dependent on the relationship between the specific heat capacity, density, thickness and conductivity of a material [15]. For any given conductivity, the higher the density and specific heat, the lower the diffusivity. Concrete and bricks exhibit low diffusivity because it has very low conductivity, despite its thermal mass. Steel also has high thermal mass, high density, and specific heat; however, the high thermal conductivity makes for high diffusivity and hence high heat flow through the materials.

Orientation: An important consideration at the early design stage is how to position a building on the site to be able to have less heat gain inside. An appropriate building orientation can significantly decrease the use of mechanical heating and cooling system, thereby reducing energy use. Placing the longer side of the walls of the building to face North and South is ideal, so that the building gets minimum solar exposure. If it is a residential building the kitchen should, preferably, be located on the leeward side of the building to avoid circulation of hot air and smell from the kitchen.

Shading device: The main purpose of shading devices is to prevent direct solar radiation from reaching external walls, and the most effective method to control solar heat gain into buildings is through its interception before arriving at the building envelope. Shading windows, walls, and roofs are effective solar control measures at the stage in design when the building orientation and form size are being decided. Also, to avoid the inflow of heat, whether direct or indirect, the surfaces on which the sun's rays fall must be protected. Windows are the main component that allows the penetration of solar which increases the risk of indoor overheating. The roof is also another important element of the exterior building envelope because it is exposed to solar radiation for the most part of the day. Proper attention must be given to these building components at the design stage. The design of shading devices can be difficult because one needs to understand the movement of the sun and its angle of position. Shadings act as important solar gain controls provided that their design and installation do not compromise the comfort of the building occupants. A well-designed overhang, on windows, can considerably shade the window from solar impact. Other shading strategies are roof overhangs (eaves), balconies, and trees. Properly shaded indoor spaces also enhance the effectiveness of indoor ventilation. Furthermore, the selection of any shading device and their method differ, depending on the type of building, expected thermal conditions, and the location of such buildings.

Natural ventilation; Increasing the air movement rate in indoor spaces increases the cooling efficiency in hot and warm seasons. Natural ventilation is one of the passive design strategies, which enhances indoor air quality in hot and dry regions by providing fresh air. There are three categories of ventilation: mechanical ventilation, mixed-mode ventilation (or hybrid ventilation), and natural ventilation. Mechanically ventilated spaces are ones that are ventilated by equipment such as motor-driven fans and blowers. Mixed-mode ventilation, also known as hybrid ventilation, refers to a combination of natural ventilation (from the operable window) and mechanical system. Naturally, ventilation refers to intentionally designed passive methods of introducing subaerial to space without the use of mechanical means. When wind flows around a building, the windward and leeward areas witness a drop in pressure. The openings in the building will take advantage of the dynamic pressure drop to drive air through these openings helping to remove the heat and pollutants from the indoor space. The difference in wind pressure between the openings on the high-and low-pressure sides is important to adequately remove the heat and pollutants from the space. Air movement is the key requirement in the overall ventilation process when integrating and designing building façade, building forms, and orientation. Buildings located in tropical climates can rely on natural ventilation as long as they are properly designed.

Applying natural ventilation in buildings can reduce energy consumption and greenhouse gas emission considerably [16], and can reduce the overheating of indoor places. The efficiency of natural ventilation in reducing the cooling load in tropical climates is also dependent on some other factors such as outdoor micro-climate and the nature of the terrain. Authors analyzed the factors affecting indoor air temperature in the tropical climates, paying particular attention to an indoor comfort level. Results demonstrated that the indoor thermal comfort is increased by the natural ventilation system, while energy consumption decreased by 31.6% with respect to a typical mechanically ventilated one [17]. Thus, natural ventilation has become an increasingly attractive method of reducing energy use and cost in buildings.

Designing natural ventilation can be extremely complex because of the interaction between cross ventilation and the stack effect, especially in a building that has a complex design. Natural ventilation can also be influenced by occupant behaviour, for example, a person near to a window may choose to close it. However, if this is done against the wish of the other occupants it may cause thermal discomfort to them. Furthermore, natural ventilation provides indoor environments that are more pleasurable and cheaper to run compared to the static indoor climate achieved by centralized air-conditioning. In the humid tropics characterized by high temperature and relative humidity with low wind velocity, one strategy for buildings in providing relatively satisfactory indoor space is the use of natural ventilation to enhance evaporative and convective cooling of occupants [18]. The role of natural ventilation as an energy conservation strategy is a path towards more sustainable buildings. Natural ventilation is an energy conservation method that may help reduce buildings' energy consumption, improves thermal conditions, and maintain a healthy indoor environment. Reduction in energy consumptions in buildings can also be achieved through night ventilation. According to [19], night cooling is a relatively simple strategy that can effectively reduce indoor temperatures during the summertime, and account for overall energy reduction in buildings.

The design strategy (in the use of natural ventilation) aims to provide thermal comfort and acceptable indoor air temperature with the minimum use of energy in buildings located in the tropics. This is unlike in cold climates where the indoor temperature in a building is controlled by HVAC system, exposing the occupants to a single temperature [20]. Natural ventilation can be classified into three different types and these are; single-sided ventilation, cross-ventilation, and stack ventilation. These ventilation strategies influence the indoor ventilation efficiency and airflow pattern resulting in different indoor thermal conditions. In single ventilation, the air enters and leaves at the same side of the room, while in stack ventilation the thermal buoyance and wind pressure would cause the pressure difference between two openings, on the same side of the wall, and then encourage the stack effect. In cross ventilation, both sides of the walls have openings so that air flows from one side of the opening to the other side, bringing airflow across the entire room, and at the same time carries off the heat and pollutants from indoors. Therefore, windward and leeward pressures are important elements for cross ventilation. Natural ventilation utilization in buildings, compared to mechanical ventilation, has some advantages such as:

1) It is fossil fuel-free and has no negative impact like air pollution and global warming.
2) It requires less construction and operation cost and low maintenance cost.
3) It is reliable and easy-to-use in many types of buildings. The potential for personal control of the environment increases the user's satisfaction and productivity.

However, natural ventilation has some disadvantages. Some of the disadvantages are summarized below:

1) There is no guarantee in securing a stable indoor environment, compared to the steady conditions of mechanical ventilation.
2) It is very difficult to naturally ventilate buildings that have deep plans, or those requiring high control levels of the indoor environment like in hospitals.
3) It guarantees less security and safety when compared to mechanically ventilated buildings.

7. Conclusion

This paper highlighted the growing concern about rising temperatures caused by climate change and recommended some passive design techniques in the use of appropriate building materials to enhance the thermal comfort of building occupants. Thermal comfort in a building is important to be considered at the initial stage of building design. A naturally ventilated building that is properly designed can provide thermal comfort to the occupants and at the same time uses less energy. This review paper highlighted some building materials which when used to construct buildings are capable of providing thermal satisfaction to building occupants. These building materials have a range of properties that aid passive cooling. The information gathered from the overview of this paper will serve as a guide to professionals in the built environment.

Conflict of Interest

The authors declare that they have no competing interests.

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