DOI: 10.23968/2500-0055-2023-8-4-68-81

ADOBE BRICKS TO HOLLOW SANDCRETE BLOCK WALLING IN TROPICAL BUILDING CONSTRUCTION: MATERIAL IMPACT ON SUSTAINABLE INDOOR THERMAL COMFORT ATTAINMENT

Sule Adeniyi Olaniyan*

Ladoke Akintola University of Technology, Ogbomoso, Nigeria

*Corresponding author's e-mail: saolaniyan@lautech.edu.ng

Abstract

Introduction: Tropical climate is characterized by high temperature, the consequence of which induces indoor thermal discomfort. This is attributed to high solar gains through various elements of the building envelope, including windows, walls, and roof among others. However, in an attempt to optimize indoor thermal comfort with minimal or no recourse to mechanical installations, this study explores the roles of the walling fabrics by comparing varying thermo-physical properties of two identified masonry units in the study area of Ogbomoso, Nigeria (adobe bricks and hollow sandcrete blocks), with a view to identifying a more thermally comfortable and sustainable material option. **The methodology** involves virtual models of two similar residential buildings each composed of either adobe bricks or sandcrete blocks, as masonry units. These models were subjected to energy performance simulation analyses using DesignBuilder software, over a 12-month cycle period, to experience year-round differential thermal conditions. Through the observed comparative annual heat loads as experienced in the models, the results show improved indoor thermal comfort in the brick building (i.e., 7119.54 KWh), with heat loads being 11% lower than that of the sandcrete building (i.e., 8875.65 KWh) due to the brick walling fabric. This may be associated with the brick's lower thermal conductivity (U-Value) of 1.798 W/m^2-K, compared with the sandcrete blocks' value of 1.999 W/m^2-K. **Results**: In general, adobe bricks as a walling unit exhibit more thermal resistance against the harsh outdoor weather conditions than sandcrete blocks. The study is part of an ongoing effort towards reviving this partially neglected low impact material — adobe brick — with a view to attaining sustainable indoor thermal comfort as well as protect the environment in the study area.

Keywords: adobe brick, sandcrete block, simulation, sustainable, thermal comfort, tropics.

Introduction

Over the past decades, architectural practice has faced a lot of challenges and transformations as our living conditions changed in different contexts considering social, technological, economic, political, and more importantly, environmental impacts. Our emerging housing typologies, in the tropical region particularly, as a consequence of our evolving patterns of living, are largely influenced by the phenomenal global environmental conditions (Altan et al., 2015). The tropical region falls between two lines of latitude, the Tropic of Cancer, 23.5 degrees north, where the sun is directly overhead at noon on June 21 (midsummer in the northern hemisphere), and the Tropic of Capricorn, 23.5 degrees south where the noon sun is directly overhead on December 21 (midsummer in the southern hemisphere). The region includes much of Central and South America, most of Africa, among others, as it is home to around 40% of the world population (Karyono, 2017; JCU, 2014). Its climate is mainly characterized by an elevated temperature and a high relative air humidity as these account for some level of indoor thermal discomfort ordinarily (Prianto and Depecker, 2003). However, buildings are required to offer sustainable, healthy and comfortable indoor environment, irrespective of the outdoor climatic conditions (Lotfabadi and Hançer, 2019). The consequence of these is the need for integration of the passive design approach (Bay and Ong, 2006). Alternatively, active energy sources such as mechanical cooling systems involving mechanical ventilation, air conditioning systems, are introduced for improved indoor thermal comfort. However, the latter often consume substantial energy among all building services (about 20–40% of the total energy needs), without which significant energy savings would have been achieved with the attendant reduced electricity costs (Kenisarin and Mahkamov, 2016; Prianto and Depecker, 2002; Raja et al., 2001).

It has been established that the building sector is responsible for around 39% of world CO_2-equivalent emissions. This is indicated in various submissions, including the Global Status Report for Buildings and Construction of 2019 (Ascione et al., 2021; Attoye et al., 2017). Besides, the sector is liable for about 36% of global energy consumption, 50% of extraction of raw materials, and 1/3 of drinking water consumption (Ascione et al., 2021; Lotfabadi et al., 2016; Nejat et al., 2015; World Energy Council, 2013). In this alarming scenario, the global building stock is expected to increase

For citations: Olaniyan, S. A. (2023). Adobe bricks to hollow sandcrete block walling in tropical building construction: material impact on sustainable indoor thermal comfort attainment. Architecture and Engineering, No 4 (8), pp. 68-81. DOI: 10.23968/2500-0055-2023-8-4-68-81.

and double by 2060 because of new constructions, particularly in developing countries, due to the rapid growth in population, economic activities and fast urbanization, with an attendant increase in CO_2 emissions (Lotfabadi, 2013). The building sector is a major energy consumer in tropical countries, apart from the industrial and transportation sectors (Prianto and Depecker, 2002). Thus, without any initiatives, suitable policies and action plans, energy demand in the construction sector could increase by 50%, with the consequent impact on global and local warming (Attoye et al., 2017; Camanzi et al., 2017; Jiang et al., 2016). This may otherwise affect the general wellbeing of the occupants. Thus, energy saving in this sector is important.

Towards such energy saving approach in building design and construction for indoor thermal comfort of the occupants in the tropical area, various attempts have been made by various researchers. Givoni (1976), Kwong et al. (2014), Longo et al. (2011), among others, demonstrate significant potentials of energy savings and improvements of indoor environmental quality accruable from adoption of natural ventilation. Attoye et al. (2017), Koukelli et al. (2022) as well as Quesada et al. (2012) illustrate integration of passive dynamic adaptive façade systems as the threshold between building and exterior environment to improve indoor thermal comfort (while reducing the building's energy consumption). Ascione et al. (2021) study the best trade-off among transparent envelope solutions, thermal mass of the building, and radiative characteristics of the roof. Thermo-physical properties of the materials used in the building envelope have also been studied by Pacheco-Torgal et al. (2014) as well as Pacheco-Torgal and Jalali (2011). In general, improvement of the construction methodology, energy efficiency technologies, adoption of passive design, use of renewable energy, and appropriate selection of building materials may constitute important strategies for the energy saving approach (Abanda et al., 2015) in this regard.

As a major point of departure, the focus of this study is on building materials. It examines the implications of the varying constituents of the building walling fabrics with emphasis on the locally available low impact building material, specifically adobe bricks, in place of the predominantly adopted sandcrete blocks in the study area. This is with a view to attaining more sustainable comfortable indoor thermal environment with minimal impact on the environment.

Literature Review

Thermal comfort refers to that condition of mind, which expresses satisfaction with the thermal environment based on the heat balance of the human body (Shastry et al., 2016). This may also refer to the state of mind that expresses mental satisfaction with the surrounding environment (Prianto and Depecker, 2003). It can be measured by both environmental and personal parameters. While the former is defined by such factors as ambient temperature, mean radiant temperature, water vapor pressure or relative humidity, and relative air velocity, the latter is defined by the clothing level or thermal resistance as well as activity or metabolic rate (Shastry et al., 2016; Prianto and Depecker, 2003). Attainment of thermal comfort is essential for the general wellbeing of occupants as a building does not only confer a spatial form to accommodate people but also acts as a device to modify an extreme outdoor environment to a moderately comfortable to keep their activities at a normal metabolic rate (Vale and Vale, 2017).

In practical dimensions, Omonijo (2017) outlines guidelines towards achieving occupants' thermal comfort in standard dwellings: adequate availability of thermal capacity in the building structure and on the interior envelope surfaces of habitable rooms; provision of additional levels of thermal insulation for exposed opaque walls and, when required, for exposed ground floor elements; proper adjustment of the window size as a function of orientation, room size, and occupant requirements, for passive solar heat gains; provision of internally insulated shutters on exposed glazing elements, for control of excess heat losses during evenings and at night; provision of controllable means for ventilation, such as adjustable trickle vents, extract fans, and/or individual heat recovery ventilators; provision of operable shading devices on the north-, east- and west-facing windows with adjustable blinds for control of excess solar heat gains. Other considerations affecting the energy requirements of buildings as highlighted by Al-ajmi and Hanby (2008) include: building location (altitude, latitude, longitude, and orientation); local weather conditions; heat transfer and storage characteristics of the building's elements, which depend on the various thermo-physical properties of the building components; windows, doors, and other openings; shading of the exterior surface; building dimensions; indoor temperature, number of occupants, lighting and building usage; primary and secondary air-conditioning systems; ventilation and infiltration. Each of these factors influences the cooling load of the building as the impact of each factor varies from building to building subject to the architectural design, building function, and material composition (Al-ajmi and Hanby, 2008).

Rapid growth in population, economic activities and general urbanization during the last decades in the tropical countries have had several environmental, economic, and social consequences, with an increase in energy consumption. More houses, schools, hospitals, roads, railways, bridges, public libraries, and other public facilities are needed to be built to accommodate people and meet the population growth. These have raised concerns over depletion of local natural resources and supply difficulties as the building sector constitutes one of the major end users of energy (Koukelli et al., 2022; Kwong et al., 2014). Buildings account for about 15% of emissions, while transport and industry are 14 and 21%, respectively, and the remainder is emitted by other activities (Karyono, 2015, 2017; Karyono and Bachtiar, 2017). Thus, efficient and sustainable utilization of energy is essential in conserving the fast-depleting resources.

One of the main aims for sustainable development is to reduce the use of non-renewable energy resources. In view of industrialization and the expansion of modernization, urban areas have increased in size and so has the global population, with an expected annual growth of 1.8% (Mahravan and Vale, 2017). For these reasons, and to achieve sustainable growth objectives, energy saving in this sector is important. Thus, the building stock should be re-developed from the energy viewpoint. In effect, it is necessary to design comfortable buildings that do not use, or hardly use, active mechanical installations (Bastide et al., 2006). Thus, the building envelope shall be the focus of this study. The envelope constitutes the primary subsystem through which energy losses occur between indoor and outdoor environments of the building (Ascione et al., 2021). The idea is to reduce the heat transfer through it, while still ensuring comfort for the occupants. An improvement of the building envelope and the energy efficiency may reduce the ambient temperature and building's impact on the available natural resources. In this case, adequate climatic responsiveness and adaptiveness of the elements of the building envelope to extreme heat changes in an energy-efficient way can result in reduced building's energy consumption (Koukelli et al., 2022). This, therefore, gives way to comparative research work on two locally available walling elements as separate constituents (individually) of the building envelope in the study area, adobe bricks and hollow sandcrete blocks.

Brick is one of the oldest, most popular and environmentally friendly construction materials because of its durability, ease of handling, aesthetics and local availability (Abdullah et al., 2015). Adobe brick is essentially a dried mud brick, combining the natural elements of earth, water, and sun. It is an ancient building material usually made with tightly compacted sand, clay, and straw or grass mixed with moisture, formed into bricks, and naturally dried or baked in the sun without an oven or kiln (Craven, 2019). Bricks are used for exterior and interior walls, partitions, piers, footings, and other load-bearing structures (Duggal, 2008). Recipe for its construction varies according to climate, local customs, and the historical era. Many building structures of architectural significance such as the Great Wall of China, Colosseum in Rome, pyramids in Egypt, the San Miguel Mission in Santa Fe, New Mexico, and the Taj Mahal in India, among others, were built with bricks (Craven, 2019; Phonphuak and Chindaprasirt, 2015). Introduction of chopped straw and grass to the clay mixture of the naturally sun-baked brick improves its quality and reduces distortions and cracking. The brick firing is also used to improve its strength and durability (Pacheco-Torgal, 2015; Phonphuak and Chindaprasirt, 2015). However, introduction of Portland cement in the 21st century led to development of masonry hollow sandcrete block, which is characterized with faster hardening and higher compressive strength (Olaniyan, 2021). Hollow sandcrete blocks are masonry units manufactured from a mixture of cement, sand, and water, and play a crucial role in the building construction. Hollow sandcrete blocks are largely used for load-bearing and non-load-bearing walls and foundations (Sholanke et al., 2015; The Constructor, 2022).

Thus, masonry hollow sandcrete blocks subsequently became an alternative to bricks, thereby leading to significant reduction in the use of the latter (Bingel and Bown, 2009; Smith et al., 2016). This development led to partial abandonment of the brick, despite its huge potentials in building energy moderation and conservation. In this context, these potentials accruable from old but partially abandoned bricks as opposed to prevailing sandcrete blocks in the tropical study area of Ogbomoso, Nigeria, are subjected to thermal performance analysis using a simulation tool, DesignBuilder. This paper, therefore, deals with optimization of building energy efficiency in the tropical city of Ogbomoso through comparative evaluations of relative thermal performance of walling fabrics, using two locally available building materials, adobe bricks and hollow sandcrete blocks. This approach attempts to reduce residential building cooling energy needs for attainment of indoor thermal comfort in the study area, by maximizing the advantages of the thermo-physical properties of the constituents of the low impact material, adobe brick. This is part of an ongoing research work as life building models will be constructed for direct validation at a later stage.

Research Methodology

The Study Area: Climate and Design Implications

Ogbomoso lies on 8° 10' north of the equator and 4° 15' east of the Greenwich Meridian. The city is situated within the derived savannah region and it is a gateway to the northern part of Nigeria from the south. It is characterized by the tropical wet and dry climates as it falls within the transition zone lying between the rainforest and the savannah, with a mean annual rainfall of about 1200 mm. The variation in the precipitation between the driest and wettest months is 178 mm. Both the highest and lowest relative humidity occur in January (42.54%) and September (85.18%), respectively. The highest and lowest number of rainy days are recorded in July (24.70 days) and December (0.73 days), respectively. There is an average of 76.53 hours of sunshine per month as around 2323.51 hours of sunshine are counted through the year. This climate is considered to be ‘Aw’ according to the Köppen–Geiger climate classification. The wet season falls between April and October while the dry season is usually experienced between November and March. The dry season exhibits a typical harmattan season where high radiation cooling under clear skies at night causes temperature to fall as low as 18°C. The average lowest and highest temperatures of about 28.3 °C and 23.8 °C are usually experienced in March and August, respectively. The average temperatures vary during the year by 4.6°C (en.climate-data.org, 2022; Femi et al., 2015; Olaniyan, 2012). Below is the summary of the climatic data for Ogbomoso, the study area (Table).

The climate is characterized by high solar radiation (i.e., radiation value of over 10 KJ/m^2/day for some months). This usually results in indoor thermal discomfort of the interior spaces in most parts of the year. Hence, there is the need for proper thermal analyses of the materials for the building envelope, for appropriate design interventions in the area (Olaniyan, 2012).

Materials and Methods

In this study, impacts of the varying walling fabrics (i.e., building materials) on attainment of sustainable indoor thermal comfort for residential buildings are examined. Virtual models of two similar residential buildings with bricks and sandcrete blocks (separately as walling components) are the objects of assessments for comparison. The two buildings represent a commonly adopted building typology (design) in the study area. While the first building type, tagged ‘Sandcrete Building’ (SB) is made up of a predominantly adopted masonry unit, hollow sandcrete block, the second building type, the ‘Brick Building’ (BB) is constructed of an age-long local building material, adobe brick (i.e., sun-baked earth block in this context). Figs. 1 and 2 give general outlooks of the structures.

The typical floor plan of either of the buildings is as shown in Fig. 3. It is a four-bedroom apartment with an approach balcony, occupying a total area of 103.85 square meters.

The wall of the Sandcrete Building is constructed of 225 mm hollow sandcrete blocks while that of the Brick Building is made of 230 mm traditional sun-baked bricks. Both structures are finished with 12 mm thick sand-cement mortar on both internal and external surfaces. As commonly found in the study area, both roofs are constructed of 0.45 mm thick long span aluminum sheets on a timber roof carcass, finished underneath with 6 mm thick

Summary of the climatic data for Ogbomoso, the study area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. temperature (°C)	27.3	28.3	28.3	27.5	26.4	25.0	24.1	23.8	24.2	25.0	26.4	26.8
Min. temperature (°C)	21.5	23.1	24.1	24.1	23.6	22.6	21.9	21.5	21.9	22.3	22.9	21.4
Max. temperature (°C)	34.2	35.1	35	33.3	31.4	29.2	28.0	27.5	28.5	29.8	31.9	33.5
Precipitation / Rainfall mm (in)	5 (0.2)	13 (0.5)	40 (1.6)	78 (3.1)	121 (4.8)	154 (6.1)	175 (6.9)	180 (7.1)	182 (7.2)	105 (4.1)	13 (0.5)	4 (0.2)
Humidity (%)	43%	50%	62%	73%	79%	83%	84%	85%	85%	83%	71%	50%
Rainy days (d)	1	2	5	9	14	16	19	18	18	13	2	1
Avg. sun hours (hours)	9.2	8.7	8.0	7.0	5.6	4.4	4.2	3.7	4.2	5.2	7.3	9.0

a) (source: en.climate-data.org, 2022)

b)

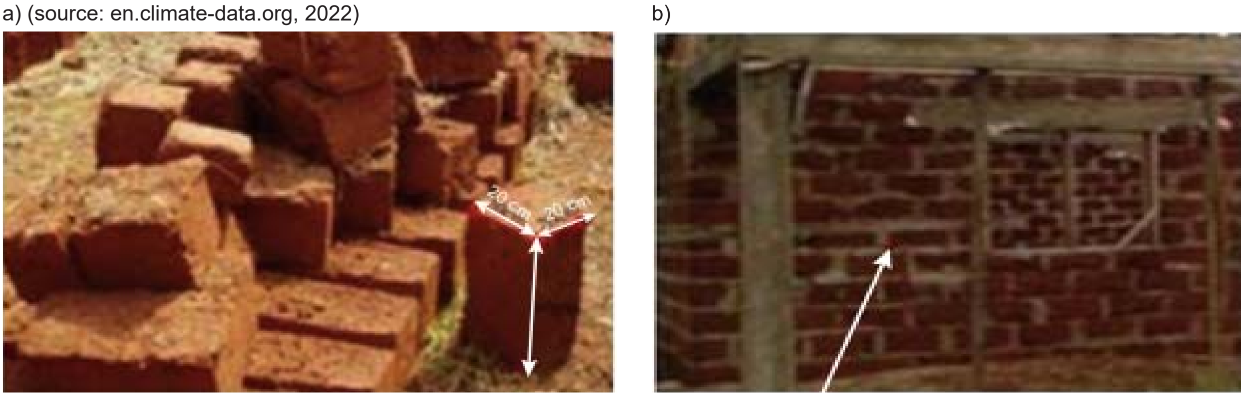


Fig. 1. Illustrations of the components of the adobe brick masonry units for the Brick Building: (a) individual sun-baked brick unit; (b) typical constructed walls joined with cement-sand mortar (images adopted from: Abanda et al., 2015).

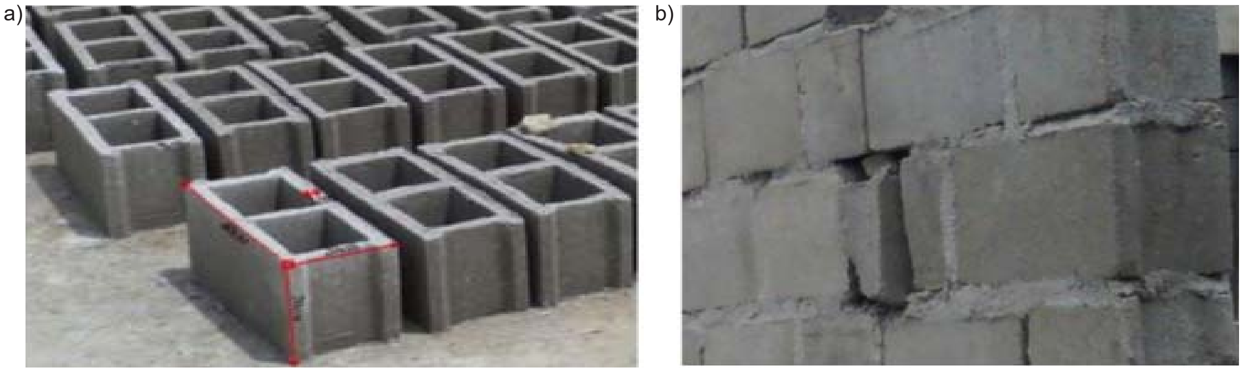


Fig. 2. Illustrations of the components of the hollow sandcrete masonry units for the Sandcrete Building: (a) individual hollow sandcrete block unit; (b) typical constructed walls joined with cement-sand mortar (images adopted from: Abanda et al., 2015)

asbestos ceiling sheets. The windows made of 6 mm thick clear glass are complemented with 40 mm thick wooden panel doors.

Virtual Building Modeling and Simulation Approach

Virtual models of the two buildings were subjected to energy performance simulation analysis. This is a powerful tool that architects, engineers, and other relevant professionals use to analyze how the form, size, orientation, and type of building systems affect overall building energy consumption. It is used to optimize building energy efficiency with respect to building input parameters (Al-ajmi and Hanby, 2008; Altan et al., 2015). This analysis is useful for informed design decisions to improve building energy performance in respect of the buildng envelope, glazing, lighting, HVAC, etc. As a modern design tool, it allows us to use the numerical simulation to analyze the influence of design elements on indoor thermal comfort for sustainable housing development (Altan et al., 2015). In many cases, few building simulations runs in the early phases of a project assist in attaining the best design solutions (Energy Design Resources, 2000).

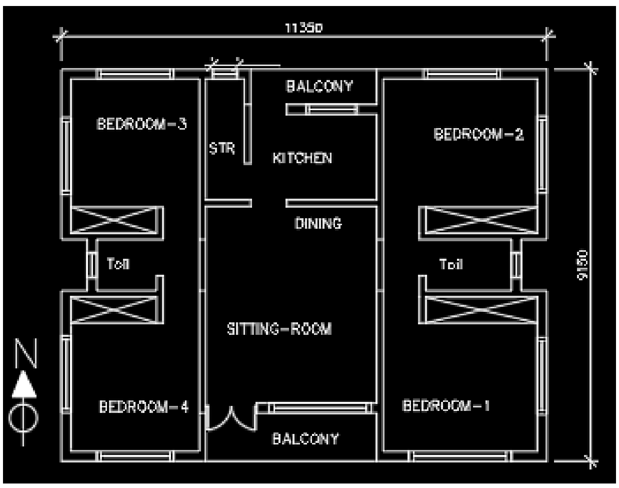


Fig. 3. Typical floor plan of the building model

In this study, DesignBuilder software was adopted for the building simulation work (DesignBuilder, 2021) as a typical virtual building model as illustrated in Fig. 4. The software is integrated with EnergyPlus, the US Department of Energy (DOE) third (3rd) generation dynamic building energy simulation engine for modeling building, heating, cooling, lighting, ventilation and other energy flows. This integration within DesignBuilder allows for complete simulations within the interface, which constitutes an excellent feature for ease of simulation. DesignBuilder uses construction components to model the conduction of heat through walls, windows, roofs, ground and other opaque parts of the building envelope. In this case, the physical properties of each element have been defined for the building (DesignBuilder, 2021). These simulations are run for the whole year (i.e., 12 months) as hourly, daily and monthly results are available. Passive solar gains and indoor comfort temperature due to the alternative walling fabrics, adobe bricks and hollow sandcrete blocks (external walls and partitions) in particular, obtained through

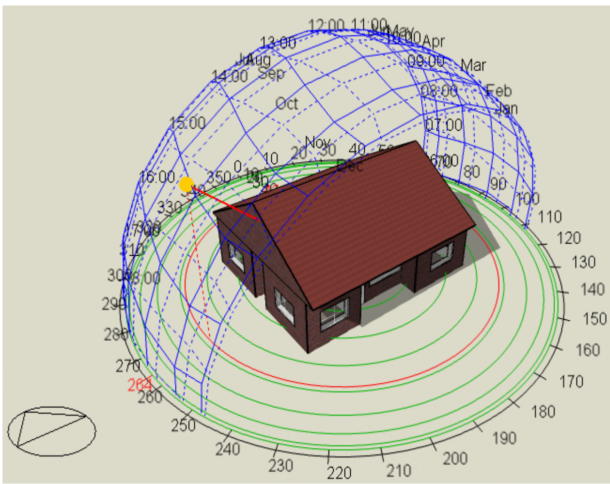


Fig. 4. Typical virtual model of the building as displayed in DesignBuilder Interface (sandcrete: U-Value (W/m^2K) = 2.137; R-Value (m^2-K/W) = 0.468)

cooling design simulations in the study area, are the simulation output variables considered relevant for the analysis. Thus, effects of the varying walling fabrics on indoor thermal comfort are compared to establish their individual impacts with a view to making necessary recommendations for the study area.

Results and Discussion

Arising from the geographical location of the study area in relation to the simulation output, relevant climatic data particularly, solar radiation (both direct and diffuse) is analyzed as presented in Fig. 5. It could be observed that high solar radiation values are recorded particularly between October and May, with each month experiencing almost 100 kwh/m^2 area of diffuse radiation. The trend is similar for direct radiation over the same period. March witnessed the highest diffuse and direct radiation values of 114.13 kwh/m^2 and 84.45 kwh/m^2, respectively. Details of this simulation output as captured directly from DesignBuilder interface are shown in Appendix I for referencing and verification. Of particular interest is the impact of this radiation data, which forms the basis for the indoor solar gains through the walling fabrics, among others.

The primary focus of this study is to establish comparative heat gains due to the walling fabrics of hollow sandcrete blocks and adobe bricks, as a basis for their respective indoor thermal comfort analyses. Comparative monthly heat gains due to the walling fabric received by the east end of indoor spaces of Bedrooms 1 and 2, by both SB and BB are as shown in Figs. 6 and 7. Details of these on a typical dry-season peak day (i.e., March 23) are as shown in Appendix.

Similarly, Figs. 8 and 9 illustrate comparative heat gains received by west end bedrooms 3 and 4.

The overall annual heat gains for the entire building through the walling fabric are illustrated graphically in Fig. 10.

From the results above, it could be observed that for every month, heat gains received by the building interior both in the east and west ends are more for the sandcrete building. Consequently, the annual heat load for the entire building due to the sandcrete blocks is 8875.65 KWh, with high values recorded in the months of March, April, and May (i.e., 791 KW/m, 788 KW/m, and 778 KW/m, respectively). This is significantly more than that of the brick building, which has the annual heat load of 7119.54 KWh, with high values also recorded in the months of March, April, and May (i.e., 726.77 KWh, 726.32 KWh, and 715.80 KWh, respectively). These are direct reflections of the components of the walling fabric.

From the foregoing, comparative annual heat loads as experienced in the building upon which indoor thermal comfort is based is 11% lower in BS (7119.54 KWh) due to the brick walling fabric. This may be associated with the brick's lower thermal conductivity (U-Value) of 1.798 W/m^2-K, which may even be as low as 1.5 W/m^2-K (Delgado and Guerrero, 2006), compared with the sandcrete block's value of 1.999 W/m^2-K. It should be noted that the ability of adobe brick to conduct heat depends on its moisture content, which is considered advantageous in moderate and hot climates because of the phase transition of the water. As the material dries, the water evaporates, leading to heat loss in the form of latent heat, which in turn causes the external surface temperature to decrease (Quagliarini et al., 2015).

From the thermal analyses above, adobe brick as a walling unit exhibits more thermal resistance against the harsh outdoor weather conditions to effect more thermally comfortable indoor environment. This position aligns with the findings of Martín et al. (2010) who analyzed comfort conditions inside earth buildings in Spain. It also agrees with the results obtained from several other related studies inclusive

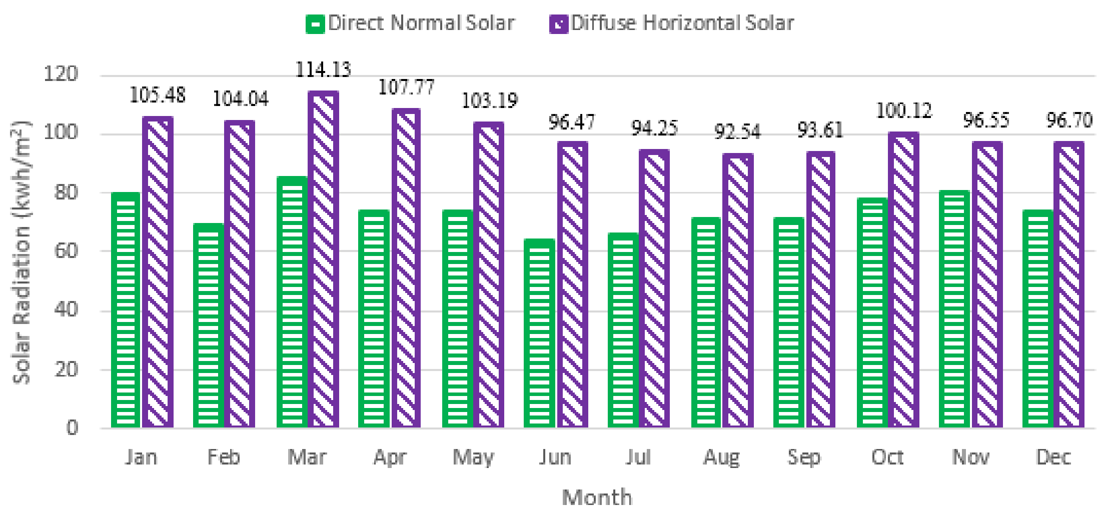


Fig. 5. Monthly solar radiation (direct and diffuse) for the study area

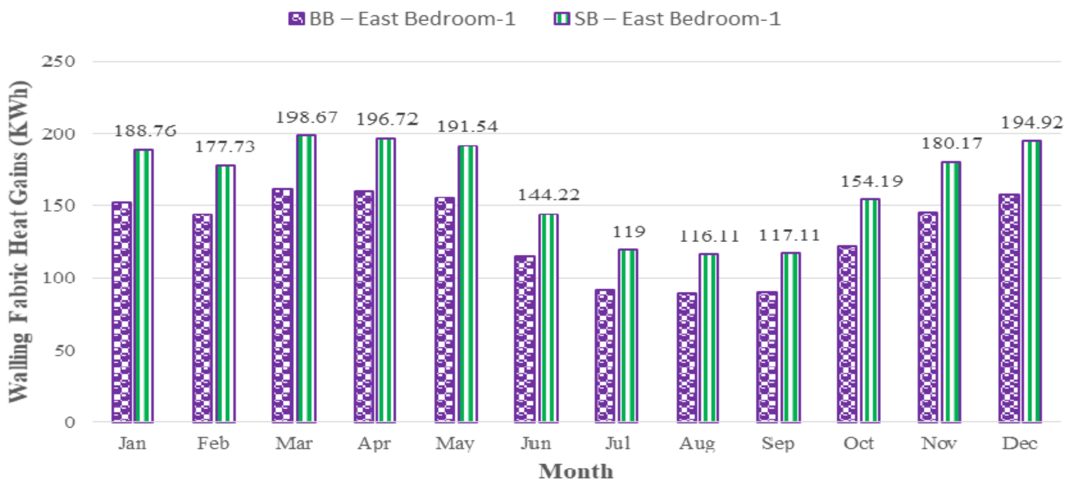


Fig. 6. Comparative monthly heat gains through the walling fabric received by east bedroom-1 for both sandcrete building and brick building

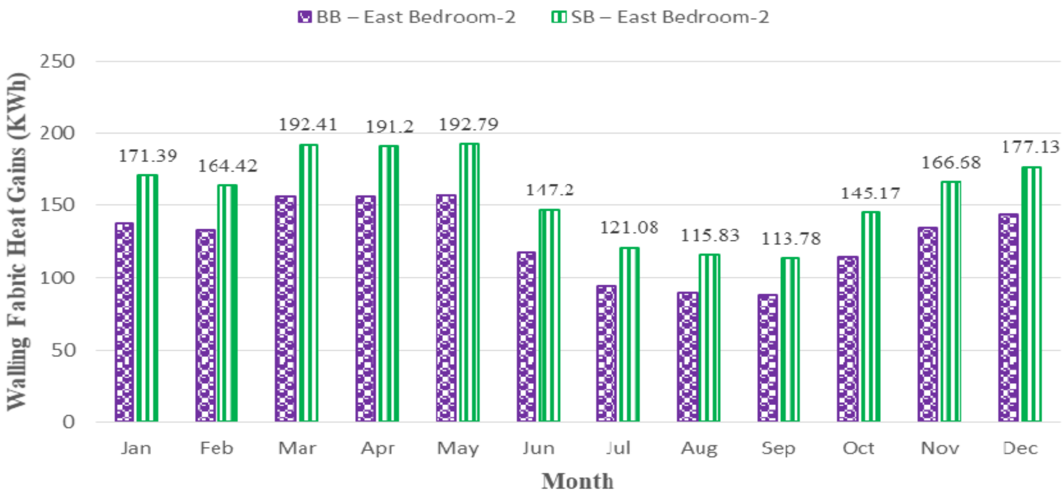


Fig. 7. Comparative monthly heat gains through the walling fabric received by east bedroom-2 for both sandcrete building and brick building

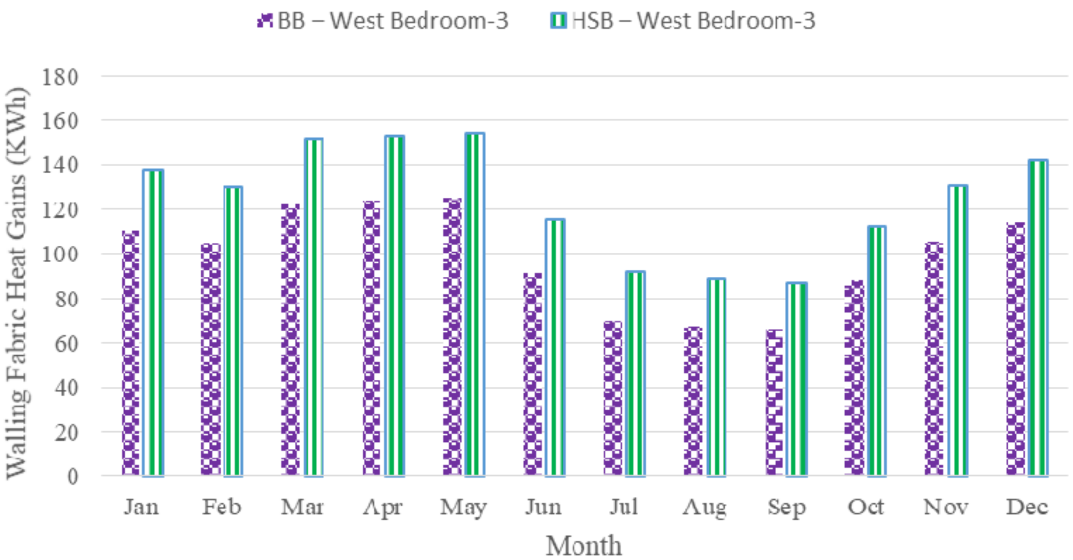


Fig. 8. Comparative monthly heat gains through the walling fabric received by west bedroom-3 for both sandcrete building and brick building

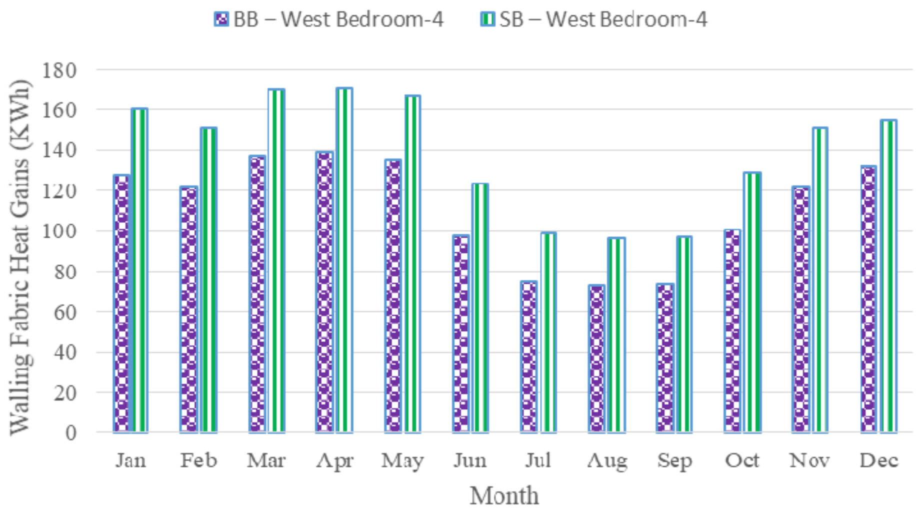


Fig. 9. Comparative monthly heat gains through the walling fabric received by west bedroom-4 for both sandcrete building and brick building

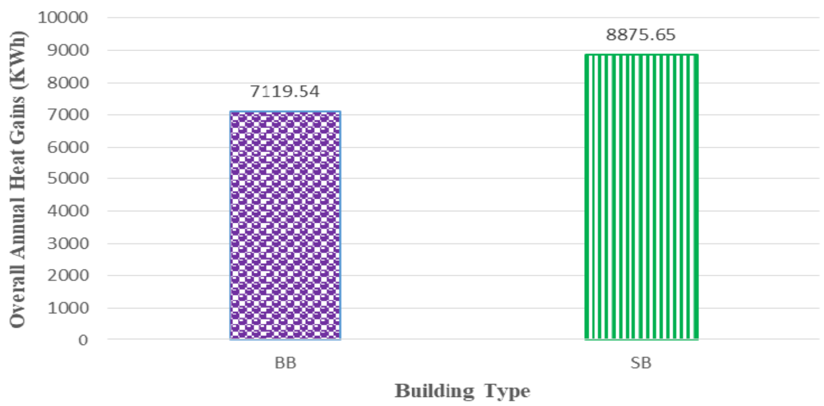


Fig. 10. Comparative annual heat gains through the walling fabrics

of Algifri et al. (1992), Chel and Tiwari (2009), Sale (1990), etc., as they all show that an adobe brick house can maintain natural indoor thermal comfort. It could therefore be demonstrated that compared with sandcrete blocks, adobe bricks provide a more comfortable indoor thermal environment in the tropical study area of Ogbomoso.

This research advances current knowledge on improving indoor comfort temperature ranges in naturally conditioned dwellings, at no extra construction costs. It also expands understanding of the thermal performance of different building residential types using conventional and alternative building materials.

Future Research Project / Research Validation

The simulation research approach was employed to theoretically predict the thermal roles of the components of the building fabrics (i.e., adobe bricks and hollow sandcrete blocks, in this case) and their impacts on the thermal conditions of the interior. However, the results obtained constitute the preliminary outputs, which require further validation using more empirical analysis. Thus, the information gained from the simulation exercise will inform comparative modeling/simulation of different building propositions, using comparative building fabrics as the building envelopes (by applying combinations of different thermal insulating materials as components of the building fabrics). Through trial experimentations, the result will evolve preliminary design guidelines for the proposed responsive architectural design solution in the study area. To achieve this, full scale testing, involving thermal analysis, will be carried out over a 12-month period using three prototype models as shown in Fig. 11.

Three prototype life building models will be constructed. Each model will be 2 m x 2 m x 1.8 m. The first model will be made of the building fabric prevailing in the study area and will serve as the control model. Components of the building fabric will consist of materials for the floor, wall, window, ceiling, door, and roof. The other two models will be constructed of different low impact building materials in the study area and serve as comparative bases for building performance assessment. Data collection in respect of these is expected to last one year. Subsequently, results of the life models will be compared with the simulated outcomes for validation and acceptability of the proposed design guidelines.

Conclusion

Tropical region is characterized by harsh outdoor weather conditions. However, the primary role of a building is to shield the interior from the impacts of such outdoor climatic elements. This is usually achieved through adoption of any available fabrics of building envelope. This is usually supported with additional mechanical installations such as fans, air-conditioners, etc. for indoor thermal comfort attainment. However, the rising energy costs, coupled with undesirable carbon emissions associated with such active installations have necessitated the need for more research on possible adoption of more low impact building materials available in the study area. Consequently, this study has demonstrated, with regard to the indoor thermal comfort attainment, that the partially abandoned locally available building material, adobe brick, as a walling fabric is more suitable than the predominantly adopted hollow sandcrete blocks in the study area. This is with a view to minimizing building construction impacts on the environment for overall sustainable utilization of the available limited resources. Therefore, wherever it is practically possible, adoption of adobe bricks as an enclosing material in the tropical city of Ogbomoso and its environment should be encouraged for inexpensive residential apartments. This is an attempt to revive an age-long partially abandoned locally available material for overall sustainable construction purposes. It should be emphasized that this result is part of an ongoing research work as life building models are to be constructed for direct validation of the results at a later stage.

Funding

The financial support from 'TETFund Institution Based Research (IBR) Grant-2020', a research component of the 'Tertiary Education Trust Fund', an educational support organ of the Federal Government of Nigeria is duly acknowledged.

Fig. 11. Illustrations of the proposed prototype life building models

References

Abanda, H., Tah, J. H. M., and Elambo Nkeng, G. (2015). Earth-block versus sandcrete-block houses: embodied energy and CO_2 assessment. In: Pacheco-Torgal, F., Lourenço, B. P., Labrincha, J. A., Kumar, S., and Chindaprasirt, P. (eds.). *Eco-efficient Masonry Bricks and Blocks. Design, Properties and Durability*. Cambridge: Woodhead Publishing, pp. 481–514. DOI: 10.1016/B978-1-78242-305-8.00022-X.

Abdullah, M. M. A., Ibrahim, W. M. W., and Tahir, M. F. M. (2015). The properties and durability of fly ash-based geopolymeric masonry bricks. In: Pacheco-Torgal, F., Lourenço, B. P., Labrincha, J. A., Kumar, S., and Chindaprasirt, P. (eds.). *Eco-efficient Masonry Bricks and Blocks. Design, Properties and Durability*. Cambridge: Woodhead Publishing, pp. 273–287. DOI: 10.1016/B978-1-78242-305-8.00012-7

Al-ajmi, F. F. and Hanby, V. I. (2008). Simulation of energy consumption for Kuwaiti domestic buildings. *Energy and Buildings*, Vol. 40, Issue 6, pp. 1101–1109. DOI: 10.1016/j.enbuild.2007.10.010.

Algifri, A. H., Bin Gadhi, S. M., and Nijaguna, B. T. (1992). Thermal behaviour of adobe and concrete houses in Yemen. *Renewable Energy*, Vol. 2, Issue 6, pp. 597–602. DOI: 10.1016/0960-1481(92)90024-W.

Altan, H., Gasperini, N., Moshaver, S., and Frattari, A. (2015). Redesigning terraced social housing in the UK for flexibility using building energy simulation with consideration of passive design. *Sustainability*, Vol. 7, Issue 5, pp. 5488–5507. DOI: 10.3390/su7055488.

Ascione, F., Bianco, N., Iovane, T., Mastellone, M., and Mauro, G. M. (2021). The evolution of building energy retrofit via double-skin and responsive façades: A review. *Solar Energy*, Vol. 224, pp. 703–717. DOI: 10.1016/j.solener.2021.06.035.

Attoye, D. E., Aoul, K. A. T., and Hassan, A. (2017). A review on building integrated photovoltaic façade customization potentials. *Sustainability*, Vol. 9, Issue 12, 2287. DOI: 10.3390/su9122287.

Bastide, A., Lauret, P., Garde, F., and Boyer, H. (2006). Building energy efficiency and thermal comfort in tropical climates: Presentation of a numerical approach for predicting the percentage of well-ventilated living spaces in buildings using natural ventilation. *Energy and Buildings*, Vol. 38, Issue 9, pp. 1093–1103. DOI: 10.1016/j.enbuild.2005.12.005.

Bay, J.-H. and Ong, B.-L. (2006). *Tropical sustainable architecture: social and environmental dimensions*. London: Routledge, 310 p.

Bingel, P., and Bown, A. (2009). Sustainability of masonry in construction. In: Jamal M. Khatib (eds.) Woodhead Publishing Series in Civil and Structural Engineering, Sustainability of Construction Materials. Woodhead Publishing, pp. 82-119. DOI: 10.1533/9781845695842.82.

Camanzi, L., Alikadic, A., Compagnoni, L., and Merloni, E. (2017). The impact of greenhouse gas emissions in the EU food chain: A quantitative and economic assessment using an environmentally extended input-output approach. *Journal of Cleaner Production*, Vol. 157, pp. 168–176. DOI: 10.1016/j.jclepro.2017.04.118.

Chel, A. and Tiwari, G. N. (2009). Performance evaluation and life cycle cost analysis of earth to air heat exchanger integrated with adobe building for New Delhi composite climate. *Energy and Buildings*, Vol. 41, Issue 1, pp. 56–66. DOI: 10.1016/j.enbuild.2008.07.006.

Craven, J. (2019). *All about adobe - sustainable and energy efficient*. ThoughtCo. [online]. Available at: thoughtco.com/what-is-adobe-sustainable-energy-efficient-177943 [Date accessed June 15, 2022].

Delgado, M. C. J. and Guerrero, I. C. (2006). Earth building in Spain. *Construction and Building Materials*, Vol. 20, Issue 9, pp. 679–690. DOI: 10.1016/j.conbuildmat.2005.02.006.

DesignBuilder (2021). An online based simulation software acquired as an annual package via: https://designbuilder.co.uk [Date accessed 01 November, 2021].

Duggal, S. K. (2008). *Building materials*. 3rd edition. New Delhi: New Age International Publishers, 525 p.

En.climate-data.org (2022). *Ogbomosho climate (Nigeria)*. [online] Available at: https://en.climate-data.org/africa/nigeria/oyo/ogbomosho-525/ [Date accessed May 12, 2022].

Energy Design Resources (2000). *Building simulation*. [online] Available at: https://datacenters.lbl.gov/sites/default/files/Design%20Brief_Chiller%20Efficiency.pdf [Date accessed October 17, 2021].

Femi, A. B., Khan, T. H., Ahmad, A. S. B. H., and Bin Udin, A. (2015). Impact of tertiary institutions on house rental value in developing city. *Procedia - Social and Behavioral Sciences*, Vol. 172, pp. 323–330. DOI: 10.1016/j.sbspro.2015.01.371.

Givoni, B. (1976). *Man, climate and architecture*. 2nd edition. London: Applied Science Publishers Ltd., 483 p.

Jiang, W., Liu, J., and Liu, X. (2016). Impact of carbon quota allocation mechanism on emissions trading: An agent-based simulation. *Sustainability*, Vol. 8, Issue 8, 826. DOI: 10.3390/su8080826.

JCU (2014). *State of the Tropics. A report prepared by* James Cook University, Townsville (Australia), p. 462

Karyono, T. H. (2015). Predicting comfort temperature in Indonesia, an initial step to reduce cooling energy consumption. *Buildings*, Vol. 5, Issue 3, pp. 802–813. DOI: 10.3390/buildings5030802.

Karyono, T. H. (2017). Climate change and the sustainability of the built environment in the humid tropic of Indonesia. In: Karyono, T. H., Vale, R., and Vale, B. (eds.). *Sustainable Building and Built Environments to Mitigate Climate Change in the Tropics.* Cham: Springer, pp. 9–25. DOI: 10.1007/978-3-319-49601-6_2

Karyono, T. H. and Bachtiar, F. (2017). Adapting city for frequent floods: a case study of Jakarta, Indonesia, In: Karyono, T. H., Vale, R., and Vale, B. (eds.). *Sustainable Building and Built Environments to Mitigate Climate Change in the Tropics.* Cham: Springer, pp. 103–111. DOI: 10.1007/978-3-319-49601-6_8.

Kenisarin, M. and Mahkamov, K. (2016). Passive thermal control in residential buildings using phase change materials. *Renewable and Sustainable Energy Reviews*, Vol. 55, pp. 371–398. DOI: 10.1016/j.rser.2015.10.128.

Koukelli, C., Prieto, A., and Asut, S. (2022). Kinetic solar envelope: performance assessment of a shape memory alloy-based autoreactive façade system for urban heat island mitigation in Athens, Greece. *Applied Sciences*, Vol. 12, Issue 1, 82. DOI: 10.3390/app12010082.

Kwong, Q. J., Adam, N. M., and Sahari, B. B. (2014). Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review. *Energy and Buildings*, Vol. 68, Part A, pp. 547–557. DOI: 10.1016/j.enbuild.2013.09.034.

Longo, T. A., Melo, A. P., and Ghisi, E. (2011). Thermal comfort analysis of a naturally ventilated building. In: *Proceedings of Building Simulation 2011, 12th Conference of International Building Performance Simulation Association*, 14–16 November, 2011, Sydney, Australia, pp. 2004–2010.

Lotfabadi, P. (2013). The impact of city spaces and identity in the residents' behavior. *Humanities and Social Sciences Review*, Vol. 2, No. 3, pp. 589–601

Lotfabadi, P., Alibaba, H. Z., and Arfaei, A. (2016). Sustainability; as a combination of parametric patterns and bionic strategies. *Renewable and Sustainable Energy Reviews*, Vol. 57, pp. 1337–1346. DOI: 10.1016/j.rser.2015.12.210.

Lotfabadi, P. and Hançer, P. (2019). A comparative study of traditional and contemporary building envelope construction techniques in terms of thermal comfort and energy efficiency in hot and humid climates. *Sustainability*, Vol. 11, Issue 13, 3582. DOI: 10.3390/su11133582.

Mahravan, A. and Vale, B. (2017). The sustainable portion of gross domestic product: a proposed social ecological economic indicator for sustainable economic development. In: Karyono, T. H., Vale, R., and Vale, B. (eds.). *Sustainable Building and Built Environments to Mitigate Climate Change in the Tropics*. Cham: Springer, pp. 53–69. DOI: 10.1007/978-3-319-49601-6_5.

Martín, S., Mazarron, F. R., and Cañas, I. (2010). Study of thermal environment inside rural houses of Navapalos (Spain): the advantages of reuse buildings of high thermal inertia. *Construction and Building Materials*, Vol. 24, Issue 5, pp. 666–676. DOI: 10.1016/j.conbuildmat.2009.11.002.

Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., and Majid, M. Z. A. (2015). A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries). *Renewable and Sustainable Energy Reviews*, Vol. 43, pp. 843–862. DOI: 10.1016/j.rser.2014.11.066.

Olaniyan, S. A. (2012). Optimizing thermal comfort for tropical residential designs in Nigeria: how significant are the walling fabrics? In: *2nd Conference "People and Buildings"*, September 18, 2012, London, UK.

Olaniyan, S. A. (2021). Pore structure as a determinant of flexibility in sustainable lime-cement mortar composites. *European Journal of Engineering and Technology Research*, Vol. 6, Issue 6, pp. 113–122. DOI: 10.24018/ejeng.2021.6.6.2598.

Omonijo, A. G. (2017). Assessing seasonal variations in urban thermal comfort and potential health risks using Physiologically Equivalent Temperature: A case of Ibadan, Nigeria. *Urban Climate*, Vol. 21, pp. 87–105. DOI: 10.1016/j.uclim.2017.05.006.

Pacheco-Torgal, F. (2015). Introduction to eco-efficient masonry bricks and blocks. In: Pacheco-Torgal, F., Lourenço, P. B., Labrincha, J. A., Kumar, S., and Chindaprasirt, P. (2014). *Eco-efficient masonry bricks and blocks: design, properties and durability*. Cambridge: Woodhead Publishing, pp. 1–10. DOI: 10.1016/B978-1-78242-305-8.00001-2.

Pacheco-Torgal, F. and Jalali, S. (2011). *Eco-efficient construction and building materials*. London: Springer, 247 p. DOI: 10.1007/978-0-85729-892-8.

Pacheco-Torgal, F., Lourenco, P. B., Labrincha, J., Chindaprasirt, P., & Kumar, S. (2014). *Eco-efficient Masonry Bricks and Blocks: Design, Properties and Durability* (1st ed., Vol. 55). Elsevier Science. https://doi.org/10.1016/C2014-0-02158-2

Phonphuak, N. and Chindaprasirt, P. (2015). Types of waste, properties, and durability of pore-forming waste-based fired masonry bricks. In: Pacheco-Torgal, F., Lourenço, P. B., Labrincha, J. A., Kumar, S., and Chindaprasirt, P. (2014). *Eco-efficient masonry bricks and blocks: design, properties and durability*. Cambridge: Woodhead Publishing, pp. 103–127. DOI: 10.1016/B978-1-78242-305-8.00006-1.

Prianto, E. and Depecker, P. (2002). Characteristic of airflow as the effect of balcony, opening design and internal division on indoor velocity: A case study of traditional dwelling in urban living quarter in tropical humid region. *Energy and Buildings,* Vol. 34, Issue 4, pp. 401–409. DOI: 10.1016/S0378-7788(01)00124-4.

Prianto, E. and Depecker, P. (2003). Optimization of architectural design elements in tropical humid region with thermal comfort approach. *Energy and Buildings*, Vol. 35, Issue 3, pp. 273–280. DOI: 10.1016/S0378-7788(02)00089-0.

Quagliarini, E., D'Orazio, M., and Lenc, S. (2015). The properties and durability of adobe earth-based masonry blocks. In: Pacheco-Torgal, F., Lourenço, P. B., Labrincha, J. A., Kumar, S., and Chindaprasirt, P. (2014). *Eco-efficient masonry bricks and blocks: design, properties and durability*. Cambridge: Woodhead Publishing, pp. 361–378. DOI: 10.1016/B978-1-78242-305-8.00016-4.

Quesada, G., Rousse, D., Dutil, Y., Badache, M., and Hallé, S. (2012). A comprehensive review of solar facades. Opaque solar facades. *Renewable and Sustainable Energy Reviews*, Vol. 16, Issue 5, pp. 2820–2832. DOI: 10.1016/j.rser.2012.01.078.

Raja, I. A., Nicol, J. F., McCartney, K. J., and Humphreys, M. A. (2001). Thermal comfort: use of controls in naturally ventilated buildings. *Energy and Buildings*, Vol. 33, Issue 3, pp. 235–244. DOI: 10.1016/S0378-7788(00)00087-6.

Saleh, M. A. E. (1990). Adobe as a thermal regulating material. *Solar & Wind Technology*, Vol. 7, Issue 4, pp. 407–416. DOI: 10.1016/0741-983X(90)90025-W.

Shastry, V., Mani, M., and Tenorio, R. (2016). Evaluating thermal comfort and building climatic response in warm-humid climates for vernacular dwellings in Suggenhalli (India). *Architectural Science Review*, Vol. 59, Issue 1, pp. 12–26. DOI: 10.1080/00038628.2014.971701.

Sholanke, A. B., Fagbenle, O. I., Aderonmu, A. P., and Ajagbe, M. A. (2015). Sandcrete block and brick production in Nigeria - prospects and challenges. *International Journal of Environmental Research*, Vol. 1, No. 4, pp. 1–17.

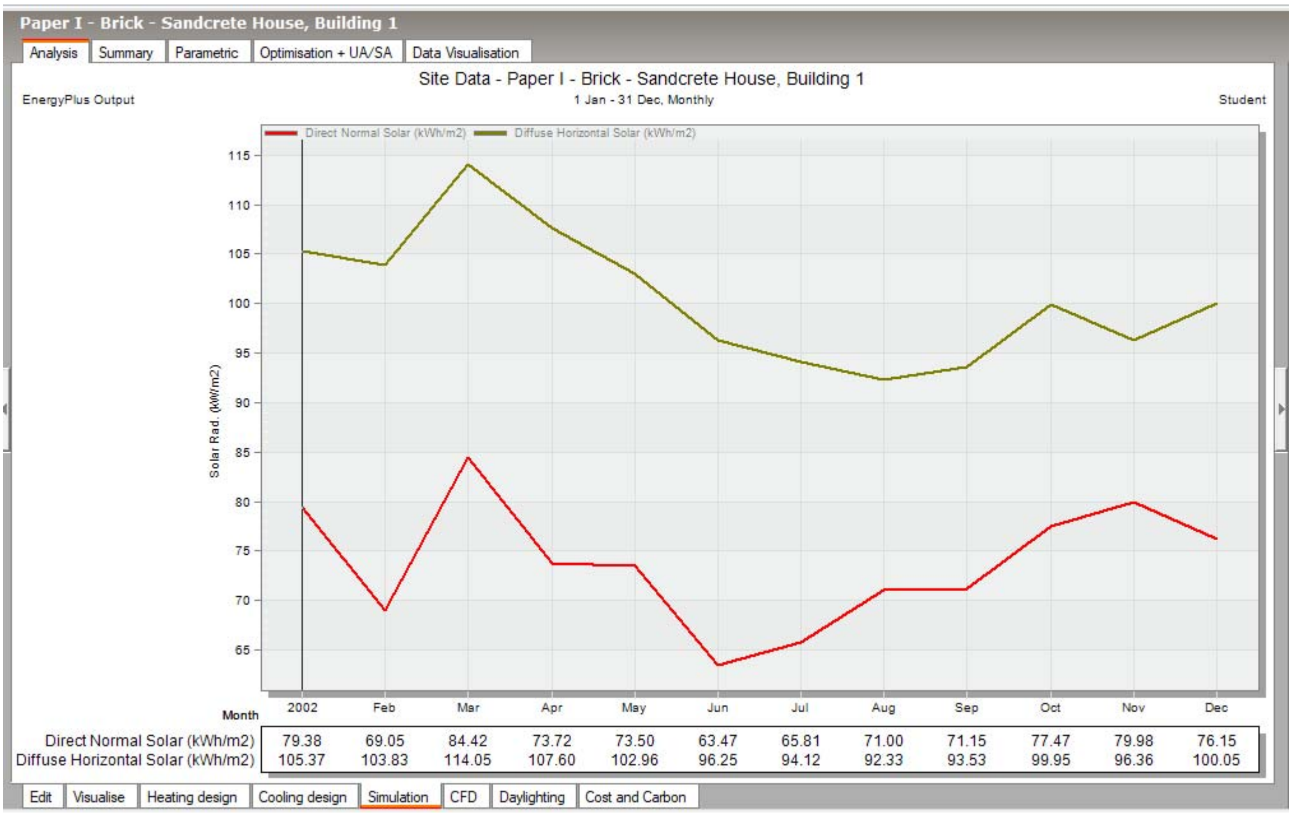
Smith, A. S., Bingel, P., and Bown, A. (2016). Sustainability of masonry in construction. *Sustainability of Construction Materials (Second Edition)*, pp. 245–282. DOI: 10.1016/B978-0-08-100370-1.00011-1.

The Constructor (2022). *Sandcrete block manufacturing and testing*. [online] Available at: https://theconstructor.org/building/sandcrete-block-manufacturing-testing/25382/ [Date accessed June 9, 2022].

Vale, R. and Vale, B. (2017). Introduction: the tropics: a region defined by climate. In: Karyono, T. H., Vale, R., and Vale, B. (eds.). *Sustainable Building and Built Environments to Mitigate Climate Change in the Tropics.* Cham: Springer, pp. 1–6. DOI: 10.1007/978-3-319-49601-6_1.

World Energy Council (2013). *World Energy Resources: 2013 Survey*. London: World Energy Council, 468 p.

Appendix: Simulation Output for Direct and Diffuse Solar Radiations in the Study Area



Month	2002	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Direct Normal Solar (kWh/m2)	79.38	69.05	84.42	73.72	73.50	63.47	65.81	71.00	71.15	77.47	79.98	76.15
Diffuse Horizontal Solar (kWh/m2)	105.37	103.83	114.05	107.60	102.96	96.25	94.12	92.33	93.53	99.95	96.36	100.05

САМАН ВМЕСТО ПУСТОТЕЛЫХ ПЕСКОБЕТОННЫХ БЛОКОВ СТЕН В ТРОПИЧЕСКОМ СТРОИТЕЛЬСТВЕ: ВЛИЯНИЕ МАТЕРИАЛОВ НА ДОСТИЖЕНИЕ УСТОЙЧИВОГО ТЕПЛОВОГО КОМФОРТА В ПОМЕЩЕНИИ

Суле Адении Оланиян

Технологический университет Ладок Акинтола, Огбомошо, Нигерия

E-mail: saolaniyan@lautech.edu.ng

Аннотация
Введение: Тропический климат характеризуется высокой температурой, вследствие чего возникает тепловой дискомфорт в помещении. Это объясняется высоким притоком солнечной энергии через различные элементы ограждающих конструкций здания, включая, среди прочего, окна, стены и крышу. Тем не менее, в попытке оптимизировать тепловой комфорт в помещении с минимальным использованием механических приборов или вообще без них в этом исследовании анализируется роль стеновых материалов путем сравнения различных теплофизических свойств двух идентифицированных кладочных блоков в исследуемой зоне Огбомошо, Нигерия — саманного кирпича и пустотелых блоков из пескобетона — с целью определить более термически комфортный и устойчивый вариант материала. **Методика** включает в себя виртуальные модели двух одинаковых жилых домов, каждый из которых состоит либо из саманного кирпича, либо из пескобетонных блоков в качестве каменной кладки. Эти модели были подвергнуты анализу энергетических характеристик с использованием программного обеспечения DesignBuilder в течение двенадцатимесячного цикла, чтобы рассмотреть круглогодичные дифференциальные температурные условия. Благодаря наблюдаемым сравнительным годовым тепловым нагрузкам, полученным в моделях, результаты показывают улучшение теплового комфорта внутри кирпичного здания (т.е. 7119,54 кВтч), причем тепловые нагрузки на 11 % ниже, чем у здания из пескобетона (т. е. 8875,65 кВтч) за счет кирпичной облицовки. Это может быть связано с более низкой теплопроводностью кирпича (U-значение) 1,798 Вт/м^2-К по сравнению со значением пескобетонных блоков в 1,999 Вт/м^2-К. **Результаты**: В целом, саман в качестве стенового блока демонстрирует бóльшую термическую устойчивость к суровым погодным условиям, чем пескобетонные блоки. Исследование является частью продолжающейся работы по возрождению такого частично забытого экологичного материала, как саманный кирпич, с целью достижения устойчивого теплового комфорта в помещениях, а также для защиты окружающей среды в исследуемой зоне.

Ключевые слова: саман, пескобетонные блоки, моделирование, экологичность, тепловой комфорт, тропики.