UTM UNIVERSITI TEKNOLOGI MALAYSIA

IJBES

International Journal of Built Environment and Sustainability
Published by Penerbit UTM Press, Universiti Teknologi Malaysia
IJBES 10(1)/2023, 73-85

Evaluation of Thermal Admittance of Compressed Earth Bricks C.E.B Configurations for School Buildings in Hot-dry climate region of North-western Nigeria

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ABSTRACT

Permeation of heat into the school building enclosure through external walls components of the building resulting into the numerous consequences which causes unhealthy indoor living conditions for teaching and learning activities, which has a negative impacts on the students general academic performance and their productivity, the study carried out a fieldwork experimentation where four experimental models (chambers) were built using four dissimilar compressed earth (C.E.B) configurations; compressed earth horizontal hollow brick (C.E.H.H.B), compressed earth vertical hollow brick (C.E.V.H.B), compressed earth cellular brick (C.E.C.B), and compressed earth solid brick (C.E.S.B) respectively, data were collected from fieldwork experimental chambers using two distinct wall surface temperature measuring devices; an onset UX120-M600 4-channel analogue data logger and Testo 835 Infrared thermometer which were utilized to measure the interior wall surface temperature facing the west direction of each experimental chamber to determine the rate of thermal admittance of the entire chambers built with distinct C.E.B configurations, the extracted data using surface temperature measuring instrument were analyzed using the spss software package for identification of the C.E.B configurations with the least thermal permeation from outdoor environment to indoor space of the school building via external walls of the building. After the statistical analysis, the study's outcome revealed that compressed earth horizontal hollow brick (C.E.H.H.B) has a minimum heat transfer rate of (34.933^{OC}) and (35.7493^{OC}), among other C.E.B configurations. This undoubtedly indicated the appropriate C.E.B configurations for school buildings in hot-dry climate regions of northwestern Nigeria.

Article History

Received : *29 September 2022*
Received in revised form: *06 December 2022*
Accepted : *08 December 2022*
Published Online : *31 December 2022*

Keywords:

Compressed Earth Brick (C.E.B) Configurations, Wall Building Envelope, thermal Admittance, Thermal Performance, thermal properties, hollow block/Block cavity, School Building.

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DOI: 10.11113/ijbes.v10.n1.1069

1. Introduction

Compressed earth bricks are made from earth, a naturally abundant and non-exhaustible material due to its replenishing characteristics. It is manufactured using a manual moulding machine or an automatic hydraulic machine, and there are several types of C.E.B, distinguished by their mixing processes or final product finishes: sun-dried C.E.B, backed C.E.B, and C.E.B with cement stabilizers for added strength, either sundried or backed (Maimagani et al., 2022).

Compressed Earth Brick (C.E.B) is the predominant material for buildings construction regardless of its typologies in all parts of the climatic regions of Nigeria before the foreign incursion into the west coast of Africa (Adeniyi et al., 2019). Discoveries of advanced building materials such as concrete masonry units, also called sandcrete hollow blocks. However, it replaced the Compressed Earth Brick (C.E.B.), considered an energy-efficient, environmentally-friendly building material. Compressed Earth Brick (C.E.B) is regaining its lost acceptance in the building industry due to its exceptional sustainable characteristics (Akhter and Sarker, 2018).

Compressed Earth Brick (C.E.B.) is acknowledged to have a high thermal performance. However, the study is craving to explore more options C.E.B configurations to further determine a more improved C.E.B configuration in term of thermal performance to achieve a more sustainable walling material that will enhance school building indoor living condition, student wellbeing and energy saving for cooling for the attainment of comfortable school building interiors. The study proposed four distinct varieties C.E.B configurations as in indicate in figure 1. Compressed earth horizontal hollow brick (C.E.H.H.B), compressed earth vertical hollow brick (C.E.V.H.B), compressed earth cellular brick (C.E.C.B), and compressed earth solid brick (C.E.S.B) respectively.

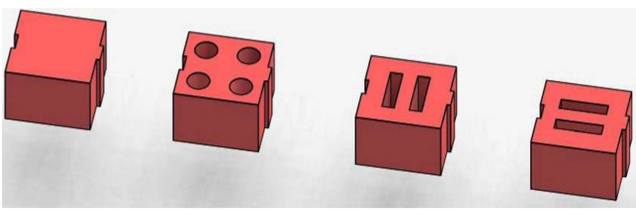


Figure 1. Compressed earth brick (C.E.B) configuration

Traditional brick walls remain an appropriate construction material for construction of low and medium rise buildings, providing weather protection, fire, and sound insulation, flexible to achieve any desired form, shape, and it requires minimal maintenance for long period (Sassine et al., 2017). The solar heat transfer in buildings depends on the building materials used. The dimension, sizes, the cavities options of blocks are also characterized with distinct thermal properties and play a crucial role in the heat permeation between outdoor and indoor environment (S.O. Adepo et al., 2020).

Earth is an old building material widely used in extreme hot-dry desert countries with a tremendous advantage in thermophysical properties over conventional building material such as sandcrete hollow block also called concrete masonry unit (Al-Ajmi et al., 2016). Earth is an environmentally friendly building material that improves the comfort of a building's interior without using an artificial cooling system. Earth also has a huge potential to lessen the negative effects of greenhouse gas emissions from the building sector, which are a current global concern. (Papayianni and Pachta, 2017; Maimagani et al., 2021).

Earth brick as a building material for construction is considered to be sustainable building material due to its affordability, environmental friendliness, and energy-efficient building materials (Maimagani et al., 2021; Sutcu et al., 2014; Arrigoni et al., 2017; Stone et al., 2014; Pandey and Bajracharya, 2017; Onyegiri and Ugochukwu, 2019). Earth as a building material has been used for building construction since the ancient period, mostly in developing countries. Concrete, concrete blocks supplanted the materials, and cement which is not as sustainable as earthen materials economically and environmentally, and it is in abundance and low cost in production (Fernandes et al., 2019; Costa et al., 2019; Muazu, 2017; Teixeira et al., 2020; Doc et al., 2017; Pica, 2018; Hegediš et al., 2019).

Adopting a sustainable building strategy will lead to attainment comfortable indoor environment, which increases occupant productivity and healthy indoor living conditions. These include appropriate building materials selection, building orientation, indoor spaces configuration, and construction methods (Musa and Abdullahi, 2018; Napier, 2015; Mydin and 1, 2017; Ochedi and Taki, 2019).

Building envelope composed of several components of the building such as the foundation, walls, roof, windows, shading devices, and fenestration. However, these parts of the building components serve as a barrier of the indoors space of the building from the outside environment. Moreover, walls are opaque parts of a building that make up a significant part of the building envelope, which greater parts of its surface area are exposed to the harsh external weather conditions (Hamimi et al., 2016; Udawattha and Halwatura, 2017; Maimagani et al., 2019; Jannat et al., 2020).

Thermal admittance is the ability of a material to exchange heat with its surroundings environment when the weather changes. The rate of thermal admittance is based on density, thermal capacity, and thermal conductivity of the material. It has also been affected by changes in temperature and the resistance of the air at the surface. Furthermore, the thermal admittance of a building material is measured by its U-value. The higher the U-value, the better the material is at transferring heat from the outdoor environment to the indoor environment. The lower the U-value, the better the material is at averting heat transfer inside the building interiors (Shaik and Talanki Puttaranga Setty, 2016).

Thermal performance in buildings involves selecting energy-efficient building materials to minimize overreliance on artificial means to achieve comfortable building interiors, increase occupant wellbeing and productivity, and reduce lifecycle costs while optimizing energy savings (Gorse et al., 2016; Mirrahimi et al., 2016; Kwag, Adamu, and Krarti, 2018).

The thermal performance of the building can be enhanced by curtailing the heat transfer via the external walls building envelopes. Furthermore, the wall component of the building forms the greater part of the entire building, which regulates the fluctuations of the external weather conditions of the outdoor environment and serves as a third layer of the human skin for maintaining a stable body temperature (Mirrahimi et al., 2016; Kočí et al., 2019; Jannat et al., 2020). The author further elucidated that thermal properties of the building materials have a greater impact on the comfortable building interiors conditions to the building occupants. Thermophysical properties of building material determine the indoor air temperature and cooling demand, with or without the employing the artificial means (Jannat et al., 2020).

The thermal properties of the building materials determine the rate of heat permeation into the building enclosed spaces from the external environment, and in turn, has a significant influence on a comfortable indoor area of the building, earth brick has high thermal resistance properties, and it is the preferable walling material especially for external wall to prevent heat infiltrations into the building interiors (Tammy et al., 2017). A suitable selection of exterior wall materials will reduce the rate of heat transfer from the exterior environment to the interior spaces of the building, thereby reducing the need for mechanical systems to attain comfortable building indoors (D Wang, W Yu, X Zhao, 2018). The heat transfer in buildings is determined by the thermal characteristics of the enveloping materials (Adepo et al., 2020). Wall components with exceptional thermal properties reduce the need for artificial cooling, hence reducing the cooling load and environmental effect of the building (Odunfa et al., 2018).

Construction of building with blocks with hollows, cores, voids or cavities have many advantages over solid blocks, such as better thermal performance sound and acoustic insulation (Arsenovic et al., 2010; Caruana et al., 2014; Ismaiel et al., 2022). The study reveals that wall building components with a high number of cavities within the block have a low rate of heat transfer from the exterior environment to the interior of the structure (Fogiatto et al., 2016). The size, shape, and number of cavities on a given block play a significant effect in rate of heat transfer from an external wall surface of buildings to the building interior spaces (Adepo et al., 2020; Sassine et al., 2020).

School buildings are among the building typologies that require indoor comfort to enhance students' performance and staff productivity. It's an academic setting where students spend significant time in lecture halls, libraries, studios, and laboratories. Students' performance and comfortable indoor environments has a significant relationship (Khaled M. Dewidar1, 2012; Rider, 2014; Radha and Husein, 2018; Ji, 2019). School buildings are vital spaces with a considerably higher occupancy rate than other buildings, as students spend 25% more time than in any other building. School buildings have a higher level of social responsibility for educational reasons than other buildings. (Kati and Krsti, 2021).

Educational building interiors are anticipated to be comfortable and healthy for living conditions and learning, as it directly relates to the student's well-being and academic performance (Keco, Pont, and Mahdavi, 2019). Sadat, Tahsildoost, and Hafezi (2016) state that thermal discomfort in school buildings can lead to unsatisfactory conditions for students learning activities, thereby creating an unconducive environment for teaching and learning which in turn negatively affect their rate of assimilation and level comprehension. The school building is vital since it serves as a learning environment where students spend considerable time studying in academic learning spaces. The school building is an enclosed space where quality scholars, professional researchers, and future educators are trained to assume future responsibilities in our ever-changing world (Alwetaishi et al. 2018).

Discomfort in building interiors becomes a concerning issue in the built environment as it significantly negatively affects the building occupants' emotions, health, general performance and productivity. However, the comfortable indoor space of the buildings plays a vital role in its occupants' physiological comfort and psychological responses (Haruna et al., 2014). Comfortable building interiors have a significant influence on psychological, physiological balance, performance and productivity, as well as the well-being of the building occupants (Barbhuiya and Barbhuiya, 2013; Geng et al., 2019).

1.1 Description of Study Area

The study area is located in Nigeria, in the north-western region of the countries according to geopolitical zoning. The climate zone is also classified as hot and dry, characterized by high temperatures, very low relative humidity, and little rainfall. 2018's (Maimagani et al., 2022). Moreover, the average temperature of Birnin kebbi is 28.9oC. January is the coolest month, with a mean temperature of 25.1°C. Figure 4 shows that April is the hottest month of the year, with an average temperature of about 33.6 °C. Sokoto state is to the northeast, Zamfara state is to the east, and Niger state is to the south. Kebbi state also shares borders with two other African countries, the Niger Republic to the north and the Benin Republic to the west (Maimagani et al., 2022).

Figure 2. Map of Nigeria indicating North western geopolitical zone (Source: AbdulKadir et al., 2015).

The blue shaded portion of Figure 2 show the states that constitute the Northwestern part of Nigeria. North-western Nigeria is the area of study and it is characterized by intense solar radiation permeating into the building enclosures through building components, especially wall components, because it forms the major part of the entire building. The school buildings in the study area are educational structures where teaching and learning processes occur. There is a need to achieve indoor comfort to enhance academic activities without relying on artificial ways. However, school buildings in tropical regions of north-western Nigeria need to embrace the use of earth as a wall material to achieve a comfortable indoor learning space without much reliance on altricial means.

The north-western part of Nigeria is located in a tropical area of the continent of Africa which is identified with the harsh climatic condition that has negative impacts school buildings due to their exposure to external environment, which in turn has a severe impact on academic learning activities for both students and academic staff. In tropical developing countries with severe temperatures, building envelopes are particularly prone to solar heat gain due to their exposure. As a result, building residents suffer from insomnia, exhaustion, boredom, headaches, and asthma (Akande, 2010; Press and Range, 2018).

In this West African nation such as Nigeria, earth was widely used as the principal building material across all building types. Before the colonial master's inversion, earth was widely employed as a construction material in Nigeria because of its low cost and abundance. The human resources involved are also somewhat low-skilled. In comparison to the sandcrete hollow block or the concrete masonry unit, it is more eco-friendly and uses less energy.

2. Material and Method

2.1 Fieldwork Experiment

Field experiments in this study include the fabrication of C.E. B manual molding machine that produces four types of compressed earth brick (C.E.B) configurations, compressed earth horizontal hollow brick (C.E.H.H.B), compressed earth vertical hollow brick (C.E.V.H.B), compressed earth cellular brick (C.E.C.B), and compressed earth solid brick (C.E.S.B). The moulded bricks of various C.E.B configurations are used as a walling material to construct a small size experimental chamber as shown figure 3.

However, the total number of experimental chambers constructed was four number, C.E.B configurations. Having the same size (1425mm X 1425mm X 2800mm), orientation, headroom, and roofing material, the only differentiating factor is the design pattern of the C.E.B configurations. The four chambers would be subjected to temperature measurement (thermal admittance) using the Onset Hobo datalogger and Testo infrared thermometer.

Figure 3. The four experimental chambers/models

2.2 Method of Data collection

The study employed two distinct wall surface temperature measuring devices for collection of data such as; HOBO 4 - Chanel Analog data logger (UX120-006M), and an infrared thermometer (testo 845) in order to carry out this study efficiently. The two temperature measuring instruments can deliver a reliable result. The sequence of their operations for effective data collection is illustrated schematically in figure 4, and figure 5, respectively.

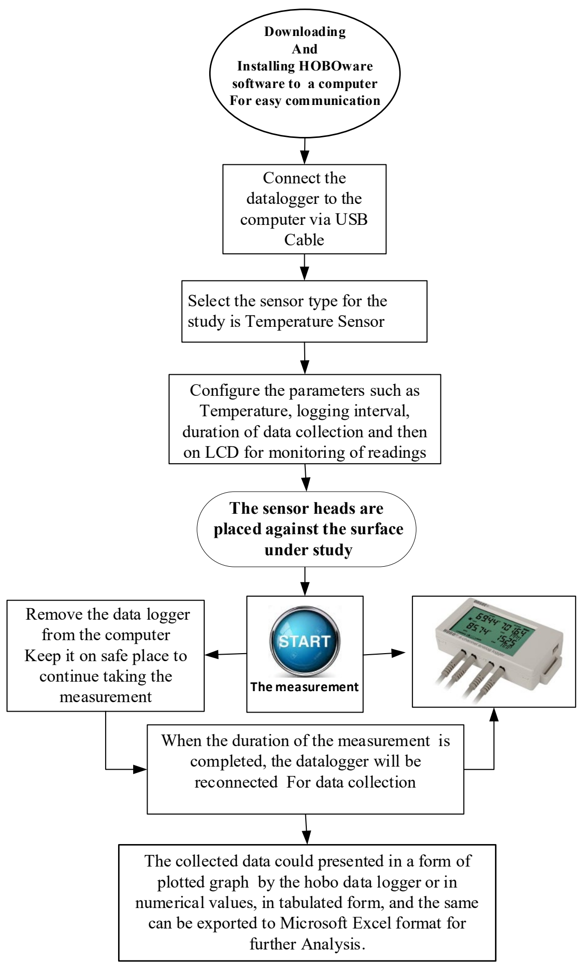


Figure 4. HOBO 4 -Chanel Analog data logger (UX120-006M) sequence of operation.

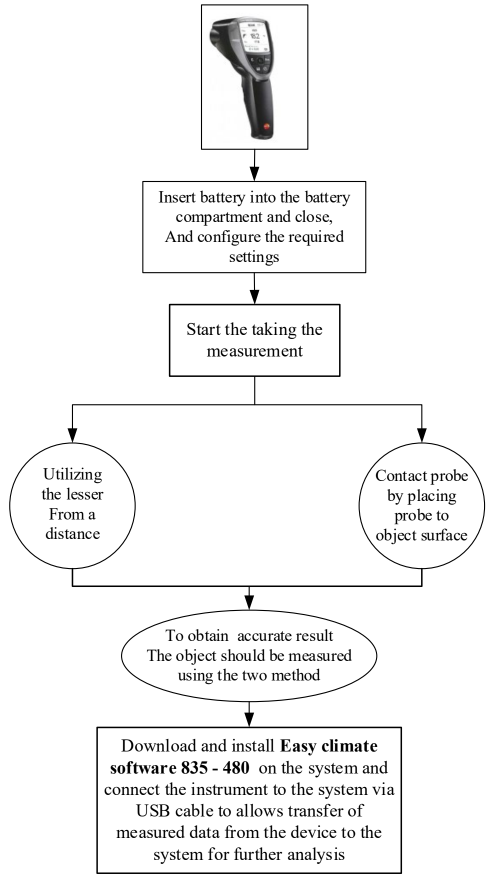


Figure 5. Process of operating the testo 835 infrared thermometer

Additionally, a floor layout for the C.E.B configurations is depicted in figure 6. Figure 7. Shows a cross-section of the experimental chamber and how the hobo data sensor heads are pressed on the interior wall surface to monitor the rate of thermal admittance from the outside to the chamber's interior. Figure 8. illustrates a cross section of a C.E.B configuration experimental chamber or model and demonstrates how infrared data is obtained from the wall surface of a C.E.B configuration.

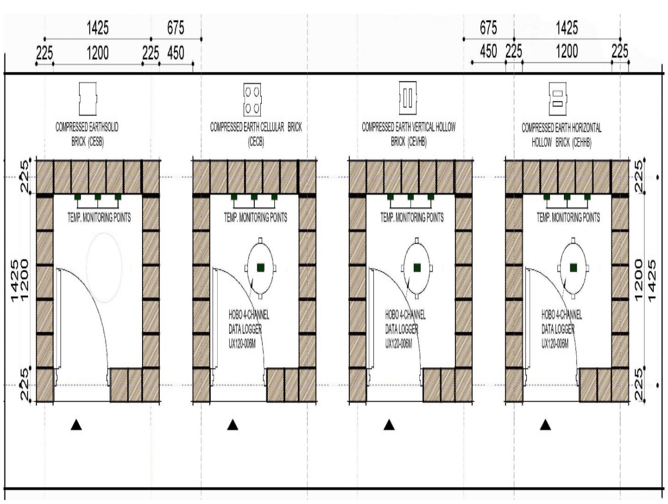


Figure 6. Floor plan of four experimental models (C.E.B) configuration.

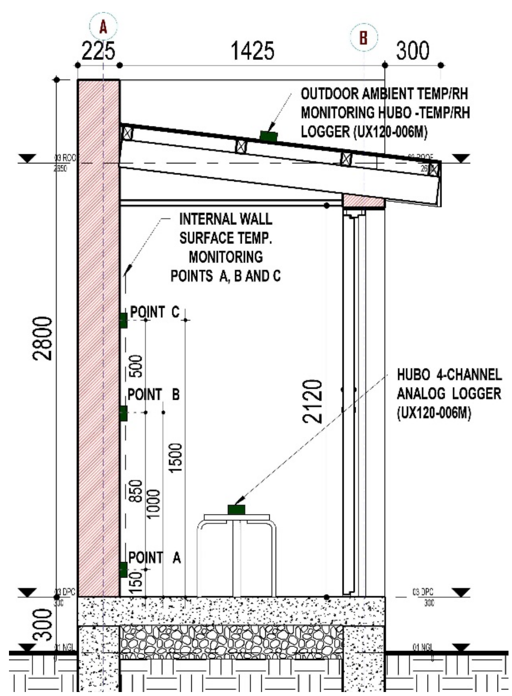


Figure 7. Section through the experimental chamber illustrating the internal surface temperature measuring

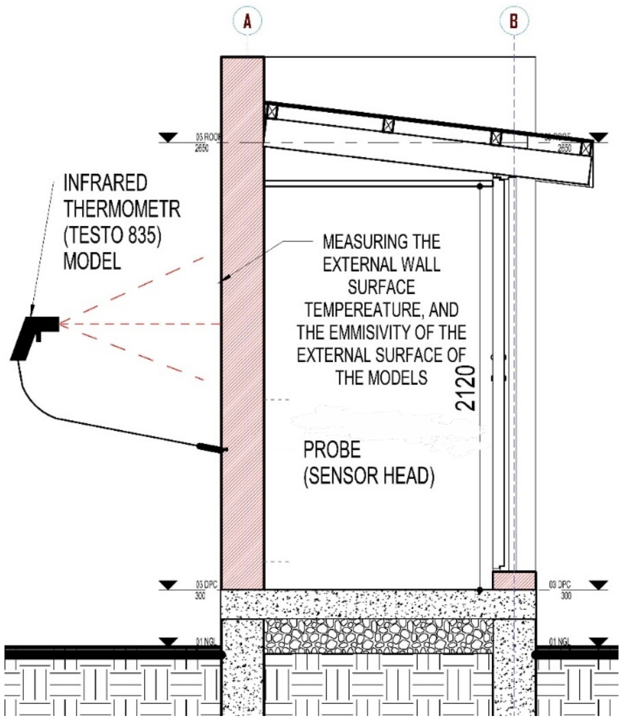


Figure 8. Section indicating the external surface temperature measurement of the model's

Figure 9. Internal Walls surface temperature measuring points

2.3 Data Collection

The study employed Hobo data UX120-006M logger analog and testo Infrared thermometer professional temperature measuring instrument for data collection. Each experiment chamber's internal wall surface temperature was recorded, the wall facing the west direction, using the 4 - Chanel Analog data logger UX120-006M temperature sensors placed at three different points. Furthermore, Point A at 150mm, Point B at 1000, and Point C at 1500mm, respectively, as illustrated in Figure 9. These three points represent the human position in different postures in lying, sitting (on the chair or a floor), and standing positions by the universal standard for humans (Leonardo da Vitruvian Man).

However, the 4-channel UX120-006M Hobo data logger data collection for each experimental chamber's wall surface temperature measurement lasted for three months, from March, April, and May 2019. The hottest month of the year in the study area is the month of April. The study intends to cover a month before April and a month after April. The wall surface temperature measurement commenced in March and ended in May. Moreover, the testo infrared thermometer was also used to monitor each chamber's internal wall surface temperature at 6:30 pm when sunset on the 10th, 20th, and 30th of April 2019, as shown in figure 10.

Figure 10. Testo Infrared thermometer surface temperature monitoring

3.0 Data Analysis

The data collected from the experimental chamber for three months using 4-channel hobo data logger to identify the C.E.B configurations with the least rate of thermal admittance were analyzed using spss software. The analysis outcome for May, April and March 2019 is presented in a tabulated format as indicated in Table 1, Table 2 and Table 3, respectively.

Table 1. Rate of thermal Admittance into the internal wall surface in March 2019

Month	C.E.B. Configuration	Point	Mean	Std. Deviation	Overall Mean	SD
March	CEHHB	A	35.94	3.15	**35.35**	**2.99**
		B	35.54	3.09		
		C	34.57	2.78		
	CEVHB	A	36.24	3.42	35.70	3.20
		B	35.87	3.33		
		C	35.00	2.84		
	CECB	A	35.99	3.25	35.53	3.14
		B	35.79	3.30		
		C	34.79	2.91		
	CESB	A	35.04	3.01	35.67	3.20
		B	35.82	3.27		
		C	36.14	3.35		

The S.P.S.S analysis result presented in table 1 reveals that the compressed earth horizontal hollow brick (C.E.H.H.B.) has the least rate of thermal admittance into the internal wall surface for March 2019, where the overall mean temperature was (**35.35** ^{oc}). Moreover, for April 2019, the result presented in Table 2 also reveals that the compressed earth horizontal hollow brick (C.E.H.H.B.) has the least rate of thermal admittance for overall mean temperature was (35.75 ^{oc}). And finally, Table 3 also presented C.E.H.H.B having least thermal admittance (35.26 ^{oc}).

Table 2. Rate of thermal admittance into the internal wall surface in April 2019

Month	C.E.B. Configuration	Point	Mean Temp.	Std. Deviation	Overall Mean Temp.	SD
April	CEHHB	A	37.78	2.42	**35.75**	**2.147**
		B	38.26	2.63		
		C	38.47	2.64		
	CEVHB	A	38.33	2.75	37.92	2.59
		B	38.01	2.71		
		C	37.40	2.35		
	CECB	A	37.79	2.64	37.88	2.44
		B	37.73	2.67		
		C	38.10	2.72		
	CESB	A	38.13	2.73	37.68	2.58
		B	37.85	2.69		
		C	37.05	2.35		

However, the analysis of the three-month (March, April, and May 2019) internal wall surface temperature monitoring data of C.E.B. configurations (C.E.H.H.B., C.E.V.H.B., C.E.C.B., and C.E.S.B.) reveals month of April was having higher overall mean temperature as 35.75 ^{oc} as presented in table 2, the month of March 35.35^{oc} as shown in table 1 and then the month of May as indicated in table 3 having the least overall mean temperature 35.26 ^{oc}, respectively. Moreover, this is an affirmation that the month of April has a higher temperature.

Table 3. Rate of thermal admittance into the internal wall surface in May 2019

Month	C.E.B. Configuration	Point	Mean	Std. Deviation	Overall Mean	SD
May	**CEHHB**	A	35.53	2.97	**35.26**	**2.81**
		B	35.74	2.93		
		C	36.12	2.59		
	CEVHB	A	36.87	3.12	36.59	2.93
		B	36.58	3.04		
		C	36.34	2.65		
	CECB	A	36.66	2.92	37.10	2.15
		B	36.39	2.71		
		C	38.23	2.76		
	CESB	A	36.86	2.76	37.01	2.96
		B	37.04	3.03		
		C	37.15	3.10		

A further statistical test was conducted to examine whether there is a clear and statistical difference in the heat permeation/thermal admittance between the four different C.E.B. Configurations. The mean rate of the thermal admittance of the four C.E.B.s configuration was used to conduct a test of differences. The coefficient of the difference was determined using One-Way Analysis of Variance (ANOVA) at a 5% level of significance as presented in table 8.

Table 4. Rate of thermal admittance C.E.B configuration

Test Variables		Sum of Squares	df	Mean Square	F	Sig.
Thermal Admittance	Between Groups	20666.982	3	6888.99	799.72	.000
	Within Groups	922894.75	107136	8.61		
	Total	943561.73	107139			

The F statistics (107136) = 799.72 and Sig (P-value) = 0.000, = 0.05 for the Thermal Admittance are reported in Table 4 as the test result for differences using the One-Way ANOVA achieved. The analysis showed that the four C.E.B. configurations (C.E.H.H.B., C.E.V.H.B., C.E.C.B., and C.E.S.B.) have considerably varied mean thermal admittance values (because the p-values are greater than the alpha value of 0.05). As a result, for the duration of the experiment, the thermal admittance of the four different C.E.B. configurations is not the same.

Since this result demonstrates a statistically significant difference in Thermal Admittance between the four C.E.B. configurations (C.E.H.H.B., C.E.V.H.B., C.E.C.B., and C.E.S.B), it is unclear where the difference exists. Multiple comparisons (Turkey post-hoc-test) were performed to determine whether groups differed from one another. Table 5 shows the post-doctoral test.

Table 5. Thermal admittance (Tukey HSDa)

S/N	CEB Configuration	N	Subset for alpha = 0.05 1	2	3	4
1	CEHHB	26785	**35.7493**			
2	CESB	26785		36.6300		
3	CEVHB	26785			36.7660	
4	CECB	26785				36.8470
	Sig.		1.000	1.000	1.000	1.000

The means for groups in homogeneous subsets are indicated.

a. Harmonic Mean Sample Size = 26785.000 is used

A Tukey post hoc test result (mean) of the four groups reported in tables 4 and 5 revealed that C.E.H.H.B. has a stronger thermal resistance advantage, with the lowest heat permeability of 35.7, followed by C.E.S.B., which has a heat permeation of 36.6. The C.E.V.H.B. has a mean of 36.7 as well. Finally, C.E.C.B. has the highest mean value at 36.8. This stance is further illustrated in Figure 11 by a homogeneous mean plot.

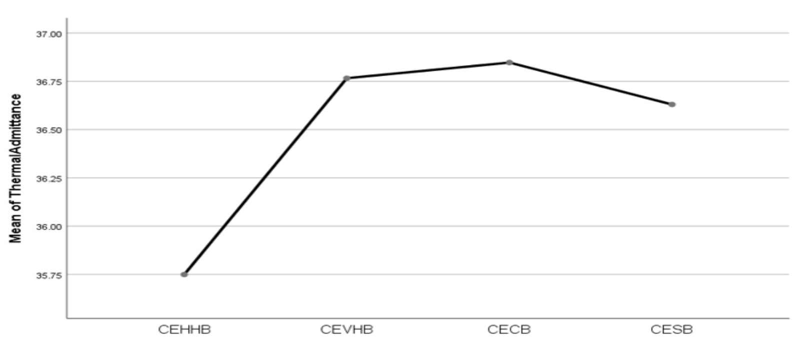
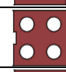
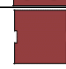


Figure 11. Thermal admittance by C.E.B

The data collected using Testo infrared thermometer was also analysed using spss statistical analysis software package to identify the (C.E.B) configurations; with lower rate of thermal admittance via external to internal C.E.B configurations experimental chambers, respectively.

Table 6. C.E.B wall surface temperature values in 10th April 2019

S/N	C.E.B Configuration	C.E.B Diagram	Internal wall surface Temperature
1	CEHHB		**36.0**
2	CEVHB		38.4
3	CECB		37.8
4	CESB		37.4

Inferring to obtained result from the testo infrared thermometer presented the table 6, table 7, and table 8. The result shows the (C.E.H.H.B.) has a lower rate of heat permeation values than C.E.B configurations; compressed earth horizontal hollow brick (C.E.H.H.B), compressed earth vertical hollow brick (C.E.V.H.B), compressed earth cellular brick (C.E.C.B), and compressed earth solid brick (C.E.S.B) respectively. However, the result shows C.E.H.H.B has a better thermal resistivity considering the values of the results obtained with the aids of using an infrared thermometer.

Table 7. C.E.B wall surface temperature values in 20th April 2019

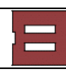
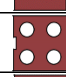
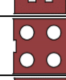
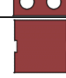
S/N	C.E.B Configuration	C.E.B Diagram	Internal wall surface Temperature
1	CEHHB		**34.3**
2	CEVHB		36.2
3	CECB		35.8
4	CESB		35.5

Table 8. C.E.B wall surface temperature Values in 30th April 2019

S/N	C.E.B Configuration	C.E.B Diagram	Internal wall surface Temperature
1	CEHHB		**34.5**
2	CEVHB		35.6
3	CECB		36.8
4	CESB		38.5

The result in Table 6, Table 7, and table 8 reveal that compressed earth horizontal hollow brick (C.E.H.H.B.) has the least heat admittance through the west wall internal surface temperature (heat gain) of (36.0^{oc}), (34.3^{oc}), and (34.5^{oc}) between the other C.E.B configurations, and this has indicated that the C.E.H.H.B. has a better thermal resistance in comparison to another C.E.B configuration.

4.0 Result and Discussion

The outcome of the study analysis reveals that the C.E.H.H.B configuration has least rate of heat transfer via wall component of the building compared to its other C.E.B configurations. The comfortable building indoors environment depends on the lower rate of thermal admittance of the wall building material. The C.E.H.H.B is the prepared C.E.B configuration for constructing school buildings in hot and dry regions of northwestern Nigeria. Due to its numerous sustainable advantages for enhancing the students' healthy indoor living conditions and improving their learning activities and academic performance. C.E.H.H.B designed configuration is an appropriate wall construction material for a school building in hot and arid zone areas.

5.0 Conclusion:

The study indicated that embracing (C.E.H.H.B) as a sustainable wall material for constructing of school buildings in northwestern Nigeria has a manifold advantage apart from enhancing teaching and learning activities. It also boosts students' comprehension due to the conducive interior spaces that enable the building's indoor environment suitable for learning. Moreover, other building typologies in the study area could equally enjoy. Benefits from using (C.E.H.H.B) as a wall construction material in any other part of the world with a similar climatic condition as hot and arid zone could also benefit from the study findings and adopt (C.E.H.H.B) configuration as a sustainable wall material for the construction of buildings.

Acknowledgements

We would like to thank the management of The Waziri Umaru Federal Polytechnic for their assistance and enabling environment in carrying out this research, as well as TETFUND for giving the funding opportunity to carry out this research as part of the research project intervention.

Conflict of interest

The authors state that they have no conflicts of interest.

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