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ORIGINAL RESEARCH ARTICLE

MODELLING OF HEAT TRANSFER THROUGH HOLLOW BLOCKS PRODUCED WITH RICE-HUSK-ASH BLENDED CEMENT

O. M. Kamiyo

Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria.

**Corresponding author's email address: okamiyo@unilag.edu.ng*

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ABSTRACT

Hollow sandcrete blocks are widely used in many countries of the world. In recent years, cement content is being partially substituted by admixtures especially agricultural wastes. Modeling of heat transfer characteristics of these modified blocks is essential in order to predict their thermal performance. This study focuses on this modeling with the aid of a finite-volume based computer code. Specifically, for regular, two-cavity blocks produced with the cement partially substituted with rice husk ash (RHA). The result showed that as the percentage substitution of RHA increased, thermal gradient across the width of the block increased, while the rate of heat flow reduced. The second part of the study examined the effect of heat transfer through the air-gap as compared to a similar study regarding it as vacuum. The heat flow through the air-gaps of the building bricks affected the pattern of heat flow within the bricks, hence, they could not be regarded as a vacuum. The results of this study will be useful to building professionals in the choice of building blocks and proper estimation of air- conditioning load in buildings.

1.0 Introduction

Hollow sandcrete blocks containing a mixture of sand and cement are used extensively in many countries of the world especially sub-Saharan Africa, Caribbean islands and Asia. In Nigeria, sandcrete block is the major cost component of most common buildings.The high and increasing cost of constituent materials of sandcrete blocks has contributed to the non-realization of adequate housing for both urban and rural dwellers. Hence, availability of alternatives to these materials for construction is highly desirable. In particular, materials that can complement cement in the short run, and especially if cheaper to produce has been of great interest (Chandrasekhar et al., 2003; Nair et al., 2006; Okunade, 2008).

Wall properties such as thermal resistance, comprehensive strength, weight, rigidity and cost play major roles in modern building designs. As a way of enhancing these properties and lower the cost, admixtures are introduced (Rodriguez de Sensale et al.,2008; Okunade, 2008; Turgut and Yesilata, 2008; Nair et al., 2006; Oyekan and Kamiyo, 2011). Use of agricultural wastes is one of the common approches (Ganesan et al., 2008; Cisse and Laguerbe, 2000; Nair et al., 2006; Chandrasekhar et al., 2003; Kamiyo and Oyekan, 2011; Adesanya and Raheem, 2009).

Thermal properties of the wall of a building play a major role in the estimation of the air condition load of the building space. Increasing the thermal resistance of the wall material is desirable and therefore the focus of many recent researches (Cianfrini et al., 2017; Idan and Feldman, 2017; Costa, 2014; Al-Tamimi et al., 2017; Tang et al., 2015; Gijon-Rivera et al., 2016; Shibib et al., 2013; Balaji et al., 2014).

A survey of existing literature shows that thermal properties of most cementitious materials are found to change with the presence of admixtures (Cisse and Laguerbe, 2000; Oyekan and Kamiyo, 2011) and size (with arrangement) of air-gaps in hollow bricks/ blocks (Al-Hazmy,

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2006; Oluleke et al., 2012; Idan and Feldman, 2017; Costa, 2014, Li et al., 2008; Al-Tamimi et al., 2017; Tang et al., 2015)

Al-Hazmy (2006) studied the heat transfer through a convectionals hollow brick with the aim of determining the effect of blocking the holes with insulators on the heat transfer rate. The results showed a 36% reduction in the heat transferred by the brick when hollow. Similarly, Gijon-Rivera et al. (2016) performed numerical analysis of the effect of heat conduction of building blocks made of different materials on congugate heat and mass transfer. The red bricks was found to be the best choice for air quality purposes in comparison with other building materials for all Rayliegh numbers considered.

Additionally, Tang et al. (2015) conducted parametric investigation of thermal performance of a wall by varying the arrangement of holes, insulation and building materials. The results of the study showed that as the number of holes increases, thermal conductivity reduces and, in some cases, between 20% and 61%. Oluleke et al. (2012) also carried out a finite element modeling of low heat conducting bricks. They reported that, in conventional bricks, increasing the number of holes beyond four gives minimal thermal resistance advantage. However, in their work, they assumed the holes to be vacuum i.e. there was no heat transfer.

It is noteworthy that with heat transfer in building materials, there have been resurgence of interest in recent times with limited literature on those with admixtures which are already in use. Therefore, this study focused on this problem. The research is on two parts : (i) to determine the effect of the substitution of rice husk ash as partial replacement to cement on the heat flow across sandcrete blocks; (ii) to reinvestigate the brick configuration of Oluleke et al. (2012) by imposing realistic conditions so as to determine its actual thermal performance.

2. Materials and Method

2.1 Mathematical formulation

The computational geometry, Figure 1, coincides with the physical geometry. Parallel path heat flow is assumed, i.e. heat flows directly from the hot to the cold surface perpendicularly and uniformly; signifying 1-D heat transfer situation. This method is used because heat flows laterally through block face shells so that transverse isothermal planes result (ASHRAE, 2017). Convective heat transfer within the holes is not considered as it is reported by Lacarrière et al., (2003) to be negligible.

The block is assumed exposed to solar radiation and hot outside air that heat its outer surface to temperature TH while the inner surface is assumed maintained by air-cooling at temperature TC (<TH).

The equation for general heat conduction for non-homogeneous material, for unsteady heat flow through a constant area is given by

$$\rho . c . \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) \qquad (1)$$

where T is temperature, ρ is density, c is specific heat, kx,y,z is thermal conductivity in x, y and z directions respectively. However, for a 1-D, unsteady heat conduction in a homogeneous material with no internal heat generation, the equation reduced to

$$\frac{dT}{dt} = \propto \frac{\partial^2 T}{\partial y^2} \qquad (2)$$

The boundary conditions employed are, at t = 0, and y=0, TH = 32°C and $\frac{\partial T}{\partial x} = 0$; at y = 225mm, TC = 22°C, convective heat transfer coefficient, h= 15 W/m^2 K.

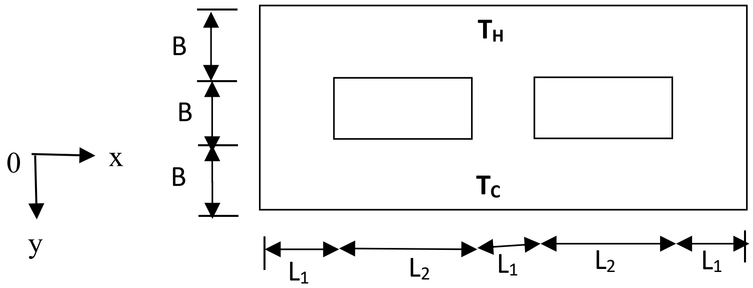


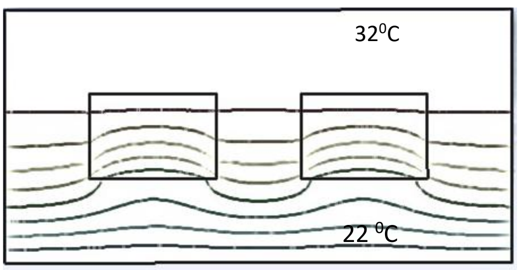
Figure 1: Computational geometry

The material constituents, their mix, presence of admixtures and production process are important factors that determine the properties of sandcrete blocks. In this study, the blocks produced with standard 1:6 cement-sand mix proportion are employed.The substitution of cement with rice husk ash and the batching of cement and sand were by volume. Blocks with 0% (control), 5%, 10% and 15% RHA substitution were used. The block dimensions are 450mm x 225mm x 225mm (with one-third of the volume void) which lead to B = 75mm; L_1 = 75mm; L_2 = 112.5mm. Futher details of the material contents, production and thermal properties of the blocks were as reported in Oyekan and Kamiyo (2011).

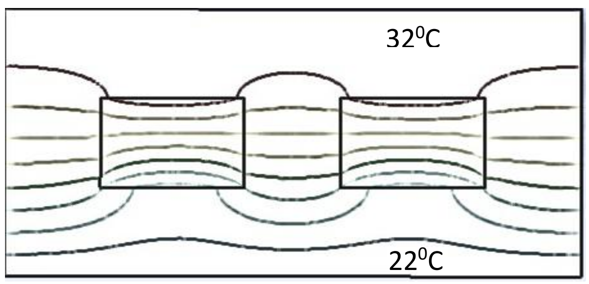
3. Results and Discussion

3.1 RHA block simulation

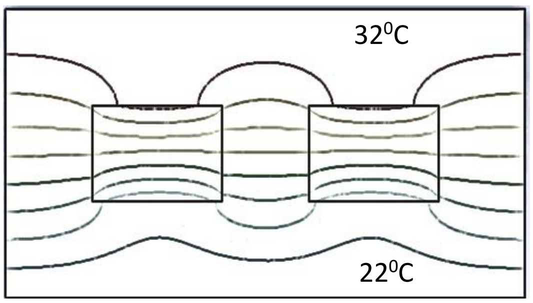
After numerical experiments to determine grid independence, a set of simulations were also carried out to determine the time steady state was reached. Figure 2 shows temperature variation with time across the width of the 15% RHA block when subjected to ambient temperature of 32°C on the upper side (outside) and air-cooled temperature of 22°C on the lower side (inside).



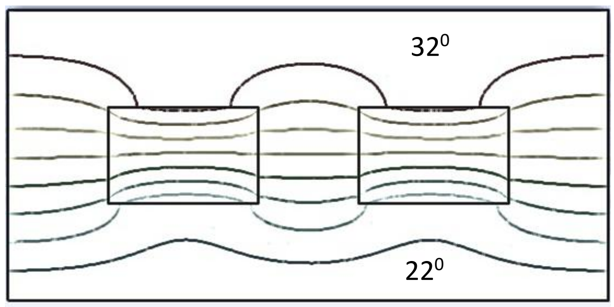
(a) 1200 seconds



(b) 2400 seconds



(c) 3600 seconds



(d) 7200 seconds

Figure 2: Evolution of the isotherms in the 15% RHA block.

It can be observed that, the temperature distribution obtained at 1200 seconds, Figure 2(a), is quite different from that at 2400 seconds, Figure 2(b), while that obtained at 7200 seconds, Figure 2(d), is the same as that at 3600 seconds, Figure 2(c). Therefore, it can be concluded that steady state is reached at 3600 seconds. In addition, the change in temperature with time is monitored at point y = 180mm. The outcome is shown in Figure 3.

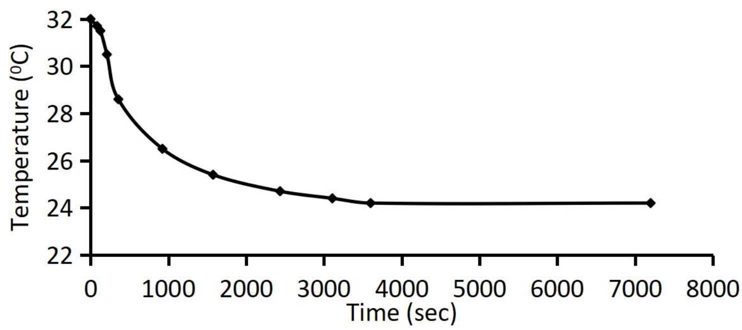
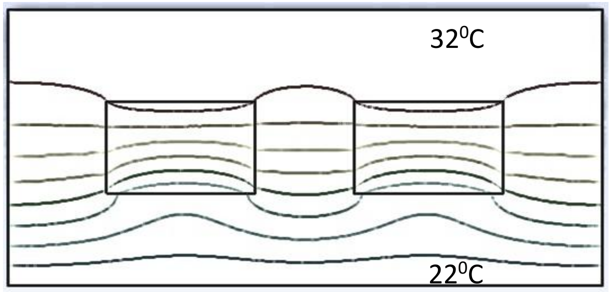
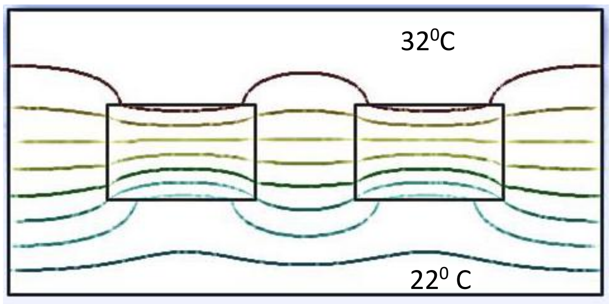


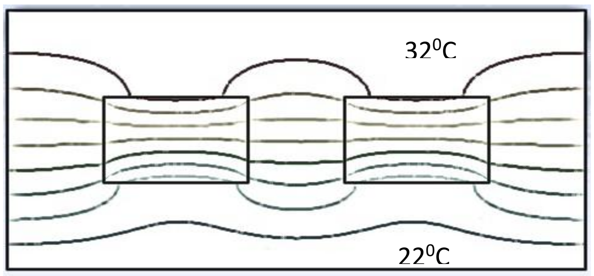
Figure 3: Temperature change with time at y = 180mm to steady state



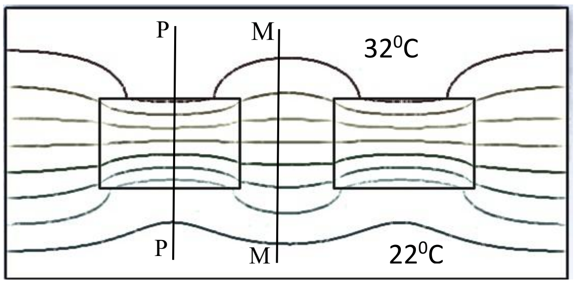
(a) 0% RHA



(b) 5% RHA



(c) 10% RHA



(d) 15% RHA

Figure 4: Temperature distribution at steady state for various % substitution

Figure 4 (a-d) show results for temperature distribution at steady state in blocks with 0% (the control block), 5%, 10% and 15% RHA substitutions. For the control block, Figure 4(a), the temperature at the hot surface remains unchanged up to the holes. Thermal stratification within the holes somehow affects the temperature pattern within the solid part. On the inner part, thermal gradient increases, showing three isotherms between the hole and the inner part of the block.

For 5% RHA block, Figure 4(b), the temperature pattern across the block changed slightly. The first isotherm has now extended closer to the outer surface. On the cooler part of the block, the thermal stratification that was noticeable in the 0% RHA block has reduced to only one isotherm between the holes and the cold surface. The isotherm skewed slightly towards the holes in form of two little humps. For the 10% RHA block, Figure 4(c), the humps of the last isotherm become pronounced. At 15% RHA substitution, Figure 4(d), the humps have become more pronounced. This implies that, as the RHA substitution increases, the temperature at the cooler part becomes more uniform and tends towards that of the cold surface of the block.

For all the blocks, heat transfer within the holes is highly stratified. Thermal gradient within the holes appears the same with five isotherms in each case. The temperature patterns indicate that there is a reduction in heat conduction from outside of the block to inside of the block. This reduction in heat flow between the two edges shows that, the air within the cavity of the blocks, as expected, helps in reducing the rate of heat transfer into the building.

Increasing the percentage substitution of RHA with cement in the block seems to introduce thermal stratification between the outer edge of the block and the holes while reducing further the thermal gradient between the holes and the inner edge resulting in increased thermal resistance. This is further corroborated by Figure 5 for temperature variation along section P-P (Figure 4(d) as example) for all the blocks.

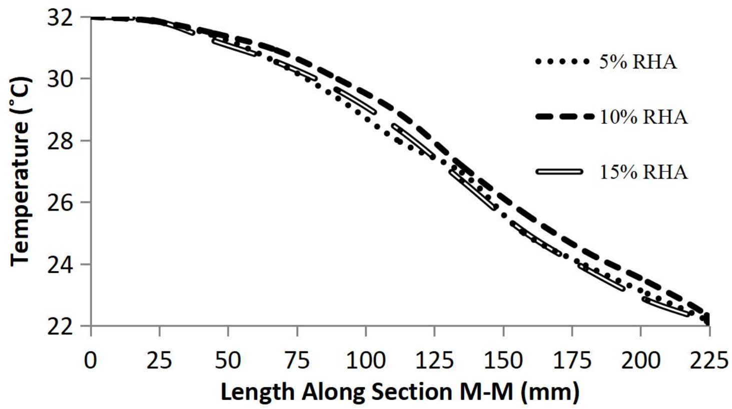


Figure 5: Temperature against length for different RHA percentage along section M-M.

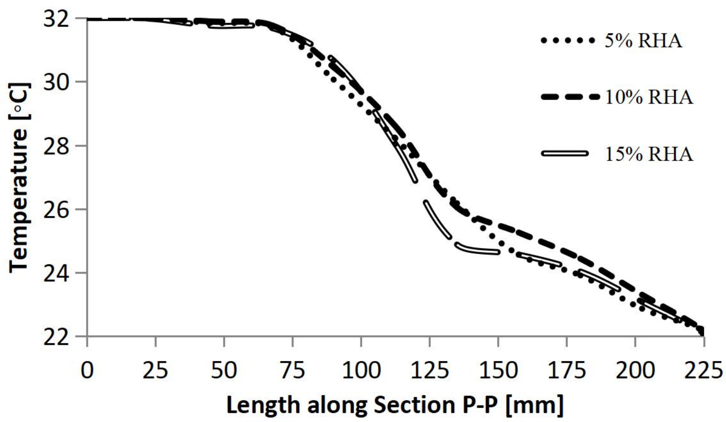


Figure 6: Temperature against length for different RHA percentage along section P-P.

Figure 5 shows temperature profile across the solid middle part of the blocks (section M-M) in Figure 4(d) as example for others. It can be seen that thermal gradient increases as the % RHA substitution increases. From Fourier's equation for heat conduction in solid materials, for the same area and quantity of heat transfer, k is inversely proportional to thermal gradient. This then implies that k should be reducing as thermal gradient increases. Therefore, it is then concluded that increasing substitution of RHA with cement reduces the thermal conductivity of the block. Similar pattern is observed for the temperature profile across the holes, section P-P, Figure 6.

It is well known that the thermal conductivity of cementitious materials (concrete, blocks, bricks, etc) being within the range of 0.1- 5.0 W/mK is higher than that of air (0.022 W/mK). Introducting holes in the block or brick is with the aim of reducing the rate of heat transfer from outside of the building to the cool space within.

In their work on modelling heat conduction in conventional and interlocking building bricks with regular and staggered holes, Oluleke et al. (2012) assumed no heat transfer through the holes thereby making the cavities to be a vacuum. This assumption however not only suppressed convection but also eliminates heat conduction. In reality, this is not so. This study therefore reconsiders their work for conventional, regular hollow brick with two cavities by relaxing the vacuum assumption.

3.2 Brick simulation

In this study, the brick is subjected to 40°C outside temperature. With convective heat transfer coefficient of 15 W/m^2 °C at the inner side of the brick, the inner temperature was found to be 26.22°C when the thermal conductivity of the solid part is 0.72 W/m °C and the hole a vacuum. The temperature distribution reported, Figure 7, showed high thermal stratification on the outer (lower) part of the brick. The vacuum assumption in the holes tends to inhibit heat flow across thereby limiting the heat tranfer to the inner (upper) side to only through the solid part around the holes. This, therefore, affects temperature distribution on the inner side. Realistic modeling of the case study reveals different temperature distribution, Figure 8.

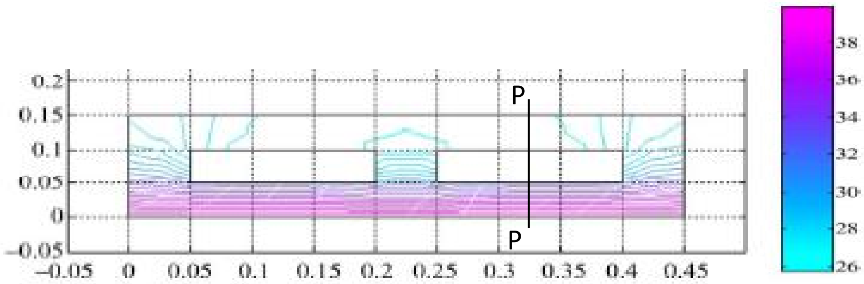
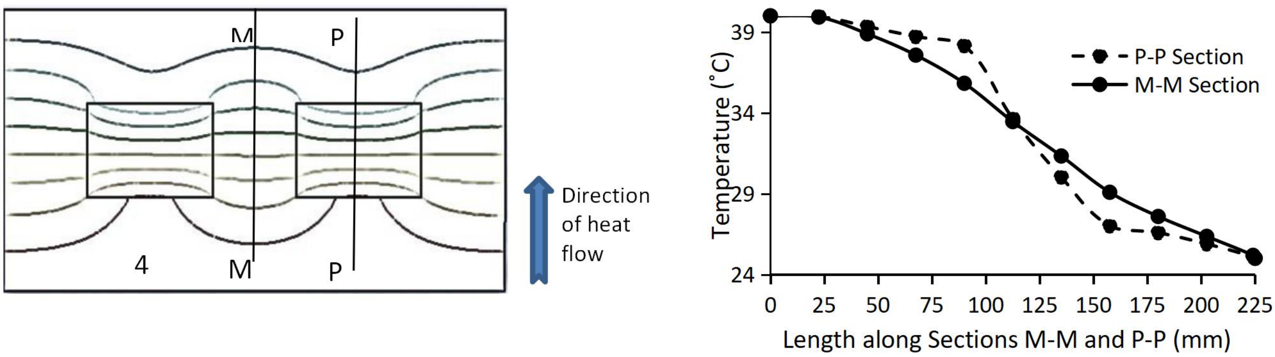


Figure 7: Temperature distribution within regular hollow brick with two air cavities heated from lower side with the holes as vacuum (Oluleke et al., 2012).



(a) (b)

Figure 8: (a) Temperature distribution for the brick at steady state, and, (b) temperature against length along sections M-M and P-P.

Figure 8 shows the temperature distribution for the brick at steady state, Figure 8(a), and temperature against length along sections M-M and P-P, Figure 8(b). For temperature variation across the solid middle part of the brick (section M-M), the higher temperature at the outer (lower) edge of the brick is maintained to some extent into the brick. Resistance to heat flow within the holes due to lower thermal conductivity of air within the hole creates high thermal gradient across the area. This reduces heat flow into the inner (upper) part. The inner temperature is found to be 24.2°C which is lower than 26.22°C reported by Oluleke et al. (2012).

Across section P-P, temperature remains almost constant till the hole is reached. High thermal gradient is shown across the hole due to higher thermal resistance of air. Temperature thereafter varies gradually till the inner edge temperature of 24.20C is reached. A similar plot of temperature variation across the section P-P through the hole in the brick of Oluleke et al. (2012), Figure 7, would have given a plot similar to Figure 9.

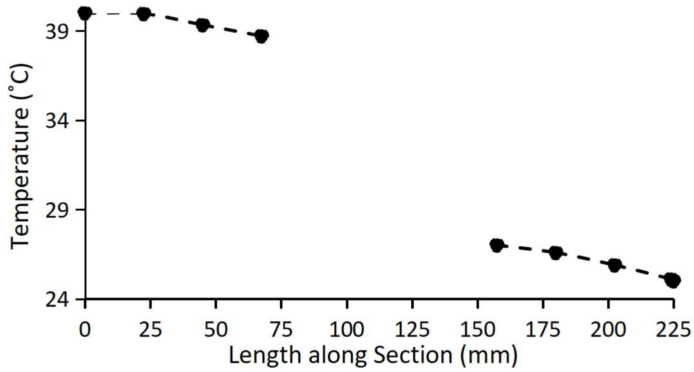


Figure 9: Temperature against length along Section P-P in Figure 6.

4. Conclusion

Heat transfer in convectional hollow sancrete block has been modelled and pattern of heat flow within the block has been analysed. First part of the modelling examined the effect of the substitution of cement with rice husk ash (RHA) on the temperature distribution within sandcrete blocks. The result shows that as the percentage substitution of RHA increases, thermal gradient across the width of the block increases while the rate of heat flow reduces. This implies addition of RHA to the block increases the thermal resistance of the block and makes it suitable wall material for minimizing air-conditioning load in buildings. It is clear that the heat flow through the air-gaps of the building bricks affects pattern of heat flow within the bricks, and hence, could not be regarded as a vacuum.This study could be useful to building professionals in making a choice of building blocks and proper estimation of air-conditioning load in buildings.

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Corresponding author's e-mail address: okamiyo@unilag.edu.ng