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DYNAMIC THERMAL PERFORMANCE OF RUBBERIZED MASONRY HOLLOW CONCRETE BLOCK WALLETTE'S WITH MORTAR AS SURFACE FINISHING

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ABSTRACT

In this study, the thermal and dynamic thermal performance of crumb-rubber modified masonry hollow concrete blocks and wallette's with mortar plaster on both sides as surface finishing was investigated. An investigation was carried out on the plain reference and modified samples with varying content of non-biodegradable waste tyre (crumb-rubber) partially substituted for coarse aggregate (granite) by volume at 0%, 5%, 10%, 15%, 20%, and 25%. Thermal properties were measured based on the Non-steady state using a KD 2 Pro thermal analyzer while the dynamic thermal properties were evaluated using the 'dynamic thermal properties calculator' software tool. Result reveals that the thermal conductivity of reference masonry hollow concrete block units (1.380W/mk) has been greatly reduced to 0.610W/mk indicating 55.8% reduction while heat capacity, diffusivity, and effusivity decreased by 43.3%, 53.8%, and 55% respectively. Furthermore, the combined thermal admittance (*Y*-value) of the modified blocks and mortar in form of wallette's increased slightly with 5% replacement of crumb-rubber but decreased by 20.1% with further increase in crumb-rubber content up to 25% also the result reveals that the thermal transmittance (*U*-value) decreased continuously by 13.8% while the thermal decrement was not significantly affected but the associated time lag increased considerably which could offer a significant reduction in temperature fluctuation which is very important in terms of building thermal efficiency and comfort.

KEYWORDS: *rubberized concrete blocks, wallette's, mortar, thermal, dynamic thermal,*

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INTRODUCTION

Solid waste materials disposal is considered one of the most challenging environmental problems faced globally. Open-air combustion of end-of-life tyre is considered to be one of the cheapest and easiest ways to eradicate them from the environment which also come with its environmental consequences such as air pollution and groundwater poisoning. The air pollution generated by the emission of a large quantity of greenhouse gases during open-air combustion of waste tyres makes the method undesirable which has also been banned by law in many countries [24] and [25]. It was revealed that every year around 9 billion kilograms of end-of-life tyres are discarded everywhere throughout the world, which was likewise evaluated to associate with 1 billion waste tyres generated annually [27], [7], and [8]. The number of end-of-life tyres existing in Nigeria as of 2018 was estimated to be 37million with an annual generation rate of 15% [19].

The application of end-of-life tyres in the construction industry is now well-developed as it helps in improving sustainability in two ways. First, reuse of the materials which otherwise will burden the environment and will be occupying scarce land resources. [10], Second, it minimizes the degradation of land and the environment as a result of comparatively less digging. ‘‘Recycling’’ is an all-prevailing practice now as it conserves the planet’s resources [26]. The characterization of crumb-rubber aggregate from end-of-life waste automobile tyres reveals low specific gravity (0.95Kg/m^3), small water absorption (2-4%), low thermal conductivity (0.14W/mk) high dynamic modulus and damping properties, and high resistance to weather (i.e non-biodegradable), [4]. Rubberized concrete has low thermal conductivity compared to the plain reference samples has proven and documented in the literature [5],[16], and [18] with potential additional advantages of managing waste tyre constituting environmental nuisance by converting waste into resources. It was reported that the inclusion of rubber particles from end-of-life tyres as a partial replacement for fine and coarse aggregate reduced the density and compressive strength with an increase in the rubber content. However, load-bearing and non-load bearing blocks can be produced with rubber content up to 15% [9], [16], [24], and [27]. Masonry concrete in form of hollow concrete blocks is becoming widely accepted as a construction material for walling units in our buildings, hence the partial replacement of mineral aggregates with rubber-tyre particles in concrete blocks would be a very good and promising way to utilize the large quantities of waste rubber-tyres. The use of waste rubber-tyres particles in masonry hollow concrete blocks would not only make good use of such waste materials by converting waste into a resource but will help to enhance some masonry hollow concrete blocks inherent properties such as thermal insulation which brings about thermal comfort in a building envelope in terms of lowering the internal heat of a building by reducing the rate of heat transfer and also maintaining the internal room temperature in winter cold.

The thermal properties of most cementitious materials are found to change with the presence of admixtures [6] and [21]. The change is found to depend on the admixture’s grain structure or interstitial arrangement within the main material, thermal properties, and other microstructural parameters including the volumetric fraction of each constituent, the shape of the particles, and the size distribution of the particles.

This study aimed to carry out a dynamic thermal analysis of rubberized masonry hollow concrete blocks wallette's with masonry mortar as surface finishing on both sides of the wall to enable us to access its effect on thermal insulation.

Dynamic Thermal Properties

The thermal transmittance value derived from the steady-state calculations (*U*-value) is not an appropriate indicator of the thermal performance of building elements by themselves; as two walls with the same U-value can absorb and release heat at different rates [13]. A steady-state analysis is concerned only with the thermal conductivity of the material; the influence of heat capacity is ignored. Intermittent occupancy and associated heating or cooling operation combined with external diurnal variations mean that the building is more often in a state of flux and, particularly in hot summer conditions, the dynamic behavior of the whole building should be assessed to optimize the selection of envelope materials for greatest combined thermal comfort and energy performance. The material bulk properties of heat capacity (*C*), density (ρ), and thermal conductivity (λ) play an important role in the cyclic performance of the construction, which is significant when the outdoor temperature is cycling below and above the desired indoor temperature. Materials with beneficial thermal properties are either insulating materials or materials with thermal mass [22]. and the effect of thermal mass and thermal insulation which are representatives of dynamic and steady-state thermo-physical properties of materials must be taken into account simultaneously [13].

The optimum design performance of building fabric is subject to a trade-off between the dynamic thermal behavior (temperature buffering and thermal storage) and thermal resistance to heat transfer, where for example a combination of minimal thermal storage but high thermal resistance is required in a climate where the cooling load dominates such as Nigeria.

There are several methods available for assessing the dynamic performance of a building. One of the simplest, based on a variation of the frequency-domain method, is the Admittance method created by the UK Charted Institute of Building Services Engineers (CIBSE). The CIBSE admittance method is a cyclic model in which the assumption is that weather is represented as a harmonic with a period of 24 hours. It uses the material's admittance (explained next) as well as time lag and decrement factors, to define their dynamic response. This cyclic model can be used to make a rapid assessment of peak summertime temperatures, space cooling loads, and preheat requirements and is very useful in the design stage of a project. However, according to CIBSE, because of the simplicity of the model, its application can be limited especially at predicting summertime overheating as the true benefit of mass cannot be assessed (CIBSE, 2006).

Thermal Admittance (measured in W/m^2K) is a factor that represents the quantity of heat that passes through a unit area of a material (BSI, 2007: p. 3). Admittance is equal to the walls U-Value in steady-state but differs when the time dependency is taken into account. It is likely to be high for constructions that have high thermal mass materials in their inner layers and low if they have insulating materials so it can also be an indication of the construction's thermal mass. In multilayered structures, admittance is mainly determined by the properties of the material in the layers adjacent to the internal surface. Therefore, admittance is effectively a dynamic U-Value concerned only with the part of the construction that influences the internal space.

Thermal Admittance Y (W/m²K), for one-dimensional heat flow, can be calculated using the temperature distribution Equation 1 in a homogeneous construction element subject to one-dimensional heat flow is given by the thermal diffusion equation.

$$\frac{\partial^2 T}{\partial x^2} = \frac{\rho C_p}{\lambda}\frac{\partial T}{\partial t} \quad (1)$$

Where, T = temperature (°C), x = distance in direction perpendicular to surface of slab (m^2), ρ = density (kg/m^3), Cp = specific heat capacity (J/kg K), λ = thermal conductivity (W/m K), and t = time (s).

Thermal Comfort

Thermal comfort can be defined as the condition of mind which expresses satisfaction with the thermal environment [17]. Thermal comfort in a house is as good as the worth of the house itself [23]. Scientifically, thermal comfort is achieved between the indoor temperature of 20°C and 28°C while optimum relative humidity is between 30% and 60% [3]. Indoor thermal comfort is essential for occupants' well-being, productivity, and efficiency. The hot-dry climate with its extremely high temperatures and intense solar radiation is becoming hotter and drier in this era of climate change and global warming. Thus, providing for indoor thermal comfort and reducing energy use in buildings is becoming increasingly difficult. This has called for new ways of thinking and a re-evaluation of the existing methods of tackling this problem [2]. The primary function of all buildings is to adapt to the prevailing climate and provide an internal and external environment that is comfortable and conducive to the occupants. However, in this era of climate change and global warming, providing comfort for the occupants of a building is quite challenging and very fundamental [2].

This is a result of the growing range of challenges now facing designers and engineers to provide buildings that will be fit and comfortable for the 21st century. Thermal comfort has to do with the temperature that the resident considers as comfortable to stay in. Indoor thermal comfort is achieved when occupants can pursue without any hindrance, activities for which the building is intended. Hence, it is essential for occupants' well-being, productivity, and efficiency.

Thermal comfort in the context of hot climates is dominated by cooling [20] [1] and [12]. Six major factors determine comfort CIBSE (2007). They are Ambient air temperature, humidity, radiation, air movement, clothing, and activity.

MATERIAL AND METHODOLOGY

Material

The cement used for this study is a general-purpose blended limestone Portland cement CEM II (42.5RMPa) that conforms to BS EN 197-1:2011 and having a specific gravity of approximately

3.15. Clean water from the laboratory tap was used for the concrete mix. Fine aggregate (sharp river quartzite sand) with size 75µm-4.76mm, a specific gravity of 2.65 and bulk density of 1,454 Kg/m^3, coarse aggregate with size ranging between 9.52 - 10mm, a specific gravity of 2.66 and bulk density of 1,635 Kg/m^3; crumb-rubber aggregate of particle size ranging between 4 - 9mm, a specific gravity of 1.14 and bulk density of 528Kg/m^3 were used for the concrete mixes and production of the masonry hollow concrete blocks. Crumb-rubber surface treatment method by soaking in sodium hydroxide (NaOH) solution was adopted for this research due to its effectiveness in enhancing the hydrophilic properties of the rubber and increasing the intermolecular interaction forces between rubber and calcium silicate hydrate gel which enhances the strength of the composite matrix as reported in the literature [14].

Mix Proportions

The mix design for the masonry concrete was based on an absolute volume method according to BS EN 206:2013+A1:2016 design, a mix ratio of 1:1.5:3, compressive strength of 30N/mm^2 at 28 days (Grade 30 Concrete) with water/cement ratio of 0.42, and aggregate/cement ratio of 4.5:1 was used to produce a trial mix which was tested for compacting factor, strength, density, and finishing properties. The mix was eventually subjected to adjustment, adopted, and applied to all the concrete mixes. A total number of six (6) mixes were prepared: One control mix with no crumb-rubber aggregate and five concrete mixes in which the 9.52-10 mm coarse aggregate (granite) was partially replaced by crumb-rubber aggregate at 5%, 10%, 15%, 20% and 25% by volume. The mix proportions were constant in terms of mix design ratio, water/cement ratio, sizes, type of natural and crumb rubber-tyre aggregate used for the study. A mix ratio of 1:3 (cement: sand) with a water/cement ratio of 0.6 was used for the production of general-purpose masonry mortar for plaster finishing with strength grade M20.

EXPERIMENTAL PROCEDURES

Non-steady state transient line heat source (TLS) method with the aid of a hand-held thermal property's analyzer (KD 2 Pro) by Decagon Devices, Inc. (2011) was used to measure the thermal conductivity *(k)*, thermal resistivity *(ρ)*, thermal diffusivity (α) and volumetric specific heat capacity (c) while the thermal effusivity *(β)* *''the ability of the material to absorb and release heat with its surroundings''* were computed from the relationship between thermal conductivity, density and specific heat capacity given in Equation 2.

$$\beta = \sqrt{k\rho C} \qquad (2)$$

Where: β is the effusivity, k is the thermal conductivity, ρ is the density of the sample and c is the specific heat capacity.

A total of 36 masonry hollow concrete blocks (450 x 225 x 225) mm specimens (average of six samples per mix) and 3 masonry mortar samples were produced, cured, and tested for thermal properties after 28 days.

The two principal parameters that govern the dynamic thermal (storage) properties of a construction member are (i) thermal admittance, *Y*, and related quantities as specified in EN ISO 13786:2007; and (ii) surface heat capacity, *k*, (*the ability of a material to store heat*) as specified in EN ISO 13790:2004. These were determined for masonry hollow concrete block wallette's with mortar plaster finishing on both sides of the wall and exposed external wall, based on EN ISO 13790: 2004, using the 'Dynamic Thermal Properties Calculator' software tool. The calculations assumed a vertical wall with horizontal heat flow and conventional surface boundary layer heat transfer coefficients of (i) inside surface coefficient *Rsi* = 0.13 m^2 K/W, and (ii) outside surface coefficient *Rso* = 0.04 m^2 K/W, both are taken from ISO 6946: 2007. The sol-air mean temperature variation was set at +/- 1K for direct comparison between different materials.

Figure 1: Materials and Samples Preparation of Rubberized Blocks for Thermal Test

RESULTS AND DISCUSSION

Masonry hollow concrete blocks (450 x 225 x 225) mm and mortar (70.6 x 70.6 x 70.6) mm specimens were tested for the thermal properties using a KD2 Pro thermal properties analyzer as shown in Figure 1. Average results obtained from the experimental measurement of thermal properties of rubberized masonry hollow concrete block units and mortar are presented in Tables 1 and 2. The result reveals that thermal conductivity of masonry hollow concrete blocks decreased by 55.8%, with increase crumb-rubber up to 25% thereby improving their insulating value (R-value) while the thermal diffusivity decreases by 53.8% with 25% crumb-rubber content, which implies a decline in the ability of the composite material to undergo a temperature change when exposed to a fluctuation thermal environment. Volumetric heat capacity of masonry concrete with 5% crumb-rubber content increased slightly by 3% before a steady decline to 43.3% with crumb rubber content up to 25%, while the thermal effusivity of concrete is reduced by 55% with crumb

rubber particles content up to 25%, indicating a reduction in the rate of heat absorption and release (heat exchange) of the composite material with its surrounding.
The thermal conductivity of mortar is 1.287W/mk, thermal resistivity which is the inverse of conductivity recorded 78.12 Cm°c/W, average volume heat capacity of the masonry mortar is 2.698 MJ/m³. K which is equivalent to the specific heat capacity of 1,255 J/Kg.k. The average thermal diffusivity of the masonry mortar is 0.459 mm²/s and the thermal effusivity is 2.727 W/m²ks$^{1/2}$.

Table 1: Thermal Properties of Rubberized Masonry Hollow Concrete Block Units

Sample No	Density (Kg/m³)	Temp °C	Thermal Conductivity (W/mk)	Thermal Resistivity (Cm°c/W)	Thermal Diffusivity (mm²/S)	Heat Capacity (MJ/m³. K)	Heat Capacity (J/Kg.k)	Thermal Effusivity (W/m²ks$^{1/2}$)
0% CR-MHCBU	2,079	31.41	1.380	72.57	0.576	2.830	1,361	2.849
5% CR-MHCBU	2,017	30.13	1.260	79.38	0.488	2.918	1,447	2.723
10% CR-MHCBU	1,928	29.47	0.940	106.40	0.437	1.880	975	1.846
15% CR-MHCBU	1,882	28.85	0.820	121.98	0.365	1.833	974	1.682
20% CR-MHCBU	1,792	27.64	0.730	137.01	0.311	1.721	960	1.500
25% CR-MHCBU	1,686	27.15	0.610	163.99	0.266	1.606	953	1.285

Table 2: Thermal Properties of Masonry Mortar

Sample No	Density (Kg/m³)	Temp °C	Thermal Conductivity (W/mk)	Thermal Resistivity (Cm°c/W)	Thermal Diffusivity (mm²/S)	Heat Capacity (MJ/m³. K)	Heat Capacity (J/Kg.k)	Thermal Effusivity (W/m²ks$^{1/2}$)
A	2,160	30.59	1.270	79.10	0.457	2.729	1,263	2.733
B	2,131	30.58	1.283	78.26	0.454	2.707	1,270	2.714
C	2,160	30.57	1.308	77.00	0.467	2.658	1,231	2.735
Average	2,150	30.58	1.287	78.12	0.459	2.698	1,255	2.727

The dynamic thermal simulation and performance of masonry concrete block wall built with rubberized masonry hollow concrete block units and masonry mortar plaster on both faces are illustrated on the graph in Figure 2 showing the internal surface heat flow (q_{is}) and external surface heat flow (q_{es}) and the internal environmental temperature fluctuation (θ_{ei}) with response to temperature deviation in form of 24-hours cyclic sinusoidal inputs.

The results indicate that the thermal admittance (*Y*-value) for the masonry hollow concrete block wallette's increased slightly with 5% crumb-rubber content but decreased with a further increase in crumb-rubber content up to 25%. The reference masonry hollow concrete block wallette have a *Y*-value of 4.68W/(m²k) and time lag Ø of 5.15h while 5, 10, 15, 20 and 25% crumb-rubber content have *Y*-value of 4.71, 4.04, 3.98, 3.87 & 3.74 W/(m²k) and time lag Ø (h) of 5.31, 4.15, 4.16, 4.07 and 4.01 respectively indicating 20.1% decrease in thermal admittance with 25% crumb-rubber content. Furthermore, the result reveals that the thermal transmittance (*U*-value) of masonry hollow concrete block wallette decreased continuously with the increase in crumb-rubber content up to 25%. The reference masonry hollow concrete block wallette have a U-value of 2.17W/(m²k) while 5, 10, 15, 20 and 25% crumb-rubber have U-value of 2.15, 2.05, 2.00, 1.95 and 1.87 W/(m²k) respectively indicating 13.8% decrease in thermal transmittance with 25% crumb-rubber content.

Such dynamic thermal behaviour indicates that for heat exchange between the internal environmental node (θ_{ei}) and the sol-air node (in either direction), the total heat flux and the rate of change in heat flux decrease with increasing crumb-rubber content in the wall panel due to the temperature fluctuation, i.e., a higher thermal buffering effect Hall *et al.,* (2012).

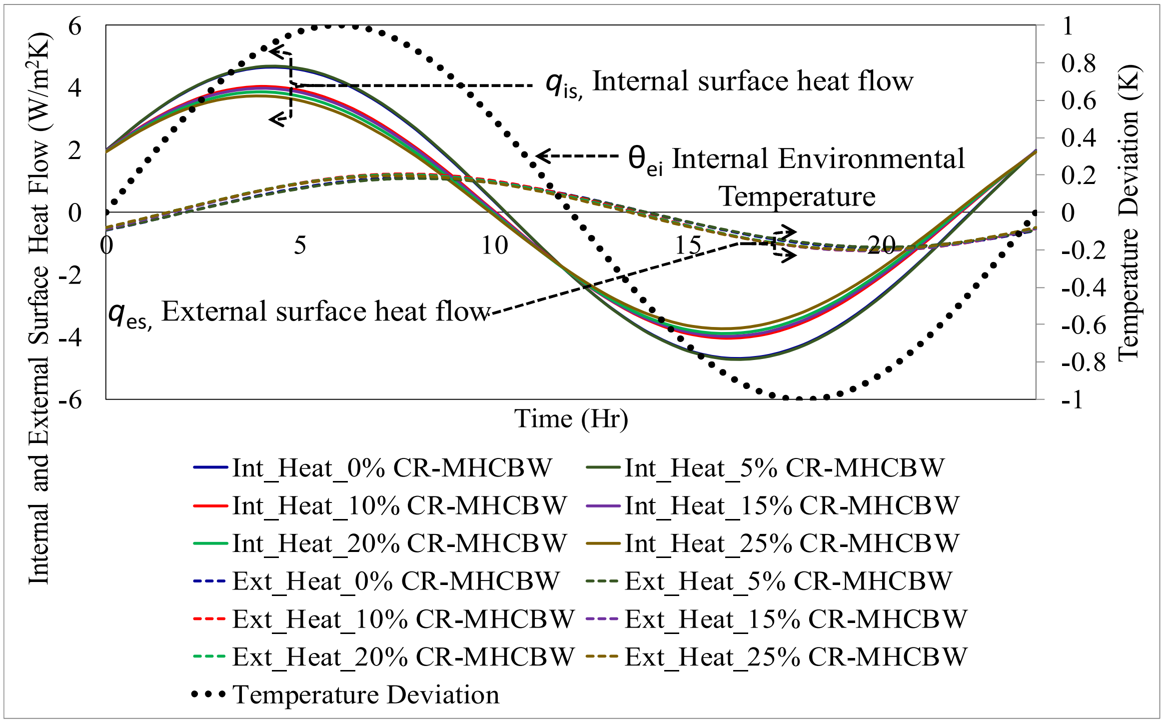

Figure 2: Surface Heat Flow and Internal Environmental Fluctuation for Rubberized Masonry Wallette with Masonry Render (Plaster)

Figure 2 further reveals from the dynamic thermal response of the tested mixes that there is no significant difference in internal environmental node temperature fluctuation (θ_{ei}), i.e., almost typical. However, 5, 10, 15, 20, and 25% crumb-rubber masonry wall panels appear to cause a significant and proportional reduction in internal surface heat flow (q_{is}) compared to that of the reference mixes increasing thermal resistance along which is important in terms of both buildings' thermal efficiency and comfort. This behaviour could be attributed to the fact that incorporating crumb-rubber aggregate to produce concrete block units used in the masonry wallette increased thermal resistance but also decreased volumetric heat capacity which is highly desirable in the cold region but not necessarily important in the temperate and hot climate.

The total thermal resistance (R_T) which is the inverse of thermal transmittance was found to increase with an increase in crumb-rubber aggregate substitution. The reference masonry hollow concrete block wallette have a R_T - value of 0.461(m^2k)/W while 5, 10, 15, 20 and 25% crumb-rubber masonry hollow concrete wall panels have R_T - value of 0.465, 0.488, 0.500, 0.513 and 0.535(m^2k)/W respectively indicating 16.1% increase in thermal resistivity with 25% crumb-rubber content. The surface heat capacity, *k* (kJ/m²k), of the masonry hollow concrete wall panel recorded the highest surface heat capacity (k_m, *k* and k_{30}) values with 5% crumb-rubber content. The results further revealed that after the slight increase in surface heat capacity with 5% crumb-rubber content there was a gradual decrease with further increase in crumb-rubber content up to 25% which will have a serious adverse effect on thermal mass (the ability of the material to store heat) most especially in the cold region but for the tropical region with a temperate and hot climate like Nigeria the thermal mass effect will have little or no significant effect and therefore not necessarily desirable. A slight increase in surface heat capacity with 5% crumb-rubber content will be desirable in the cold region. The decrement factor (*f*) of the modified masonry hollow concrete blocks wallette's increased slightly with an increase in crumb-rubber content, it is normally used to represent the reduction in temperature gradient formation (as a function of time) across a construction member due to heat storage within that member. Fabrics with high thermal decrements like the crumb-rubber masonry hollow concrete block wallette's can be theoretically utilized to considerably decrease heating/cooling loads. Surface factor, *F* (*dimensionless and it is the ability of the wallette surface to gain heat by absorbing the incident radiative heat*), of masonry hollow concrete block wallette increased slightly with an increase in crumb-rubber content up to 25% partially replaced in coarse aggregate (granite) by volume. Time lag for thermal admittance, Ø (h), of masonry hollow concrete block wallette increased slightly with 5% crumb-rubber content but decreased gradually with further increase in crumb-rubber content up to 25%. Decrement factor time lag, ω (h), of masonry hollow concrete block wallette indicates an increase with an increase in crumb-rubber content up to 25% while the time lag for the surface factor, ψ (h), of masonry hollow concrete block wallette decreased steadily with the percentage increase in crumb-rubber content up to 25%. Hall *et al.,* (2012) in similar research conducted, reported that the substitution of crumb-rubber for mineral aggregate in concrete appears to cause a significant reduction in both thermal admittance and thermal transmittance of a plain rubberized concrete (PRC) and self-consolidating rubberized concrete (SCRC) making it to offers greater resistance to exchange of that heat with the surrounding environment.

CONCLUSIONS

Thermal (conductivity, resistivity, diffusivity, and effusivity) and dynamic thermal performance of rubberized masonry hollow concrete block wallette's ''with mortar as surface finish have been analysed'' with the impact on thermal insulation outlined in the following conclusions:

i. Thermal conductivity of masonry concrete block units (1.380W/mk) has been greatly reduced to 0.610W/mk indicating a 55.8% reduction which can be attributed to the low thermal conductivity of the crumb-rubber compared to that of the granite, the heat capacity of the masonry concrete hollow concrete block units reduced with increase in percentage crumb-rubber particles which can be attributed to the low specific gravity of crumb-rubber compared to that of the granite, thermal resistivity was observed to have been greatly enhanced by 55.8%, thermal diffusivity was observed to have decreased by 53.8% and thermal effusivity was observed to have decreased by 55% with 25% crumb-rubber particles content.

ii. Thermal properties (conductivity, heat capacity, diffusivity, and effusivity) of rubberized masonry concrete hollow concrete blocks increased with an increase in density (unit weight) with exception of thermal resistivity which is the inverse of thermal conductivity.
iii. Thermal admittance (*Y*-value) of masonry hollow concrete block wallettes with mortar as surface finishing and response to temperature deviation in form of 24-hours cyclic sinusoidal inputs show a slight increase in thermal admittance with 5% crumb-rubber content (increase in thermal storage capacity otherwise known as thermal mass) but decreased by 20.1% with further increase in crumb-rubber content up to 25% (decrease in thermal storage capacity). This result indicates that the slight increase in the thermal storage capacity (thermal mass) of the wallettes is very good for the cold region by absorbing heat from and releasing it to space through cyclical temperature variations, thus evening out temperature variations and so reducing the demand on building services systems. Also, the decrease in thermal mass is very attractive for a tropical region like Nigeria.
iv. Thermal transmittance (*U*-value) of masonry hollow concrete block wallette with mortar as surface finishing and response to temperature deviation in form of 24-hours cyclic sinusoidal inputs decreased continuously by 13.8% with the increase in crumb-rubber content up to 25%. This implies a reduction in the ability of the wallette to transmit heat through a unit area in unit time per unit difference in temperature of the individual environment between which the structure intervenes.
v. Incorporating crumb-rubber did not significantly affect thermal decrement, but increased the associated time lag considerably. This could offer a significant reduction in temperature fluctuations, which is important in terms of building thermal efficiency and comfort.
vi. Rubberized masonry concrete blocks wallette's with masonry mortar as surface finishing offered a significant reduction in temperature fluctuations by increasing thermal resistance, which is important in terms of both buildings thermal efficiency (energy-efficient building-minimizing in use of energy and embodied CO_2) and comfort.

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REFERENCES

[1] Adelaja, A.O. Damisa, O. Oke, S.A. Ayoola, A.B. and Ayeyemitan, A.O. (2008). ''A survey on the energy consumption and demand in a tertiary institution,'' Maejo International Journal of Science and Technology, (2), pp. 331-344.
[2] Akande. O.K. and Micheal A. Adebamowo. (2010), ''Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate of Nigeria,'' Proceedings of Conference: *Adapting to Change:*

New Thinking on Comfort Cumberland Lodge, Windsor, UK, 9-11 April 2010. London: Network for Comfort and Energy Use in Buildings.

[3] AL-Ajmi, F. Loveday, and D.L, Hanby, V.I. (2006). ''The cooling potential of the earth–air heat exchangers for domestic buildings in a desert climate,'' *Building and Environment*. 41(3): 235–244.

[4] Al-Sakini, (1998), ''Behaviour and Characteristics of chopped worn-out tyres lightweight concrete'', Msc Thesis university of Technology, Baghdad, Iraq.

[5] Benazzouk, A. Douzane O. Mezreb. K. Laidoud B. and Queneudec. M. (2008). "Thermal Conductivity of Cement Composites Containing Rubber Waste Particles: Experimental study and modeling," Construction and Building Materials, 22, pp.573–579.

[6] Cisse, I. K. and Laguerbe, M. (2000). "Mechanical characterization of filler sandcretes with rice husk ash additions," Study applied to Senegal. Cem. Concr. Res. 30(1):13–18.

[7] Erdogan, S. O. Mohammed, L. and Umur. K. S. (2010). "Compressive Strength Abrasion Resistance and Energy Absorption Capacity of Rubberized Concrete with and without slag".

[8] Forrest M.J. and Rapra, S. (2014). ''Recycling and Re-use of waste Rubber'' published by Smithers Rapra.

[9] Gheni A. Elgwady, M., and Myers, J. (2017). ''Thermal Characterization of Concrete Masonry Units Manufactured Using Recycled Tires as and Aggregate''. 13th Canadian Masonry Symposium Halifax, Canada. June 4th -June 7th, 2017.

[10] Güneyisi, E. and Gesoglu, M. (2011). "Permeability properties of self-compacting rubberized concretes," *Construct*. *Build*. *Mater*., 25, 3319-3326.

[11] Hall, M. R. Najim, K. B. and Hopfe, C.J. (2012). "Transient thermal behaviour of crumb rubber-modified concrete and implications for thermal response and energy efficiency in buildings," Applied Thermal Engineering, 33-34:77-85.

[12] Isa, M.H.M. Zhao, X., and Yoshino, H. (2010). ''Preliminary Study of Passive Cooling Strategy Using a Combination of PCM and Copper Foam to Increase Thermal Heat Storage in Building Façade,'' Sustainability, 2(8), pp. 2365-2381.

[13] McMullan, R. (2007). ''Environmental Science in Buildings,'' 6th ed.; Palgrave Macmillan: New York, NY, USA, 2007.

[14] Mohammadi. I. (2014). ''Investigation on the Use of Crumb Rubber Concrete (CRC) for Rigid Pavements'', Thesis submitted for fulfillment of requirements for the degree of Master of Engineering University of Technology Sydney School of Civil end environmental engineering Centre for Built Infrastructure Research.

[15] Mohammed, B.S. et al. (2012). ''Properties of Crumb rubber hollow concrete block.'' Journal of Cleaner Production 23(1): p.57-67.

[16] Najim, K.B. and Hall, M.R. (2012). "Mechanical and dynamic properties of self-compacting crumb-rubber modified concrete" Construction and Building materials, 27(1):521-530

[17] Nyuk H.W. and Shan, K. (2003). ''Thermal comfort in classrooms in the tropics,'' *Energy* and Buildings 35 (2003) 337–351.

[18] Ocholi, A. Ejeh S.P. and Sanni M.Y. (2014). ''An Investigation into the Thermal Performance of Rubber-Concrete'', Academic Journal of Interdisciplinary Studies MCSER Publishing, Rome-Italy Vol 3 No 5 July 2014 Doi:10.5901/ajis. 2014.v3n5p29

[19] Ocholi, A. Sanni M.Y. and Ejeh S.P. (2018). ''The impact resistance effect of partially replacing coarse aggregate with ground-rubber aggregate in concrete''. http://dx.doi.org/10.4314/njt.v37i2.7 Nigeria Journal of Technology (NIJOTECH) p.330-337.

[20] Ogunsote, O. O. (1991). ‘‘Introduction to building climatology,’’ *A basic course for architecture students.* Zaria: Ahmadu Bello University Press.
[21] Okpala, D.C. (1993). “Some engineering properties of sandcrete blocks containing rice husk ash,” Build. Environ., 28(3): 235-241.
[22] Paver Institute and Clay Brick (2006). ‘‘The Role of Thermal Mass in Energy-Efficient House Design’’, Austral Bricks: Langford, Australia.
[23] Rawi, M. SeNSe, L. and Al-Anbuky, A. (2009). ‘‘Passive House sensor networks,’’ Human-centric thermal comfort concept.
[24] Siddique, R. and Naik, T.R (2004), ‘‘Properties of Concrete containing Scrap-tire rubber-an overview’’, waste management., 24, 563-569.
[25] Sukontasukkul, P. and Chaikaew, C. (2006)., ‘‘Properties of Concrete Pedestrian block mixed with crumb rubber,’’ Construct, Build. Materials.20, 450-457.
[26] Terro, M.J. (2006). ‘‘Properties of concrete made with recycled crushed glass at elevated temperatures’’, Build Environ 41:633–9.
[27] Yang, Y. Chen, J., and Zhao, G. (2000). “Technical Advance on the Pyrolysis of Used Tires in China,” Dept. of Chem. Eng., Zhejiang University YuQuan Campus, Hangzhou.