Comparison of the Thermal Properties of some Selected Ceiling Materials for Cost Effectiveness in Nigeria.

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ABSTRACT: This study compared the thermal characteristics of a few different building materials utilized for the ceiling. The findings indicate that the five samples; polyvinyl chloride (PVC), plaster of Paris (POP), asbestos, cardboard, and plywood, that were examined in terms of their thermal properties can be divided into two main groups based on their thermal absorptivities: PVC, cardboard, and plywood have higher thermal absorptivities, while POP and asbestos have lower thermal absorptivities. According to the molecular perspective on thermal absorptivities, the best insulating materials must have lower thermal absorptivities. Thus, these suggest that, when compared to PVC, cardboard, and plywood, asbestos and POP are recommended as ceiling materials with good thermal insulation efficacy and cost effectiveness. For the two categories of materials; substances with lower thermal absorptivities and substances with higher thermal absorptivities, thermal mathematical modeling have also been established. To display the similarities and contrasts between the many samples under investigation, graphs and tables have also been used.

KEYWORDS: Ceiling materials, Thermal properties, thermal conductivity, thermal diffusivity and thermal absorptivity.

1 INTRODUCTION

Construction cost planning involves a systematic analysis of the structure of a building which enables a price for each consequent parts to be valued against each performance requirement. Several designs may then be programmed and valued so that a number of alternatives is offered to satisfy building requirement (Wang, 2019). The largest thermal gain in the modern world happens through a house's roof. The building's primary purpose is to maintain a minimal energy footprint while providing residents with a healthy and comfortable thermal environment. However, the usage of zinc-made roofs without ceilings is widespread in Nigeria, which results in strong heat transfer to the interior environment and the possibility of thermal discomfort for residents (Etuk *et al*., 2017). The majority of construction materials, in particular roofing and walling materials, are efficient heat conductors. When a structure is constructed, sheet metal made of materials like zinc and aluminum is frequently used for the roofing and walling. However, these materials are extremely uncomfortable for the building's occupants. Extreme thirst, a high body temperature, nausea, mental malfunction, etc. are just a few examples of this heat pain (Hust *et al*., 1975).

Utilizing radiant barriers, which lower the heat flux, is one technique to lessen thermal discomfort. Heat is transmitted into interior spaces of buildings through roofs, walls, and partially through cooling panels because to the prevalent materials used as roofing sheets and materials like zinc and aluminum that have significant thermal conductivity. Since the heat flow in any building is dependent on the thermal properties of the materials used in the building, understanding the thermal characteristics of materials is crucial when choosing the type of material to be used as a radiant barrier (insulator) (Onyeaju *et al*., 2012).

The optimum aim of the thermal characteristics' comparison of different building materials utilized for the ceiling is to ensure a healthy and comfortable thermal environment at a minimal cost. This is to enable a price for each consequent parts to be valued against each performance requirement in a house's roof for the building's occupants in developing countries.

Observation in the current competitive world suggests that those who are financially secure and economically favored typically choose the most expensive ceiling materials without taking into account how well these materials insulate against heat (Gesa *et al*., 2014). Based on this fact, the purpose of this study project is to examine the thermal characteristics (thermal insulation effectiveness) of the most popular ceiling materials in Nigeria.

2 MATERIALS AND METHODS

The materials employed in this research effort included five samples of materials that are frequently used as ceiling materials, including polyvinyl chloride (PVC), plaster of Paris (POP), cardboard, asbestos, and plywood. These materials are coded as shown in Table 1.

Table 1: Material and code of the select ceiling samples

S/N	MATERIALS	SAMPLES
1	PVC	A
2	POP	B
3	Cardboard	C
4	Asbestos	D
5	Plywood	E

A few of the samples were procured from Lagos, while others were gathered in a building supply store in Folagbade, Ijebu Ode, Ogun State, Nigeria. The samples were marked with labels and molded to fit the brass Lee's disc equipment. After processing, each sample's diameter was increased to 8.7 cm.

These tests were conducted in the laboratory of the Physics Department of the College of Science and Information Technology at Tai Solarin University of Education in Ijagun, Ijebu-Ode. And all necessary safeguards were done.

Thermal conductivities were determined for each of the ceiling materials (samples) using the steady state method. Lee's disc apparatus (steam method) was used.

The mixing method and cooling correction method, which account for any potential heat loss owing to radiation, were used to calculate each sample's specific heat capacity. The samples' densities were calculated using the displacement and weighing techniques. The mathematical relationships between the attributes were used to calculate further properties.

2.1 THEORETICAL CONSIDERATIONS

1. The thermal conductivity for each of the material was calculated using the equation (Hust *et al*., 1975; (Etuk *et al*., 2017):

$$m \times c \times g = k\frac{\pi d^2}{4} \times \frac{(t_1 - t_2)}{x}, \qquad (1)$$

2. The specific heat capacity for each of the material was calculated using the equation (Etuk *et al*., 2017):

$$c = \frac{C}{M} = \frac{Q}{M(T_2 - T_1)}, \qquad (2)$$

3. The thermal resistivity of each of the materials was calculated using the equation (Etuk *et al*., 2017):

$$r = \frac{1}{k}, \qquad (3)$$

4. The density of each of the materials was calculated using the equation (Etuk *et al*., 2017):

$$\rho = \frac{m}{v}, \qquad (4)$$

5. The thermal diffusivity of each sample was determined using the equation (Tidwell, 1990; Etuk *et al*., 2017):

$$\lambda = \frac{k}{pc}, \qquad (5)$$

6. The thermal absorptivity of each of the material is determined with the equation (Etuk *et al*., 2017):

$$\alpha = \left(\frac{\omega}{2\lambda}\right)^{\frac{1}{2}}, \qquad (6)$$

Also, the thermal absorptivity was calculated using the equation (Etuk *et al*., 2017):

$$Q = m \times c \times \Delta T, \qquad (7)$$

These parameters are defined as, M is the mass of the brass disc = 450g, C is the specific heat capacity of the brass disc = 380JKg^{-1}k^{-1}, g is the slope obtained from temp-time graph of each of the material, k is thermal conductivity (to be obtained for each of the material), d is the diameter of each of the sample = 8.7cm, t_1 is the temperature of the brass at steady state, t_2 is the temperature of steam chamber at steady state, x is the thickness of each of the material, Q is the quantity of heat supplied, C is the specific heat capacity of each material, $T_2 - T_1$ is the change in temperature, r is resistivity of each material. k is the thermal conductivity of each material, v is the volume of each sample when displaced in water, p is the density of each material, ΔT is the change in temperature and $\omega = \frac{2\pi}{24}$.

3. RESULTS AND DISCUSSION

Table 2 shows the experimental results for the specific heat rapacity C, density ρ, thermal conductivity k, thermal diffusivity λ, thermal resistance r, and thermal absorptivity α for the different ceiling materials. From this table, the specific heat capacity lies between 843 $Jkg^{-1}k^{-1}$ in Asbestos and 2499 $Jkg^{-1}k^{-1}$ in Plywood, thermal conductivity range for the different materials lies between 0.0702 $wm^{-1}k^{-1}$ and 0.4060 $wm^{-1}k^{-1}$ for PVC and POP respectively. In all, the ranges of thermal conductivities of the ceiling material fall within the conductivities of construction and heat-insulating materials given by Tidwell & Weir (1990) as 0.023 and 2.9 $wm^{-1}k^{-1}$. This even substantiates why they are used as heat-insulating materials. thermal diffusivity lies between 3.943 $x10^{-8}m^2/s$ in PVC and (18.54) $x10^{-8}m^2/s$ in POP while, thermal absorptivity lies between 8.40m^{-1} in POP and 18.22m^{-1} in PVC.

Table 2: The results from the experiments for each of the samples

Sample code	Specific heat capacity (C) ($JKg^{-1}k^{-1}$)	Density (ρ) (Kgm^{-3})	Thermal conductivity (k) ($Wm^{-1}k^{-1}$)	Thermal diffusivity (λ) (m^2s^{-1})	Thermal resistivity (r) ($w^{-1}mk$)	Thermal absorptivity (Xm)
A	1570.0	1134.0	0.0702	3.943	14.25	18.22
B	1470.0	1490.0	0.4060	18.540	2.463	8.40
C	2365.0	970.8	0.1838	8.005	5.441	12.77
D	843.0	1928.8	0.2137	13.140	4.680	9.97
E	2499.0	589.5	0.0997	6.768	10.03	13.95

According to Table 2 and the graphs in Figures 1–5, there are significant differences in the thermal characteristics, which are clearly visible in the pertinent graphs for the effectiveness of thermal insulation; samples made of POP and asbestos are more effective at providing insulation. This conclusion results from the low heat absorptivity that was discovered when compared to PVC, cardboard, and plywood. When compared to samples of PVC, cardboard, and plywood, POP and asbestos exhibit lower temperature sensitivities, which is indicated by their low absorptivity. The samples that stand out in comparison to POP and asbestos exhibit some signs of compatibility since their thermal diffusivities and absorptivities are nearly identical. Thermal diffusivities of PVC, Cardboard, and Plywood samples are almost half those of POP and Plywood samples, and thermal absorptivities of POP and Asbestos samples are nearly half those of PVC, Cardboard, and Plywood samples.

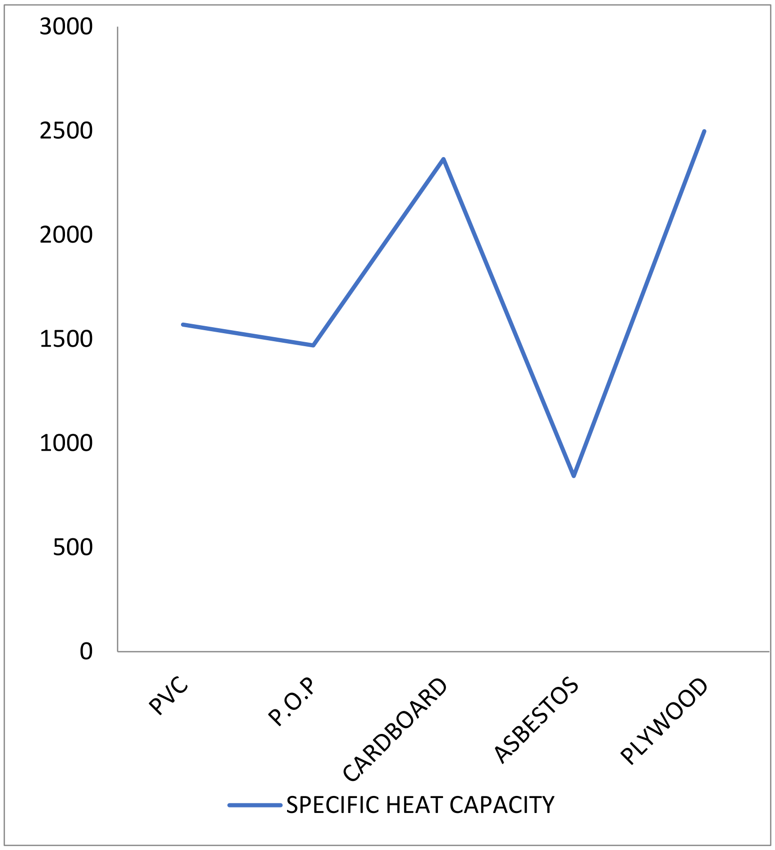

Fig 1: Showing the specific heat capacities of the ceiling materials

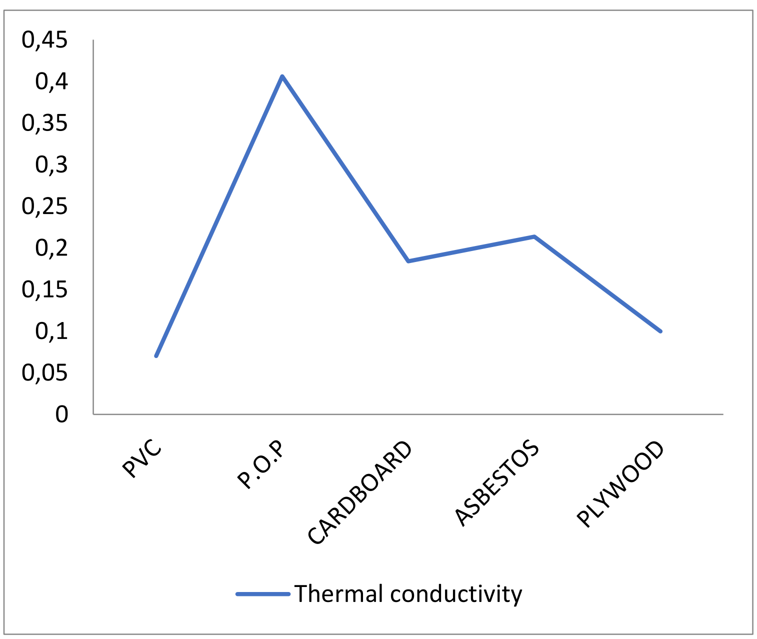

Fig 2: Showing the thermal conductivities of the ceiling materials

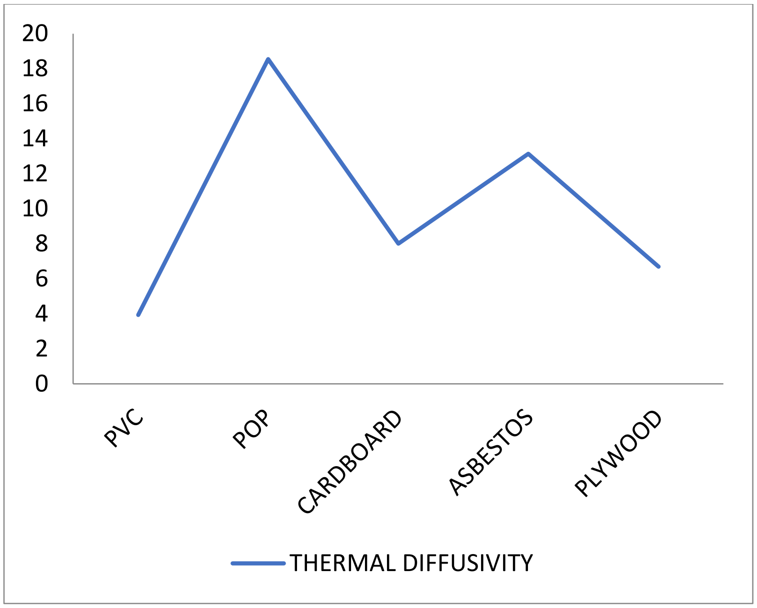

Fig 3: Showing the thermal diffusivities of the ceiling materials

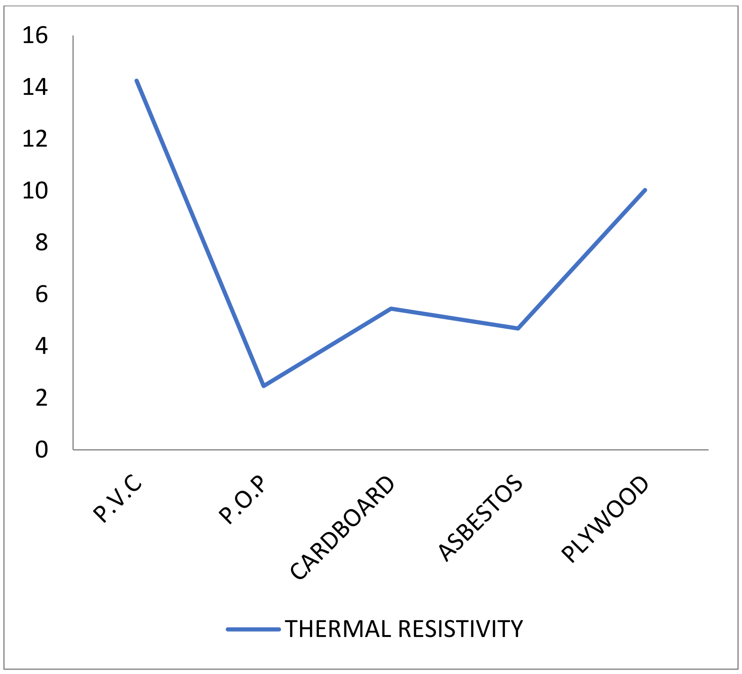

Fig 4: Showing the thermal resistivity of the ceiling materials

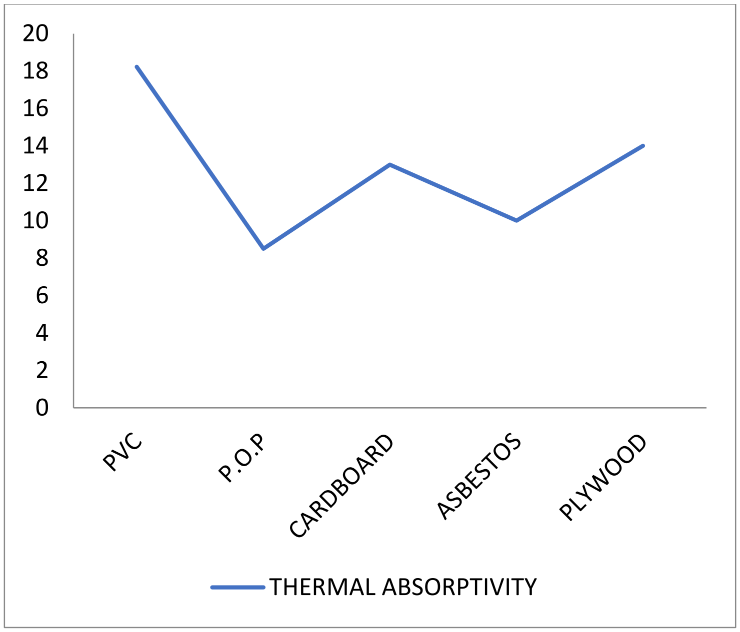

Fig 5: Showing the thermal absorptivity of the ceiling materials

Since the temperature as a function of thickness and time can be estimated using the equation (Tidwell & Weir, 1990):

$$T_{(x,t)} = T_m - A_s \exp(-\alpha x) \cos w\,(t - t_0) - \left(\frac{\alpha x}{\pi}\right), \qquad (8)$$

where A_s is the daily temperature amplitude at the surface of ceiling material at $x = 0$, t is the time of the day in hours, t_0 is the time of minimum temperature at the surface in hour; α is the thermal absorptivity (m^{-1}), w is the angular frequency and T_m is calculated from the surface hourly temperature average, T_{hss} (^0c); therefore, on a 24- hour period, the equation above becomes (George *et al*., 2010):

$$T_{(x,t)} = T_m - A_s \exp(-\alpha x) \cos\left(\frac{2\pi}{24}\right)(t - t_0) - \left(\frac{12\alpha x}{\pi}\right). \qquad (9)$$

Therefore, the model for temperature variation with thickness x and time t can be developed using the equation and the table of results. The model can be represented as the following equations (George *et al*., 2010):

For PVC:

$$T_{(x,t)} = T_m - A_s \exp(-18.22x) \cos\{0.262(t - t_0) - 18.22x\} \qquad (10)$$

For POP:

$$T_{(x,t)} = T_m - A_s \exp(-8.4x) \cos\{0.262(t - t_0) - 8.4x\} \qquad (11)$$

For cardboard:

$$T_{(x,t)} = T_m - A_s \exp(-12.77x) \cos\{0.262(t - t_0) - 12.77x\} \qquad (12)$$

For asbestos:

$$T_{(x,t)} = T_m - A_s \exp(-9.98x) \cos\{0.262(t - t_0) - 9.98x\} \qquad (13)$$

For plywood:

$$T_{(x,t)} = T_m - A_s \exp(-13.9x) \cos\{0.262(t - t_0) - 13.9x\} \qquad (14)$$

The equations are compatible when the models are taken into account. This demonstrates that when the same thickness and duration are employed, the temperature variation or thermal response for POP and asbestos ceiling materials will be identical due to their similar thermal qualities. Additionally, PVC, cardboard, and plywood are compatible and would differ little to not at all due to their identical thermal qualities.

Table 2 results for the thermal conductivity of each material indicate good agreement with the suggested values for heat insulating materials as well as the standard value of a bad conductor acceptable for building materials found in textbooks. Since they all fall between 0.023 and 2.9wm-1k-1, which is the range for Tidwell's conductivity construction and heat insulation materials, they are all poor conductors suitable for building materials (Tidwell & Weir, 1990). But according to George *et al*. (2010), the best insulating materials must have a lower thermal absorptivity.

Thus, these suggest that, when compared to PVC, cardboard, and plywood, asbestos and POP are recommended as ceiling materials with good thermal insulation efficacy and for each consequent parts to be valued against each performance requirement as readily available in the local market structure (Kanthana, 2018). When compared to PVC, cardboard and plywood still perform better in terms of thermal absorption. Decisions on the alternatives are always made such as that will give the owner the value for his money from the established cost plan.

4.0 CONCLUSION AND RECOMMENDATION

POP and asbestos have low thermal resistivity despite having high thermal conductivity. However, when it comes to the effectiveness of insulation, thermal absorptivity which has to do with the absorption and retention of heat plays a crucial role. Lower molecular heat content of a material as it absorbs heat from the source is clearly indicated by lower absorptivity of a material. Low thermal absorptivity with higher or lower diffusivity, thus, depicts strong thermal insulation efficiency from a molecular perspective. The study recommends that POP and asbestos be utilized as ceiling materials in homes, businesses, and educational institutions. However, plywood and cardboard were recommended for the middle class since they are less expensive and provide better insulation than PVC and others home owners, who cannot afford the cost of POP and asbestos.

REFERENCES

Etuk, S., Agbasi, O., Abdulrazzaq, Z. & Robert, U. (2017). Investigation of thermophysical properties of alates (swarmers) termite wing as potential raw material for insulation, *Int. J. Sci. World* 6 (1), 1-7.

George, N. J., Obianwu,V. I., Akpabio, G.T. & Obot, I. B (2010). Comparison of Thermal Insulation Efficiency of some Selected Materials used as Ceiling in Building design, *Am. J. Eng. Res.*,2(3), 253-259.

Gesa, N. F., Atser, R. A. & Aondoakaa, S. I., (2014). Investigation of the Thermal Insulation Properties of Selected Ceiling Materials used in Makurdi Metropolis (Benue State Nigeria), *Am. J. Eng. Res.*, 3 (11), 245–250.

Hust, J. G., & Girratano, P. J. (1975). Thermal conductivity and electrical resistivity standard reference materials: Austenitic Stainless Steel, SRM's 735 and 798, from 4 to 1200 K; Cryogenics Division, NBS Institute for Basic Standards, Boulder, Colorado 80302. *National Bureau of Standard Special publication* C13.10. 260- 46.

Onyeaju, M.C., Osarolube, E., Chukwuocha, E.C., & Omasheye, J.C.G. (2012): Comparison of the Thermal Properties of Asbestos and Polyvinylchloride (PVC) Ceiling Sheets Materials Sciences and Applications, *Int. J. Sci. World* 3, 240-244.

Twidell J. & Weir, T. (1990). *Renewable Energy Resources,* London, E and F.N Spon, 418.

Wang, Y. (2019). Strategic cost management. A review of research status at home and abroad. *Modern Economy* 10, 513-522.

Kanthana, D. (2018). The effects of cost management quality on the effectiveness of internal control and reliable decision making: Evidence from Thai Industrial firms. Advances in Social Science, Education and Humanities Research 211, 60-70.