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Archives of Applied Science Research, 2010, 2 (3): 253-259

(http://scholarsresearchlibrary.com/archive.html)

ISSN 0975-508X
CODEN (USA) AASRC9

Comparison of thermal insulation efficiency of some select materials used as ceiling in building design

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Abstract

In this study, comparison of thermal insulation efficiency of some select materials frequently used as ceiling in building design was investigated. The results show that the five samples A,B,C,D, and E analysed in terms thermal properties can be thermally characterized into two major groups: sample A and C with higher thermal absorptivities and samples B,D and E with lower thermal absorptivities. Based on the molecular point of view of thermal absorptivities, samples B,D and E are recommended as the best materials with high thermal insulation inefficiency. Thermal mathematical medellings have also been developed for the two groups of materials which are substances with lower thermal absortivities and substances with higher thermal absorptivities. Graphs and tables have also been used to show the similarities and the differences for the different samples investigated.

Keywords: Thermal insulation efficiency, Ceiling materials, thermal absorptivity, Thermal conductivity and thermal diffusivity.

INTRODUCTION

In our homes, indoor thermal discomfort it has been very challenging and it depends on one or more of the materials used either as ceiling board; rock used as walling materials; wood used in making doors; wood sample used in making roofing support; the roofing sheet itself or combination of all of them. One of the special concerns of the trained builders is to design a building that the indoor emironmental condition is thermally tolerable and conducive to the occupants of the building [1, 2]. Besides the wall, the ceiling, the door and the roofing materials, used for flooring and carpeting also generate heat thereby contributing in no small measure to the thermal discomfort of a building.

In this work, emphasis is on the comparison of the thermal insulation efficiency of the different frequently used ceiling materials based on their thermal properties. The ceiling materials are made from different materials with different thermal conductivities, thermal absorptivities, thermal diffusivities and thermal resistivities. Depending on how large or small the value of these thermal properties, a particular ceiling material may be more efficient in terms of thermal insulation than another. Observation in the present competitive world reveals that people that are economically favoured usually go for the most costly ceiling materials without any preference to the thermal insulation efficiency of the most sought after ceiling materials. It was based on this premise that this work is designed to investigate the thermal properties and thermal insulation efficiency of the most frequently used ceiling materials and to develop a mathematical model based on their thermal properties that can be used to predict and compare the suitability of the ceiling materials in terms of thermal response. The model designed from experimental values and the existing theory on temperature variation with thickness can estimate the thermal response of the different ceiling materials at different period of the day.

Heat propagated in interior spaces is through roofs and walls and partly through ceiling and ceiling panels by the process of conduction and radiation [3]. To reduce this heat propagation, materials of tolerable thermal response are needed to be used in the ceiling, walling as well as the roofing design [4]. Researches by [5,6,7,8]. Posit that substances with higher thermal diffusivities and lower solar radiation absorptivity have tolerable temperature responses and this makes them to be used as better ceiling and ceiling panels.

MATERIALS AND METHODS

Five samples of materials frequently used as ceiling materials which include PVC, POP, cardboard, Asbestos and suspended ceiling materials coded as tabulated in table 1 were the materials used in this study.

Table 1: Material and code of the select ceiling samples

S/n	Material	Sample
1	PVC	A
2	POP	B
3	Cardboard	C
4	Asbestos	D
5	Suspended	E

These samples were collected at the building material shop at Ikot Ekpene, Akwa Ibom State, Nigeria. The samples were labeled and shaped to take the dimensim of the Lee's disc apparatus. The diameter and the thickness of each of the specimens were finally processed to be 6.04 ± 0.05cm and 2.50 ± 0.05cm respectively.

Thermal conductivities were determined for each of the ceiling samples using the steady state method. Lee's disc apparatus was used [9]. The problem of redistribution of water under the influence of a temperature gradient was completely avoided as the entire samples were completely dry. Heat conducted across the sample, at the steady state, equals the rate at which it is emitted from the exposed surface [10]. This principle of consecration of energy and other precautionary practices were strongly upheld in order to reduce the experimental error to the bearest minimum.

The specific heat capacity was determined for each sample by method of cooling correction, described by [11,12], which takes care of any heat that might be lost due to radiation. In this experiment, copper-constantan thermocouple was used for temperature measurements.

The bulk densities were measured for each of the ceiling sample using the weighing and displacement methods [5]. Thermal diffusivity , λ , absorptivity α , resistivity r were calculated for each sample using the equations (1), (2) and (3) respectively, shown below.

$$\lambda = \frac{K}{PC} \quad (1)$$

$$\alpha = \left(\omega/2\lambda\right)^{1/2} \quad (2)$$

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

Where ω = 2π / period, λ = thermal diffusivity, α = thermal absorptivity, k = thermal conductivity, c = specific heat caplets; ρ = density of the sample, and r = thermal resistivity.

The temperature of a porous material at any depth is dependent on the net amount of heat absorbed by the material which is a factor of thermal conductivity, the heat energy required to bring about any given change in temperature of material (thermal capacity) and the energy required for charges such as evaporation which occurs constantly at the surface [15, 16]. Variation of temperature with thickness in solid materials is a determining factor on whether or not the material can be used as a heat sink or source.

The temperature as a function of thickness and time can be estimated from an equation given by [17].

$$(T(x,t) = T_m - A_s \exp(-\alpha x)\cos(\omega\{(t - t_0) - \alpha x/\omega\} \quad (4)$$

Where A_s = daily temperature amplitude at the surface of ceiling material at x =0, t = time of the day in hours; t_o = time of minimum temperature at the surface in hours; α = thermal absorptivity (m^{-1}), ω = angular frequency T_m is calculated from the surface hourly temperature average T_{hss} (^{0}c) as

$$T_m = \sum_{m=1}^{24}\left[T_{hss}/24\right] \quad (5)$$

On a 24 – hour period, equation (4) becomes

$$T(x,t) = T_m - A_s \exp(-\alpha x)\cos\{\left(2\pi/24\right)(t - t_0) - 12\alpha x/\pi\} \quad (6)$$

Thermal diffusivity is calculated using the relation in (1) given by [17,18]. Again, thermal diffusivity λ is used in calculating thermal absortivity α in equator (2).
Table 2: was obtained as the error treated mean values of the thermal parameters measured and calculated as the case may be.

Table 2: statistics of the thermal properties of the different ceiling samples

Sample	Density (ρ) (kg/m^3)	Specific heat Capacity (c) (Jkg^{-1} k^{-1})	Thermal conductivity (k) (wm^{-1}k^{-1})	Thermal diffusivity (λ) (m^2/s)x10^{-8}	Thermal resistivity (r) w^{-1} mk	Thermal absorptivity x m^{-1}
A	1136.20 ± 2.71	15 71.09 ± 5.12	0.0802 ± 0.0085	4.491 ± 0.121	12.469 ± 0.211	28.46 ± 1.13
B	1492.83 ± 3.35	1468.80 ± 6.00	0.3171 ± 0.0094	1.446 ± 0.661	3.154 ± 0.113	15.86 ± 1.41
C	971.80 ± 1.25	2366.70 ± 4.17	0.0925 ± 0.0025	4.021 ± 0.191	10.810 ± 1.011	30.07 ± 0.99
D	1929.50 ± 3.21	842.90 ± 2.96	0.2261 ± 0.0369	1.390 ± 0.191	4.423 ± 0.0913	16.17 ± 1.03
E	418.33 ± 2.64	1357.50 ± 6.51	0.0858 ± 0.0094	1.51 ± 00.710	11.655 ± 0.781	15.52 ± 11.6

RESULTS AND DISCUSSION

Table 2 shows the experimental results for the thermal conductivity k, specific heat rapacity C, density ρ, thermal absorptivity α, thermal resistance r, and thermal diffusivity, λ for the different ceiling materials. From this table, thermal conductivity range for the different materials lies between 0.0802±0.0085 wm^{-1}k^{-1} and 0.3171±0.0094 wm^{-1}k^{-1} for sample A (PVC) and sample B.(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 [19] as 0.023 and 2.9 wm^{-1}k^{-1}. This even substantiates why they are used as heat-insulating materials. The specific heat capacity lies between 842.90±2.96 Jkg^{-1}k^{-1} in Asbestos and 1571.09±5.12 Jkg^{-1}k^{-1} in PVC. Thermal absurptivity lies between 15.52±1.61m^{-1} in suspended ceiling and 30.07±0.99m^{-1} in cardboard, while thermal diffusivity lies (413.90±0.678) x10^{-8} m^2/s in asbestos and (4.491±0.121) x10^{-8}m^2/s in PVC. From table 2 and the graphs shown in figures 1-4, there are great variations of the thermal properties as crystally seen in the relevant graphs in terms of thermal insulation efficiency; samples E, B and D are more efficient in terms of insulation. This conclusion is due to the observed low value of thermal absotptivity when compared to samples A, and C. The low absorptivity indicates that samples E,B and D have low temperature responses when compared to sample A and C. The two samples that seem to be odd when compared to E, B and D, show some traces of compatibility as their thermal absorptivities and thermal diffusivities are almost alike. The thermal diffusivities of samples A and C are almost twice that of samples E,B and D and the thermal absorptivities of samples E,B and D are almost 50% of that of the samples A and C.

Developing the model for temperature prediction and variation with thickness x at time t, we use equation (6) and table 2. The modal can be represented as equations 7 - 11:

For sample A.

$$T(x,t) = T_m - A_s \exp(-29.59x)\cos\{0.265(t-t_0) - 29.60x\} \quad (7)$$

For sample B.

$$T(x,t) = T_m - A_s \exp(-17.29x)\cos\{0.262(t-t_0) - 17.28x\} \quad 8)$$

For sample C

$$T(x,t) = T_m - A_s \exp(-31.06x)\cos\{0.262(t-t_0) - 31.07x\} \quad (9)$$

For sample D

$$T(x,t) = T_m - A_s \exp(-17.47x)\cos\{0.262(t - t_0) - 17.48x\} \qquad (10)$$

For sample E

$$T(x,t) = T_m - A_s \exp(-17.13x)\cos\{0.262(t - t_0) - 17.14x\} \qquad (11)$$

Considering the models in equations (7) – (11), (8) (10) and (11) are compatible. This shows that using ceiling materials of samples B, D and E, temperature variations or thermal response will be similar due to their similarities in thermal properties when the same thickness and time, t is used. On the other way round, samples A and C are compatible and they would have little or no variation

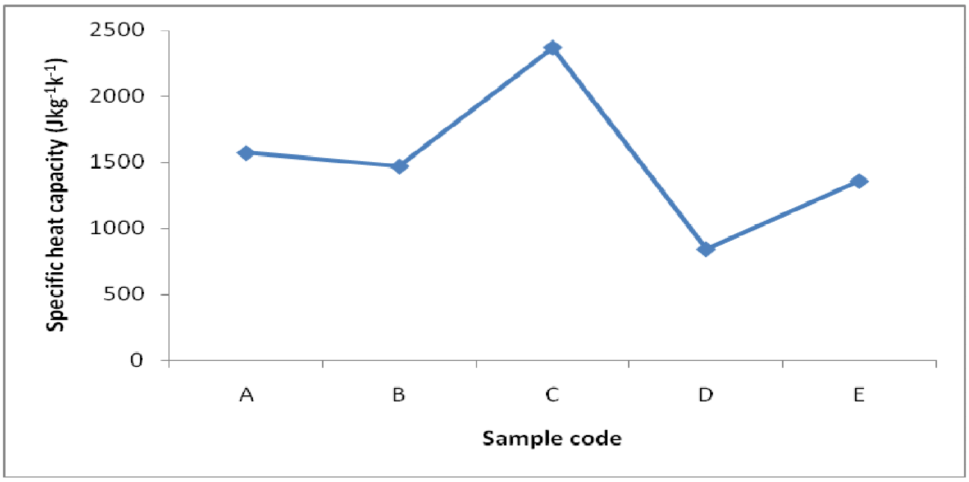

Fig. 1: A graph of specific heat capacity against sample codes

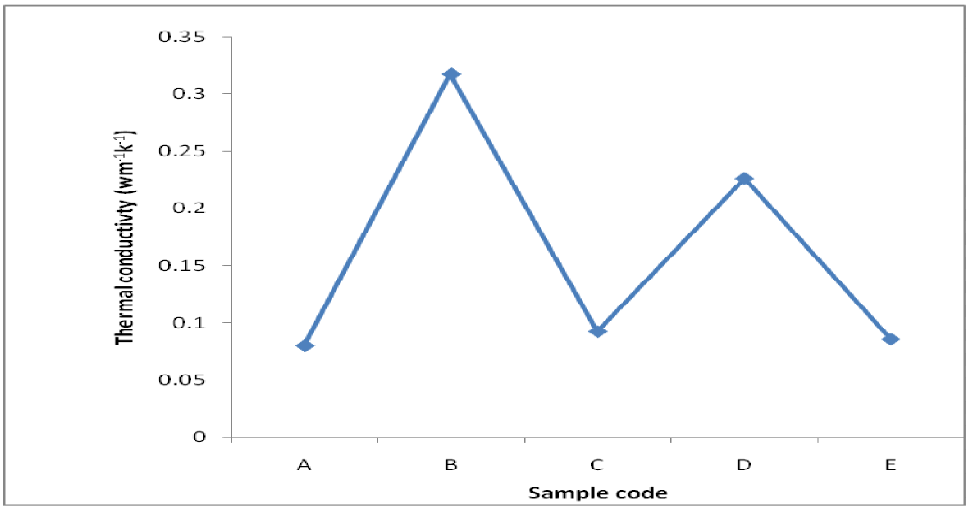

Fig. 2: A graph of Thermal conductivity against sample codes

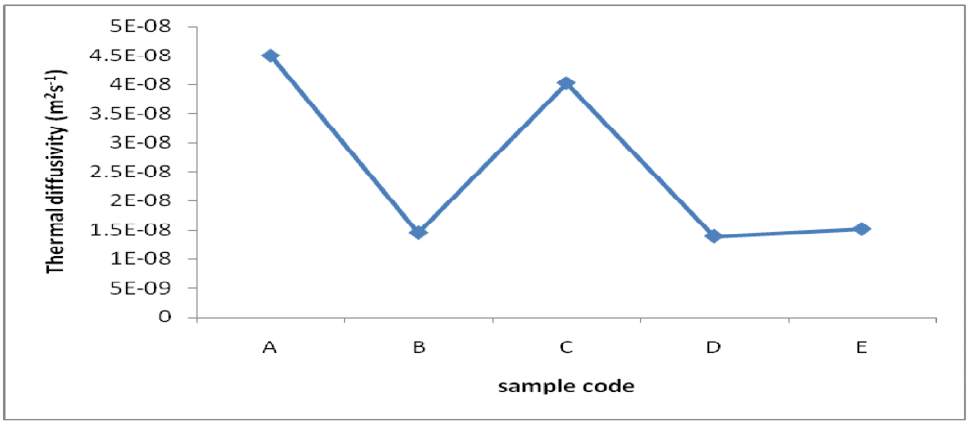

Fig. 3: A graph of Thermal diffusivity against sample codes

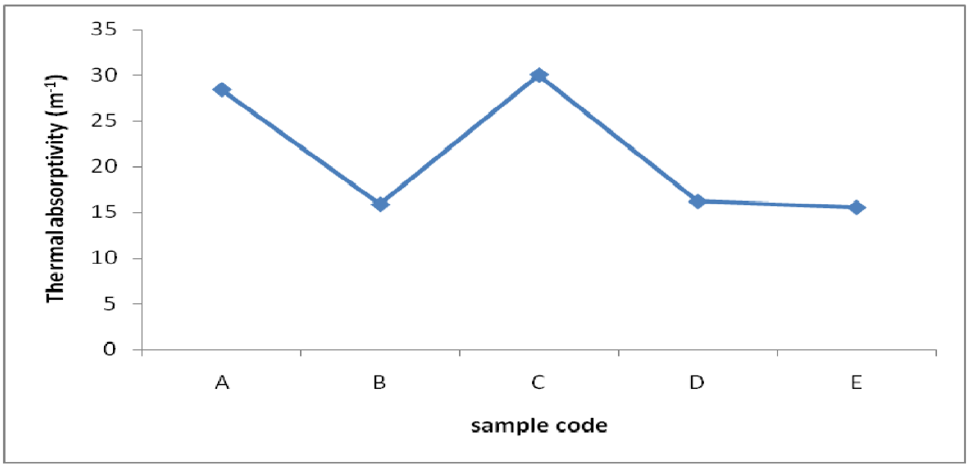

Fig. 4: A graph of Thermal absorptivity against sample codes

CONCLUSION

Generally, in terms of thermal conductivities, the samples show good compliance with standard values obtained in textbooks and the values recommended for heat-insulating materials. However, thermal absorptivity which is usually lower for best insulation indicates that samples B,D and E are recommended as ceiling materials that would have good thermal insulation efficiency when compared to sample A and C.

Although thermal resistivities are low in samples B and D recommended, thermal absorptivity which has to do with absorption and retention of heat plays the major role when it comes to insulation efficiency. Lower absorptivity in materials is a clear indication of lower molecular heat content of a material as it receives heat from the source. Hence from the molecular point of view, low thermal obsorptivity with higher or lower thermal diffusivity portrays good thermal insulation efficiency.

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