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# Investigation of the Thermal Insulation Properties of Selected Ceiling Materials used in Makurdi Metropolis (Benue State-Nigeria)

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***ABSTRACT:*** *In this research, the thermal insulation properties of three selected materials namely: Plaster of Paris (P.o.P), Plywood and Isorel (Masonite) used as ceiling boards in Makurdi, Benue state-Nigeria have been investigated. The selection of these insulation materials is based upon their predominant usage as padding materials in the tropical Makurdi metropolis. To achieve this, the steady-state method using Lee-Charton's apparatus was adopted to analyze the thermal conductivities of the chosen materials. The results obtained show that, P.o.P exhibits the best insulation property followed by Plywood then Isorel ceiling board with thermal conductivities of 0.1185w/mk, 0.1768w/mk and 0.4498w/mk respectively. Their corresponding thermal resistivities are 8.4388mk/w, 5.6561mk/w and 2.2232mk/w. From the results, P.o.P is recommended for its best insulation property. The research therefore provides a guide to intending builders and civil Engineers for selecting of housing insulation materials in Makurdi metropolis as well as other humid zones of tropical Africa.*

***KEYWORDS:*** *Thermal Insulation, P.o.P, Plywood, Isorel (Masonite), Lee-Charlton's method, Makurdi.*

**Preamble:** Makurdi metropolis is situated in the tropics of Nigeria on 7.74°N, 8.51°E and has an elevation 104m above the sea level. The city which is located on the banks of River Benue, a major tributary of the River Niger, has a land area of about 3,993.3 $Km^2$ [1] with a population of about 292,645 inhabitants [2]. As a result of her location, the city has an adversely high average annual temperatures of up to 35$^o$C within the year. This has left the inhabitants of the city with choices of various ceiling boards in search of a naturally aesthetic cool shelter. Between luxury and comfort, the elite class have been caught in the web of preference to some insulating materials such as, plywood, Isorel (Masonite) and plaster of Paris popularly known as P.o.P among other types. This work therefore investigates the thermal insulating behavior of these materials commonly used as ceiling pads in housing construction in Makurdi metropolis, Benue State.

## I. INTRODUCTION

Thermal insulators have been used in heat storage systems to prevent temperature gradient thereby minimizing heat losses to the surroundings [3]. In housing construction, insulators are used to prevent heat exchange across the boundaries of shelters. These insulating materials are usually made in various types, varieties and forms like loose fill, rigid boards, pipes and foam. Proper selection of insulating material is based on the thermal property which includes the thermal conductivity, specific heat capacity and thermal diffusivity [4]. The thermal insulation is provided by embedding insulation materials at least on the roof areas and the vertical walls of the system [5]. Poor thermal insulation in heat reservoirs and shelter systems leads to high heat losses or heat gains as the case may be [6].Plywood, Isorel (Masonite) and Plaster of Paris (P.o.P) ceiling boards are currently used as thermal insulation materials for the ceiling purpose in Benue State, Nigeria mainly due to availability in the market or their stunning appearance and not on their low thermal conductivity. However, some of these thermal insulators are not suitable ceiling materials to be used in Makurdi. This work therefore sets to determine among other things, the insulation material(s) that provides better solution as ceiling materials in terms of thermal conductivity or resistivity thereby provides a guide for civil Engineers and builders.

## II. THERMAL CONDUCTIVITY

The thermal conductivity (k) of a material is a measure of the effectiveness of the material in conducting heat [8]. Good heat insulators should have low thermal conductivities in order to reduce the total coefficient of heat transmission. The thermal conductivity of a material therefore represents the quantity of heat that passes through a meter thickness per square per second with one degree difference in temperature between the faces. In a steady state, that is, where the temperature at any point in the material is constant with time; thermal conductivity is the parameter which controls heat transfer by conduction [4]. The rate of heat flow, H is given by Fourier's law:

$$H = -kA\frac{\partial\theta}{\partial x} \qquad (1)$$

where k is the thermal conductivity, A is the area of the test piece normal to the heat flow and $\frac{\partial\theta}{\partial x}$ is the temperature gradient.

Thermal conductivity is regarded as the most important characteristic of a thermal insulation since it affects directly the resistance to transmission of heat that a material offers. The lower the thermal conductivity value, the lower the overall heat transfer. The thermal conductivity of insulating materials has been found to vary with density, moisture content, temperature, direction of heat flow with respect to grain for fibrous materials, the presence of defects in the material and porosity [8].

**Measurement of Thermal Conductivity of Insulators:** The methods of measurement of thermal conductivity can be divided into steady state methods and non-steady state methods. Steady state methods are widely used as they are mathematically simpler. For materials of low thermal conductivity, steady state methods can be very time consuming and involve expensive apparatus. Non-steady state methods have experimental advantages once the much more difficult mathematical treatment has been worked out. In non-steady state methods, heat transfer have the potential of directly determining thermal diffusivity, however they are not as accurate as steady state methods when applied to dry materials [9]. A steady state method is therefore preferred in analyzing the thermal conductivity of dry materials. The Lee-Charlton's method as a steady state method is therefore employed in this research.

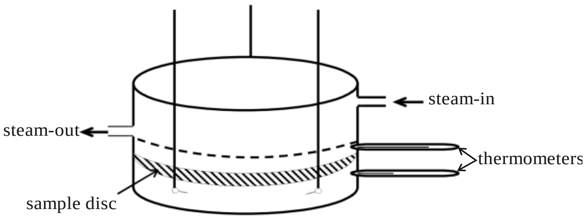


**Figure 1. Lee-Charlton's Disc for Measurement of Thermal Conductivity**

By measuring how fast the brass cools at the steady state temperature $T_1$, the rate of heat loss can be determined. If the disc cools down at a rate, $\frac{dT}{dt}$ then the rate of heat loss is given by

$$H = mc\frac{dT}{dt} \qquad (2)$$

where, m is mass of the brass disc, C is specific heat capacity of brass.

At steady state, heat conducted through the bad conductor (sample disc) per second will be equal to heat radiated per second from the exposed portion of the metallic disc.

$$kA\left[\frac{T_2-T_1}{x}\right] = mc\frac{dT}{dt} \qquad (3)$$

Therefore, k is defined as, $k = \frac{Mc\frac{dT}{dt}}{A\frac{(T_2-T_1)}{x}}$ (4)

where k is the coefficient of thermal conductivity of the sample, A is area of the sample in contact with the metallic disc, x is thickness of the sample, $T_2$ -$T_1$ is temperature difference across the sample thickness, m is mass of the metallic disc, C is heat capacity of the metallic disc and $\frac{dT}{dt}$ is rate of cooling of the metallic disc at $T_1$.

Thermal diffusivity, $\delta$ and resistivity, $r$ are calculated using equation (5) and (6)

$$\delta = \frac{k}{cp} \qquad (5)$$

$$r = \frac{1}{k} \qquad (6)$$

where $\delta$ is thermal diffusivity, k is thermal conductivity, $r$ is thermal resistivity, $cp$ is volumetric heat capacity expressed as: $cp$ = Specific heat capacity x density (*i.e* $cp = C \times \rho$) (7)

## III. MATERIAL AND METHODS

**Materials :** Circular discs of the three predominantly used insulating materials in Makurdi: Plaster of Paris (P.o.P), Plywood and Isorel (Masonite), vernier caliper, micrometer screw gauge, mass balance, retort stands, heat source, steam boiler, water, Mercury in glass thermometers, stop watch and Lee-Charlton's apparatus.

**Table 1. Material Specification**

| Materials | Thickness (m) | Mass (Kg) | Specific heat capacity (J/kgk) | Diameter (m) | Mean surface Area ($m^2$) |
|---|---|---|---|---|---|
| Plywood | 0.003 | 0.0168 | 2500 | 0.11 | 0.0095 |
| P.o.P | 0.003 | 0.0250 | 1090 | 0.11 | 0.0095 |
| Isorel(Masonite) | 0.003 | 0.0256 | 2100 | 0.11 | 0.0095 |

**Method:** Sample Plywood and Cardboard were obtained from building material shops at modern market Makurdi, Benue State while P.o.P board was obtained from the building site along International Market Road Makurdi. The samples were shaped to have equal cross-sectional areas. Using mass balance, micrometer screw gauge and vernier caliper, the mass (kg), height (m) and diameter (m) respectively of the samples were obtained and related parameters calculated and presented in table 1. The setup was then arranged as shown in appendix A3.The steam boiler was filled with water to nearly half and heated to produce steam that causes the rise in temperature of the brass disc and sample specimen until steady temperatures $T_1$ and $T_2$ were obtained after a certain time interval.The specimen was then removed and the brass disc heated directly by the steam chamber till its temperature was slightly above $T_1$. The steam chamber was then removed and sample specimen placed on the brass disc. The initial temperature was noted and cooling temperature drop recorded continually in intervals of one minute till there was no observable change in temperature. The result was tabulated as shown in table 2. From the temp.-time plot (fig. 2), cooling rates were determined from the slopes then thermal properties computed.

## IV. TESTS AND ANALYSIS OF RESULTS

**Table 2. Cooling Rate of the Selected Insulation Materials**

**Ambient Temperature = 31°C**

| Time | Temperature Variation (°C) | | |
|---|---|---|---|
| x 60 (s) | P.o.P | Plywood | Isorel |
| 0 | 88 | 94 | 94 |
| 1 | 83 | 90 | 91 |
| 2 | 80 | 87 | 88 |
| 3 | 77 | 84 | 86 |
| 4 | 75 | 82 | 84 |
| 5 | 73 | 79 | 82 |
| 6 | 71 | 77 | 80 |
| 7 | 69 | 76 | 78 |
| 8 | 68 | 74 | 77 |
| 9 | 66 | 73 | 75 |
| 10 | 65 | 71 | 74 |

Using equation (4), $k = (Mc\ dT/dt)/[A\ (T_2 - T_1)/X]$and fig. 1, the thermal conductivity of each of the selected material was calculated and presented in table table 3.0.

**Table 3. Thermal Properties of the Selected Ceiling Boards**

| Sample | Density ($kg/m^3$ ) | Thermal Conductivity (k) (w/mk) | Thermal Diffusivity($\delta$) ($m^2/s$)$\times$ $10^{-7}$ | Thermal Resistivity (r) (mk/w) |
|---|---|---|---|---|
| Isorel | 898.25 | 0.4498 | 2.3845 | 2.2232 |
| P.o.P | 876.55 | 0.1185 | 1.2403 | 8.4388 |
| Plywood | 589.47 | 0.1768 | 1.1997 | 5.6561 |

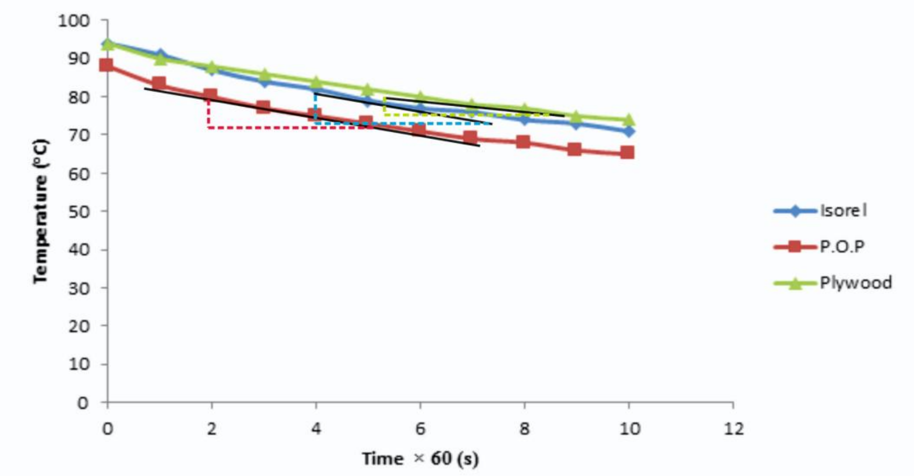


Figure 1. The Cooling Curve for the Three Selected Materials

## V. DISCUSSION OF RESULTS

Table 1 is the material specification of the selected materials showing the thickness, area, mass and specific heat capacity of the chosen samples. Since thermal conductivity is a function of thickness and area, the specimens were carefully prepared with equal thicknesses and cross-sectional areas. Table 2 and Fig. 1 show the cooling rates of the selected materials at ambient temperature of $31^oC$. The results show that within the prevailing tests, P.o.P exhibits the best cooling rate followed by plywood then isorel (Masonite). The cooling curves of the three sampled materials taken at every one minute show that both materials have a similar cooling pattern. Table 3 presents the calculated thermal parameters such as thermal conductivity, k; thermal diffusivity, $\delta$ and thermal resistivity, *r* for the three selected materials. The results show that, all the materials are good insulating materials since their thermal conductivities fall within the conductivities of construction and heat-insulating materials given by [10], as 0.023 - 2.9$Wm^{-1}$ $k^{-1}$.

Isorel popularly called Masonite Ceiling has a thermal conductivity of 0.4498$Wm^{-1}$ $k^{-1}$, Thermal diffusivity of 2.3845 $\times$ $10^{-7}$ $m^2/s$ and thermal resistivity of 2.2232mk/W. P.o.P has a thermal conductivity of 0.1185$Wm^{-1}$ $k^{-1}$, Thermal diffusivity of 1.2403 $\times$ $10^{-7}$ $m^2/s$ and thermal resistivity of 8.4388mk/W while Plywood has a thermal conductivity of 0.1768$Wm^{-1}$ $k^{-1}$, Thermal diffusivity of 1.1997 $\times$ $10^{-7}$ $m^2/s$ with thermal resistivity of 5.6561mk/W. theoretically, a substance with a large thermal conductivity value is a good conductor of heat; one with a small thermal conductivity value is a poor heat conductor, that is a good insulator. In order words a good insulation material will have high resistivity-value for thickness other than 1m.Thermal diffusivity measures the ability of a material to transmit a thermal disturbance. It indicates how quickly a material's temperature will change. Thermal diffusivity therefore increases with the ability of a body to conduct heat and decreases with the amount of heat needed to change the temperature of a body. It is of little interest in many thermal insulation systems since in these, approximately steady state conditions normally exist.

## VI. CONCLUSION

From the results in Table 3, we have observed that among the materials studied, P.o.P provides the best thermal insulation since it has the lowest thermal conductivity (highest thermal resistivity) followed by Plywood then Isorel (Masonite) ceiling board. From the result of the research, the best insulation material to be used in the tropical city like Makurdi is P.o.P. However, from the economic point of view, it is commendable to choose an insulating material with a lower thermal conductivity and more affordability to average number of inhabitants when considering housing construction in a densely populated city like Makurdi. Hence Plywood is recommended for the lower or middle class who cannot cope with the exorbitant cost of P.o.P since it is less expensive and offers better insulation property than Isorel (Masonite).

## REFERENCES


[1] Ityavyar J.A, Inah E.I and Akosim, C- Assessment of Captive Management of Nile Crocodile, *Crocodylus niloticus*, in Three Towns of Benue State, Nigeria in *Journal of Research in Forestry, Wildlife And Environment*. Volume 3 No. 2 September, 2011.

[2] GeoNames geographical database, 18th, January 2012.

[3] Turner W.C and Malloy J. F, "Thermal Insulation Handbook'', Published by McGray-Hill Book Company New York 1988.

[4] Ayugi G, "Thermal properties of selected Materials for Thermal Insulation available in Uganda" B.Sc thesis Dept. of Physics Makerere University. 2009

[5] Novo A. V, Bayon J.R, Castro-Fresno D and Rodriguez-Hernandez J. ' Review of Seasonal heat Storage in Large Basin: Water Tanks and Gravel Water Pits. Applied Energy, 87: 390, 397. 2010

[6] Bauer D, Marx R, Nulbicker-Lux J, Ochs F, Heidemann W and Muller- Steinhagen H, "German Central Solar Heating Plants with Seasonal heat Storage, Solar Energy 84:612, 623. 2010

[7] Mohammad Al-Homoud S, "Performance characteristics and Practical application of Common Building Thermal Insulation Materials. Building and Environment, 40: 353, 366. 2005

[8] Rajput. Engineering thermodynamics, New Delhi: Lax Mi Publications, 2005.

[9] Mohesemin N, M, "Thermal Properties of food and Agricultural Materials. Gordon and Breach Science Publishers, New York. 1980.

[10] Mahhrer Y, "Journal of Soil Science, 134 (6), 381-387, 1982

[11] The World Gazetteer". Archived from the original on 2013-02-09


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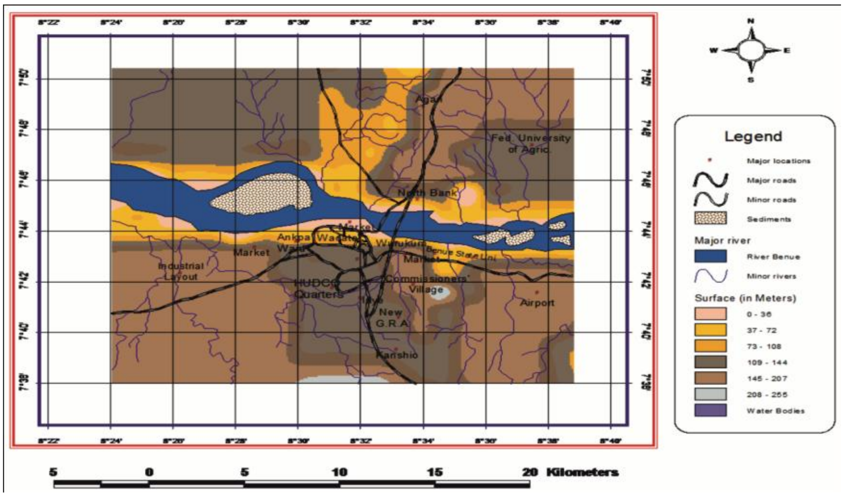
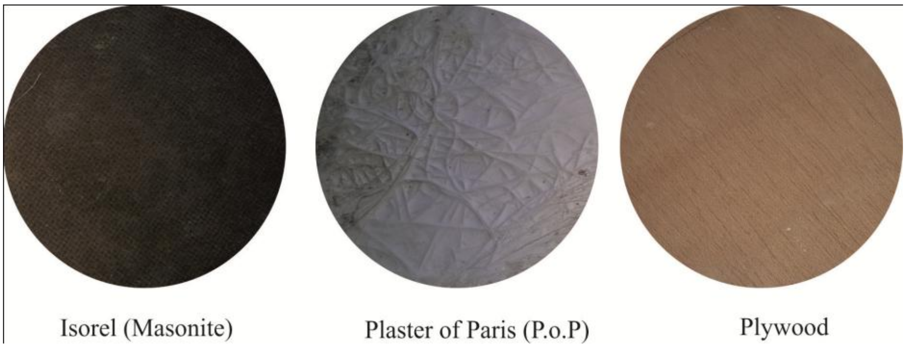
**APPENDIX**




**A1: Map of Benue State Showing the Study Area**




**A2: Test Specimens Showing the Selected Insulating Materials**

**A3: Experimental Set-up of Lee-Charton's Method in Determination of Thermal Conductivity**