Published by Nigerian Society of Physical Sciences. **Hosted by** FLAYOO Publishing House LTD

Check for updates

Proceedings of the Nigerian Society of Physical Sciences

Journal Homepage: https://flayoophl.com/journals/index.php/pnspsc

Thermal properties of some selected materials used as ceilings in building

Godwin B. Egbeyale*, Adegbenro S. Ajani, Tomisin M. Oyatomi

Department of Physics and Materials Science, Kwara State University, Malete, Nigeria

ABSTRACT

Thermal properties of materials are a crucial area of interest in the building industry. This study investigated the thermal properties of Polyvinyl Chloride (PVC), Plaster of Paris (POP), asbestos, and cardboard, commonly used as ceiling materials. The steady-state method was employed to determine the thermal properties; thermal conductivity, thermal resistivity, thermal diffusivity, thermal absorptivity, and density). The obtained results of thermal conductivity of PVC, POP, and Asbestos cardboard are 0.1083 W/mK, 0.1314 W/mK, 0.1068 W/mK and 0.0851 W/mK, respectively, and are within range of values 0.0851-0.1314 W/mK The thermal resistivity of the cardboard, POP, Asbestos and PVC are 11.7509 $(W/mK)^{-1}$, 7.6103 $(W/mK)^{-1}$, 9.3633 $(W/mK)^{-1}$ and 9.2336 $(W/mK)^{-1}$, respectively. The results of thermal diffusivity of PVC, Asbestos, POP, and cardboard are 6.34×10^{-7} m^2/s, 6.0×10^{-8} m^2/s, 1.20×10^{-7} m^2/s, and 8.0×10^{-8} m^2/s, respectively. The results of thermal absorptivity of cardboard, PVC, POP, and Asbestos are $21.31 \text{ x} 10^{-2}$ m^{-1}, 7.57×10^{-2} m^{-1}, 17.40×10^{-2} m^{-1}, and 15.07×10^{-2} m^{-1}, respectively. The density results of POP, PVC, Asbestos, and cardboard are 79.84 kg/m^3, 203.59 kg/m^3, 824.13 kg/m^3, and 645.81 kg/m^3 respectively. The results revealed some materials' thermal properties to understand their behavior as they interact with heat fluctuation. In comparison, the results revealed that PVC and asbestos are better materials for building insulation since they have good thermal efficiency.

Keywords: Density, Thermal efficiency, Thermal absorptivity, Temperature.

DOI:10.61298/pnspsc.2024.1.109

1. INTRODUCTION

Ceiling materials are overhead interior surfaces that can cover the upper limits of the room. They are not generally considered structural elements but finished surfaces concealing the underside of the room structure or the floor of the store above. In tropical areas, the use of zinc-made roofs without ceilings is very common, thus there is intense heat transfer to the internal environment, which may cause thermal discomfort to the inhabitants [1]. One way to reduce thermal discomfort is by the use of a radiant barrier (i.e. ceiling board) which reduces the heat flux.

However, the knowledge of the thermal properties of different materials is very important in the choice of the types of materials to be used as a radiant barrier since the heat flow through any building depends on the thermal properties of the materials use in the building [1, 2]. The study of the thermal properties of materials will help to know whether materials are suitable for use as ceiling materials in our houses, schools, and industries or not.

Heat propagated in the interior spaces in buildings through roofs and walls and partly through ceiling panels by the process

*Corresponding Author Tel. No.: +234-805-3023-851.
e-mail: godwinegbeyale@gmail.com (Godwin B. Egbeyale)

of conduction and radiation [3–6]. This is because the common materials used as roofing sheets are materials like zinc and aluminum which have high thermal conductivity [7].

To reduce the intensity of this heat, there is a need to use materials of tolerable thermal responses as ceiling materials in buildings. Good insulating materials will have a high value of thermal resistivity. This implies that different types of ceiling materials will have different thermal behaviors.

An insulator is a material used to inhibit or prevent the conduction of heat or electricity [8–10]. Proper selection of insulating materials is based on their thermal properties which include: thermal conductivity, thermal absorptivity, thermal diffusivity, and specific heat capacity [9–11]. The primary functions of insulators in buildings are: To conserve energy, reduce heat loss or heat gain, maintain a temperature condition, maintain the effective operation of equipment or chemical reaction, assist in maintaining the product at a constant temperature, prevent condensation, create comfortable environmental condition and protect personnel. Insulation reduces heat transfer through the envelope in the building. Whenever there is a temperature difference, heat flows naturally from a warmer space to a cooler space. To maintain comfort in the harmattan (the coldest season of the year), the heat lost must be replaced by the heating system; and in summer (the warmest season of the year), the heat gained must be removed by the cooling system. Therefore, it makes sense to study the thermal properties of insulators to reduce gains or loss of energy in buildings and to increase comfortable conditions in houses, schools, and industries.

Novo justified that, thermal insulation is provided by embedding insulation materials at least on the roof areas and the vertical walls of the systems. Insulating materials are usually made in various types with different designs which leads them to categorize into good and bad insulators on their properties [12].

In this work, emphasis is laid on the study and comparison of the thermal properties of some selected materials which include PVC (Polyvinylchloride), POP (plaster of Paris), asbestos, and cardboard used as ceilings in buildings. Depending on how large or small the value of their thermal properties, particular ceiling materials may be more efficient in terms of thermal insulation than another [5].

2. MATERIALS AND METHODS

The steady-state method was employed in carrying out this research. A detailed description of the materials and their functions is presented as well as step by step description of methods for the research. In this work samples such as PVC, POP, cardboard, and Asbestos were collected from different building stores. They were then prepared to suit the purpose of the experiment. The composite samples have been prepared by using the hand-lay-up technique to measure the thermal conductivity (using Lee's apparatus). Figure 1 is the description of the sample shape with a dimension of 110mm diameter and thickness of 5mm.

2.1. PROCEDURE

The samples were labeled and shaped to take the dimensions of Lee's disc apparatus. The diameter of each sample was measured using a Vernier caliper and the thickness was measured using a micrometer screw gauge. The mass of each sample was measured using a weighing balance. The density was found by making use of the mass per unit volume of each sample. The drilled metal discs i.e. A, B, and C heater discs and sample discs of Lee's disc apparatus were assembled, and the fan and windows of the laboratory were completely closed to avoid excess loss of heat. The two thermometers were inserted into the two drilled metal discs on either side of the sample disc, and the spaces around the thermometer bulbs were filled with oil to maximize the thermal contact. The heater disc was connected to a low voltage power supply where the voltage was adjusted until a steady state was reached. The temperature readings were taken by using two thermometers respectively, the rate of loss of heat of the end disc C was found by heating up to 10 ^{0}C above the steady state of these temperatures below. For cardboard, we have $\theta_1 = 98$ °C and $\theta_2 = 68$ °C, Asbestos, $\theta_1 = 104$ °C and $\theta_2 = 68$ °C, POP, $\theta_1 = 124$ °C and $\theta_2 = 71$ °C and for PVC, $\theta_1 = 80$ °C and $\theta_2 = 43$ °C, the temperature θ_2 were recorded earlier for each sample. The thermal conductivity K, density ρ, thermal diffusivity λ, and resistivity, were measured for each sample using the equations (1)-(6).

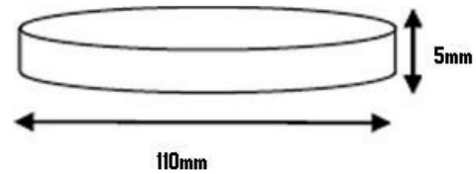

Figure 1. Dimension of specimen.

$$H = \frac{kA(\theta_2 - \theta_1)}{x} = mc\frac{d\theta}{dx}. \quad (1)$$

Thus,

$$k = \frac{mcx}{A(\theta_1 - \theta_2)}\frac{d\theta}{dx}, \quad (2)$$

where H is the rate of heat flow, m is the mass of the disc, c is the specific heat capacity of metal disc, x is the thickness of the sample materials, A is the cross-sectional area of the sample, $\theta_1 - \theta_2$ is the difference in the steady-state temperature and $\frac{d\theta}{dx}$ is the gradient from the cooling curve.

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

$$\rho = \frac{m}{x}, \quad (4)$$

$$\lambda = \frac{k}{\rho c}, \quad (5)$$

$$\alpha = \sqrt{\frac{\omega}{2\lambda}}, \quad (6)$$

where m is the mass of the sample under dry conditions (g), v is the volume of the sample under absolute compact conditions in cm^3, $\omega = 2\lambda/T$, and T is the period.

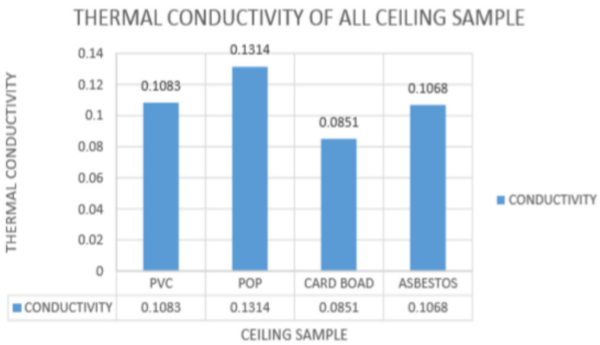

Figure 2. Comparison of thermal conductivity.

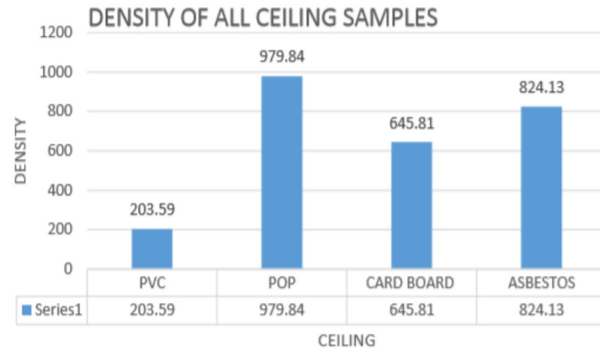

Figure 3. Density comparison of all ceiling samples.

3. RESULTS AND DISCUSSION

In this section, the results obtained from the experiments are presented and discussed in detailed. Since the investigation was done for different samples, the results are compared to find the best ceiling material for building insulation purposes.

3.1. SAMPLE MASS AND DIMENSIONS

The mass of each sample was measured with a weighing balance and their dimensions also measured with the aid of micrometer screw gauge and the vernier calipers. The results are presented in Table 1. The results presented in the above table are useful in the deduction of other relevant parameters needed in this research work. For each sample at room temperature, (34 °C), the temperature variation with corresponding time interval is taken and the results are presented below.

3.2. RATE OF HEAT LOST

A graph of temperature θ, was plotted against time and the slope was obtained which represents the rate of heat loss. The results presented above indicate that asbestos has the lowest rate of heat loss while POP has the highest rate of heat loss. The results of Tables 1 and 2 are used to obtain the thermal conductivity of each sample which are presented in the next section.

3.3. THERMAL CONDUCTIVITY

The thermal conductivity of these samples was computed from the results of the mass presented in Table 1 and the rate of heat loss presented in Table 2. Equation (2) was invoked for this computation and the thermal conductivity of each sample is presented below in Table 2.

From Table 2, the results of thermal conductivity of all ceiling sample materials showed that, the POP ceiling has highest value of 0.1314 W/mK, while the card board has the least value of 0.0851 W/mK, where the PVC (0.1083 W/mK) and asbestos (0.1068 W/mK) fall in between them.

The thermal conductivity of all ceiling sample materials of this research corresponded to the results of previous researchers, which were showed that, all the materials sampled in this research are good insulating materials since their thermal conductivities fall within the range heat-insulating materials (0.0023 - 2.9 W/mK) [13].

3.4. THERMAL RESISTIVITY

The results obtained from the successful calculated thermal resistivity of all ceiling samples were showed in Table 3.

From Table 3, the result of thermal resistivity of all ceiling sample showed that, the thermal resistivity of cardboard ceiling has the highest value of 11.7509 mK/W, while POP has the least value of 7.6103 mk/W, the asbestos value (9.3633 mK/W) and PVC value (9.2336 mK/W) fall in between them. Thermal resistivity which was regarded as the reciprocal of thermal conductivity of ceiling material is very important in this research because its lead to classification of the ceiling insulating materials based on their thermal efficiency. A good insulation material will have high resistivity-value for thickness other than 1m [9–14].

3.5. DENSITY

The result from the successful calculated density of each ceiling material were shown in Table 4. From the table, the result showed that POP has the highest density value of 9709.84 kg/m^3 while the PVC has the least density value of 203.59 kg/m^3, where the asbestos (824.13 kg/m^3) and the card board (645.81 kg/m^3) densities value fall in between them. The density of a ceiling material which was regarded as the dry mass per unit volume of a ceiling material under the absolute compact condition in cm^3 is very important in this research because it aids to calculate the result of another thermal parameter (i.e., thermal diffusivity) such that we can be able to classify these ceiling materials based on thermal efficiency.

3.6. THERMAL DIFFUSIVITY

The result obtained from the successful calculated thermal diffusivity of all ceiling sample materials were showed in the Table 5, also the comparison of these thermal parameter is shown in Figure 4.

From Table 5 the result showed that, the thermal diffusivity of PVC has the highest value of 6.34×10^{-7} m$^2/s$ while asbestos has the least value of 0.60×10^{-7} m$^2/s$, where POP with the value of 1.20×10^{-7} m$^2/s$ and card board with value of 0.80×10^{-7} m$^2/s$ fall in between them. Thermal diffusivity measures the ability of a material to transmit a thermal disturbance; it indicates how quickly a materials 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 [9–16]. Hence the

Table 1. Sample, mass and dimensions.

Sample	Mass (kg)	Thickness (m) ($\times 10^{-3}$)	Diameter (m)
PVC	0.0020211 ± 0.0000001	6.9 ± 0.01	0.0428 ±0.0001
POP	0.0125786 ± 0.0000001	9.4 ± 0.01	0.0416 ±0.0001
Cardboard	0.0029558 ± 0.0000001	3.4 ± 0.01	0.0414 ±0.0001
Asbestos	0.0081264 ± 0.0000001	7.1 ± 0.01	0.0422 ±0.0001

Table 2. Thermal conductivity of selected ceiling materials.

Sample type	Thermal conductivity k (W/mK)
PVC	0.108±0.001
POP	0.131±0.001
Cardboard	0.085±0.002
Asbestos	0.106±0.001

Table 3. Thermal resistivity of selected ceiling materials.

Sample type	Thermal resistivity (mK/W)
PVC	0.9.2±0.1
POP	7.6±0.1
Cardboard	11.7±0.1
Asbestos	9.3±0.1

Table 4. Density of selected ceiling materials.

Sample type	Density ρ (kg/m^3)
PVC	203.509 ± 0.001
POP	979.804 ± 0.001
Cardboard	645.810 ± 0.002
Asbestos	824.130 ± 0.001

Table 5. Density of selected ceiling materials.

Sample type	Thermal diffusivity λ (m^2/s)
PVC	$6.34\times10^{-7} \pm 1.00\times10^{-2}$
POP	$1.20\times10^{-7} \pm 1.00\times10^{-2}$
Cardboard	$0.80\times10^{-7} \pm 2.00\times10^{-2}$
Asbestos	$0.60\times10^{-7} \pm 1.00\times10^{-2}$

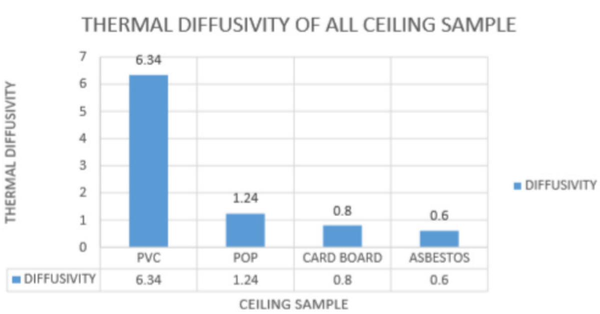

Figure 4. Comparison of thermal diffusivity.

thermal diffusivity parameter is very vital and important in this research because it enable us to calculate the thermal absorptivity and to give us opportunity classify these ceiling insulators materials base on thermal efficiency.

Table 6. Thermal absorptivity of selected ceiling materials.

Sample type	Thermal absorptivity α (m^{-1}) ($\times 10^{-2}$)
PVC	7.573 ± 2.00
POP	17.407 ± 2.00
Cardboard	21.319 ± 2.80
Asbestos	15.070 ±1.60

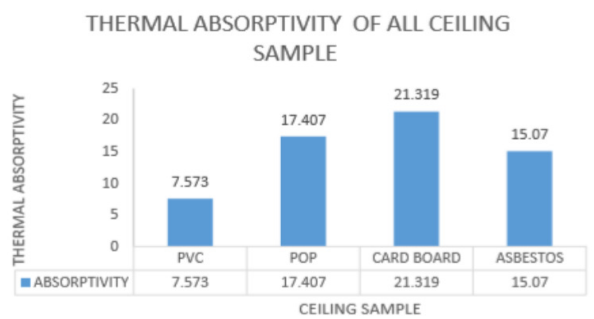

Figure 5. Comparison of thermal absorptivity.

Table 7. Specific heat capacity of the materials.

Sample type	Specific heat capacity (J/kg K)
PVC	841
Asbestos	816
Cardboard (wood)	1300-2400
POP	1090

3.7. THERMAL ABSORPTIVITY

The results obtained from the successful calculated thermal absorptivity of all ceiling sample were showed in Table 6. Also the comparison of these thermal parameters is shown in Figure 5.

From Table 6, the results showed that the card board ceiling has the highest thermal absorptivity of 21.319 m^{-1} while PVC has the least thermal absorptivity of 7.573 m^{-1}, where the POP (17.407 m^{-1}) and asbestos (15.070 m^{-1}) fall in between them. Thermal absorptivity according to Ref. [5] falls between these values.

3.8. SPECIFIC HEAT CAPACITY

The Table 7 shows the constant specific heat capacity of some materials that were used in this research. In general, by considering the absorptivity thermal parameter we can says that, the PVC and asbestos have the lower absorptivity values and then followed by POP, where the card board has the highest value of thermal absorptivity.

According to Ref. [5], the classification of good ceiling insulating materials can be based on the thermal absorptivity. Therefore, by considering the two thermal parameters in this work,

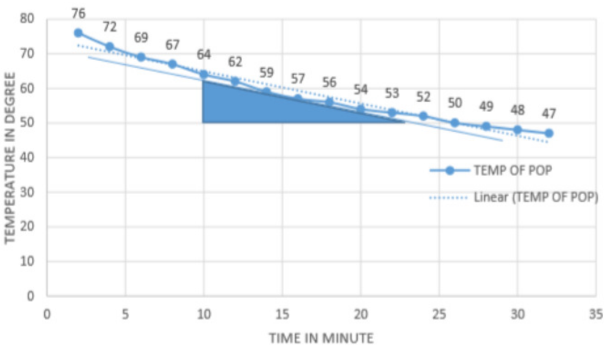

Figure 6. Graph of temperature against time for POP ceiling material.

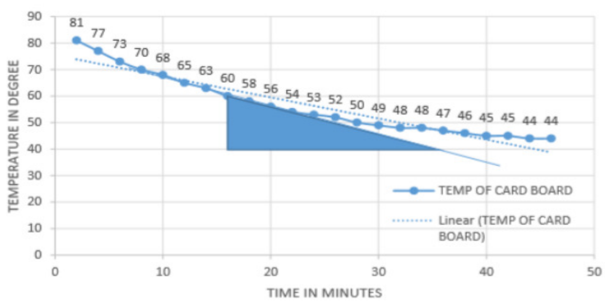

Figure 7. Graph of temperature against time for card board.

the lower the thermal absorptivity value irrespective of lower or higher of thermal diffusivity portray a good thermal insulation efficiency of ceiling materials in building. Figures 6 and 7 revealed the thermal diffusivity of each material to the amount of heat received.

4. CONCLUSION

The thermal conductivity of four ceiling samples under this investigation ranged from (0.0851–0.1314 W/mK). The results revealed that the thermal property of some materials is a means of understanding behaviour of the materials as they interact with heat fluctuation. The results obtained corresponded to the results of previous researchers, which showed that all the materials sampled in this research are good insulating materials since their thermal conductivity falls within the range (0.023-2.9 W/mK), according to [16, 17]. If ceiling materials are classified based on good or best thermal efficiency in the building, then PVC and asbestos are the best ceiling insulating materials, with high thermal efficiency followed by POP, while cardboard remained the least. We have seen in this research that (i) the beauty of material should not be the choice for choosing ceiling material and (ii) thermal properties play a role in the building industry.

ACKNOWLEDGMENT

I would like to thank some of our technologists in the Department of Physics and Materials, the Faculty of Pure and Applied Science, and the Central Laboratory, for their efforts in making this work a success.

References

[1] S. E. Etuk, L. E. Akpabio & K. E. Akpabio, "Determination of thermal properties of Cocos Nucifera trunk for predicting temperature variation with its thickness", The Arabian Journal for Science and Engineering **30** (2017) 121. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=5e932a85cc07ea12bb5ffd01a907bdfa56117d87.

[2] I. Ugur & S. Demirdag, "Investigation of the Relation between the Specific Heat Capacity and Material Properties of Some Natural Building and Facing Stones", International Journal of Rock Mechanics & Mining Sciences **43** (2006) 831. https://doi.org/10.1016/j.ijrmms.2005.12.003.

[3] S. K. Alausa, O. O. Oyesiku, J. O. Aderibigbe & O.S. Akinola, "Thermal properties of calamus deërratus, raphia hookeri and synthetic board in building design in South Western Nigeria", African Journal of Plant Science **5** (2011) 281. https://doi.org/10.5897/AJPS.9000252.

[4] C. Michels, R. Lamberts & S. Guths, "Theoretical/Experimental Comparison of Heat Flux Reduction in Roofs Achieved through the Use of Reflective Thermal Insulators,"Energy and Buildings **40** (2008) 438. https://doi.org/10.1016/j.enbuild.2007.03.012.

[5] N. J. George, V. I. Obianwu, G. T. Akpabio & I. B. Obot, "Comparison of thermal Insulation efficiency of some select materials used as ceiling in building design", Archives of Applied Science Research **2** (2010) 253. http://scholarsresearchlibrary.com/archive.html.

[6] M. Alam, S. Rahman, A. Halder, P. K. Raquib, & M. Hasan "Lee's and charlton'smethod For investigation of thermal conductivity of insulating materials", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) **3** (2012) 53. https://api.semanticscholar.org/CorpusID:11708317.

[7] M. C. Onyeaju, E. O. Arolube, E. E. Chukwuocha, C. E. Ekuma & G. J. Omasheye, "Comparison of the thermal properties of asbestos and Polyvinylchloride Ceiling Sheets", materials Sciences and applications **3** (2012) 240. http://dx.doi.org/10.4236/msa.2012.34035.

[8] R. A. Serway & J. S. Faugn, *College physics*, 2nd edition, Saunders College Publishing, 1989, pp. 277. https://www.amazon.com/College-Physics-Revised-Raymond-Hardcover/dp/B010WFDW9S.

[9] G. F. Newton, A. A. Roy & A. I. Solomon, "Investigation of thermal insulation properties of selected ceiling materials used in Makurdi Metropolis (Benue State, Nigeria)", American Journal of Engineering research (AJER) **1** (2014) 245. https://api.semanticscholar.org/CorpusID:53318041.

[10] R. C. Mohapatra, A. Mishra & B. B. Choudhury. "Experimental study on thermal conductivity of teak wood dust reinforced Epoxy composite using lee's apparatus method", International journal of Mechanical Engineering applications **2** (2014) 98. https://doi.org/10.11648/j.ijmea.20140206.13.

[11] G. B. Egbeyale & J. A. Adegoke, "Influence of heavy metals on thermal conductivity of clay as a building material", Egyptian Journal of Basic and Applied Sciences **6** (2019) 1 https://doi.org/10.1080/2314808X.2019.1670426.

[12] A. V. Novo, J. R. Bayon, D. C.Fresno & H. J. Rodriguez, "Review of seasonal heat storage in large basin: water tanks and gravel water", Pits Applied Energy **87** (2010) 390. https://doi.org/10.1016/j.apenergy.2009.06.033.

[13] E. B. Ettah, J. G. Egbe, S. A. Takim, U. P. Akpan & B. Everest, "Investigation of the thermal conductivity of polyvinyl chloride ceiling material produced in Calabar for application tropical climate zones", Journal of Polymer and Textile Engineering (IOSR-JPTE) **3** (2016) 34. http://iosrjournals.org/iosr-jpte/papers/Vol3-issue2/E03023438.pdf.

[14] A. A. Mohammed, V. V. S. Kesava Rao & S. R. pal singh, "Determination of thermal conductivity of plaster of Paris", International EJournals **52** (2010) 528. https://www.scribd.com/document/477596757/iejmae-52-pdf.

[15] S. X. Xu, Y. Li & Y. P. Feng, "Study of temperature profile and specific heat capacity in temperature modulated dsc with a low sample heat diffusivity", Thermochimica Acta **360** (2000) 131. https://doi.org/10.1016/S0040-6031(00)00564-5.

[16] S. Zhu, C. Li, C. H. Su, B. Lin, H. Ban, R. N. Scripa & S. L. Lehoczky, "Thermal diffusivity, thermal conductivity, and specific heat capacity measurements of molten tellurium", Journal of Crystal Growth **250** (2003) 269. https://doi.org/10.1016/S0022-0248(02)02250-9.

[17] Y. Zhang , K. Lin , Q. Zhang & H. Di, "Ideal thermo-physical properties for free-cooling (or heating) buildings with constant thermal physical property material", Energy and Buildings **38** (2006) 1164. https://doi.org/10.1016/j.enbuild.2006.01.008.