Investigation of Thermal Properties of Plantain (Musa paradisiaca) and Mfang Aya (Thaumatococcus daniellii) as Thermal Radiation Insulator

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Abstract
Thermal properties of Plantain (*Musa paradisiaca) and Mfang Aya (Thaumatococcus daniellii))* were determined using the steady state method. In this study the mean thermal conductivity of *Musa paradisiaca* was found to be 0.0374 $Wm^{-1}K^{-1}$ with a mean bulk density of 200.0 kg/m^3 while *Thaumatococcus daniellii* shows a mean thermal conductivity of 0.0427$Wm^{-1}K^{-1}$with a mean bulk density of 287.0 kgm^{-3}. The mean specific heat capacity of *Musa paradisiaca* was obtained as 2606.5 $Jkg^{-1}K^{-1}$ for density range of 0.146-0.237kg/m^3 while mean specific heat capacity of *Thaumatococcus daniellii* is 1041.9 $Jkg^{-1}K^{-1}$for density 0.211-0.365kg/m^3 and the heat transfer models for the material are also obtained. The thermal properties values obtained show similarities with other local materials which previously have been observed to be good thermal insulators, hence *Musa paradisiaca and Thaumatococcus daniellii* are encouraged to be seen as potential thermal insulators.
Keywords: Thermal properties , *Musa Paradisiaca*, *Thaumatococcus daniellii*, Thermal conductivity, specific heat capacity and bulk density.

1.0 Introduction
Radiation transport energy from one place to another usually through material medium or vacuum. This radiation could be heat, solar, ionizing and transported through solids (conduction), fluids (convection) and vacuum (radiation). Excess of this radiation exposed on human body have deleterious effect on it, which include skin cancers, opacity, etc, therefore there is need to protect the body and even the environment against excessive radiation exposure.

The high cost of building materials in recent time is a thing of concern for those who seek affordable and comfortable accommodation. Therefore there is need to source for an alternative building materials that is less expensive and could be sourced locally. One of the building materials that caught the attention of home seekers is an alternative material for naturally cooling of building especially during hot seasons to replace the mechanical air conditioning system. This is necessary because the zinc used in the roofing of houses is made from aluminum which conductor of heat. Therefore attention is now turned to local materials that could be used as thermal insulators and many researchers have evaluated the thermal properties of different local materials in order to ascertain their suitability as potential thermal insulators and cooling agents.

The thermal properties of materials that determine their suitability as cooling agents are thermal conductivity, specific heat capacity, thermal diffusivity, thermal absorptivity and bulk density. Researches have been undertaken on the thermal properties of various local materials, this include, oil palm and Raffia fibres as potential thermal insulators (Akpabio *et al*., 2001), investigation of *Ceiba Pentandra* cotton as cooling agent (Etuk and Akpabio, 2004) and study on *Cocos Nucifera* (coconut palm) trunk (Ajibola and Onabanjo,1994) and extension of the work on the possibility of using the *Cocos Nucifera* trunk for predicting temperature variation (Etuk *et al.,* 2005). However the list may not be complete but there is no evidence carried out on *Musa Paradisiaca*.

Plantain (*Musa paradisiaca*) known locally as ukom in Ibibio of Akwa Ibom people is a fruit in the class of banana but less sweet as banana. It is widely cultivated in southern Nigeria. It has a smooth straight stem with broad green leaves which could be used as feed for livestock, wrapping of food items while the fruit is food, a good source of plant iron and is highly medicinal.

Thaumatococcus daniellii known as Mfang Aya (Ibibio name) has a long straight stem and large blade green leaves commonly found in the rainforest in Akwa Ibom state, Nigeria, Western Africa. It is a rhizomal forest herb and a raw material for thaumatin which is identified as the sweetest naturally occurring substance (Mc Whirter, 1983). It could be used as a sweetener for the production of beverages and confectionaries and the plant is known for its resilient to local harvesting. The nutritional quality and essential oil composition of the plant tissue and seed has been studied by (Abiodun *et al.,* 2014). It is used in making mats used as beddings, roofing and for decoration of dwelling places.

The aim of this paper is to investigate the thermal properties of *Musa Paradisiaca and Thaumatococcus daniellii*fibre boards to ascertain its propriety as a potential thermal insulator for building.

2.0 Materials and Method

2.1 Sample Collection

Plantain (*Musa paradisiaca*) stems were locally sourced from plantain plantation in Uyo while *Thaumatococcus daniellii* were sourced from the rain forest in Oboyo Ikot Ita, Nsit Ibom in Akwa Ibom State, Nigeria and identified in the Department of Forestry, University of Uyo, Nigeria.

2.2 Sample Preparation

The stem of the freshly harvested plantain plant was cleared of the covering and graded using a grater to form a fibre and form four moulds. For *Thaumatococcus daniellii* the fresh plant stem was opened with knife and the fibre obtained. The moist samples were compressed under pressure by placing a 20 kg weight on each of the moulds and allowed to stand for four days for complete compression. The compressed mould was seasoned to dry at ordinary temperature under the sun for 30 days and finally dried in an oven (FANEM 315SC) at a temperature of 60^0 c for 40 hours to complete dryness. To ensure that the samples are dried their masses were measured with a sensitive Mettler model P165 weighing balance produced by Gallenhamp in intervals until the mass were constant. The dried samples were shaped to 6.05 ±0.05cm diameter and 1.50±0.10 cm thickness.

3.0 Experimental Procedure

Thermal conductivity for the material under study was determined using the steady state method with Lee's disc apparatus and according to method of (Etuk *et a.l,* 2010). This involves the measurement of the transported temperature through the materials at steady state. At steady state the rate of emission of heat at the exposed surface is equal to the heat conducted through the material.

The thermal conductivity (λ) is obtained from a modified Fourier heat equation given as

$$\lambda = \frac{mc_p S_c h}{A(\theta_f - \theta_i)} , \qquad 1$$

where A is the area of the sample in m^2, c_p is the specific heat capacity at constant pressure of the disc J $(kgk)^{-1}$, h is the thickness (m) of the fibre board, m is the mass of the disc and S_c is the slope of the cooling curve, θ_f, and θ_i are the upper and lower steady state temperatures measured in k and λ in $Wm^{-1}k^{-1}$. Other thermal properties such as C_p, density (ρ) were determined experimentally using method of (Etuk .,2010) while thermal diffusivity (D) and thermal absorptivity (α) were obtained from Eq. (2) (Khatry *et a.l,* 1978) and 3 (Sodha *et al,*1997)

$$D = \frac{\lambda}{\rho c_p} \qquad 2$$

$$\alpha = \sqrt{\frac{\omega}{2D}} \qquad 3$$

where ω is the angular frequency.

Radiation transport could be through solids (conduction), fluids (convection) and space (radiation) and a porous insulation material like fibre boards or pressed powder boards contains all these media, therefore the thermal conductivity for these materials is a combination of thermal conductivities of these media given as (Beck *et al.,* 2004)

$$\lambda = \lambda_{solid} + \lambda_{rad} + \lambda_{gas} + \lambda_{couple} \qquad 4$$

The total conductivity is λ, while the coupling term accounts for the gas condition that thermally short circuits the high thermal resistance between the points within the fibres.

Heat flow equation through a solid is given as (Ekpe *et al.,* 1996)

$$\frac{\partial^2 T}{\partial X^2} = \frac{\rho c}{\lambda}\frac{\partial T}{\partial t} \qquad 5$$

The general solution of Eq. (5) is given as

$$T(x,t) = A_0 + \sum_{m=1}^{\infty} A_m \exp\{i(m\omega t + \delta_m x)\} \qquad 6$$

where $$\delta_m = \sqrt{m}\ (\frac{\omega\rho c}{2\lambda})^{1/2}(1-i) \qquad 7$$

Substituting Eq. (7) into Eq. (6) modified the heat equation as

$$T(x,t) = T_m - A_0 \exp(-\alpha x)\cos\{\omega(t - t_0 - \frac{\alpha x}{\omega})\} \qquad 8$$

A_o is the daily temperature amplitude at x=0^0c
t is the time of the day in hours
x is the coordinate through the thickness of the material studied
t_0 is the time of minimum temperature at the surface in hours
α is thermal absorptivity
w is the angular velocity per day, $\omega = 2\pi T^{-1}$
T_m is calculated from the hourly surface temperature average T_{av}(0^0c)

$$T_m = \sum_{n=1}^{24} \frac{T_{av}}{24} \qquad 9$$

Hence Eq. (8) becomes

$$T(x,t) = T_m - A_0 \exp(-\alpha x)\cos\{\frac{\pi}{12}(t - t_0 - \frac{12\alpha x}{\pi})\} \qquad 10$$

4.0 Results and Discussion
Tables 1 and 2 report the thermal properties of *Musa paradisiaca and Thaumatococcus daniellii* respectively obtained from this study.

Table 1: Thermal properties of *Musa paradisiaca*

Sample code	λ ($Wm^{-1}k^{-1}$)	ρx10^3 kgm^{-3}	C_p $Jkg^{-1}k^{-1}$	D x 10^{-8} m^2s^{-1}	α (m^{-1})
M_1	0.0456	0.237	2782.5	6.915	22.93
M_2	0.0339	0.199	2625.5	6.488	23.67
M_3	0.0308	0.146	2230.6	9.457	19.61
M_4	0.0393	0.222	2793.0	6.338	23.95
Mean	0.0374	0.200	2606.5	7.230	22.54

Table 2: Thermal properties of *Thaumatococcus daniellii*

Sample code	λ ($Wm^{-1}k^{-1}$)	ρ x10^3 kgm^{-3}	C_p $Jkg^{-1}k^{-1}$	D x10^{-7} m^2s^{-1}	α (m^{-1})
M_1	0.0660	0.365	1019.2	1.774	14.32
M_2	0.0364	0.211	1056.0	1.634	14.92
M_3	0.0352	0.285	1075.5	1.148	17.80
M_4	0.0332	0.288	1017.8	1.133	17.78
Mean	0.0427	0.287	1041.9	1.422	13.71

The value of thermal conductivity is identified as the property of a material that determines the suitability of the body as a thermal insulator. This quantity depends on the rate of transfer of heat energy from one point to another while the rate of the energy transport is measured by the temperature difference between the materials. In this study the thermal conductivity of *Musa paradisiaca* is ranged between 0.0308 -0.0456 $Wm^{-1}K^{-1}$ with a mean of 0.0374 $Wm^{-1}K^{-1}$ for a mean bulk density of 200.0 kg/m^3 while *Thaumatococcus daniellii* shows a thermal conductivity of ranged 0.0332 – 0.0660 $Wm^{-1}K^{-1}$ and mean value of 0.0427$Wm^{-1}K^{-1}$with a mean bulk density of 287.0 kgm^{-3}. The thermal conductivity values for both materials lies within the range of 0.0433 $Wm^{-1}K^{-1}$ obtained for Zea mays stem of heartwood (cork) fibre board (Etuk *et al.,* 2010), 0.0412 Wm^{-1} K^{-1} for *Ceiba Pentandra* cotton (Etuk and Akpabio, 2004). However, these value is less than value for Raffia palm (Akpabio *et al.,* 2001), *Cocos nucifera* trunk (Ajibola and Onabanjo, 1995, Etuk *et al.,* 2005).

Another thermal property is the specific heat capacity of a material. It is a measure of the ability of the material to retain heat and depends on the mass, nature and temperature difference within the material. The specific heat capacity of *musa paradisiaca* was obtained as ranged between 2230.6 -2793.0 Jkg^{-1} K^{-1} with mean of 2606.5 $Jkg^{-1}K^{-1}$ for density range of 0.146-0.237kg/m^3 while specific heat capacity of *Thaumatococcus daniellii* is 1017.8 -1075.5$Jkg^{-1}K^{-1}$ with mean of 1041.9 $Jkg^{-1}K^{-1}$for density 0.211-0.365kg/m^3. It could be observed in the results that the c_p for *Musa paradisiaca* is higher than the c_p value for Zea mays straw and heartwood (Etuk *et al.,* 2010) whereas c_p for *Thaumatococcus daniellii* is less than that of Zea mays fibre board. Equations 1to 4 shows the dependence of the D and α on λ, ρ and c_p of the materials where α has an inverse relationship on diffusivity (D).

The comparison of the thermal properties of the materials under study with previous works by Etuk *et al.,* (2010) and Etuk and Akpabio (2004) shows some similarities in properties, and it is observed that *Musa* *paradisiaca* and *Thaumatococcus daniellii* exhibit low diffusivity value hence the these materials could save as thermal insulators. This work underscore why the leaves of *Musa paradisiaca* and *Thaumatococcus daniellii* are often used by the locals in Akwa Ibom State as roofing materials in homes and covering while in farms.

Again, comparing the values of the thermal conductivities for these materials with non plant material used for lateral and bottom insulation in a solar oven shown in Table 3 (Nandwani, S. S, 1988) shows that *Musa paradisiaca* comparable to glass wool while the thermal conductivity of *Thaumatococcus daniellii* is within the range of aluminum paper and pine fibre boards.

Table 3: Thermal conductivities of common materials used in solar oven

Materials	λ ($Wm^{-1}K^{-1}$)
Aluminum	0.0465
Pine fibre boards	0.0519
Asbestos Sheet	0.3190
Glass wool	0.0372

From Eq. (10) the heat flow model for the materials could be obtained as,
The heat flow model for *Musa paradisiaca* is given in Eq. (11)

$$T(x,t) = T_m - A_0 \exp(-22.54x)\cos\{0.26(t - t_0 - 86.09x)\}\ . \qquad 11$$

While the heat model for *Thaumatococcus daniellii* is given in Eq. (12)

$$T(x,t) = T_m - A_0 \exp(-13.71x)\cos\{0.26(t - t_0 - 52.36x)\} \qquad 12$$

The expected challenge in the use of these materials for this purpose is having them in large quantity but the challenge could be surmounted if individuals and government agencies could establish their plantations. However, the good thing about the use of these materials is that they could be used raw or processed into ceiling boards for the purpose of thermal insulation against heat from solar radiation emitted from the aluminum roofing prominently used in homes in the area of study.

5.0 Conclusion

The thermal properties results obtained for this study were found to have similarities with values obtained for similar local materials conducted by researchers in the same area. The thermal conductivities of these materials under investigation are low with a high resistivity which favor them as construction materials for interior insulation of building. Again the models obtained from this work could be used in the design of naturally cooled building in tropical region. These materials are found to be suitable as thermal insulators for our dwelling places and an alternative to costly building materials used for air conditioning.

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Reference

Abiodun, O.A, Akinso, R., Olosunde, O.O., Adegbite, J. A., and Oluronke, O. (2014). The Nutritional Quality and Essential Oil Composition of the Thaumatococcus daniellii Tissue and Seed. *Food Chemistry*

Ajibola, K. and Onabanjo, O. B (1995): Investigation of Cocos nucifera as potential insulator for buildings. *Renewable Energy,* 6(1) 81-85

Akpabio, L. E., Ekpe, S. D., Etuk, S. E and Essien, K. E (2001). Thermal Properties of Oil Palm Fibres. *Global Journal Pure Applied Sciences,* 7(3), 575-578

Beck, A, Heineman, M., and Fircke, J. E. (2004). Thermal Transport in Straw Insulation. *Journal of Thermodynamics, Environment and Building Sciences*, 3(5), 227-234

Ekpe, S.D., Akpabio, L. E., and Eno, E. E (1996). Thermal Properties of Soil Samples in Uyo Local Government Area of Akwa Ibom State. Nigeria. *Global Journal of Pure and Applied Sciences,* 2(1), 45-52

Etuk, S. E and Akpabio, L. E (2004). Investigation of Ceiba pentandra (cotton) as a Potential Thermal Insulators. *Journal of Raw materials Research,* 1(1), 4-10

Etuk, S. E., Akpabio, L. E and Akpabio, K. E (2005). Determination of Thermal Properties of cocos Nucifera Trunk for Predicting Temperature Variations with its Thickness. *Arabian Journal of Sciences and Engineering,* 30(13)

Etuk, S. E., Akpabio, L. E and Akpan I. O (2010). Comparative Study of Thermal Transport in Zea mays Straw and Zea mays Heartwood (cork) Boards; *Thermal Sciences* 14(1), 31-38

Khatry, A. B., Sodha, M. S., and Malik, M. A. S.,(1978). Periodic Variation of Ground Temperature with Depth. *Solar Energy,* 20(5), 425-427.

Mc Whirter, N (1983). Guinness Book of World Records 1984. Guinness Superlatives London.

Nandwani, S.S (1998). Experimental and Theoretical Analysis of a Simple Solar Oven in the Climate of Costa Rica. *Solar and Wind technology,* 8, 159-170

Sodha, M.S., Goyal, I.C., Kaushiks, C., Tiwari, G. N., and Seth,A. K.,(1997). Periodic Heat Transfer with Temperature Dependent Thermal Conductivity:, *International Journal of Heat Mass Transfer,* 22(5), 281-777