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INVESTIGATION OF *RAPHIA HOOKERI* TRUNK AS A POTENTIAL CEILING MATERIAL FOR PASSIVELY COOLED BUILDING DESIGN

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Abstract

The present economic situation in Nigeria has made the search for alternative structurally and thermally suitable indigenous building materials necessary. This paper investigates and records the thermal properties of *Raphia hookeri* trunk with a view to establish its suitability as ceiling panel in building design for the tropical region, from the thermal properties point of view. Results indicate that thermal conductivity of *Raphia hookeri* trunk is 0.053 ± 0.002 $Wm^{-1}K^{-1}$. It has a bulk density of 278.667 ± 2.054 Kgm^{-3}. The specific heat capacity for the trunk is 2456.33±5.73 $Jkg^{-1}K^{-1}$. Its thermal diffusivity value is (7.633 ± 0.202 × 10^{-8} m^2s^{-1}, while its thermal absorptivity is 21.808 ± 0.278 m^{-1}. The results show that the thermal properties of *Raphia hookeri* trunk compare favourably with those of other good insulators. If properly harnessed, it could be used as efficient ceiling panel for passively cooled building design. A model for the estimation of temperature variation with thickness of the sample has been developed based on the experimental values and the existing theory on temperature variation with thickness of materials.

Résumé

Etuk, S. E., Akpabio, L. E. & Akpabio, E.: *Enquête sur le tronc de* Raphia hookeri *comme une matière potentielle de plafond pour le plan de bâtiment passivement refroidi.* La situation économique contemporaine au Nigéria a fait que la recherche pour les matériels indigènes de construction qui sont convenables du point de vue structural et thermique comme alternative est devenue nécessaire. Cet article fait l'enquête et l'enregistrement des propriétés thémiques du tronc de *Raphia hookeri* en vue d'établir s'il est convenable comme caisson de plafond dans le plan de bâtiment pour la région tropicale du point de vue des propriétés thémiques. Les résultats indiquent que la conductivité thermique du tronc de *Raphia hookeri* est 0.0053 ± 0.002 $Wm^{-1} K^{-1}$. Il a une valuer de densité massive de 278.667 ± 2.054 Kgm^{-3}. Sa valeur de diffusivité thémique est (7.633 ± 0.202 × 10^{-8} m^2s^{-1}), alors que sa valeur d'absorptivité thémique est 21.808 ± 0.278 m^{-1}. Les résultats montrent que les propriétés thémiques du tronc de *Raphia hookeri* se comparent favorablement avec celles des autres bons isulants. S'il est bien exploité il pourrai être utilisé comme caisson de plafond efficace pour le plan de bâtiment passivement refroidi. Un modèle pour l'estimation de la variation de température avec épaisseur de l'échantillon a été développé basé sur les valeurs expérimentales et les théories existantes de la variation de température avec l'épaisseur des matériels.

Introduction

Heat transmitted through uninsulated ceilings or roofs, unprotected windows and walls into spaces in the tropical region by the process of conduction and radiation is one of the factors causing environmental discomfort. One of special importance in design, particularly in warm climates, is the consideration of the indoor environmental conditions most conducive to comfort, health, safety and general well-being of the occupants (Ajibola & Onabanjo, 1995; Van Straaten, 1967). Many building materials used for roofing, like zinc aluminium etc., are conductors of heat. The use of such roofing materials increases the rate of heat transmission into the interior space or indoor environment. Various researches are being carried out to determine the qualities of local materials with suitable structural and thermal properties for use as building materials. Several types of timber are also investigated for building purposes. Among such investigations are those of Ajibola & Onabanjo (1995) and Bolza & Keating (1961).

At pressent, most ceiling materials like asbestos and cardboard, cork, etc. for building design are very expensive and out of the reach of the common man. In recent times, local timbers have been harnessed to meet local building needs. In tropical countries some traditionally used timbers with useful properties are becoming scarce and extinct owing to deforestation coupled with increasing demand for timber. This has resulted in the introduction of alternative timber materials with less established local performance as substitutes; for example, Costa & Golubovie (1984) found out that there are many timber resources with suitable properties for construction. The properties of these materials are, however, not well established. The palm family is one such timber resource which is abundant but not fully utilized (Ajibola & Onabanjo, 1995).

Raphia hookeri, a monocotyledonous plant in the palmae family, is characterized by solid unbranched trunks crowned by fan-shaped pinnate leaves at full maturity (Child, 1974). A typical tall *Raphia hookeri* gets to a height of 15 m (Akpabio *et al.*, 2001). *Raphia hookeri* produces piassava from their leafstalks which are retted and the fibres beaten out. Piassava fibres are used to make brushes for street sweeping, rug-washing and other scrubbing-brushes. Locally, it is used to make climbing ropes. Decorative hats, mats, and baskets are woven with piassava. Another important fibre from *Raphia hookeri* is the raffia, soft silk-like fibre from epidermis of the tender leaves of the palms. Raffia is used for ornamentation of masquerades and the weaving of ornamental baskets, purses, brooms, shoes, bags, wall mats, flower-vases, and other novelty objects. It is also used for making Barrister's and Judge's wig locally. Tie tie, the fibrous outgrowth on the stem of *Raphia hookeri,* is used in binding wattle sticks and rafter members in thatched houses. In Africa, *Raphia hookeri* is mainly planted for wine, the raw material used for distilling local gin (EtukUdo, 2000).

According to Ajibola & Onabanjo (1995), most studies on palm species in general have focused on their mechanical propertise. Studies on the thermal properties of timber has been conducted on Cocos *nucifera* (Ajibola & Onabanjo, 1995). To date, no study has been conducted on the thermal properties of *Raphia hookeri* timber. The only known work is the investigation carried out on the thermal properties of Raffia palm fibres (Akpabio *et al.,* 2001). This study focuses on the thermal properties of *Raphia hookeri* trunk. The study is necessary because the fibre composition of palm timber differs considerably from that of other timber types (Ajibola & Onabanjo, 1995).

It is expected that *Raphia hookeri* timber may exhibit different thermal properties from other wood species. The properties to be examined are the density, specific heat capacity, thermal conductivity, diffusivity absorptivity and spatial thermal resistance. From the absorptivity values, a temperature-thickness variation model shall be developed for the timber material samples. The purpose is that if the material had a low thermal conductivity it could be gainfully used to reduce heat conduction through roofs into interior spaces in tropical regions.

Experimental

The three main processes of heat transmission in materials are thermal conduction through the solid phase, and radiation and convection through porous materials. Convection can be neglected for small pore sizes while radiation transport strongly depends on temperature, and is significant at high temperatures. The temperature of a porus 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 a given change in temperature of the material (thermal capacity) and the energy required for changes such as evaporation which occurs constantly at the surface. 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.

Temperature as a function of thickness and time can be estimated from an equation given by Moustafa *et al.* (1981), Ekpe & Akpabio (1994), Ekpe, Akpabio & Eno (1996), Akpabio *et al.* (2001).

$$T_{(x,t)} = T_m - A_s \exp(-\alpha x) \cos[\omega\{(t - t_0) - ax/\omega\}] \quad (1)$$

where A_s = daily temperature amplitude at the surface of *Raphia hookeri* trunk sample, that is x = o; 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; is calculated from the hourly surface temperature average T_{hss} (°C) as

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

On a 24-h period equation (1) becomes

$$T_{(x,t)} = T_m - A_s \exp(-\alpha x) \cos[(2\pi/24)(t - t_0) - 12ax\pi] \quad (3)$$

Thermal diffusivity is determined using the relationship given by Silva *et al.* (1998) and Suleiman *et al.* (1997).

$$\lambda = k/(\rho c) \quad (4)$$

where λ = thermal diffusivity; k = thermal conductivity; ρ = density; c= specific heat capacity.

The thermal diffusivity (λ) is used in calculating the thermal absorptivity α using the equation

$$\alpha = [\omega/2\lambda]^{1/2}.$$

The three *Raphia hookeri* (Raphia palm) trunks used were obtained from Ukana Offot Street in Uyo, Akwa Ibom State, Nigeria. After felling old and already tapped Raphia palm trees, the trunks were cut into logs and sawed into planks of portable lengths. The planks were labeled and seasoned to a required diameter and thickness They were subsequently shaped to the required diameter and thickness. The prepared samples were finally stored at room temperature, ready for thermal properties determination.

The thermal conductivities were determined using the steady state method (modified Lee's disc apparatus) (Ekpe & Akpabio, 1994; Akpabio *et al.*, 2001). The heat conducted across the timber sample at steady state equals the rate at which it is emitted from the exposed surface. The specific heat capacities were determined for each timber sample using the method described by Okeke *et al.* (1991) which takes into account heat losses due to radiation. A copper-constant thermocouple was used for temperature measurement. Bulk densities were also measured for each timber

TABLE 1

Experimental result showing thermal properties of Raphia hookeri (*Raffia palm*) *trunk*

Sample	*Density* (ρ kgm^{-3})	*Thermal conductivity* ($kWm^{-1}K^{-1}$)	*Specific heat capacity* ($CJkg^{-1}K^{-1}$)	*Thermal resistivity* ($rW^{-1}mK$)	*Thermal diffusivity* ($\lambda m^2 s^{-1} \times 10^{-8}$)	*Thermal absorptivity* (αm^{-1})
Sample 1	276	0.051	2463	19.608	7.5	22.019
Sample 2	279	0.052	2457	19.231	7.5	22.019
Sample 3	281	0.055	2449	18.182	7.9	21.387
Mean value ± S.E.	278.667± 2..054	0.053± 0.002	2456.33± 5.73	19.007± 0.132	7.633± 0.020	21.808± 0.278

sample using the weighing and displacement methods (Akpabio *et al.,* 2001). The thermal diffusivity and absorptivity were calculated for each sample using equations (4) and (5), respectively.

Results and discussion

Table 1 shows the experimental results for the thermal conductivity k, specific heat capacity c, density ρ, thermal diffusivity λ and thermal absorptivity α for the timber samples. From Table 1, it is observed that the thermal conductivity of *Raphia hookeri* timber ranges between 0.051 and 0.055 $Wm^{-1}K^{-1}$. This implies that the rate of heat flow by conduction through the samples is very low. The range of bulk density for completely dry *Raphia hookeri* timber is observed to be between 276-281 kgm^{-3}. Specific heat capacity of the samples is between 2449-2463 $Jkg^{-1}K^{-1}$. Thermal absorptivity of the samples lies between 21.39 and 22.02 m^{-1}, while the thermal diffusivity of the test samples lies between 7.5×10^{-8} and 7.9×10^{-8} m^2s^{-1}.

Substituting the respective values of the absorptivity into equation (3) we have the following equations for predicting the sample temperature at any given thickness x, and time of the day t, for each *Raphia hookeri* sample, while the equation formed by substituting the mean absorptivity value gives the general equation for such prediction for any *Raphia hookeri* timber sample.

For test sample 1

$$T_{(x,t)} = T_m - A_s \exp(-22.03x) \cos[0.262(t - t_o) - 22.02x] \quad (6)$$

For test sample 2

$$T_{(x,t)} = T_m - A_s \exp(-22.02x) \cos[0.262(t - t_o) - 22.02x] \quad (7)$$

For test sample 3

$$T_{(x,t)} = T_m - A_s \exp(-21.39x) \cos[0.262(t - t_o) - 21.39x] \quad (8)$$

For mean value

$$T(x,t) = T_m - A_s \exp(-21.81x) \cos[0.262(t - t_o) - 21.81x] \quad (9)$$

Isachenko, Osipove & Sukomel (1987) and Twidell & Weir (1990) state that the thermal conductivities of construction and heat insulating materials lie between 0.023 and 2.9 $Wm^{-1}K^{-1}$. The results of the experiment show that thermal conductivity of *Raphia hookeri* timber falls within the range of good heat insulator. Its thermal conductivity value is lower than most of those commonly used building materials (Nandwani, 1988; Agarwal, 1967). The low density of *Raphia hookeri* timber is an added advantage it has as insulating material. Its thermal resistivity value is higher than those of other commonly used building materials and wood based insulator listed by Agarwal (1967), Ajibola & Onabanjo (1995) and Van Straaten (1967). Hence, it is a better thermal insulator compared with similar wood-based insulators. Equation (9) gives the required general mathematical model for estimation of temperature variation with thickness of *Raphia hookeri* timber sample.

Conclusion

The results obtained in this study reveal that *Raphia hookeri* trunk has low bulk density, low thermal conductivity but high thermal reseistivity which compare favourably with those of other good thermal insulators. This shows that the trunk of mature but tapped *Raphia hookeri* which, hitherto, has been lying waste, but for its use as firewood, can effectively be used in the building industry as ceiling panels to limit the rate and amount of heat flow or propagation through roofing material into the interior space or indoor environment in tropical regions. It can be sucessfully used if the planks from the fresh trunk are seasoned to complete dryness, treated and made into suitable panels.

Planting of *Raphia hookeri* with the aim of using the trunk as ceiling panels, after the palm wine has been tapped, should be encouraged and embarked upon, in order to augment the source of insulators. Individuals as well as the govement should go into the production of heat resistant ceiling sheets for naturally cooled building design using *Raphia hookeri* trunk. This would not only boost the economy of both the individuals and government, but would also make the ceiling material affordable to people in the low income class.

It is assumed that *Raphia hookeri* trunk-made ceiling board would be cheaper compared with asbestos ceiling board since its production would neither require sophisticated technology nor additional raw material except by chemical pre-treatment against possible insect infestation.

References

AGARWAL, K. N. (1967) Thermal data of building fabrics and their applications in building design. *Building Digest* No. 52, Central Building Research Institute, Rookee, India.

AJIBOLA, K. & ONABANJO, B. O. (1995) Investigation of *Coco nucifera* as a potential insulator for buildings, *Renewable Energy* **6** (1), 81-84.

AKPABIO, L. E., EKPE, S. D. EUTK, S. E. & ESSIEN, K. E. (2001) *Thermal properties of oil and raffia fibres, Global J. Pure Appl. Sci.* **7**(3), 575-578.

BOLZA, E. & KEATING, W. G. (1961) *African timber - the properties, uses and characteristics of 700 species.* Australia: Commonweath Scientific and Industral Research Organization (CSIRO).

CHILD, R. (1974) *Coconut,* 2nd edn. Harlow: Longman.

COSTA, R. & GOLUBOVIE, I. (1984) *Some Nigerian timbers: an index of 23 species.* Studies in Environmental Design in West Africa.

EKPE, S. D. & AKPABIO, G. T. (1994) Comparison of the thermal properties of soil samples for a passively cooled building design. *Tr. J. Phys.* **18** (2), 117 - 122.

EKPE, S. D., AKPABIO, L. E. & ENO, E. E. (1996) Thermal properties of soil samples in Uyo Local Government Area of Akwa Ibom State of Nigeria. *Global J. of Pure and Appl. Sci.* **2** (1), 45-52.

ETUKUDO, I. (2000) *Forests: Our divine treasure.* Uyo: Dorand Publishers.

ISACHENKO, V. P., OSIPOVE, V. A. & SUKOMEL, A. S. (1987) *Heat transfer.* Moscow: Mir Publishers.

MOUSTAFA, S., JARRAR, D., EL-MANSY, H., AL-SHAMI & BRUSEWITZ, G. (1981) *J. sol. Energy* **27**, 83-88.

NANDWANI, S. S. (1988) *Experiemental theoretical analysis of a simple solar oven in the climate of costa Rica* - 1. *Solar Wind Technol.* **8**, 159-170.

OKEKE P. N., OSUWA J. C. MENKITI A. I. OFOEGBU C. O. & EMEREOLE H. U. (1991) Preliminary Practical Physics Manual, *Nigerian University Physics Series* **2**, 222-232

SILVA, T. S., ALVES, A. S., PEPE, U., TSUZUKI, H., NAKAMURA, O., D. AGUITA NETO, M. F., AN, S. Y., FERREIRA DA SILVA, A., & VESISSID, N., (1998) Thermal diffusivity of lead iodide. *J. appl. Phys.* **83** (11); 6193-6195.

VAN STRAATEN, J. F. (1967) *Thermal performance of buildings.* National Building Research Institute South Africa Council for Scientific and Industrial Research, Pretoria. Amsterdam: Elsevier.

SULEIMAN, B. M., GUSTAVSSON, M., KARAWACHI, E. & LUNDEN, A. (1997) Thermal properties of lithium sulphate. *J. Phys. D. Appl. Phys.* **30**, 2553-2560.

TWIDELL, J. & WEIR, T. (1990) *Renewable energy resources.* London: E and F. N Spon.

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