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УДК 674

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# EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF TEMPERATURE ON THE THERMAL CONDUCTIVITY OF RAW COCONUT FIBERS

*The high energy consumption in building is a major contributor to climate change and atmosphere pollution worldwide. Insulation materials derived from natural fibers are an excellent alternative to reduce the energy demand due to their low cost, low environmental impacts during the production stage and high bio-degradation rate at the end of life. This paper presentsthe potential of coconut fibers for building application by investigating their thermal conductivity over the temperature range of -10°C to 50°C.Test data showed the thermal conductivity valueswere between 0.0379 W/(m.K) and 0.0665 W/(m.K) and that is lower than other conventional and natural fiber materials. Furthermore, theλ-values increased with an increase in mean temperature both case of 30 mm and 50 mm thickness. Finally, the relationship between thermal conductivity and mean temperatureexpressed by fitting data to a polynomial function.*
***Keywords:*** *thermal conductivity, coconut fiber, mean temperature, thermal dependence*

## Introduction

Since the energy consumption of buildings accounts for a considerable part of the global total energy, there is a strong demand to improve the energy efficiency in buildings and constructions. According to Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010, on the energy performance of buildings, new construction will have to consume nearly zero energy and that energy will be to a very large extent from renewable resources [Parliament, 2010]. This is because the construction sector has been identified as the largest energy consumer, generating up to 1/3 of global annual greenhouse gas emissions, contributing up to 40% of the global energy, and consuming of 25 % of the global water worldwide [Lemmet, 2009]. The increased consumption of natural resources for lighting, refrigeration, ventilation, recycling, heating and cooling system in commercial buildings due to the acceleration of urbanization, results in the enormous expenditure for used energy. Energy expenditure in buildings can be considerably reduced with the use of natural fibrous insulation materials. Natural fibers such as coconut fiber, sugarcane fiber, cotton, rice straw and others consist of lignocelluloses fibers are promising alternatives for use as biodegradable, renewable, and environmentally friendly building thermal insulation. Natural fibers are also increasing use as insulating materials, again mainly because of perceived superior environmental credentials compared with other traditional insulation materials. The most beneficial effect of the insulation based natural fibers is not only its low value of thermal conductivity but also the natural character of these fibers. Another advantage is that it is a renewable material which has no strong impact on the environment and health. When compared with conventional materials such as foam polystyrene or mineral wool, they have sometimes even better thermal performances. Some disadvantages are their high wettability and absorbability due to their open pore structure as well as being flammable. Besides, they are easily attacked by biological fungi and parasites [Zach et. al., 2013]. Nevertheless, they can be used as a potential insulation material in construction if they are modified properly by some physical or chemical treatments.

Coconut fiber is extracted from the husk of coconuts, is cheap and locally available in many tropical and semitropical countries. The common name, scientific name and plant family of coconut fibre is coir, cocos nucifera and arecaceae (Palm), respectively [Ali et. al., 2012]. The general advantages of coconut fibre include moth-proof; resistant to fungi and rot, provide excellent insulation against temperature and sound, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, spring back to shape even after constant use. Coconut fibre is the toughest fibre (21.5 MPa) amongst natural fibres [Munawar et. al., 2007]. They also contain a central hollow portion that runs along the fiber axis, so it can be used in acoustic and thermal insulation materials where its reduced bulk density and lightweight properties are advantageous.Currently, coconut fiber is widely used in boards, roofing materials, concrete, and other building materials [Ali et al., 2012, Lertwattanaruk and Suntijitto, 2015, Asasutjarit et. al., 2007].A detailed review on the thermal properties and water absorption of coconut fibers and its comparison with other natural fibers such as jute, flax, and sisal fibers were reported. Not only the physical, chemical, and mechanical properties of coconut fibers were investigated, but also properties of composites (cement pastes, mortar and/or concrete, etc.) in which coconut fibers were used as reinforcement, were discussed [KONGKAEW, 2016, Naidu et. al., 2017, Saw et. al., 2014, Hasan et. al., 2021, Hasan et. al., 2021, Ali, 2011, Bui et. al., 2020]. Some collected data were shown in table 1.

Table 1

**Chemical, Physical, and Mechanical compositions**

| Components | Results |
|---|---|
| Cellulose, % | 36–43 |
| Hemicellulose, % | 20 |
| Lignin, % | 41–45 |
| Diameter, μm | 200 ± 10 |
| Moisture content, % | 13.68 ± 0.05 [Suardana et. al., 2011] |
| Density, g/cm$^3$ | 1.25–1.5 |
| Tensile strength, MPa | 105–175 |
| Young's Modulus, MPa | 4–6 |
| Thermal conductivity, W/(m.K) | 0.046–0.068 [Panyakaew and Fotios, 2011] |

In terms of thermal conductivity of natural fibers, some studies revealed the potential use of these fibersin civil engineering as a thermal construction material which can reduced the environmental impacts. Manohar tests of thermal conductivity of coconut fiber at different densities were conducted at two mean temperatures [Manohar, 2012]. Experimental results showed the thermal conductivity decreased from 0.056 to 0.049 at 15.6 °C and from 0.0576 to 0.05 W/(m.K) at 21.8 °C with an increase in mean temperature and decreasing when the density increase from 40 to 90 kg/m$^3$. Other authors conducted the water absorption of raw coconut fibers over the time and showed the relationship between thermal conductivity and density of fibers. They also documented the decreased thermal conductivity when the density increased from 30 to 120 kg/m$^3$ and the values were quite low (the lowest value is 0.024 W/(m·K)) to be considered as a potential composition for the reinforcement insulation material [Bui et al., 2020].Temperature is an important factor affecting thermal properties of natural fibrous materials. Higher temperature is always related to higher thermal conductivity values [Abdou and Budaiwi, 2013].

The aim of the present study is to investigate the thermal conductivity of raw coconut fibers. Two tested samples with 30 mm and 50 mm thickness were produced and studied how the thermal conductivity values change at various mean temperatures. The relationship between thermal conductivity values and mean temperature was also expressed from the practical experiments.

## Materials and Methods

*Preparation of coconut fibers*

Coconut fibers used in this present study were collected from coconut husk in Vietnam. The length of fibers is 12–15 mm and the diameter are about0.89 ± 0.04 mm. The fibers were washed with water in order to eliminate the pollutant particles until the water is clean, they are then dried: firstly being sun dried for two days and then further oven dried at 103 °C in 24 hours until reaching constant weight.

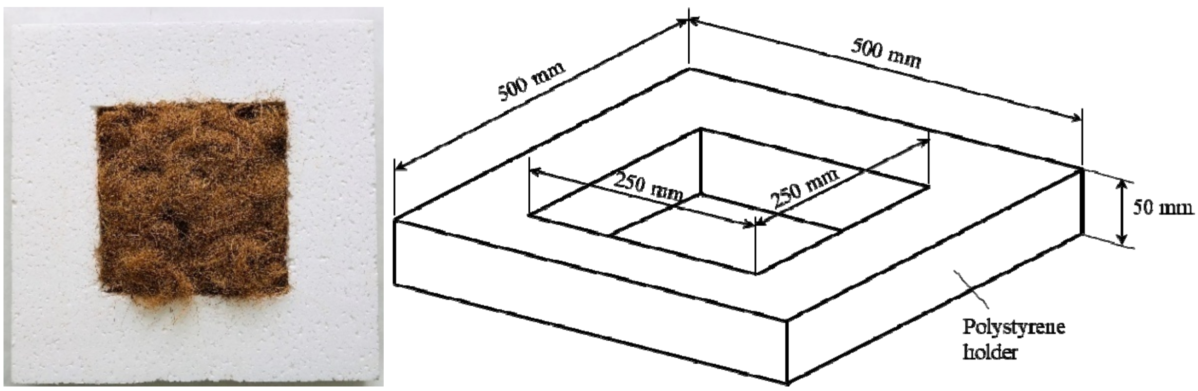


**Fig. 1. Tested sample and schematic of polystyrene specimen holder**

*Methods*

*Thermal conductivity*

Thermal conductivity of dry samples was measured across the thickness in accordance with ASTM C518, standard test method for steady-state heat transfer by means of heat flow meter apparatus at Innovation Center, University of Sopron. The λ-value was conducted on 30 mm and 50 mm thickness with dimension 250×250 mm. The tested specimen was placed in a polystyrene specimen holder with dimension 500×500 mm to ensure the one-dimensional hear flow over the metered area.

*Thermal dependence*

The thermal dependence in thermal conductivity values were measured in the temperature ranges of –10 to 50 °C at 10 °C temperature difference between the hot and cold sizes.

**Results and Discussion**

*Thermal conductivity*

The main role of thermal insulation materials in a building envelope is to prevent heat loss and provide thermal comfort for the occupants of a building. The thermal performance of a building envelope depends to a great extent on the thermal effectiveness of the insulation layer which is mainly determined by its thermal conductivity. This is the time rate of steady-state heat flow through a unit area of a homogeneous material in a direction perpendicular to its isothermal planes, induced by a unit temperature difference across the sample [C168, 2013]. According to the DIN 4108, "Thermal insulation and energy economy in buildings", materials with a λ-value lower 0.1 W/(m·K) may be classed as thermal insulating materials. Most insulating materials with thermal conductivity ranging from 0.03 to 0.05 W/(m·K) can be regarded as good [Jelle, 2011, Pfundstein et. al., 2012]. The thermal conductivity of coconut fibers at 50 mm and 30 mm thickness measured at dry state is 0.057 ± 0.001 W/(m·K) and 0.041 ± 0.0008 W/(m·K), respectively. These values come from the contribution of both air and pure fiber solid material. A comparison between the thermal conductivity of coconut fibers with other natural fibrous insulation is presented in table 2.

Table 2

**Thermal conductivity of raw coconut fiber in the present study compares with other insulation materials**

| Materials | Density, kg/m$^3$ | Thermal conductivity, W/(m.K) | Source |
|---|---|---|---|
| Present study | 33 | 0.0476–0.0665 | |
| | 50 | 0.0375–0.0467 | |
| Coconut fiber | 40–90 | 0.058–0.05 | [Manohar et. al., 2006] |
| Sugarcane fiber | 70–120 | 0.051–0.049 | [Manohar et al., 2006] |
| Oil palm fiber | 20–120 | 0.095–0.058 | [Manohar, 2012] |
| Cotton fiber | 20–60 | 0.04 | [Pfundstein et al., 2012] |
| Hemp fiber | 36.2 | 0.052 | [Volf et. al., 2015] |
| Wood fiber | 51.5 | 0.048 | [Volf et al., 2015] |
| Flax fiber | 27 | 0.052 | [Volf et al., 2015] |
| Sheep wool | 29.7 | 0.062 | [Volf et al., 2015] |

*Thermal dependence*

Uncertainty in thermal conductivity values of coconut fibers and the thermal dependence over the temperature range of –10 to 50 °C was shown in figure 2.

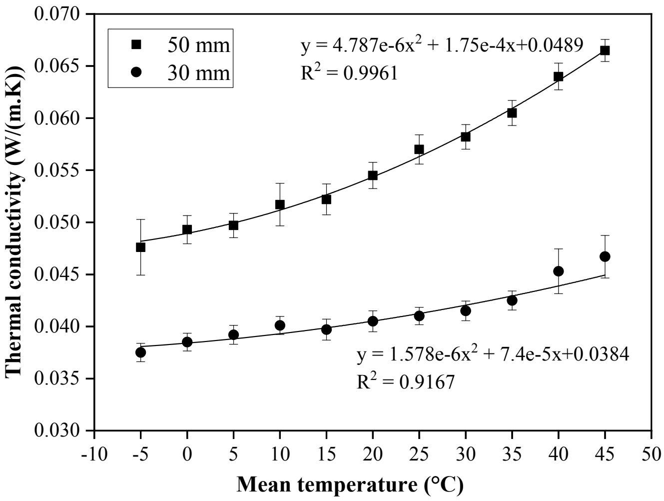


**Fig. 2. Thermal conductivity as function of mean temperature**

It can be observed that higher mean temperature is always accociated with higher thermal conductivity values. The percentage changes of thermal conductivities at 40 °C and 45 °C showed a higher ratio than others mean temperatures. According to the results, the relationship between λ-values and mean temperature can be expressed as a polynomial function with a high correlation coefficient.

**Conclusions**

The thermal conductivity of raw coconut fibers and the influence of temperature on λ-values have been experimentally investigated. Results showed the low thermal conductivity with low density of tested samples and the values increased when the mean temperature increased from –10 to 50 °C. A relationship between thermal conductivity values and mean temperatures was established and the data was fit by a nonlinear increase. It can be stated that higher operating temperature is always associated with higher thermal conductivity for all thicknesses. A comparison of the thermal conductivity of coconut fiber with other natural fibers was also shown in the study and based on the experimental results, it can be said that coconut fibers have excellent potential for building insulation materials.

**Acknowledgments**

This article was made in frame of the "EFOP-3.6.1-16-2016-00018 – Improving the role of research + development + innovation in the higher education through institutional developments assisting intelligent specialization in Sopron and Szombathely".

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УДК 674

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## EFFECT OF EXTERNAL TEMPERATURE AND CONDITIONS OF STEAMING KILN TO THE HEAT LOSS

*In wood technology the steaming is one of the most energy demanding process. The shortage of the treatment and the extra high temperature results that this technology has the highest specific energy consumption. The reduction of processing costs needs the reduction of energy consumption and on the other side this intention has an environment protecting effect too. Steaming of wood takes place in practice in steaming chambers. The heat loss of the chamber's wall can be measured with heat flow sensor and thermos vision camera. The sensors were fixed in different position on the wall and the fundation of the kiln. The foundation made of concrete and the walls is sandwich-structured composite with PUR and aluminum sandwich panel. Heat flow was measured 71.3 W/m$^2$ and 415.5 W/m$^2$ in average on the wall and the foundation respectively. The energy loss of the chamber was calculated by means of a Win Watt energy simulation software. The rate of heat loss varies by 40% as a function of insulation and the outside temperature, where 10 and 20 cm of thermal insulation and the temperature range of –5 °C to +10 °C with 5 °C steps were calculated. The possibility of using a heat exchanger to reduce the waste energy was studied also.*
***Keywords:*** *steaming, energy consumption, steaming chamber insulation/*

### Introduction

Steaming is most often used to change the unfavorable properties and color of wood (Majka and Olek 2007; Tolvaj et al. 2006, 2009; Taghiyari et al. 2011; Barański et al. 2017). Beside aesthetical result the steaming can decrease the shrinkage and dwelling of the wood as the effect of moisture change. On the steaming process the wood is warmed up in hot steam and keep in high temperature around 100 °C for 24 to 48 hours pending on the desired strength of steaming. Consequently, steaming has a large energy demand in a very short time, which means specific high energy demand, and expenses. The amount of energy used for steaming is influenced by several factors such as time of schedule, lumber's thickness, species, and density of wood, external temperature, type of steaming, and the condition of the chamber (Németh et al. 2013), and also the initial moisture content of the wood. In case of higher moisture content, the water has to be heated up to the steaming temperature which is very energy consuming taking into consideration the high specific heat of the water. It is almost three a half time higher than specific heat of wood, so to warm up energy amount of one kg water is equal to three and a half of wood. The steaming energy demand of drier wood is lower than wet wood.

Energy amount can be separated to three main part, 1) warming up the wood-water, and the chamber; 2) causing thermochemical changes in the wood structure in cell wall level; 3) heat loss. The ratio between this three main part is important from the aspects of energy efficiency. Only thermomechanical changes is the goal of the treatment; energies turned to heat up the materials and the heat loss are undesirable but necessary that is why reduction is needed.

The used energy is mainly thermal energy, which results high amount of $CO_2$ emissions. On the other hand, the transportation loss of steam in the pipe usually high, because of the high temperature difference of steam and the ambient. The heat loss can be separated to the heat loss of the chamber during the treatment and the heat loss of steam transportation. From this aspect the distance of steam source from the chamber is highly relevant.