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THE THERMAL CONDUCTIVITY OF SELECTED TROPICAL TIMBER SPECIES USING HOT BOX METHOD

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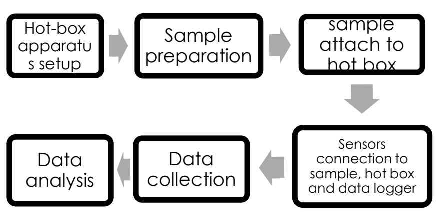
Graphical abstract



Abstract

In this study, thermal conductivity of selected tropical timber species was determined using hot box method. The test was conducted up until the heat flux, air temperature and surface temperature value at hot and cold chamber of hot box become constant. Each of the selected timber species represent hardwood and softwood as classified in MS 544: Part 2:2011. For this purpose, Chengal (Neobalanocarpus heimii – Dipteracarpaceae), Perupok (Lophopetalum spp. Celastraceae) Nyatoh (Sapotaceae) and Pulai (Alstonia spp. Apocynaceae) were tested. The thermal conductivity test was carried out based on BS EN ISO 8990:1996 standard. The thermal conductivity for Chengal, Perupok, Nyatoh and Pulai under steady state condition are 5.71 x 10^{-4}, 3.595 x 10^{-4}, 2.973 x 10^{-4} and 3.469 x 10^{-4} W/m^2K respectively. Higher thermal conductivity value is significant with high density of materials.

Keywords: Thermal conductivity, hot box method, steady-state conditions

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1.0 INTRODUCTION

Heat transfer within buildings is the result of temperature difference for internal and external building surroundings. The amount of heat that absorb through building materials depends on the thermal conductivity of the building materials.

Heat transfer through building causing the building internal temperature rising and to overcome this situation and to provide thermal indoor comfort, mechanical air conditioning system is the most common solution. The mechanical air conditioning system are one of the highest building energy consumption. Building energy consumption has become an important issues nowadays and improving energy consumption is a very important task.

Timber is a sustainable materials and considered as environmental friendly building materials due to the resource of timber can be replant. Study on the thermal characteristic of solid wood is important as these solid wood further integrated into composite materials such as wall[1]. Hot box method has been used to determined thermal analysis of inhomogeneous components [2]. Hot box method was recommended as a method to determine thermal analysis. Nussbaumer *et al*. [3] determined the impact of damaged vacuum insulation panel (VIP) on thermal performance. The VIP can attained 25% improved energy consumption and maximum of 50% energy reduction. Haavi and Jelle [4] via hot box method, studied the VIP but the components are wood frame walls. Baldinelli *et al.* [5] has done a holistic approach on investigating a wooden frame window. The window reported to has thermal transmittance of 1.64 W/(m^2K) which is a low value thanks to warm-edge spacer installed in the frame instead of aluminum spacer. Finally it is worth to mention in this hot box overview is the study done by Asdrubali and Baldinelli [2]. The study compared three standard which are European's EN ISO 8990, American's ASTM C1363-05 and Russian's

GOST 26602.1-99 in commencing hot box method. The value for thermal transmittance evaluation for aluminum frame window obtained from experimental following the three standard are very close.

Yapici *et al.* has done a study on the effect of grain angle to thermal conductivity on wood species and conclude the grain angle did not give much effect to the thermal conductivity as much as density had. [6]. Others then wood, Jalilluddin *et al.* also correlate the effect of density to thermal conductivity in the research done on sand-cement block with kenaf fibre and conclude the highest conductivity belongs to the sample with highest density [7].

The application of hot box method on timber species especially tropical timber species is important for further understanding on the thermal characteristic. Thermal analysis using hot box method is currently used worldwide. These method are commonly used for analyzing inhomogeneous material and also composite materials. Timber is considered as an inhomogeneous materials due to its uncertainty characteristic of the tree itself.

This research evaluated the value of thermal conductivity of selected tropical timber species using hot box method. The effect of density to thermal conductivity was also studied in this research. Due to the fact that the most important characteristic of timber is density because density correlate to mass. Handling high mass of timber need high energy either human energy or mechanical energy. However, there are some of others effect that are been neglected for examples, the effect of flanking heat lost, effect of thermal bridging, heat loss through metering area and the effect of timber grain angle.

2.0 EXPERIMENTAL

Malaysian timber species comprises of seven strength group (SG). Four types of species selected for these research are Chengal (Neobalanocarpus heimii – Dipteracarpaceae)(SG1), Perupok (Lophopetalum spp. Celastraceae)(SG4), Nyatoh (light and reddish timber of the family Sapotaceae)(SG5) and Pulai (Alstonia spp. Apocynaceae(SG7) [8].

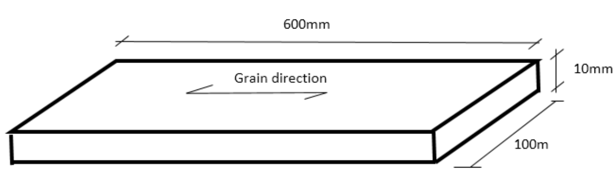

Figure 1 Specimen dimensions

The timber specimens as in Figure 1, were cut to dimension of 600mm length, 100mm width and 10mm thickness. The specimens were cut along the grain direction. Three samples were prepared for every timber species. The density and moisture content of samples are as shown in Table 1. Chengal has the highest value of density followed by Nyatoh, Perupok and Pulai. However Chengal has the lowest average moisture content value with 9.886% and Perupok has the highest average moisture content value with 10.533% followed by Nyatoh and Pulai with 10.121% and 9.995%.

Table 1 Moisture content and density of timber species

Strength group	Timber species	Density (kg/m^3)	Average moisture content (%)
1	Chengal	888.238	9.886
4	Perupok	494.232	10.533
5	Nyatoh	672.833	10.121
7	Pulai	416.758	9.995

Figure 2 illustrate the flow diagram of the overall testing procedure. The hot box test method followed the BS EN ISO 8990:1996 Determination of steady-state thermal transmission properties standard[9]. The hot box was made up of hot and cold chamber. The hot chamber are made from insulation material which is Rockwool and covered with layer of aluminium foil in the inside to provide a reflection and to retain the heat.

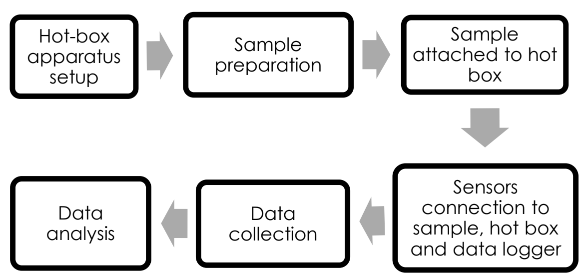

Figure 2 Flow diagram of the testing method

On the outside the Rockwoll was covered with Medium Density Fiberboard (MDF). The hot chamber heat sources are four numbers of 60 Watt light bulb. These light bulb can heat up the hot chamber until 60^{0}C to represent actual outdoor environmental conditions. Whilst the cold chamber are cold down by air conditioner which set the room to 22^{0}C until 24^{0}C. Figure 3 illustrate the setup of the hot box.

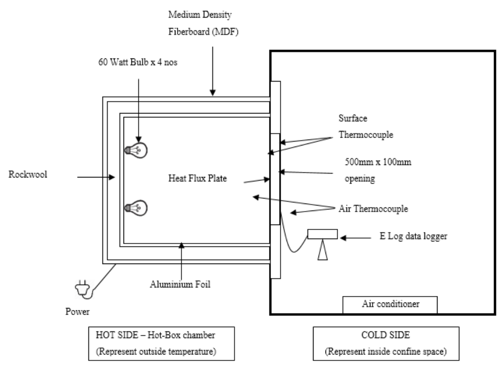

Figure 3 Scheme of the Hot-box setup

Figure 4 is the actual laboratory hot-box testing conditions. The timber specimens was fit in the opening between hot and cold chamber. The specimen's dimensions are bigger than the opening and gaps between opening and specimens are covered with aluminium foil to ovoid heat loss. Data collection using two sensors which are thermocouple and heat flux sensor. Thermocouple are mounted on the samples at hot and cold chamber to measure the surface temperature. Thermocouples are hang at hot and cold chamber to measure the air temperature. Heat flux sensor in this research HFP 01 manufactured by Hukseflux are mounted at samples surface perpendicular to the heat source in the hot chamber. All the sensors was connected to E Log data logger from LSI Lastem. Data was logged for every five minutes intervals, during the testing, the hot chamber was heated and the cold chamber was cold down, these conditions was last until steady-state conditions achieved. Steady-state was when air and surface temperature and the power input to the hot side chamber has come to constant.

Figure 4 Connection of sensors from the hot box setup to data logger

Prior to calculating thermal conductivity, others parameters that can be calculate are thermal transmittance and thermal resistance. Thermal transmittance or commonly known as U-value is an important value in evaluating insulation materials. The U-value can be calculated using (*1*. Equation 1 also known as The Fourier law equation which is widely use in the thermal transfer analysis.

Thermal transmittance (*1* :

$$U = \frac{Q}{A(T_1 - T_0)} \quad (1)$$

Where :

Q = heat flow rate (W)
A = Area perpendicular to heat flow (m^2)
T1 = Temperature interior, hot side (K)
T_0 = Temperature exterior, cold side (K)

After U-value was calculated, thermal resistance and thermal conductivity value were calculated using (*2* and (*3*.

Thermal resistance (*3*:

$$R = \frac{1}{U} \quad (2)$$

Thermal conductivity (*3*:

$$K = \frac{d}{R} \quad (3)$$

Where :
d = Specimen thickness (m)

The moisture content for the samples was calculated via oven dry method following the MS 837: 2006[10]. (*4* was used to calculate the moisture content.

Moisture content is calculate using this (*4*:

$$mc = \left(\frac{m_i - m_{od}}{m_{od}} \right) x100\% \quad (4)$$

where,

m_i = the initial mass, in grams of the test specimens or section
m_{od} = the mass in grams of oven-dry test specimens

Data for each test were statistically analysed using SPSS for each timber species. ANOVA from SPSS was used to analyse the significance difference between time and heat flux. Based on the statistical analysis, the variance analysis were statically significant.

3.0 RESULTS AND DISCUSSION

Experimental heat flux value are as Figure 5 for the selected timber species. Steady-state conditions was reach approximately 300 to 400 minutes six of testing when the heat flux, air temperature, surface temperature at hot and cold chamber become equilibrium or constant. At the moment the condition become steady-state, it was recorded that Chengal has the highest value of heat flux, and lowest is Perupok.

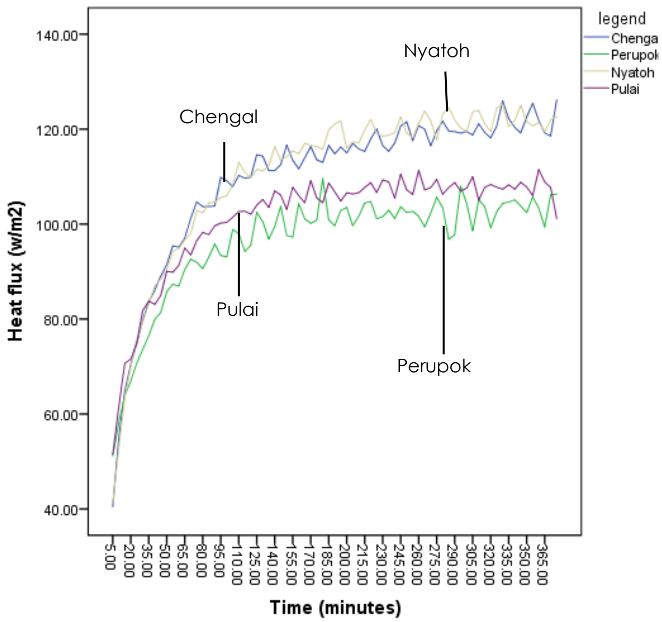

Figure 4 Heat flux (w/m2) on the timber species

To estimate the thermal conductivity, it was important to find adequate steady-state condition during the testing period. From the steady-state data collected, a linear regression to find the most close to zero value of slope. The heat flux was calculated based on linear equation under steady state condition. The linear equation of samples tested are as shown in Equation 5, 6, 7 and 8.

Chengal

$$y = 0.0348x + 109.6 \quad (5)$$

Perupok

$$y = 0.0118x + 99.37 \quad (6)$$

Nyatoh

$$y = 0.0238x + 114.12 \quad (7)$$

Pulai

$$y = -0.0017x + 108.18 \quad (8)$$

Figure 6 shows the temperature for cold surface logged until steady state conditions. The time for the temperature to reach steady state was between 300 to 400 minutes. Surface temperature at the cold chamber for the timber species increase gradually with Perupok, Pulai ang Chengal have almost the same value. Whilst the temperature for Nyatoh at steady-state was the lowest among others.

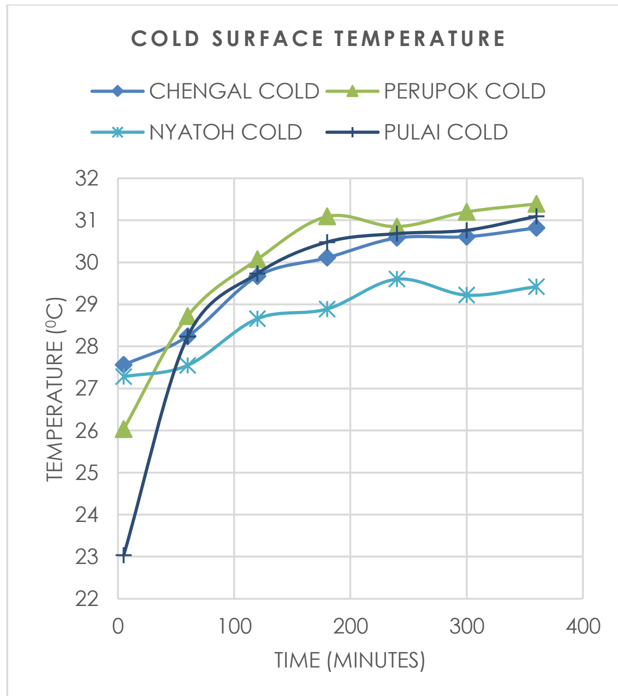

Figure 5 Surface temperature in cold chamber

Figure 7 is the surface temperature at hot chamber. The temperature difference between samples at steady-state has bigger difference among each other's compared to the conditions at cold surface. Perupok was recorded to has highest value and Chengal was the lowest.

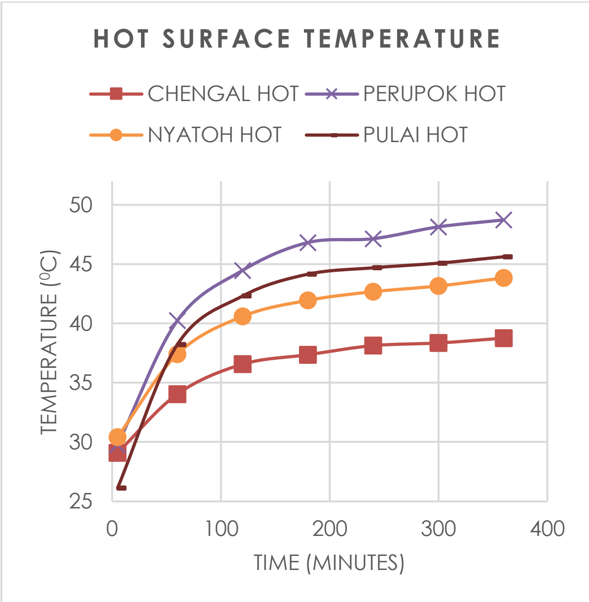

Figure 6 surface temperature at hot chamber

Figure 8 is the air value in the cold chamber during the procedure. At zero minutes the temperature was decreasing due the fact the air conditioning system was just turn on and the temperature starts to become constant at 100 minutes.

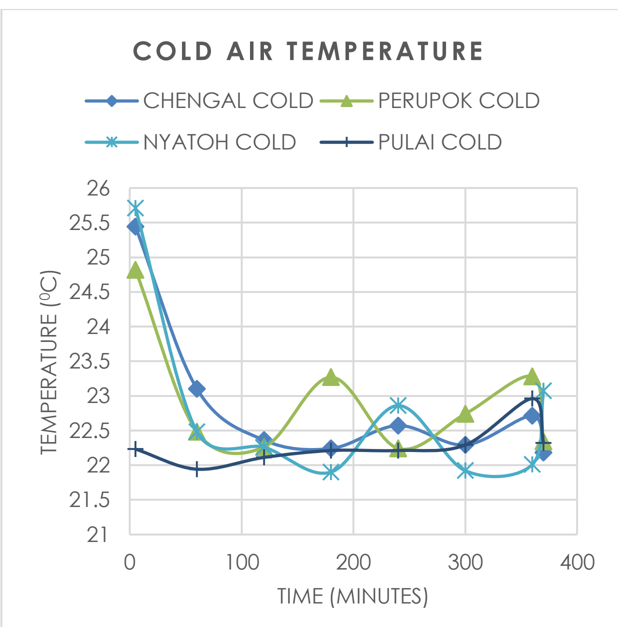

Figure 7 Air temperature in cold chamber

Figure 9 is the hot air temperature at hot chamber. The temperature shows a same increasing pattern for all samples. This is from the heating has the same value which the four numbers of 60 watts light bulb.

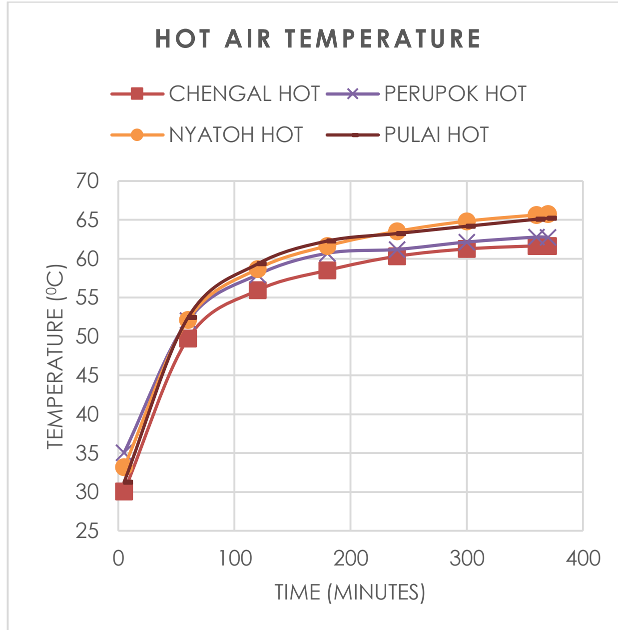

Figure 8 Air temperature in hot chamber

The temperature difference was then calculated in Kelvin and applied in (1 to get the thermal transmittance value. Further (2 and (3 was used to calculate the thermal conductivity. Results gathered from the hot-box experimental testing are listed in Table 2 and Figure 10.

It was observed that thermal conductivity for Chengal, Perupok, Nyatoh and Pulai are 5.71 x 10^{-4}, 3.595 x 10^{-4}, 2.973 x 10^{-4} and 3.469 x 10^{-4} w/m²K. It is obvious that Chengal has the highest thermal conductivity and also the highest density. Chengal's thermal conductivity value is also significant with the surface temperature at hot chamber that the surface temperature is the lowest. The Perupok, Nyatoh and Pulai thermal conductivity value was found not significant to their density. However, Nyatoh has the lowest thermal conductivity value, this value was found significant with the surface temperature in cold chamber that Nyatoh has the lowest value.

Table 2 thermal transmittance and conductivity value

Timber species	Thermal transmittance (w/m²K)	Thermal conductivity (w/m²K)
Chengal	0.0571	5.71 x 10^{-4}
Perupok	0.0360	3.595 x 10^{-4}
Nyatoh	0.0297	2.973 x 10^{-4}
Pulai	0.0347	3.469 x 10^{-4}

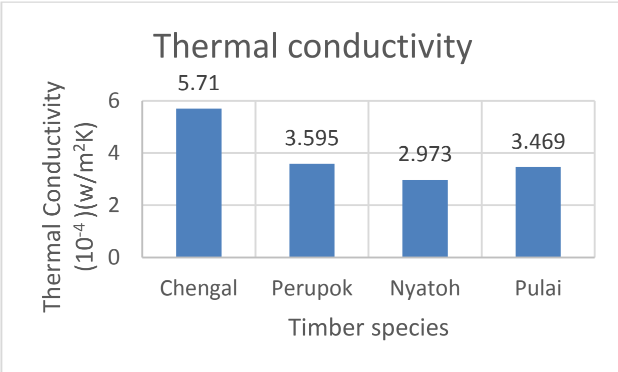

Figure 9 Thermal conductivity value for the selected timber species

4.0 CONCLUSION

An experimental study was conducted to determine the thermal conductivity of some selected tropical timber species using hot box method under constant temperature also known as steady-state conditions. The following conclusion was made based upon the data gathered and analysis done:

1. Thermal conductivity for Chengal, Perupok, Nyatoh and Pulai are 5.71 x 10^{-4}, 3.595 x 10^{-4}, 2.973 x 10^{-4} and 3.469 x 10^{-4} w/m²K. Chengal has the highest thermal conductivity value and lowest is Nyatoh.
2. Thermal conductivity is correlated with density. This was proven by Chengal that has the highest density values hence has the highest conductivity value.
3. Thermal conductivity was significant with surface temperature at hot chamber. Highest thermal conductivity can retain the temperature value of the samples that was subjected to heat.
4. Steady-state or constant temperature was reach at 300 to 400 minutes.

Acknowledgement

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