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Energy Efficiency in Green Building Materials Application for Low-Energy Indoor Eco-Friendly

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World environment climate has changed toward unpredictable weather where average global temperature has increased up to 0.74°C since 1906 until 2005 [1]. This increment is an indication of more heat from the sun is penetrated to our primary protector which is the ozone layer. Due to this scenario, the secondary protector in the forms of the buildings should play major roles in giving comfort to the human. This is where the thermal conductivity of the building material becomes an important matter to study. Thermal conductivity or k-value of solid material describes the ability of heat being transferred through conduction. High k-value describes the material as highly conductive from one point to another. In other words, high k-value material easily allows the heat transfer to pass through it, as such indicating that this is not a good property for building material. The design thickness is very crucial where it will impact the cost of producing green materials. Thicker brick uses more amount of material and hence, it increases the production cost. The requirement on heat resistivity is very important for a building to prevent the building to be hot and uncomfortable. Unlike the clay brick wall and concrete wall, the U-value for green material wall is very low and it can block the entry of large amounts of heat and thereby cooling the building.

Keywords: *green building materials, k-Value, U-Value, design thickness and heat resistivity*

1. INTRODUCTION

The wall of a building is the exterior finish or shade which functions as the main protection to reduce the absorption of heat from the sun into the building. Many materials for example concrete, clay brick, sand block, block, glass and others can be used to construct walls Conventionally, concrete and bricks are the main materials for constructing walls in this country.

Concrete wall has a natural property of absorbing high amount of heat during daytime and releasing a high amount of heat during the night. This means that concrete has a low level of heat resistance. In the physics of thermal conductivity, the k-value of concrete density is 1.0 – 1.8 W/m/K, where the k-value of concrete is high as compared to wood where its k-value is 0.15 – 0.17 W/m/K [2]. This means that wood is a material of high heat resistance. Therefore,

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it is important to find a construction material that is suitable to the needs and climate of Malaysia which is hot and damp all year, where the walls will be exposed to sun radiation all day long.

In the construction industry, the heat resistance on walls is in the R-value (thermal resistance) in unit $K.m^2/W$ and the u-value (thermal transmittance) is in unit $W/K.m^2$. the R-value is an inverse to the U-value, where R = 1/U. The u-value is obtained depending on the wall thickness where U = k/d, d being the thickness (depth) of the wall and k is the k-value for that particular material [3]. Besides that, the amount of heat absorption during daytime can be reduced by using finishes or materials that have a good heat resistivity. Finishes with good resistivity help reduce the heat gain into the building. There are various finishes that have good heat resistivity including gypsum, perlite, mineral wool among others [4]. Plastics have different characteristics where they are lightweight, and diverse in colour and shape. However, plastics are not the main material for building envelope. They may only be used as a form of finishing.

Glass is widely used in our country. Most new buildings make use of glass facades. Glass actually has a high heat transmittance rate when used as a building envelope. Therefore, they will usually be layered with solar screen. This solar screen is used to avoid a high heat absorption into the inside of the building.

2. PROBLEM STATEMENT

Currently, global warming is becoming more serious as a result of the ozone layer depletion. The high temperature of the areas outside the building's surrounding will influence the entry of heat into the building. The warm temperature inside the building causes the use of air conditioner to lower the inside temperature. However, the use of air conditioning will increase the utility cost and the usage of air compressor.

In addition, the use of non-green air conditioning system will release the chlorofluorocarbon (CFC) gas that is the main contributor to the ozone depletion. Thus, the use of green construction material especially for the walls of buildingthat receive the utmost sunlight and heat absorption into the building is very timely and encouraged?

The building envelope is a critical component of a building as it plays an important role in protecting the buildings and the occupants in them. It is also a building component that protects the building from cold or hot weather, depending on the local climate. A building envelope consists of the exterior wall, roof, door, and window [5]. Moreover, a building envelope controls the heat movement between the building's exterior surface to the interior surface.

In addition, it consists of structural elements and the enclosed space that separates the outdoor from the indoor area of that particular building [6]. A good building envelope has to be able to balance temperature, thermal heat, and moisture between day and night time [7]. Therefore, the performance of the building envelope is important in increasing the thermal comfort and energy efficiency of the building.

The materials selection has to take into consideration the local climate in order to achieve a satisfactory building envelope besides prioritising important factors which are safety, durability, and cost. Every building envelope may be made from different materials, suitable

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for the location it is used in. This research on building envelope is carried out based on the energy efficiency aspects with relation to steps in minimising energy usage in the building and indirectly minimising the introduction of heat into the building.

3. CONSTRUCTION MATERIAL AND U-VALUE

The conservation of natural resources, reduction of greenhouse gas emissions and protection of the environment have become important issues in modern construction development. These factors have urged the construction industry to shift their production methods toward more sustainable models. To achieve this objective all stakeholders and parties involved should be encouraged to be creative and efficient in their use of materials. The careful design of appropriate eco-friendly building materials has an important role in helping builders or stakeholders to start integrating sustainable design concepts [8].

However, the price is still the primary consideration in selecting construction materials because it influences the profit of construction companies. This research seeks to explore the ways in which the quality of building materials can be improved with consideration to sustainability.

Building material selection for its envelope is crucial to avoid excessive heat intrusion into the building. The needs and understanding towards heat flow through material is a must to match the building with the local climate. For the all-year hot and humid climate in Malaysia, materials that have high heat resistance is necessary to protect the building from excessive heat intensity.

Therefore, the thermal conductivity through material or better known as the k-value must be understood. Failure of the building designers in using suitable materials may result in faster heat introduction into the building. The k-value of insulation materials is the important property that is of interest when considering thermal performance and energy conservations measures [9]. ASTM standards C168-97, define k-value (unit: W/mK) as the time rate of steady state heat flow through a unit area of homogeneous material induced by unit temperature gradient in a direction perpendicular to that area [10]. The physics of thermal conductivity or k-value is the ability of the material to conduct heat. There may be two situations when a certain temperature is introduced to a material [11]:

i. Heat sink (high thermal conductivity)
ii. Heat resistance (low thermal conductivity)

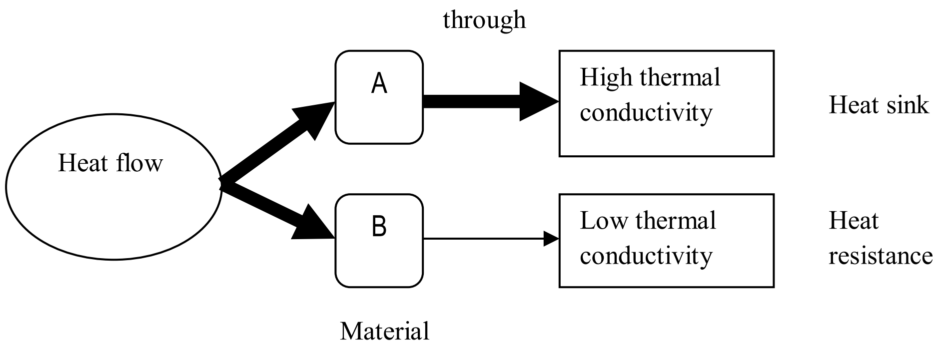

Figure 1: Comparison of thermal conductivity between heat sink and heat resistance

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Figure 1 shows the comparison of thermal conductivity between heat sink and heat resistance. Heat flows at a faster rate should a certain temperature be introduced to Material A, where the thermal conductivity rate is high. On the other hand, when the heat of a certain temperature is introduced to Material B which is of low thermal conductivity, heat flows slower. This shows that Material B has a higher thermal resistance as compared to Material A. therefore, it is known that a lower k-value means the material has a higher thermal resistance towards heat.

The better the quality of heat acquisition prevention, the better its resistive value [12]. It is preferable to have a low u-value in hot climates because it can substantially bring down the heat gain and hence the cooling load [13]. In the construction industry, suitable material selection for heat resistance is necessary to avoid heat introduction into the building. Usually, the R-value (thermal resistivity) unit: Km^2/W and u-value (thermal transmittance) unit: W/m^2K are used to calculate the rate of heat flow into the building [10]. For a wall of the building, the R-value is obtained when the thickness of materials and their k-values are available. This is because the R-value is:

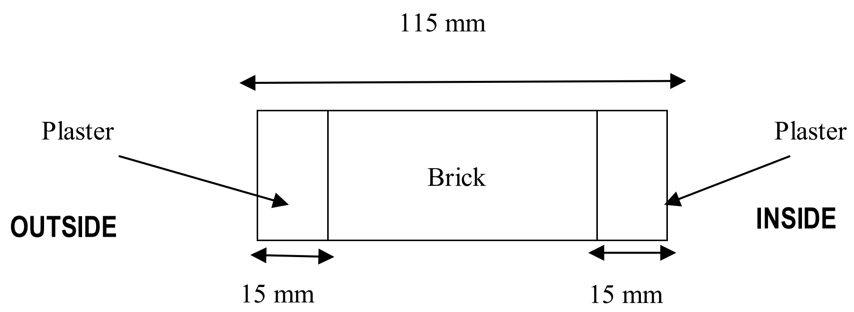
$$R = \frac{d}{k}$$

where	R	= thermal resistivity Km^2/W
	d	= material thickness, in m
	k	= k-value, in W/mK

This means that the R-value of the wall is related to the thickness and k-value of the material. When the R-value is high, the thermal resistivity is better, or the prevention of heat introduction is working. The R-value is also related to U-value because the R-value is a reciprocal of the u-value:

$$R = \frac{1}{U} \quad @ \quad U = \frac{1}{R}$$

The U-value is already known to be the reciprocal of R-value, where it is influenced by the thickness and k-value of the materials used. Thickness and k-value of the material will increase or decrease the U-value. The suggested limits for the U-values for walls and roofs of buildings in the warm climate countries are between 2.0 to 2.8 W/m^2K and 0.7 to 1.1 W/m^2K respectively [14]. Figure 2 shows that usually in Malaysia, for a brick wall of 115mm thickness, the 15mm layer of plaster on the inside and outside each have a U-value of 2.43 W/m^2K [15].



U-value = 2.43 W/m²K
Figure 2: Typical U-value in Malaysia

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Therefore, it is necessary to reduce the U-value to produce a good and effective heat prevention [16]. The selection of building material with low k-value and high wall thickness will influence the u-value. The U-value equation is as follows:

$$U = \frac{1}{Rt}$$

$$R_t = R_o + \frac{d1}{k1} + \frac{d2}{k2} + \ldots\ldots\ldots\frac{dn}{kn} + R_i$$

where

U = thermal transmission (u-value), in W/m²K
R_o = thermal resistivity of air outside, in Km²/W
R_i = thermal resistivity of air inside, in Km²/W
d = material thickness, in m
k = thermal conductivity (k-value), in W/mK

4. METHODOLOGY

The Hilton B480 Thermal Conductivity of Buildings & Insulating Materials Unit shown in Figure 3 was used to measure the thermal conductivity of the different manufactured specimens. The apparatus consists mainly of an insulated fiberglass hinged enclosure. The base section of the closure contains the heat flow meter and the cold plate assembly and mounted on four springs.

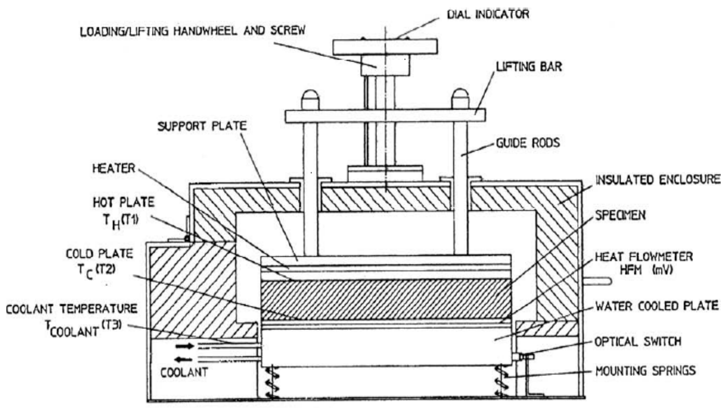

Figure 3: Cross-Sectional diagram of the B480 heat flow meter apparatus (P.A. Hilton Ltd.).

The plate is cooled with water to maintain it at a constant temperature. The enclosure lid houses the electrically heated hot plate, which is electronically controlled for setting the required temperature. A computerized system is used to determine and display the measured values of thermal conductivity.

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The faces of the enclosure are insulated to ensure an adiabatic boundary condition and to ensure that all faces of the specimen are not in direct contact with the hot and the cold plates.
Equipment: The Hilton B480 Thermal Conductivity of Buildings & Insulating Materials Unit.
Test Standard: International Standard for Steady State Measurement, ISO 8301. For the determination of the thermal conductivity, the specimen of 16.5mm is positioned between the hot and the cold plates and adjusted until the test position lamp illuminates to denote that the correct pressure has been applied. The determination of the thermal conductivity of the specimen requires the measurement of the following four parameters:

- The hot plate temperature (TH) , is set at 45ºC
- The cold plate temperature (TC), in °C
- The heat flow meter (HFM) output in (mV)

The values of TH, TC and the heat flow meter output are taken after the steady state condition has been reached. This state is reached when the difference in five consecutive readings at sampling interval gives values of thermal resistance to within (1%) without changing monotonically in one direction. The sampling interval is stated in, ISO8301, as ts=ρ.Cs. Ls. R or 300 s, whichever is the greatest, where ρ is the density in (kg/m3), Cs specific heat in (J/kg.K), Ls the thickness in (m) and R is thermal resistance in (m2.k/W) of the specimen.

The k-value is calculated based on the Eq. 1 below:

$$k = \frac{t \times [(k_1 + (k_2 \times T_{ave})) + (k_3 + (k_4 \times T_{ave})) \times HFM + (k_5 + (k_6 \times T_{ave})) \times HFM^2}{dT} \quad \text{.........Eq. 1}$$

Where;
t is thickness,

Tave = (T2+T1)/2
dT = T1-T2
k1 = -12.0723
k2 = 0.0849
k3 = 2.0949
k4 = 0.0048
k5 = 0.0022
k6 = 0.0001

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5. RESULT AND ANALYSIS

Table 1: Result k-value Block Fibre

Time	T1	T2	T4 (mV)	k (W/mK)	%diff
925	44.7	24.8	7.25	0.005709	
930	45.1	25.7	13	0.016505	65.41112
935	45.3	27.4	19.84	0.032124	48.62302
940	45.2	28.2	22.13	0.03898	17.58656
945	45.3	29.2	24.05	0.045838	14.96283
950	45.1	29.6	25.79	0.051965	11.79037
955	45.2	30.3	29.23	0.063189	17.76278
1000	45.2	30.7	32.23	0.073207	13.68399
1005	44.8	31.1	36.62	0.090411	19.02835
1010	45.1	31.4	37.37	0.092777	2.551021
1015	45.3	31.7	36.62	0.091315	-1.60161
1020	45.2	31.8	36.08	0.091034	-0.30866
1025	45.1	32.1	36.34	0.094695	3.866665
1030	45.4	32.2	36.94	0.095209	0.539105
1035	45	32.4	37.32	0.100931	5.669169
1040	45.2	32.5	37.79	0.101728	0.78334
1045	45	32.6	38.44	0.106322	4.321281
1050	45.1	32.7	39.11	0.108604	2.101623
1055	45.3	32.7	39.6	0.108543	-0.05704
1100	45.1	32.7	39.81	0.110943	2.164084
1105	45	32.6	40.22	0.112264	1.175932
1110	44.9	32.9	40.53	0.117135	4.159096
1115	44.9	32.8	40.68	0.116656	-0.411
1120	45	32.8	40.93	0.116581	-0.06409
1125	45.1	32.8	41.03	0.116	-0.50108
1130	44.9	32.8	40.94	0.117551	1.319732
1135	44.9	32.9	41.02	0.118837	1.08193
1140	45.1	32.9	41.26	0.117766	-0.90969
1145	45.1	32.9	41.05	0.117047	-0.61417
1150	45	32.9	41.09	0.118124	0.912077
1155	45.1	32.9	41.16	0.117423	-0.59691
1200	44.9	32.9	41.28	0.119741	1.935939
1205	45	32.9	41.19	0.118469	-1.07383
1210	44.9	32.8	41.16	0.11831	-0.13486
1215	45.1	32.9	41.13	0.117321	0.68394
1220	45.2	32.8	40.3	0.112638	-4.15693
1225	44.9	32.8	40.4	0.115693	2.640113
1230	44.9	32.8	40.6	0.116381	0.591021

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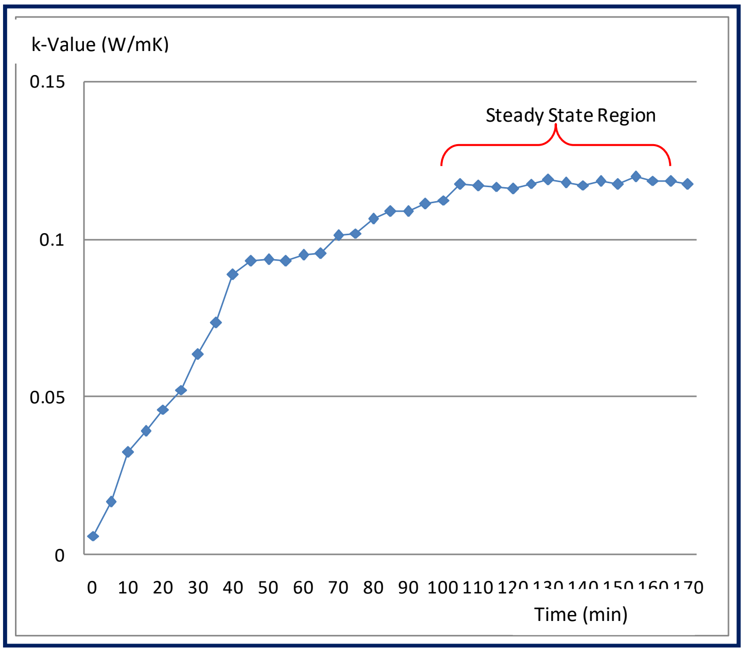

Figure 4: Result k-value vs. Time

Table 2: Steady state data

Time (min)	k-value	% difference
130	0.118837	1.08193
135	0.117766	0.90969
140	0.117047	0.61417
145	0.118124	0.91208
150	0.117423	0.59691
155	0.117834	0.34871
160	0.118469	1.07383
165	0.118310	0.13486
170	0.117321	0.84299

Table 1 shows result k-value of Block Fibre. The steady state condition is achieved at the range of 105 to 170 min based on Figure 4, in which a monotonically direction is observed. The data at 130 min to 170 min in Table 2 shows that the k-value obtained is in the 1% stability, where this is the region of acceptable k-value. The average k-value of obtained is 0.117 W/m.K. Table 3 shown the comparison of this Block Fibre with other construction materials. It is found that the Block Fibre is better than the other materials. And with this improvement k-value, the building built by this material should be cooler due to the less heat transferred into the building.

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Table 3: Comparison of Block Fibre with other construction material [2]

Material	k-value (W/m.K)
Block Fibre	**0.117**
Concrete	1.0
Cement, Portland	0.29
Brickwork	0.7
Brick dense	1.31 - 1.6

From the k-value obtained, it is found that k-value of Block Fibre material is lower than other conventional building materials. In comparison with other building materials, the Block Fibre has a lower thermal conductivity and higher insulation rate . In fact, the Block Fibre is six (6) times colder than the ordinary clay brick.

For a normal tropical climate like Malaysia, building materials that have been used must have a high insulation rate to avoid excess heat absorption inside the building area. Excessive heat inside the building will increase the interior air temperature and bring a hot and stuffy condition to the present occupants.

Therefore, a low k-value's material is necessary to prevent the absorption of excess heat into the building and then cool the building. Hence, the Block Fibre material has low k-value compared with other building materials such as clay brick and concrete. The use of Block Fibre will be able to prevent the entry of large amount of heat through the walls and then cool the interior part of building.

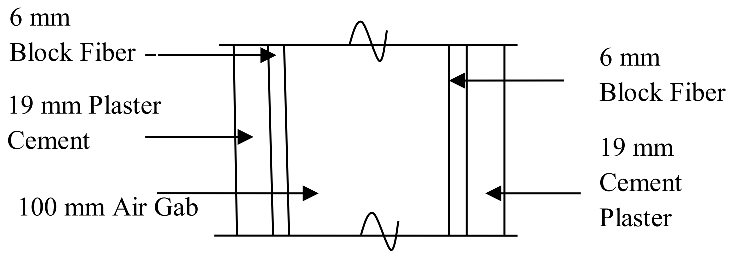

Figure 5: Cross-Sectional Detail of Block Fibre Wall

Table 4: R-Value Block Fibre

Component	t/k	R
Outside Air Film		0.044
Plaster Cement	0.019 0.533	0.036
Block Fibre Wall	0.006 0.117	0.051
Air Gap	0.16	0.16
Block Fibre Wall	0.006 0.117	0.051

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Plaster Cement Inside Air Film	<u>0.019</u> 0.533	0.036 0.120
Total R		**0.498**

R-Value = 0.498 m²K/W

U = 1/R
= 1/0.498
= **2.01 W/ m² K**

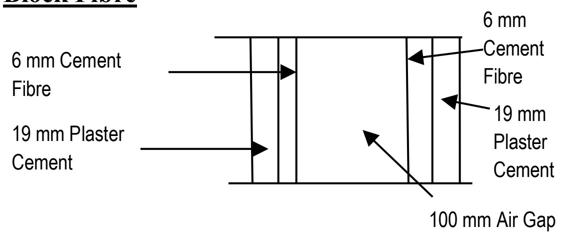
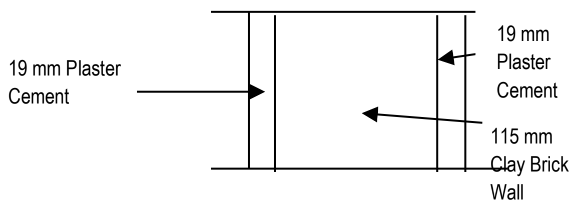
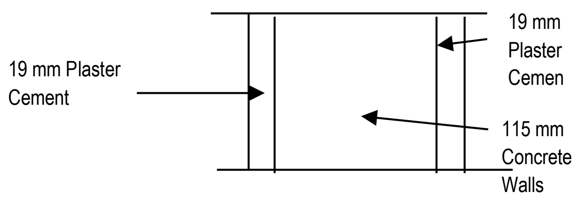
<table>
<tr><th>Wall</th><th>U Value (W/m²K)</th></tr>
<tr><td><u>Block Fibre</u>

</td><td>2.01</td></tr>
<tr><td><u>Clay Brick</u>

</td><td>2.50</td></tr>
<tr><td><u>Concrete</u>

</td><td>2.85</td></tr>
</table>

Figure 6: Comparison of U Value For Block Fibre Wall Against the Clay Brick Wall and Concrete Wall

Based on Figure 6, in the application of a wall building, U-Value obtained for Block Fibre is lower than clay brick wall and concrete wall. It shows that the Block Fibre has a high insulation rate towards heat absorption inside the building. The requirement on heat resistivity is very important for a building to prevent the building from being hot and uncomfortable. The U-value for Block Fibre wall is very low and it can block the entry of large amounts of heat and thereby cool the building rather than the wall construction made of clay brick and concrete.

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6. DESIGNING A COLD BUILDING

The design of cold building can be related to Eq. 4 where a building should receive minimal heat from the radiation of sun's energy. For a material which has an identified k-value, the thickness of the brick dense will play important role in reducing heat conduction. The design thickness is very crucial where it will impact the cost of producing brick-dense. A thicker brick uses more amount of material and hence, it increases the production cost. An oversize brick-dense will only increase the production cost with no effect to cold a building. The effective design can be achieved by considering the duration of heat that is exposed to the building in a day and it should be noted of the various designs and heat exposure for different regions in the world.

For the hot and humid climate throughout the year, such as in Malaysia, it is necessary for building materials used to have a higher insulation in order to avoid absorption of excessive heat into the building. The absorption of excess heat into the building causes the building to be warmer. Therefore, a material with low k-value is needed to prevent the absorption of excess heat into the building and then cool the building. k-value is given in the unit of W/m.K and it is derived from combination of Eq. 2 and Eq.3 which is finally forming Eq. 4

$$Q = U.A.dT \quad \ldots\ldots\ldots\ldots\ldots \quad [Eq.2]$$
$$U = 1/(t/k) \quad \ldots\ldots\ldots\ldots\ldots \quad [Eq.3]$$
$$Q = k.A.dT/t \quad \ldots\ldots\ldots\ldots\ldots \quad [Eq.4]$$

Where U is, overall heat transfer coefficient, A is surface area, dT is differential temperature and t is the wall thickness.

7. CONCLUSION

A good wall is a wall that can prevent the entry of excess heat into the building. Materials that are used to build the wall also influence the heat entry rate into a building. K-value and U-value are two matters which are closely related, whereby a thicker material will yield a lower U-value of a certain material. The lower the U-value of certain construction materials, the better the value of insulation and its quality of heat absorption prevention.

Based on the application of wall building, U-value obtained for Block Fibre is lower than clay brick walls and concrete walls. It shows that the Block Fibre has a high insulation rate towards heat absorption inside the building. The requirement on heat resistivity is very important for a building to prevent the building from becoming hot and uncomfortable. U-value for Block Fibre wall is very low, and it can block the entry of large amounts of heat and thereby cool the building as compared to use of the clay brick wall and concrete wall.

Thus, the Block Fibre is an important green material that needs to be considered by any building designer to gain a more efficient energy usage of a building and achieve a good usage of a low-energy eco-friendly indoor. Not only that but the choice of this particular material will also lead

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to a positive impact on the aspect of air-conditioning choices, operation in the building and finally with a continuous maintenance, it will create a more efficient energy usage in a building.

From the k-value obtained, it is found that k-value of Block Fibre material is lower than other building materials upon a conventional building material. Significantly, the Block Fibre has a lower thermal conductivity and higher insulation rate when compared with other building materials. The Block Fibre is six times colder than an ordinary clay brick. For a normal tropical climate like Malaysia, the building materials selected must have a high insulation rate to avoid the excessive heat absorption inside the building area. After all, the excessive heat inside the building will only increase its interior air temperature and will bring a hotter condition to its occupants. Therefore, a low k-value's material is necessary to prevent the absorption of excessive heat into the building and in turn helps cool the building.

Hence, the Block Fibre material has a lower k-value compared with other building materials such as clay brick and concrete. It is of importance that by opting for the Block Fibre as the building material, the excessive heat via the walls can be easily avoided and therefore, resulting in a cooler interior part of the building.

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