Time-lag Analysis of Potential Waste Materials as Thermal Insulation in Tropical Climate: A Preliminary Investigation

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Abstract. Energy consumption has shown that residential building is among the main contributors of energy demand. Besides, the harsh climatic conditions have causes substantial amount of energy which contributes indirectly towards the impact on carbon emission to the nations. Hence, this research utilised the potential agricultural wastes materials that is potential for insulate the thermal building performance. The outer and inner surface temperature has been measured on selected seven (7) type of wastes material from agricultural and processing sector every 30 minutes from 0900hr to 1800hr for a day in order to determine the decrement factors (DF), average daily time-lag for heat transfer as one of the thermal insulation properties. Results on the time-lag for all selected potential waste materials as thermal insulation whereas sugarcane bagasse is the lowest 107.5 minutes, followed by both coffee grounds and coconut husk with 130 minutes and wood wool with 132.5 minutes. Meanwhile, empty fruit bunch, coconut fibre and pineapple leave with time-lag of 140 minutes, 142.5 minutes and 145 minutes respectively are the highest time-lag occurred. Generally, the lowest T$_{is}$ is the better the thermal performance therefore, coconut fibre with smaller DF, larger LT but slightly higher T$_{is}$ than EFB (32°C) which is 32.2 °C might be the suitable material use as thermal insulation.

1. Introduction

Regarding to energy and climate policy for 2030, the European Union (EU) has definite objectives to be achieved including the main objectives, which are to reduce 40% of emission of greenhouse gas, to raise up to 30% of renewable energy and to develop the energy system as well as impact on energy price. The usage of bio-waste for energy production to replace wind, water and solar energy will be accepted widely EU and world as well as can reduce the waste disposal to dumping area [1].

Towards approach for material replacement empowerment and waste utilization study on reducing emission is different from energy sector as is its high carbon footprint. Meanwhile, construction sector with developing economics often undergoes rigorous scrutiny. Increasing infrastructural growth has

required high demand and production for Portland cement and emission of CO_2 to atmosphere during its production is higher and will endangered the environment. This led to study on the better alternative without polluting environment or taxing demand for natural minerals [2].

Energy consumption in the construction sector can reach up to 40% of the world's total energy demand. This was the reason why a lot of attempts were made in the construction sector to boost energy efficiency. Research focusing on building envelope isolation are performed, which helps reduce annual energy usage and air-conditioning system capacity [3].

2. Literature Review

2.1. Wastes Valorization
For millennia construction was a major human activity and one of the most important sectors of production. However, in terms of energy consumption, use of natural resources and environmental pollution, developments in the manufacture of building materials as well as in the construction industry in general have a significant impact on the environment. In fact, the fabrication of building materials uses 24% of the extracted raw materials from the lithosphere, which will only increase in the next few years as there will be an increase in both world and developing country population. Several studies have demonstrated that the current state of the construction industry is not long-term sustainable. The use of partially recycled material, i.e. waste, byproducts and end of life products both in the building and in other sectors, is one way to address this issue [4].

The process to valorized waste into more useful products is a good way of dealing with waste management and thus of increasing competition in bio-refineries in which a wide range of products can be obtained using waste as feedstock [5]. Increasing attention is focused on the use of waste and by products since, over and above the decline of raw materials used, the issue of waste generated by modern society is being tackled progressively. In 2010, data showed that waste generation in the European Union was 2.5 billion tonnes, 25% higher than in 2006 therefore, reuse or valorisation of these wastes could be a profitable way to solve this problem [4].

The application of spent coffee ground (SCG) as an additive was also examined in the production of bricks. Munoz et al. designed SCG bricks and found bricks that still have a compressive strength of over 17% SCG waste above 10 N/mm^2, so they could be used structurally. The thermal conductivity of these bricks was also lower (reduced by 50%), making it better insulators than regular bricks. There was a test on bricks partially composed of SCG, and found that up to 10% SCG still had the highest grade of mechanical standards, and the addition of 20% decreased thermal conductivity by 70% [6].

Agricultural wastes such as oil palm, pineapple eaves, sugarcane bagasse ash, fly ash, kraft pulp, coconut coir, rice husk, rice straw, kenaf, jute, hemp, corncob and sawdust were used in production of cement-based composites. The fibre content increases, despite reduced compressive and flexural strength of the material. A study has shown that the mechanical characteristics of clay brick produced by oil palm fruit and pineapple leaves have achieved the minimum requirement for conventional bricks and fibre addition reduces brick density. It is also found that the composite of recycled urban sewage sludge, bagasse and sludge provided high compressive strength values and improved thermal conductivity by 19 percent, while the bricks meet the water absorption and compressive strength requirements [7].

2.2. Thermal insulation Properties
Wall configuration (masonry structure), insulating material (type and thickness), indoor conditions like thermostat settings, and climate influence heat transmission. Climate conditions include: temperatures of outdoor air, sky and surroundings, relative humidity, wind speed, solar radiation, and cloud cover. In addition, the properties of outer surface radiation play an important role in determining the transmission load. In contexts of optimal insulation thickness, a number of economic parameters are also involved, including: the cost of insulation material and its installation, electricity costs, building lifetime, AC system performance coefficient, heating system performance factor, and inflation [8]. Insulation is more important in environments with extreme seasonal variations and small daily variations while the building's thermal mass plays a greater role in matching indoor temperatures with large diurnal ranges

in hot-dry climates. Nonetheless, different exposures might require different time lag values in order to balance the thermal effects of outdoor temperatures on the indoor environment [9].

The time lag was also found to increase almost linearly with increasing insulation thickness and that the decrement factor decreased in a roughly hyperbolic fashion [8]. In order to perform passive cooling strategy in hot- humid environment, building materials for houses need to have less thermal mass to result in shorter time lag between outdoor and indoor air temperature [10]. It is important to mention that the thickness of any shell shall not be less than 11 mm and that of any web not be less than 8 mm to maintain strength of the structure.

This criterion is used in the current investigation as a constraint to satisfy the minimum requirements to sustain the entire structure [11]. The best overall performance was achieved by a wall with three layers of insulation, each 26-mm-thick, placed at inside, middle and outside. This was closely followed by a wall with two insulation layers, each 39-mm-thick, placed at middle and outside [8]. Comparing performance of the best wall with that of a wall with one layer of insulation (78-mm-thick, placed on the inside), the following improvements were achieved: 100% increase in time lag from 6 hours to 12 hours; 10 fold decrease in decrement factor; 20% decrease in both peak cooling and heating transmission loads, and 1.6% and 3.2% decrease in yearly cooling and heating transmission loads [8].

It can be suggested that greater material density and thermal conductivity contributed to its longer time lag in releasing heat. In addition, it was observed that the outdoor air flow, particularly during the night, has no effect on reducing the indoor ambient temperature of the houses [10]. It is understood that radiation heat transfer effects become significant when the temperature difference between the surfaces is high, or when compared with natural convection heat transfer case where the heat transfer coefficient is small. It is reported that the heat transfer rate increases as we include thermal radiation effects whereas it decreases if the number of partitions increases [11].

Mass time lag largely postpones heat gain. Colours, on the other hand, significantly reduce heat gain. Building thermal mass plays a more significant role in dry climates with High daily summer temperatures, Large diurnal (daily) ranges. While, insulation is more critical than thermal mass in humid climates with: High summer temperatures and humidity, Small daily variations and Thermal storage benefits from massive walls (e.g., concrete, adobe) [9]. Moreover, the materials with high thermal capacity increase the time lag of heat transmission, so these materials adjust their temperature with radiation inside and into the air at night [12].

The surface decrement factor, DFs, and surface lag time, LTs, of the indoor surface temperature with respect to the outdoor surface, together with the daily average of the indoor surface temperature, Tis, are considered in the analysis. The surface decrement factor is calculated by

$$\text{DF}_s = \frac{T_{is_{max}} - T_{is_{min}}}{T_{os_{max}} - T_{os_{min}}} \qquad (1)$$

where Tis_{max} and Tis_{min} are the maximum and minimum of the indoor surface temperature during a day, respectively, and Tos_{max} and Tos_{min} are the maximum and minimum of the outdoor surface temperature, respectively. The surface lag time is defined as

$$\text{LTs} = t(T is_{max}) - t(T os_{max}), \qquad (2)$$

where t(Tis_{max}) and t(Tos_{max}) are the time of day when the indoor surface and outdoor surface temperatures reach their maximums, respectively. The smaller DFs, the better the thermal performance. In general, the larger the LTs, the better the thermal performance. For hot climates, the smaller Tis, the better the thermal performance; for cold climates, the larger Tis, the better the thermal performance [13].

3. Methodology

3.1. Specimens Making and Instrumentation
Seven (7) types of materials which are sugarcane bagasse, empty fruit bunch, wood wool, coconut fibre, coffee grounds, pineapple leave and coconut husk each were mixed with the polymer binder namely

epoxy in a mould of 50mm x 50mm x 15mm as stated in BS EN 310:1993 and BS EN 326-1:1993 (Table 1). Except for empty fruit bunch by using cement as binder and wood wool with thickness of 25mm in order to differentiate the effect of binder and thickness on time-lag. The samples were dried and tested for its surface temperature (Outer and Inner Surface) during day from 0900hr to 1800hr by using Infrared (IR) Thermometer (Figure 1 and 2).

Table 1. The Details of Specimens

Material	Binder	Area (m^2)	Thickness (mm)
Sugarcane Bagasse, SB (1)	Epoxy Resin	0.0025	15
Sugarcane Bagasse, SB (2)	Epoxy Resin	0.0025	15
Empty Fruit Bunch, EFB (1)	Cement	0.0025	15
Empty Fruit Bunch, EFB (2)	Cement	0.0025	15
Wood Wool, WW (1)	Epoxy Resin	0.0025	25
Wood Wool, WW (2)	Epoxy Resin	0.0025	25
Pineapple Leave, PL	Epoxy Resin	0.0025	15
Coconut Fibre, CF (1)	Epoxy Resin	0.0025	15
Coconut Fibre, CF (2)	Epoxy Resin	0.0025	15
Coffee Grounds, CG (1)	Epoxy Resin	0.0025	15
Coffee Grounds, CG (2)	Epoxy Resin	0.0025	15
Coconut Husk, CH (1)	Epoxy Resin	0.0025	15
Coconut Husk, CH (2)	Epoxy Resin	0.0025	15
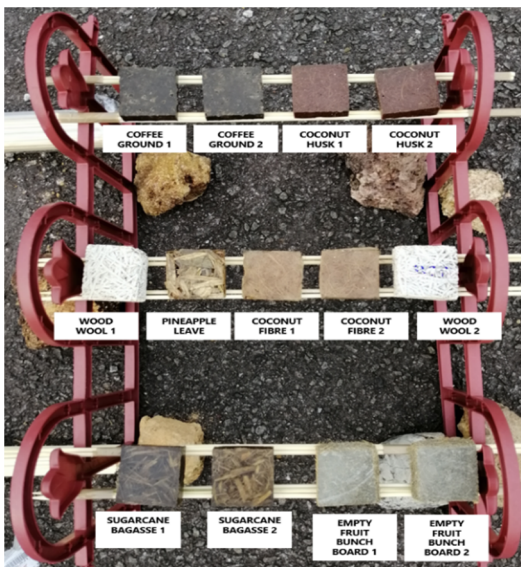
Figure 1. Specimens were exposed to sun to be tested for surface temperature

Figure 2. Measure Surface Temperature using IR Thermometer

4. Results and Discussions

4.1. Decrement Factor for Waste Materials.
Table 2 shows the decrement factor for waste materials. The peak hour lies within 1200hr to 1600hr. However, the maximum temperature occurred between 1300hr to 1400hr. Therefore, the maximum and

minimum temperature at outer and inner surfaces extracted out in order to identify the decrement factor (DF) and daily average of the indoor surface temperature (Tis) for each material.

Table 2. Decrement Factor for Waste Materials

TIME / SAMPLE	Maximum Temperature (K)	Minimum Temperature (K)	Decrement Factor (DF)	Average DF	Minimum indoor surface temperature
SB (1) - OUTER	45.2	32	0.787879		32.2
SB (1) - INNER	42.4	32		0.783645	
SB (2) - OUTER	46	32.4	0.779412		
SB (2) - INNER	43	32.4			
EFB (1) - OUTER	45.6	32.2	0.761194		32
EFB (1) - INNER	42.4	32.2		0.726751	
EFB (2)- OUTER	44.8	31.8	0.692308		
EFB (2) - INNER	40.8	31.8			
WW (1) - OUTER	40.8	30.4	0.807692		30.5
WW (1) - INNER	38.8	30.4		0.743132	
WW (2) - OUTER	41.8	30.6	0.678571		
WW (2) - INNER	38.2	30.6			
PL - OUTER	45.8	32.6	0.69697	0.69697	32.6
PL - INNER	41.8	32.6			
CF (1) - OUTER	46.2	32.8	0.58209		32.2
CF (1) - INNER	40.6	32.8		0.669423	
CF (2) - OUTER	46.4	31.6	0.756757		
CF (2) - INNER	42.8	31.6			
CG (1) - OUTER	44.4	31.2	0.787879		31.4
CG (1) - INNER	41.6	31.2		0.765152	
CG (2) - OUTER	44.8	31.6	0.742424		
CG (2) - INNER	41.4	31.6			
CH (1) - OUTER	45.6	32.6	0.615385		32.4
CH (1) - INNER	40.6	32.6		0.6062	
CH (2) - OUTER	45.6	32.2	0.597015		
CH (2) - INNER	40.2	32.2			
	Min inner surface temperature=	30.4	Low DF=	0.6062	30.5

The smaller the DF the better the thermal performance of material which are coconut husk (CH), coconut fibre (CF) and pineapple leave (PL) with 0.6062, 0.669423 and 0.69697 value respectively are the best materials as thermal insulation. For hot climate, the smaller Tis the better the thermal performance which are three materials are wood wool (WW), coffee ground (CG) and empty fruit bunch (EFB) with value of 30.5 °C, 31.4 °C and 32 °C respectively are the best materials as thermal insulation.

4.2. Time-lag for Heat Transfer in Selected Wastes Material
Table 3 shows the tabulated data of maximum temperature for outer and inner surface of the materials. From data of maximum inner temperature and its time occurrence, the time when the same temperature

occurred at outer surface estimated and evaluated as shown in Table 4. After the time for outer surface temperature evaluated, the average time-lag for each type of materials calculated.

**Table 3.** The Maximum Surface Temperature

Material	Max Outer Temperature	Time	Max Inner Temperature	Time
SG (1)	45.2	1600	42.4	1400
SG (2)	46	1400	43	1400
EFB (1)	45.6	1400	42.4	1400
EFB(2)	44.8	1400	40.8	1400
WW (1)	40.8	1400	38.8	1400
WW (2)	41.8	1400	38.2	1400
PL	45.8	1400	41.8	1400
CF (1)	46.2	1400	40.6	1400
CF (2)	46.4	1300	42.8	1400
CG (1)	44.4	1400	41.6	1400
CG (2)	44.8	1400	41.4	1400
CH (1)	45.6	1200	40.6	1400
CH (2)	45.6	1200	40.2	1400

Table 4. The Time Lag of Maximum Surface Temperature

MATERIAL	MAX OUTER TEMP	TIME	TIME OF MAX INNER TEMP	TIME LAG (min)	AVERAGE TIME LAG (min)	REMARK
SB (1)	42.4	1230	1400	90	107.5	
SB (2)	43	1155	1400	125		
EFB (1)	42.4	1145	1400	135	140	binder cement
EFB(2)	40.8	1135	1400	145		binder cement
WW (1)	38.8	1200	1400	120	132.5	thickness 25mm
WW (2)	38.2	1135	1400	145		thickness 25mm
PL	41.8	1135	1400	145	145	
CF (1)	40.6	1130	1400	150	142.5	
CF (2)	42.8	1145	1400	135		
CG (1)	41.6	1200	1400	120	130	
CG (2)	41.4	1140	1400	140		
CH (1)	40.6	1150	1400	130	130	
CH (2)	40.2	1150	1400	130		

Figure 3 shows that all time-lag for waste materials range from 107.5 minutes to 145 minutes. The time lag was also found to increase almost linearly with increasing insulation thickness. All waste materials have the same thickness which is 15mm except for the wood wool which is 25mm. However, the time-lag of WW is 132.5 minutes lower than those materials with 15mm thickness Meanwhile, for materials EFB, CF and PL with time-lag of 140 minutes, 142.5 minutes and 145 minutes respectively

are the highest time-lag occurred. On the other hand, CG and CH both have the same time-lag for 130 minutes. The highest time-lag represents the ability to stored heat max, and release heat fast the better the thermal performance of material. Therefore, three materials with highest time-lag (LTs) which are PL, CF and EFB, the material with better thermal performance.
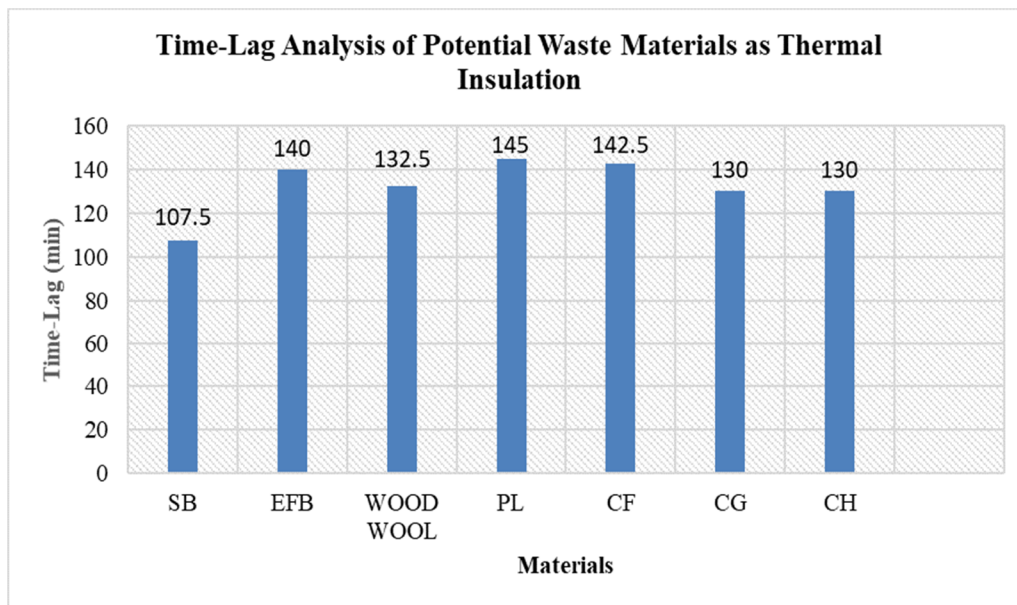
Figure 3. The Time-lag of Heat Transfer in Waste Materials

5. Conclusion

As a conclusion, all the waste materials have the potential as thermal insulation material due to their time-lag to transfer the heat from outer surface to inner surface. Thermal insulation properties are where the formation of air gap increased, thus lowered the thermal conductivity properties of material but increased its thermal resistance, resulting in better insulation properties. However, not each material possessed all three thermal performance parameters whereas coconut husk (CH) only small in DF but not Tis and LT (Table 5). Meanwhile, wood wool (WW) and coffee ground (CG) are small in Tis but not DF and LT. On the other hand, there are materials complied two out of three thermal performance parameters whereas coconut fibre (CF) and pineapple leave (PL) small in DF and LT, empty fruit bunch (EFB) small in Tis and LT. However, no specific material complied with all three thermal performance parameters. For hot climate like Malaysia, the lowest Tis is the better the thermal performance therefore, coconut fibre with smaller DF, larger LT but slightly higher Tis than EFB (32°C) which is 32.2 °C might be the suitable material use as thermal insulation. Therefore, further studies of each material should be taken and not limited to the time lag only or the thermal insulation properties. But also the physical properties such as density, weight and thickness as well as the mechanical properties such as modulus of elasticity, modulus of rupture, the structural strength of each materials correspondence to its thermal insulation properties and performance as a whole system.

Table 5. Three Type of Waste Materials complied with Thermal Performance Parameters

Parameters	Best	Better	Good
Decrement Factor, DF	CH	CF	PL
Daily average of the indoor surface temperature, T$_{is}$	WW	CG	EFB
Time-Lag, LT	PL	CF	EFB

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