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Thermal Performance and Energy Efficiency of Different Types of Walls for Residential Building

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Abstract: Decrement factor and time lag play an essential role in determining the thermal performance of a building envelope. Building walls, which form a major part of a building, have great influences on the energy consumption and indoor environment of a room. The indoor temperature considerably increases as the outdoor temperature increases. This scenario leads to excessive reliance on the mechanical cooling system, thereby increasing energy consumption. Therefore, this study aims to investigate the thermal performance and energy efficiency of different wall types. A building with a built-up area of 387.85m2 with six different wall materials is modelled and inputted in Energy Plus simulation software as an Intermediate Data Format file. The maximum and minimum surface indoor and outdoor temperatures are then obtained to determine the thermal performance of the wall material in terms of time lag and decrement factor. The energy efficiency of the wall materials is investigated by obtaining the annual cooling energy of the building made up of different wall materials. Results show that with the time lag of 1 hour, decrement factor of 0.86, annual cooling energy load of 9.52 GJ and cost consumption of RM 608.12, aerated lightweight concrete wall is the most suitable material amongst the six wall materials.

Keywords: Thermal performance, decrement factor, time lag, energy efficiency, cost consumption

1. Introduction

The main structure of a building is the wall; besides bearing the weight of the whole building, walls act as a thermal insulator of the building (Wang et al., 2018). The fundamental purpose of a building wall system is to protect and enclose the interior spaces and occupants from the outer environment by creating barriers (Lemieus & Totten, 2016). From previous study of Pathirana, et al.(2019), they concluded that the building envelope plays a vital role in regulating the temperature of the indoor air and achieving the indoor thermal comfort without the present of mechanical system. Thermal performance of a building implies the process of simulating the transfer of energy of a building to the surrounding. Heat gain or heat losses through various structural components such as walls, windows, roof are the primary variables which will affect the thermal performance of a building (Lu et al., 2005). The heat transfer through building wall system commonly comprises of convection, conduction, and radiation (Sujanova et al., 2019). According to Kanellopoulos et al. (2017), conduction is the dominant heat transfer mechanism; thus, considering the thermal properties of building materials is vital to provide a suitable environment for building occupants.

Various wall materials are available worldwide, and they are commonly distinguished as conventional wall materials and sustainable wall materials. According to Public Works Department of Malaysia (2014), the common materials for external use in Malaysia include clay bricks, cement sand bricks and concrete blocks. Conventional materials, which can be produced easily, have high durability and high resistance. However, the rapid growth of the

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construction industry has affected almost every other industry across the world. The construction industry generates nearly one-third of the total waste, most of which is used in landfills. The construction industry also generates nearly 11% of the world's greenhouse gas emissions, and the natural resources used are not sustainable (Bracco, 2019). This situation adversely affects the environment.

In recent years, energy security has become a concern in Malaysia because energy consumption has been increasing constantly but the supply does not meet the demand. The energy security problems in Malaysia are mostly caused by overreliance on fossil fuels and growing energy import dependency (Sahid, Siang & Peng, 2013). According to Malaysia Energy Statistic Handbook 2019, the total energy demand for electricity consumption in Malaysia in 2017 and 2018 reached 12,607 and 13,153 ktoe, respectively (Energy Commission, 2019). The energy used for the building is commonly for the occupant's comfort, including the air-conditioning and refrigeration system (Hassan et al., 2014). The thermal comfort level of the indoor environment is affected by the tropical climate in Malaysia. Thus, occupants often utilise the air-conditioning system for cooling (Tuck et al., 2019), contributing to 45% of the overall power usage in the building (Sadeghifam et al., 2015). Hisham et al. (2021) studied energy consumption, particularly the air-conditioning and total load in residential buildings. The result showed that 75% of occupants used the air-conditioning system every day at a rate of 0.93 kWh/day during the day and 3.43 kWh/day during the night. Kubota et al. (2011) concluded that air-conditioning system contributes for a residential house is as high as 17% of the total annual energy consumption. In addition, Ranjbar et al. (2017) determined that the total electricity consumption of an air-conditioning system can range from 28% to 46% of the total electricity usage. Therefore, the energy-saving potential of a building is considerably affected by its air-conditioning usage.

Wall materials have an essential role in conserving and reducing the energy consumption of a building (Marwan, 2020). The conservation and reduction in energy consumption are attributed to the thermal performance of wall materials. High thermal resistance can be achieved when an appropriate wall material is chosen, such as innovative wall materials which possess good thermal performance, considerably reducing the energy consumed for heating, ventilation and air-conditioning (HVAC) system. Abbood et al. (2015) studied the energy efficiency of the conventional system and industrialised building system (IBS). The result indicated that compared with the conventional system, IBS can save up to 61% of the energy consumption for the cooling and heating loads of the building. This scenario may be due to the increased thermal resistance (R-value) of the external wall in IBS, compared with that in the conventional system.

The innovative external wall materials of a building can save more than 50% of its energy consumption (Xiao, 2014). According to Ahmed (2015), the energy efficiency of a building mainly relies on the thermal properties of wall materials. The heat transfer of the wall materials is low when the wall material with low thermal transmittance is installed, thereby increasing the thermal performance of wall materials. Thus, the heating and cooling loads for the building decrease, thereby reducing the energy consumption and leading to energy cost saving of the building. Thus, sustainable wall materials are introduced to reduce the environmental footprint. For example, precast sustainable materials, such as aerated lightweight concrete (ALC) panels, are introduced. The casting of the panel is performed off-site and in a controlled environment; therefore, the waste on the site is reduced. The amount of energy used is reduced by implementing sustainable wall materials in the construction industry, improving the overall energy efficiency of the construction industry and reducing the negative impact of carbon.

Time lag (TL) and decrement factor are two of the factors which can evaluate the thermal performance of a wall (Jin et al., 2012). Time lag is the delay in time due to the thermal mass of the material (CLEAR, 2021). It is also the time taken for the outside surface temperature of the wall to propagate into the indoor surface temperature (Jannat et al. 2020). Time lag may also be affected by the density, reflectivity and thickness of the material (Cheng et al. 2005). The thicker the material is, the higher is the resistivity of the material towards heat, and the longer is the time spent for the heat waves to pass through it (Asan & Sancaktar, 1998). Figure 1 shows the schematic diagram of the heat wave propagating through the external wall and the representation of decrement factor and time lag. The indoor temperature varies, and the time is delayed when the heat wave from the outdoor environment propagates to the indoor environment. The variation rate is the time lag. Time lag is the time spent for the outer surface to propagate into the internal surface, whereas the decrement factor is the reduction in the rate of inner temperature variations (Jannat et al., 2020). Moreover, the maximum and minimum outdoor and indoor temperatures are different. Decrement factor is the rate of the difference between the maximum and minimum indoor and outdoor temperatures.

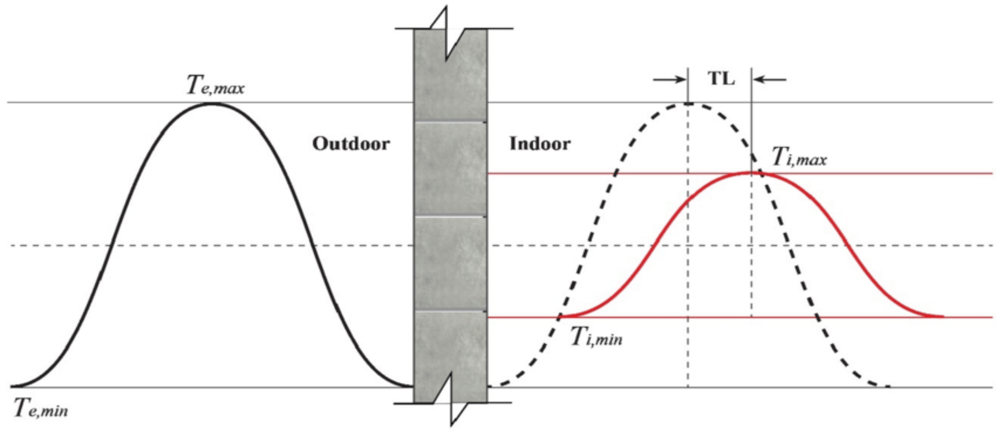

Fig. 1 - Schematic diagram of heat wave propagation through the wall and representation of decrement factor and time lag (Jannat et al. 2020)

Chameera and Rangika (2016) studied the thermal performance of materials, including brick, cement block and mud concrete block. The time lag and decrement factor are determined to study the thermal performance of the materials. Table 1 shows the porosity, time lag and decrement factor for the three types of materials. The result indicated that brick has the highest thermal performance because of its high time lag, which is 3 hours, and low decrement factor, which is 0.962. The high time lag and low decrement factor of brick are due to the high porosity of the material, which reduces the propagation of the outdoor temperature to the indoor temperature and enhances the structural cooling effect that forms time lag. Brick is then followed by cement block and mud concrete block. Mud concrete block has the lowest time lag and a high decrement factor because of the low porosity of the material.

Table 1 - Porosity, time lag and decrement factor (Chameera and Rangika, 2018)

Building wall materials	Porosity measurement (%)	Time lag (hr)	Decrment factor
Brick	24	5	0.990
Hollow cement block	18	1	0.966
Mud concrete block	23	2	0.947

Balaji et al. (2013) studied the thermal performance of building wall materials, such as cement plastering (CP), brick wall (BW), expanded polystyrene insulation (EPS), cellular concrete and dense concrete with different layers and wall configurations. When the building wall configuration is having lower thermal transmittance, the ability to minimize the fluctuations of the indoor temperature is reduced, the time lag will increase and decrement factor will then decreased (Table 2). Wall materials with a high time lag and low decrement are suitable external walls in tropical regions. Materials with high thermal inertia are susceptible to high surface heat transfer coefficient, decreasing the decrement factor.

Table 2 - Thermal performance of various wall configuration (Balaji et al. 2013)

Description of walls (from outside to inside)	Porosity measurement (%)	Time lag (hr)	Decrment factor
12.5mm CP + 230mm BW + 12.5mm CP	2.09	7.262	0.174
230mm BW	2.25	5.912	0.157
12.5mm CP + 50mm EPS + 230mm BW + 12.5mm CP	0.52	12.275	0.009
12.5mm CP 230mm BW + 50mm EPS + 12.5mm CP	0.52	8.375	0.016
150mm Cellular concrete	1.04	4.837	0.104
150mm Dense concrete	3.63	2.512	0.488

Toure et al. (2019) experimentally determined the time lag and decrement factor of stabilised earth bricks, which are commonly used in Senegal. A test cell of 1 m3, which is made up of stabilised earth bricks, is built at the University of Dakar. The result of the experimental study showed that the average time lag and decrement factor are 6 hours and 0.4, respectively (Table 3). The heat is stored in the envelope and the time taken for cooling considerably reduced throughout the warmer seasons based on the particular value for time lag and decrement factor.

Table 3 - Time lag and decrement factor. (Toure et al. 2019)

Day	Time lag (hr)	Decrement factor
1	6.02	0.41
2	6.27	0.43
3	6.27	0.38
4	6.38	0.40

Oktay et al. (2020) experimentally studied the effect of thermophysical properties on time lag and decrement factor. They concluded that time lag and decrement factor only depend on wall material thickness and are not affected by the thermophysical properties of wall materials. According to Reza and Amin (2017), the thickness and variety of wall materials affect the time lag and decrement factor of walls. Time lag increases and decrement factor decreases as the indoor combined convection and radiation heat transfer coefficient increases. They also concluded that the time lag and decrement factor of wall materials should be considered during the passive design of the building.

In general, materials with a high time lag and low decrement factor have desirable thermal performance, and they are suitable in tropic regions. They also enhance the energy efficiency of a building because the energy consumption needed for structural cooling of the building is lessened (Balaji et al., 2013). The thermal performance of a wall considerably affects the thermal comfort level and energy consumption of buildings (Jin et al., 2012). Decrement factor and time lag are crucial in enhancing thermal comfort; however, materials with high thermal resistance do not guarantee a good thermal performance, particularly in regions experiencing high thermal oscillation (Rafeel et al., 2016). High time lag with low decrement factor considerably reduces the heat transfer through the wall and reduces the total thermal load of a building. The heat propagation from the outside surface to the inside surface is reduced, thereby enhancing the energy-saving potential of a building on the cooling load (Fathipour, & Hadidi, 2017). Therefore, this study aims to investigate the thermal performance of different wall materials, including conventional and sustainable wall materials, in terms of time lag and decrement factor. The cooling energy efficiency and cost consumption on electricity are also investigated to determine the best selection of wall materials in building construction.

2. Methodology

This study investigated the thermal performance of different walls through simulation analysis. The location of study is in Penang, Malaysia, which has a tropical region climate. The geographical coordination of the building according to Google Earth is 5°16′14.9″N and 100°26′22.4″E. Figure 2 shows the average maximum and minimum temperature in Penang. Figure 2 also shows that the temperature is high in March, approximately 32 °C, and low from July to November, approximately 30 °C. Therefore, the weather data from 20–22 March were collected because of the high temperature in March.

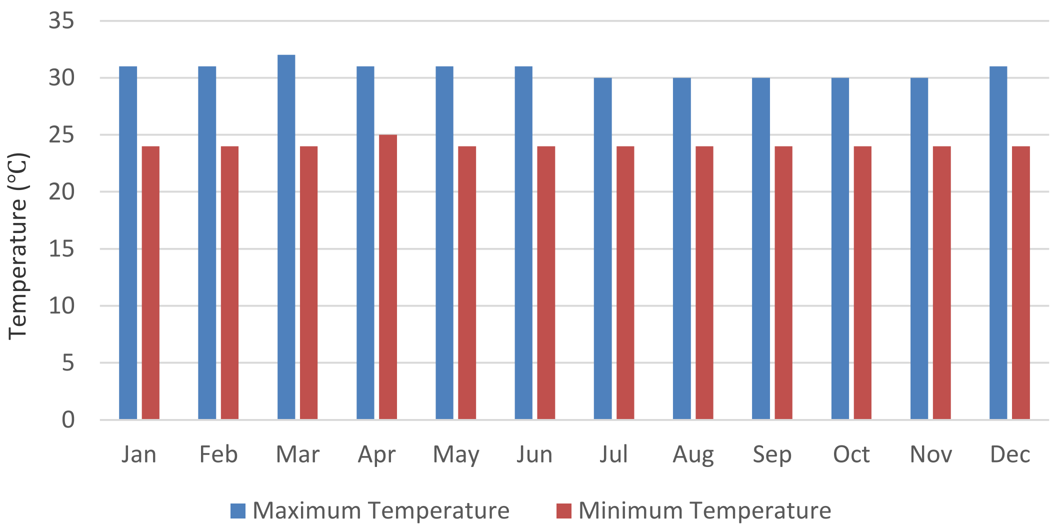

Fig. 2 - Average maximum and minimum temperature in Penang, Malaysia (Weather and Climate 2021)

In this study, EnergyPlus is used as the simulation software. This software is used because it can determine the thermal performance and energy consumed by the system or facilities in a building. This software can also determine and calculate the sub hourly or user-definable time-step between the environment and the building. Data validation is performed based on the previous research of Toure et al. (2019) to enhance the reliability of the result simulated by the simulation software. A percentage difference of 11.6% exists from the result, which is less than the average relative error for the computation and experiment result, that is, 11% ± 9% with 90% confidence. Thus, the simulation result is acceptable and reliable.

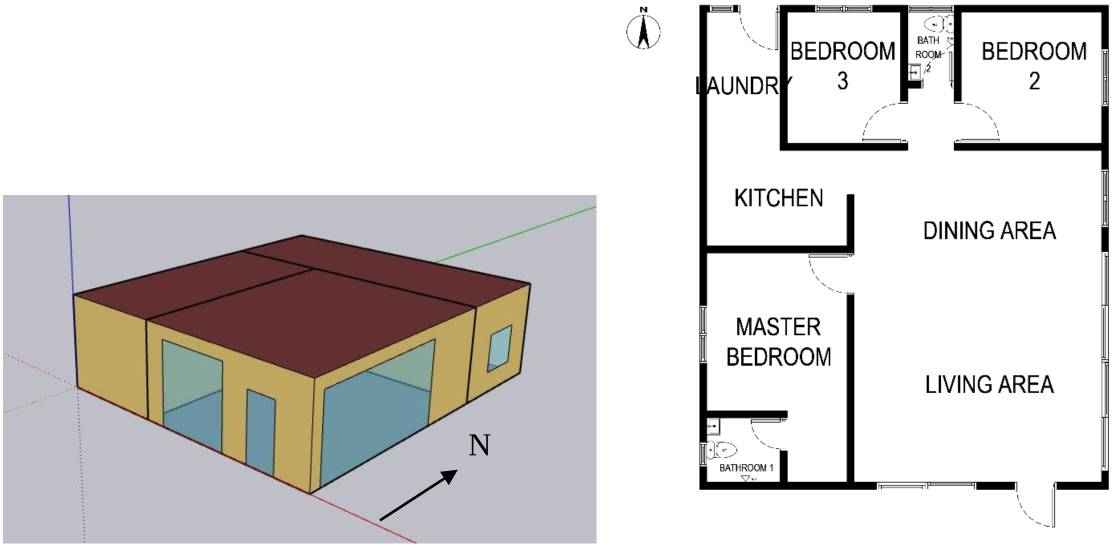

Fig. 3 - Schematic drawing and floor plan of the building

The building used in this study is a single-storey detached house with an area of 387.85 m^2, as illustrated in Figure 3. The building is separated into three spaces and thermal zones, namely, master bedroom, living room and bedroom (bedroom 2 and 3). The running period for this research is one year. The starting date of the simulation is set on 1 January 2021, and the end date is on 30 December 2021. Table 4 shows the sizing period design day for the simulation study.

Table 4 - Sizing period: Design day

Month	Maximum Dry-Bulb Temperature (°C)	Daily Dry-Bulb Temperature Range (°C)	Wet-bulb or Dew Point at Maximum Dry-Bulb (°C)
January	33.1	6.7	24.7
February	33.7	7.0	25.5
March	34.1	6.8	25.7
April	33.3	6.4	27.0
May	33.2	6.2	27.0
June	33.1	6.1	26.9
July	32.7	6.1	26.5
August	32.2	6.0	26.2
September	32.2	6.0	26.4
October	32.2	6.0	26.4
November	32.2	6.1	26.1
December	32.4	6.1	25.3

Six types of wall materials, including clay brick, cement sand brick, concrete block, Onekin lightweight structural core insulated concrete panel (OLSC), Acotec wall panel (ACOTEC) and ALC panel, are simulated in this study. The properties of the materials are shown in Table 5. The construction layer for each building structure, including the external wall, internal wall, windows, sliding door, door and roof, is then chosen in the software, as shown in Table 6. Windows and sliding door have three layers, namely, a 6 mm clear tempered glass in the inside and outside and a layer of 3 mm air in the middle. The internal wall is constructed using timber, and the roof is constructed using clay roof tiles. The floor has two layers of construction materials, namely, concrete and cement tiles. The material for the external wall is chosen based on the six types of wall materials of this study. After the materials for each structure are inputted, the details for each thermal zone of the building are inserted, as shown in Table 7.

Table 5 - Properties of the materials

Material	Roughness	Thickness (m)	Thermal Conductivity (w/m.k)	Density (kg/m^3)	Specific Heat (J/kg.k)
Clay brick	Medium rough	0.100	0.711	1788	545
Cement sand brick	Medium rough	0.100	1.0	2085	800
Concrete block	Smooth	0.100	2.25	2000	1000
OLSC	Smooth	0.100	0.1739	450	850
ACOTEC	Smooth	0.100	0.25	500	850
ALC	Smooth	0.100	0.125	650	840
Clay roof	Medium smooth	0.025	0.85	1900	850
Clear tempered glass	Very smooth	0.006	0.96	2500	840
Ceramic tiles	Very smooth	0.01	0.836	1890	750
Timber	Medium smooth	0.045	0.15	2500	560

Table 6 - Construction layer of each structure in the building

Construction Name	Layer of Construction		
	Outside Layer	**Layer 2**	**Layer 3**
Window/Sliding Door	Clear 6 mm	Air 3 mm	Clear 6 mm
Door	Timber	-	-
Internal Wall	Clay Brick	-	-
Roof	Clay Roof	-	-
External Wall	Clay Brick	-	-
Floor	Concrete	Ceramic tiles	-

Table 7 - Details of the thermal zone of the building

Field	Thermal Zone		
	101	**102**	**103**
Ceiling Height (m)	2.8	2.8	2.8
Gross External Wall Area (m^2)	11.326	37.24	44.66
Floor Area (m^2)	24.585	43.5825	31.11

HVAC system is added to the model to determine the cooling energy consumption of the building. The details of the HVAC system and zone unitary are illustrated in Tables 8 and 9.

Table 8 - HVAC template: System unitary

Name	Unitary
System Availability Schedule Name	Constant
Control Zone or Thermostat Location Name	Thermal Zone: Space 103
Supply Fan Maximum Flow Rate (m^3/s)	Autosize
Supply Fan Total Efficiency	0.7
Supply Fan Delta Pressure (Pa)	600
Supply Fan Motor Efficiency	0.9
Supply Fan Motor in Air Stream Fraction	1
Cooling Coil Type	SingleSpeedDX
Cooling Coil Gross Rated Total Capacity (w)	Autosize
Cooling Coil Gross Rated Sensible Heat Ratio	Autosize
Cooling Coil Gross Rated COP	3
Heating Coil Type	Gas
Heating Design Supply Air Temperature	25
Heating Coil Capacity (w)	Autosize
Gas Heating Coil Efficiency	0.8

Table 9 - Input details for HVAC template: Zone unitary

Zone Name	Thermal Zone: Space 103
Template Unitary System Name	Unitary
Template Thermostat Name	Building Thermostat
Supply Air Maximum Flow Rate	Autosize
Outdoor Air Method	Flow/person
Outdoor Air Flow Rate per Person	0.00944
Baseboard Heating Type	None
Baseboard Heating Capacity	Autosize
Zone Cooling Design Supply Air Temperature Input Method	SupplyAirTemperature
Zone Cooling Design Supply Air Temperature	25
Zone Heating Design Supply Air Temperature Input Method	SystemSupplyAirTemperature
Zone Heating Design Supply Air Temperature	25

The details of the building external wall surface, including the thermal properties and thickness shown in Table 5, are inputted into the EnergyPlus. Given that the solar irradiation on the north wall during March is high, the surface indoor and outdoor temperatures are obtained for the north wall to determine the decrement factor and time lag of the wall materials. The decrement factor is calculated using Equation 1, whereas the time lag is determined based on the difference in time between the maximum outdoor and indoor surface temperatures. The maximum and minimum indoor surface temperatures are remarked as Ti,max and Ti,min respectively, whereas the maximum and minimum outdoor surface temperatures are remarked as Te,min and Te,max, respectively.

$$\text{Decrement factor} = (T_{i,max} - T_{i,min})/(T_{e,max} - T_{e,min}) \quad (1)$$

The energy consumption on the cooling system is obtained by adding the HVAC system to the building. The cooling and heating points for the HVAC system are set at 25 °C (MS, 2019), which is the indoor thermal comfort level for the whole day. For this study, only heat gains through wall is being considered. The cooling and heating energy consumed by the building is then determined through simulation analysis. Comparison amongst the wall materials is performed. The monthly cost consumption on the cooling and heating energy of the building is determined by multiplying the energy consumption by the cost per kilowatt-hour. Table 10 shows the TNB domestic tariff rate. From the table, the electricity cost for the first 200 kWh is RM 0.218/kWh, whereas that for the next 100 kWh is RM 0.334/kWh. For 301 kWh to 600 kWh, the rate is Rm0.516/kWh and for 601 to 900 kWh, the rate is RM0.546/kWh. The rate of electricity for more than 901kWh will be RM0.571/kWh.

Table 10 - Domestic tariff rate (TNB, 2021)

Domestic usage	Rate (RM/kWh)
For the first 200 kWh (1 – 200 kWh) per month	0.218
For the next 100 kWh (201 – 300 kWh) per month	0.334
For the next 300 kWh (301 – 600 kWh) per month	0.516
For the next 300 kWh (601 – 900 kWh) per month	0.546
For the next kWh (901 kWh onwards) per month	0.571

3. Result and Discussion

3.1 Decrement Factor

The indoor and outdoor temperatures of the building constructed with six different types of wall materials are illustrated in Figure 4. The result indicates that the temperature variation for the concrete wall is the highest amongst the six wall materials. The percentage difference between the maximum and minimum indoor temperatures is approximately 27.33%, 25.79% and 23.74% for the first, second and third day, respectively. The large difference between the maximum and minimum indoor temperatures may be due to the high characteristic of thermal conductivity of concrete block. The comparison of cement sand brick and concrete block wall indicates that the maximum indoor temperatures of cement sand brick are 1.99%, 2% and 1.93% less than those of concrete block. For the minimum indoor temperature, cement sand brick is 1.41% higher than the concrete block wall.

Fig. 4 - Outdoor temperature and indoor temperatures of the building

Figure 5 illustrates the outdoor surface temperature for the building constructed with six different wall materials. The maximum outdoor surface temperature of OLSC is 4.68% higher than that of the concrete block. The probable reason is that the thermal resistance of OLSC is lower than that of the concrete block wall.

Fig. 5 - Outdoor surface temperature of north wall (°C)

Figure 6 shows the indoor surface temperature of the six wall materials. The average indoor surface temperature of the OLSC is the highest at approximately 39.89 °C for the three consecutive days, whereas concrete has the lowest indoor surface temperature at approximately 37.12 °C. The probable reason is that the high specific heat capacity of concrete requires a high amount of heat energy to increase the temperature. This scenario also occurs even though concrete has the highest thermal conductivity amongst the six wall materials.

Fig. 6 - Indoor surface temperature of north wall (°C)

Table 11 shows the decrement factor for the six types of wall materials. Concrete block and ACOTEC have the highest decrement factor value of approximately 0.97, whereas ALC has the lowest value of decrement factor of approximately 0.86. The decrement factor of ACOTEC is 6.01% higher than that of ALC.

Table 11 - Decrement factor of wall materials

Wall Materials	Decrement Factor			
	20/3/2021	21/3/2021	22/3/2021	Average
Clay Brick	1.05	0.94	0.89	0.96
Cement Sand Brick	1.04	0.91	0.88	0.94
Concrete Block	1.02	0.95	0.95	0.97
OLSC	1.10	0.90	0.81	0.94
ACOTEC	1.05	0.95	0.91	0.97
ALC	1.01	0.82	0.75	0.86

3.2 Time Lag

Table 12 shows the time lag of wall materials. ALC has the highest time lag of approximately 1 hour, which is approximately 50.38% higher than that of OLSC. OLSC has the lowest value of time lag of approximately 0.33 hour. Materials with a high time lag and low decrement factor have a high thermal performance and considerably increase the energy-saving potential. Thus, ALC has the highest energy-saving potential amongst the six wall materials.

Table 12 - Time lag of wall materials

Wall Materials	Time Lag (hr)			
	20/3/2021	21/3/2021	22/3/2021	Average
Clay Brick	1.00	0.00	1.00	0.67
Cement Sand Brick	0.00	1.00	1.00	0.67
Concrete Block	1.00	0.00	1.00	0.67
OLSC	0.00	1.00	0.00	0.33
ACOTEC	1.00	0.00	1.00	0.67
ALC	1.00	1.00	1.00	1.00

3.3 Cooling Energy Consumption

This simulation study is done based on the heat gains from the outdoor environment through building wall without the internal gains such as people, lights, and other electrical equipment and appliances. The cooling energy consumption is based on the energy consumed by the air-conditioning system of the building. To determine the cooling energy consumption, the air-conditioning of the building is set on–off to ensure the thermal comfort level of 25 °C in the indoor environments. Figure 7 shows the indoor and outdoor temperature of the building. From Figure 7, the outdoor temperature gradually increases from January and reach a peak of approximately 30.22 °C in March. The temperature then falls and slightly fluctuates from June to August. Then, the temperature gradually rises starting from August. Moreover, the indoor temperature in April is the highest, whereas that in December is the lowest. The maximum indoor air temperature can reach up to 33 °C from April to May.

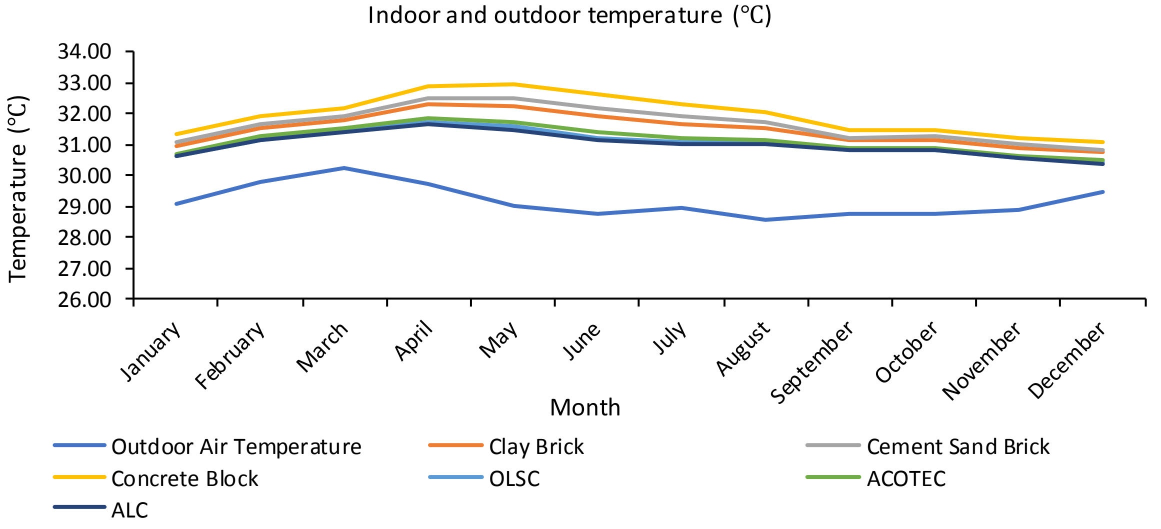

Fig. 7 - Indoor and outdoor temperatures of the building

The monthly cooling energy consumption for the building is illustrated in Figure 8. Figure 8 shows that March has the highest cooling energy because March is the hottest month in Penang. Compared with other months, August to December has an averagely low cooling energy because the outdoor temperature in these months is lower than that from January to July.

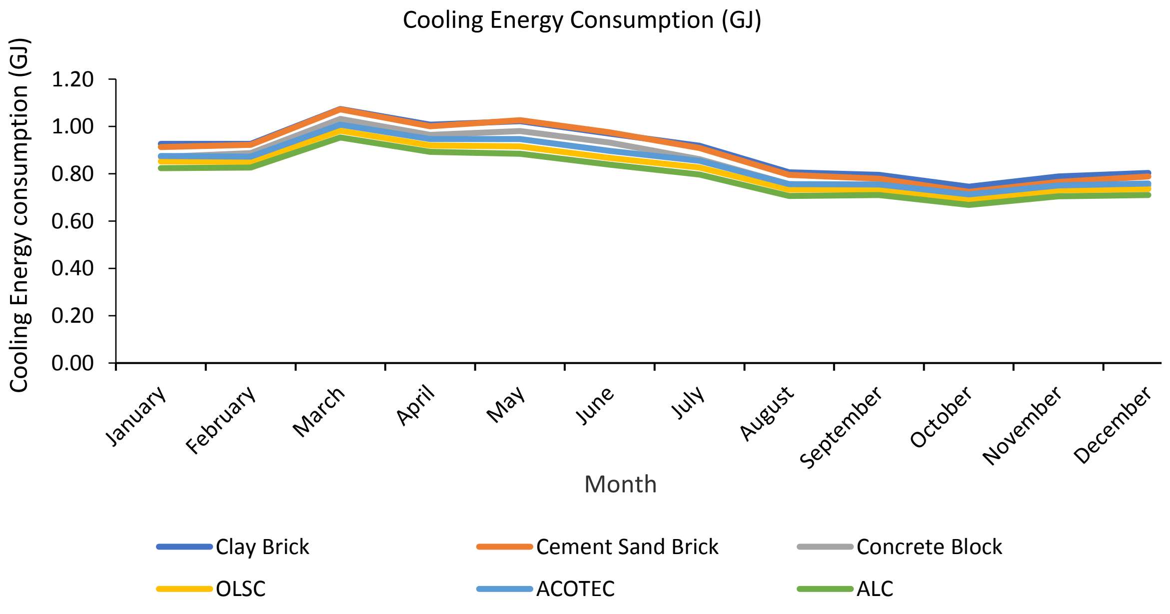

Fig. 8 - Monthly cooling energy consumption

Table 13 shows the total annual cooling energy consumption of the building for different wall materials. The building which uses clay brick as wall materials has the highest cooling energy consumption of 10.79 GJ. It is followed by cement sand brick and concrete wall materials, with a cooling energy consumption of approximately 10.67 and 10.20 GJ, respectively. OLSC and ACOTEC have an annual cooling energy consumption of 9.84 and 10.14 GJ, respectively. The building with ALC as the external wall has the lowest cooling energy consumption of 9.52 GJ. Compared with the three types of conventional wall materials, OLSC has an energy-saving potential of up to 4.6%.

Compared with the conventional wall materials, ACOTEC has an energy-saving potential of up to 3.11%. However, compared with the conventional wall materials, ALC has an energy-saving potential of up to 6.25%. Thus, the high energy-saving potential of ALC indicates that it is the most energy-efficient material amongst the six wall materials.

Table 13 - Annual cooling energy consumption (GJ)

Wall Materials	Energy consumption on cooling (GJ)
Clay Brick	10.79
Cement Sand Brick	10.67
Concrete Block	10.20
OLSC	9.84
ACOTEC	10.14
ALC	9.52

3.4 Estimation of Cooling Cost Consumption on Cooling Energy

The calculation for estimation cost of cooling energy consumption for a year is calculated and tabulated in Table 13. The cost consumption in March is the highest throughout the year probably because of the increased temperature in this month. The estimation of cost consumption is the lowest in October. The comparison of the estimation of cost consumption in March and October indicates that the cost variation of cement sand brick is the highest with a difference of 26.98%, whereas ALC has the lowest cost variation at approximately 23.51%. This finding indicates that the thermal performance of ALC is better than that of other materials, reducing the possibility of temperature variation between the indoor and outdoor environments. Hence, the energy consumption is reduced, thereby enhancing the thermal comfort of the indoor environment. The cost consumption is considerably reduced when the energy consumption decreases.

Table 14 - Estimation cost consumption (monthly; for 2021)

Month	Cost consumption (RM)					
	Clay Brick	Cement Sand Brick	Concrete Block	OLSC	ACOTEC	ALC
January	63.08	61.55	57.60	55.85	58.07	53.29
February	63.08	62.42	59.20	55.71	57.82	53.52
March	76.07	76.37	72.58	67.88	70.34	65.36
April	70.51	69.67	66.25	62.22	64.69	59.64
May	71.43	72.05	67.78	61.82	64.67	58.93
June	66.79	67.34	63.35	57.31	59.98	54.66
July	62.16	61.14	56.78	53.56	56.14	50.71
August	51.95	50.56	47.00	44.82	47.03	42.74
September	51.02	49.17	45.87	45.01	46.91	43.05
October	46.38	43.92	41.82	41.96	43.15	40.48
November	50.09	47.89	44.59	44.57	46.50	42.69
December	51.02	49.98	46.43	45.15	47.19	43.05
Total	723.58	712.06	669.25	635.86	662.49	608.12

Figure 9 shows the annual estimation of cost consumption for 2021. For clay brick, the cost consumption for cooling energy throughout the year is approximately RM 723.58. The cost consumptions for OLSC and ACOTEC are RM 635.86 and RM 662.49, respectively. The cost consumption for ALC is the lowest, which is approximately RM 608.12, because of its low cooling electricity consumption of approximately 2644.66 kWh. Therefore, compared with clay brick, ALC has a cost-saving potential of RM 115.46, which is approximately 6.87%.

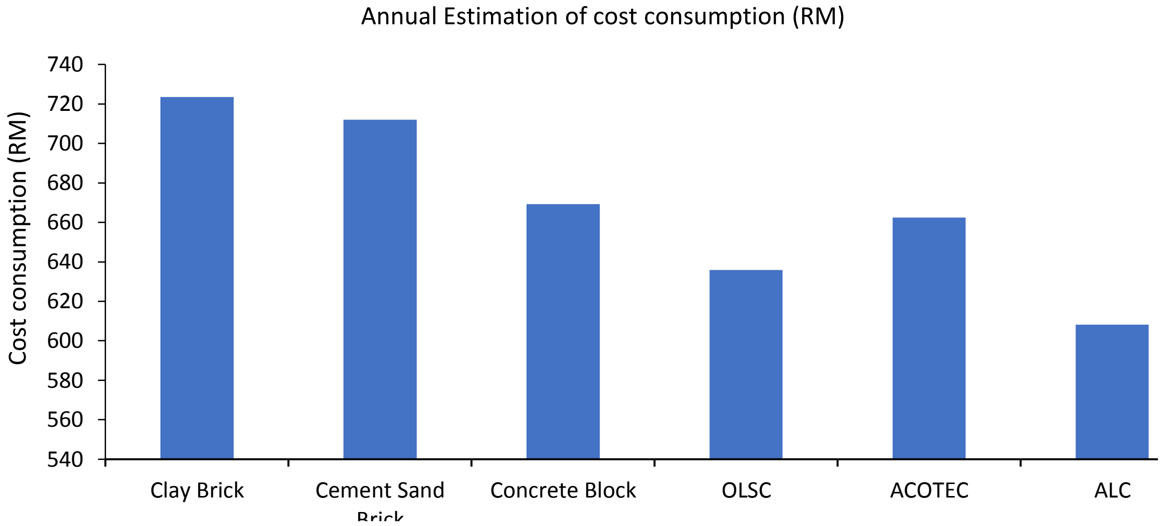

Fig. 9 - Annual estimation cost consumption (2020)

4. Conclusion

This study analysed the thermal performance and energy efficiency of different wall types. The objectives were to determine the best selection of wall materials in building construction. According to the 3-day simulation analysis, ALC has the highest time lag of 1 hr and a low decrement factor of 0.86. Given the energy point of view, the annual cooling energy needed for the building to develop indoor thermal comfort conditions is low, which is approximately 9.52 GJ. Compared with those of conventional wall materials, the energy- and cost-saving potential of ALC can reach up to 6.25% and 6.87%, respectively. Thus, the cooling energy demand for ALC is lesser than that of the other five types of wall materials, making ALC more energy- and cost-efficient than these other wall materials. The estimation cost consumption of ALC is also the lowest, which is RM 608.12 per year. Therefore, ALC is the best choice amongst wall materials for building in terms of decrement factor, time lag and energy efficiency. For future simulation study or early-stage design of a building, the internal gains such as people, lights, and other electrical equipment and appliances can be considered to enhance the accuracy of the cooling energy consumption of the building; and hence act as a guidance in selecting the best choice of wall material.

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