The Potential of Carbon Footprint Reduction of a Mid-Rise Residential Building in Sarawak

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ABSTRACT

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Carbon emission is released into the atmosphere as the result of various activities due to rapid urbanisation and thus contributed to global warming and climate change. The government has taken various initiatives to reduce the impact, including from the construction industry in order to support the carbon footprint reduction of 40% as pledged by the Prime Minister. Various strategies, such as the Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST), have been established to promote green building development in Malaysia. Recent studies suggested that the selection of sustainable materials can reduce the overall carbon emission of a building, but the cost has been identified as the main barriers. This paper aims to analyse the potential of carbon footprint reduction by using sustainable material in mid-rise residential building and subsequently to evaluate the cost implication. The impact of the conventional and the selected sustainable materials was assessed using data from the MyCREST tool while the data for cost analysis were taken from various sources of cost data such as JKR Rates online (RATOL), JKR Sarawak Schedule of Rates (SOR), and previous research. The results show that the sustainable materials such as 30% of Blast Furnace Slag (BFS) concrete mixture, Aerated Autoclaved Concrete (AAC) block, and recycled steel roof truss has the potential to reduce the carbon emission. The findings also show that sustainable materials are slightly cheaper than the conventional materials except for the AAC block and clay roof tiles. Therefore, the potential of carbon emission reduction approach by using MyCREST as a guideline tool can assist in the reduction of the environmental impact of buildings.

Keywords: *Carbon emission, sustainable building materials, cost implication.*

INTRODUCTION

Carbon emission is the amount of carbon dioxide (CO2) released to the environment as a result from various activities in the construction industry due to rapid urbanisation that contributed to global warming and climate change (Fujita et al. 2009). The greenhouse gas (GHG) emission from fossil fuel usage has been increasing at an alarming rate towards the increased mass of CO2 causing the rise in global warming which has directly affected the atmosphere in recent decades (Florides & Christodoulides, 2009) The conventional building construction uses a significant amount of raw material resources, and it is considered as one of the leading environmental polluters, which provides a significant impact on the construction industry (Ding, 2008). Buildings have caused a massive effect on the environment where it plays a significant role in producing a large number of carbon emissions (Keysar & Pearce, 2007). It is believed that the process of reducing carbon emissions will be costly; however, it has become one of the crucial elements to be considered to stabilise the environment (Banfill & Peacock, 2007).

The Malaysian government has implemented policies and initiatives to support the pledged by the Prime Minister to reduce approximately 40% carbon footprint by 2020 by using green technology and sustainable materials in buildings (Klufallah et al. 2014). According to Ohueri et al. (2019), a few researchers have carried out several studies on strategies to uplift the construction of sustainable buildings in Malaysia; however, there are limited green building in Sarawak compared to other states. While sustainable construction materials can minimise the carbon footprint, the construction industry showed less interest due to the higher cost of sustainable materials, newer equipment, plants, and machinery (Klufallah et al. 2014).

In reducing the carbon emission of a building, Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST) was established to promote a green building development which will help the government to execute its plan in reducing four megatonnes of carbon emissions per year by 2020 (Ohueri et al. 2019; Idris, 2016). MyCREST aims to provide guidelines to reduce the environmental impact from the construction sector by considering the building's life cycle perspective (CIDB, 2020). MyCREST tools will assess separately according to the design phase, construction phase and the operation and maintenance phase (Ohueri, 2019). Thus, this paper aims to estimate the potential reduction of environmental impact and the cost implication of using sustainable materials recommended in the MyCREST.

METHODS

The method used for this research is the case study method. A case study is expected to capture the complexity of a single case and the methodology that has developed within the social sciences (Johansson, 2007). It is an approach to research that facilitates the exploration of a phenomenon within its context using a variety of data sources (Tellis, 1997).

CASE STUDY BUILDING

The apartment hostel building, as shown in Figure 1, located in the district of Kota Samarahan, about 30 km away from Kuching. This four-storey building has a gross floor area of 1127 m^2 divided into four units in 1st, 2nd, and 3rd floor consists of five bedrooms, a living room, a sitting area, four bathrooms and a drying yard per unit. Meanwhile, only the ground floor is divided into three units with one common area. Each of the units consists of similar function and design. The main structure is reinforced concrete with clay bricks as the building envelope.

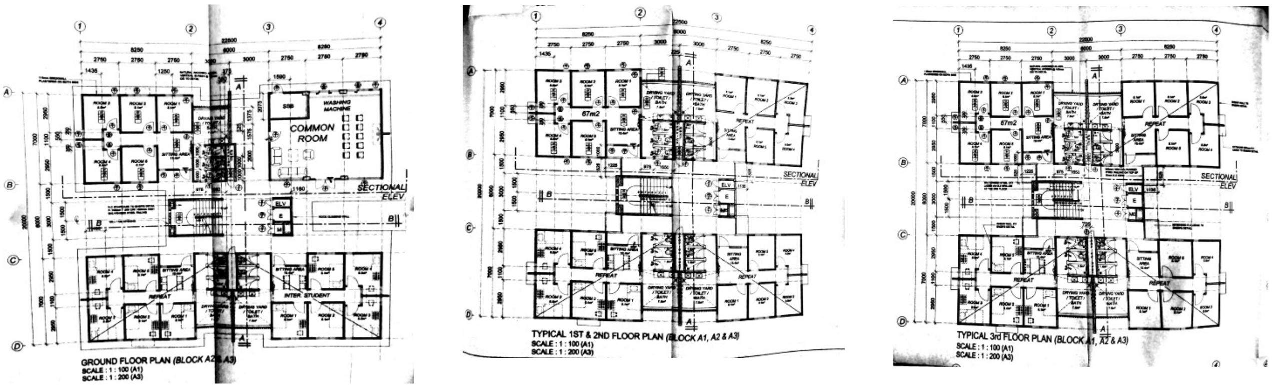

Figure 1: Floor plans of the apartment hostel

CASE STUDY FRAMEWORK

In this study, the information such as the quantity of building materials for the case study was calculated based on construction drawings and tender document. The conventional construction materials used for the mid-rise residential building will be analysed based on the amount of carbon emission released towards the surrounding environment. The quantity of the building materials is multiplied using the value of carbon emission from the MyCREST tool. Figure 2 below shows the detail of the case study framework for this study.

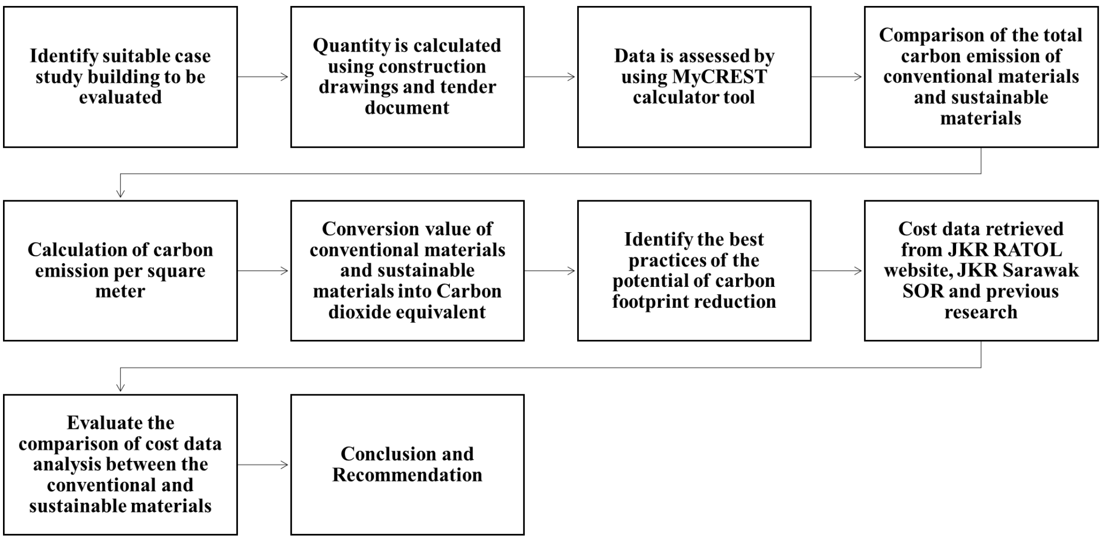

Figure 2: Case study framework

CONVENTIONAL BUILDING MATERIALS

Table 1 shows the quantity of materials used in the construction of the case study building. However, only selected conventional materials for this study such as concrete, brick, roof and roof covering are used for comparison, as shown in Table 2. The selected materials used in the study building are the most common conventional materials used in a building. The sustainable materials selected as a potential replacement were based on the availability in the market. Most of the units of materials are commonly used in the bill of quantities except for brickwall, which were measured in m3 as suggested in MyCREST tool.

Table 1: The quantity of materials used in the construction of the case study building

Item	Materials	Quantity	Unit
A	**Column**		
	Concrete	109.20	M3
	Reinforcement	6,500.00	KG
	Formwork	2,137.72	M2
B	**Beam**		
	Concrete	160.00	M3
	Reinforcement	8,715.36	KG
	Formwork	3,403.28	M2
C	**Upper floor**		
	Concrete	150.40	M3
	Reinforcement	11,115.00	KG
	Formwork	2,014.60	M2
D	**External Brick wall**		
	115mm clay brick	42.29	M3
E	**Roof**		
	Steel Roof Truss	59.00	M
	Metal Roof Covering	451.78	M2
F	**Window**		
	Aluminium frame	340.64	M2
	Glass window	250.93	M2

Table 2: Comparison of selective materials for carbon emission and cost data analysis for this case study

Item	Conventional Materials	Sustainable Materials
1.	Concrete Grade 30	30% of BFS Concrete Mixture
2.	Well burnt clay brick	Aerated Autoclaved Concrete (AAC) Block
3.	Steel roof truss	1. Recycled steel roof truss 2. Timber roof truss
4.	Metal Roof Sheet	Clay Roof Tile

GENERAL BOUNDARIES AND LIMITATIONS

The following assumptions have been considered for this research:

- AAC Block has a variety of sizes ranging from 600mm x 200mm x 100mm thick to 300mm thick (Kulbhushan et al. 2018). This study will use 115mm thick of AAC Block with an average density of 600 kg/m^3, which is the same thickness as a standard clay brick.
- The density of 30% of Blast Furnace Slag (BFS) in concrete has a maximum density of 2180 kg/m^3 (Al-Baijat & Sarireh, 2019).
- An average density of clay roof tiles is 58kg/m^2.
- The density of clay brick is 1900kg/m^3 (Kumawat et al. 2016).
- The density for steel roof truss is 7860kg/m^3 (Vidya et al. 2016).
- The material cost for concrete mixtures of 30% BFS is RM177.72 /m^3 (Onn et al. 2019). The total cost is RM293.14, including labour and plant and machinery. After it has been adjusted by using the Tender Price Index (TPI), the current price is RM 292.02/m^3. The current price is cheaper due to the lower TPI in the current year. The cost for concrete grade 30 is RM317.00/m^3 from JKR Rates Online (RATOL) (JKR, 2020).
- The average material cost for AAC Block is approximately RM74.00/m^2 while, RM51.00/m^2 for clay brick as in RATOL (JKR,2020).
- The cost metal roof sheet and clay roof tiles are RM54.00/m^2 and RM60.00/m^2 respectively, which have taken from RATOL (JKR, 2020).
- The cost for steel roof truss is RM 8.40/kg, and timber roof truss is RM5,100/m^3 taken from Sarawak Schedule of Rates (SOR) (JKR Sarawak, 2018). The updated TPI of the current cost for steel roof truss and timber roof truss is RM8.40/kg and RM5,124.54/m^3, respectively.

RESULTS AND DISCUSSION

Comparison of carbon emission of materials selection

Concrete grade 30 and 30% BFS concrete mixture

Figure 3 shows that 30% BFS concrete mixture can produce less carbon emission compared to concrete grade 30 by 32.53% reduction. 30% BFS concrete was chosen as an alternative as suggested that BFS with mixtures of around 20% to 30% substitution have the best corrosion resistance properties (Jau & Tsay, 1998). The usage of BFS leads to low permeability and penetration of chloride ions into concrete as less penetration of the chloride ions, the corrosion in the concrete will also be low thus increases the life span of the structure (Rajeswari & Kameswara Rao, 2019). Substantially, the replacement of BFS concrete mixtures enhanced the service lifespan dues to the content of the increase in chloride binding capacity, reducing the risk of corrosion (Hong & Ann, 2017).

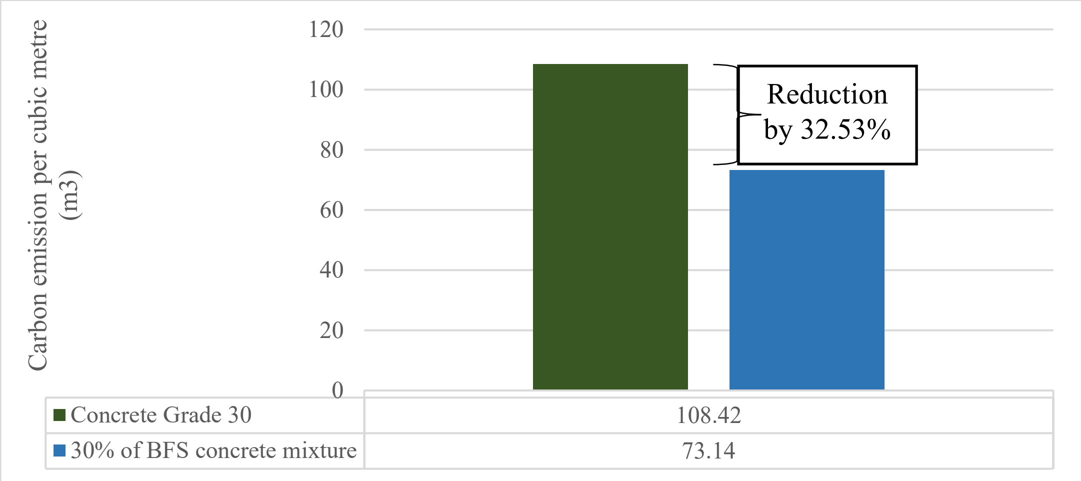

Figure 3: Emission comparison between concrete grade 30 and 30% of BFS concrete mixture

Clay brick and AAC block

Figure 4 shows that AAC Block produced lower carbon emission than clay brick whereby the carbon emission is less compared to that of clay brick by 67.05%. The use of AAC Block instead of ordinary fired clay brick reduced the environmental impact significantly (Rama Jyosyula et al. 2020). Carbon emission is lower for AAC production compared to clay brick due to the manufacturing process, which does not involve sintering or kiln heating, which eliminates the use of fossil fuel (Bulkade & Deshmukh, 2017). Moreover, AAC block is easy to handle, and low thermal conductivity results in the rapid increase in the construction speed (Vats, 2019). AAC block offers the building extra life span and will require lower maintenance cost as it requires less jointing (Shukla, 2014).

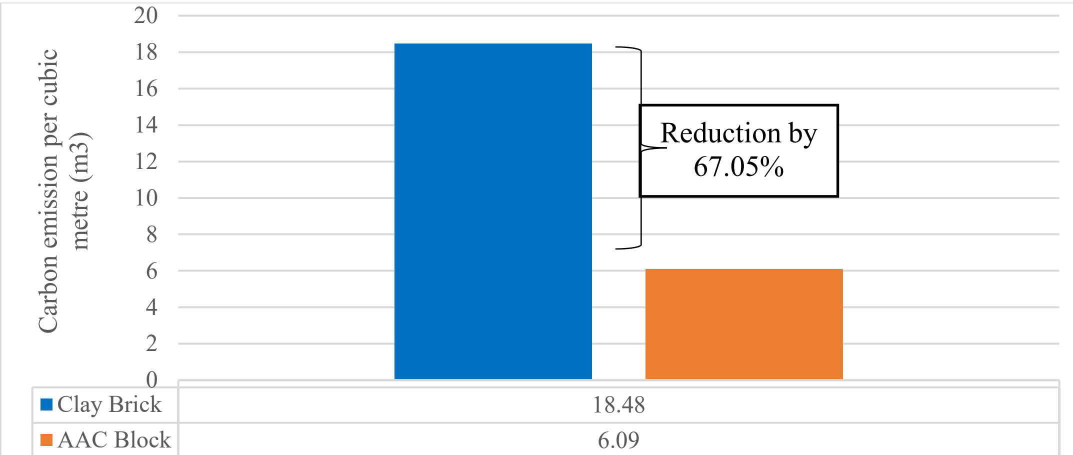

Figure 4: Emission comparison between clay brick and AAC block

Steel roof truss, recycled steel roof truss and timber roof truss

Figure 5 shows that the emission produced by recycled steel truss is lower compared to standard steel roof truss with 48.89% carbon emission reduction. Moreover, around 92.56% of carbon emission can be reduced by using timber roof truss compared to the steel roof trusses. The recycled steel for roof trusses will be the best option as it uses recyclable materials which will reduce the carbon emission (Vidya et al. 2016). Although timber roof trusses released a lower carbon emission, it is not appropriate to use due to their disadvantages such as termite infestation, challenging to obtain long pieces of timber and tendency of boards to rot due weather (Mohamed & Abdullah, 2014).

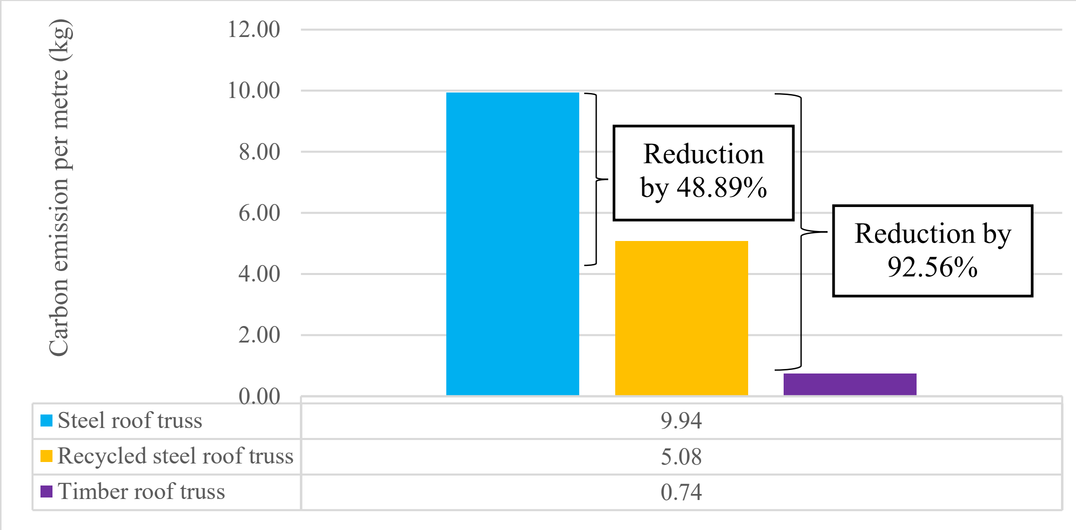

Figure 5: Emission comparison between steel roof truss, recycled steel roof truss and timber roof truss

Metal roof sheet and clay roof tile

Figure 6 shows that the clay brick tile produced high carbon emission by 76.87% than metal roof sheet. Based on the total carbon emission, the density per square metre for clay roof tile are much more than the metal roof sheet. The material to produce clay tiles has a low carbon footprint, but the production of clay tiles contributed to a higher portion of carbon footprint (Le et al. 2019). Due to the hot and humid weather in Malaysia, the usage of clay roof tile as the roof covering is suitable for better performance in the reduction of heat transition into the building (Roslan et al. 2016).

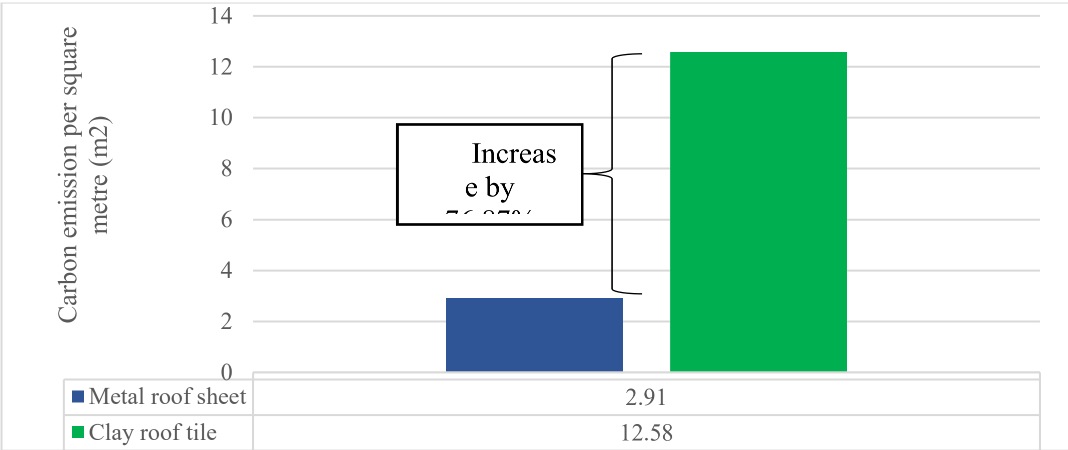

Figure 6: Emission comparison between metal roof sheet and clay roof tile

Clay roof tile provides good thermal insulation, thus providing better comfort for a home environment, including can reduce the need for air conditioning which will save energy consumption throughout the building life span (Chnebierk, 2016). Clay roofing tile was also preferred because of its durability, ease of maintenance, and low thermal conductivity (US Department of Interior, 2019).

Comparison cost of conventional materials and sustainable materials

Concrete grade 30 and 30% BFS concrete mixtures

Figure 7 shows that the overall cost can be reduced by 7.88%. The use of 30% BFS in concrete mixtures is desirable because it is environmentally friendly, and the economic advantages in reducing overall cement expenditures (Labarca et al. 2007). According to Al-Baijat & Sarireh (2019), the replacement of concrete by BFS lowering the cost of the concrete mixed as slag is much cheaper than regular concrete. BFS is not widely used due to its relatively low initial strength and increased shrinkage compared to regular concrete that must be included (Lee et al. 2019).

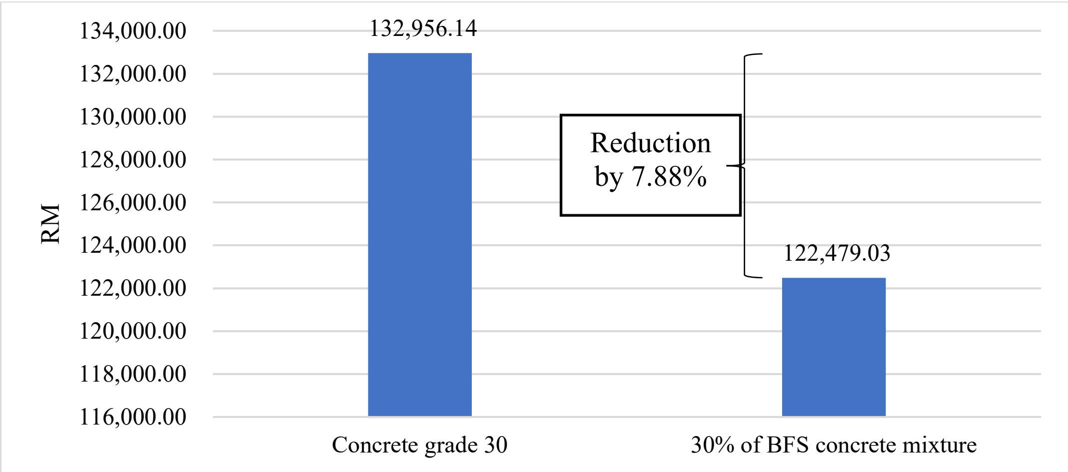

Figure 7: Cost comparison between concrete grade 30 and 30% of BFS concrete mixture

Clay brick and AAC block

Figure 8 shows that the price for AAC Block is slightly higher by 31.08% than clay brick. Despite the differences price between clay brick and AAC block, some developer preferred AAC Block due to their advantages towards the environment such as lightweight and eco-friendly product even though the initial cost is higher than clay bricks (Saiyed et al. 2015). Furthermore, AAC block has a lower thermal expansion, enhanced heat and sound insulation characteristic due to the air voids in the concrete (Hamad, 2014).

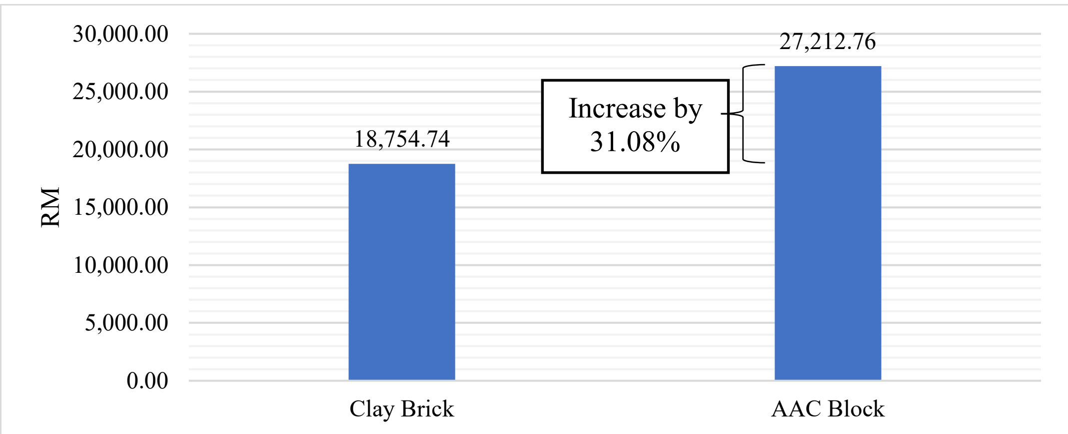

Figure 8: Cost comparison between clay brick and AAC block

Steel roof truss, recycled steel roof truss and timber roof truss

Figure 9 shows that recycled steel roof truss has a lower cost compared to steel roof truss by 2.50% reduction in comparison. Recyclable steel roof truss is the best option for sustainable material despite the high-cost production compared to the timber roof truss. Recycle steel also slightly cheaper compare to new steel (Dunant et al. 2018).

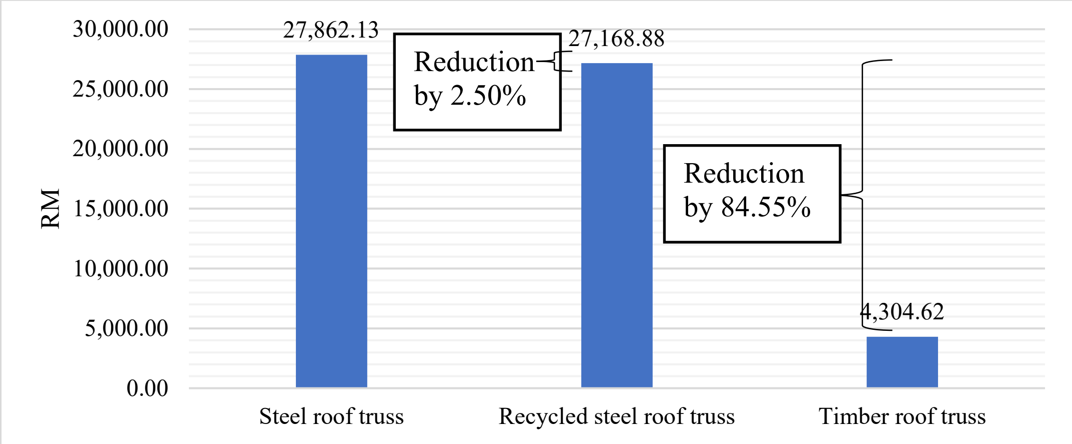

Figure 9: Cost comparison between steel roof truss, recycled steel roof truss and timber roof truss

A comparison of lifespan between steel and timber is discussed whereby the timber roof truss has lower service life compared to the steel roof truss. Subsequently, the impacts such as maintenance and service are also twice for timber roof truss due to its lower lifespan. Hence, the lifecycle cost of timber roof construction also increased as the service life is halved from the recycled steel roof truss.

Metal roof sheet and clay roof tile

Figure 10 shows that the comparison cost for clay roof tile is much higher by 10.00% compared to metal roof sheet. Roslan et al. (2016) and US Department of the Interior (1993), highlighted that sheet metal roofs became popular because they were cheaper and lighter, and easier to install than clay roof tile. The cost of clay roof tiles, however, are relatively high due to higher material and transportation cost to the site, and it requires a more substantial roof structure than lightweight roof claddings (Building Research Levy, 2015).

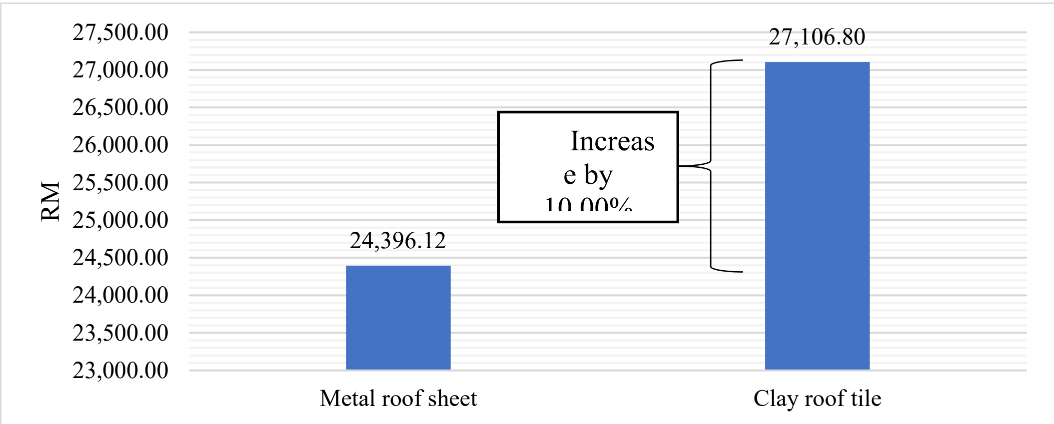

Figure 10: Cost comparison between metal roof sheet and clay roof tile

Clay roof tile is the best option as roofing materials despite its high cost compared to other variants of roofing materials such as metal roof tile (Romanova & Skanavi, 2017). Clay tile is considered as a sustainable product where during peak temperature, clay tile absorbs the heat which provides a cold indoor temperature, while at night, it released the absorbed heat thus, keeping the living space stay warm (Mohamed & Abdullah, 2014).

Comparison of carbon emission reduction between conventional materials and sustainable materials

Table 3 shows that the carbon emission released by the selection of conventional materials and sustainable material for this study. The usage of 30% BFS concrete mixture can reduce the carbon emission by 32.53% reduction in comparison to the standard concrete grade 30. Next, the AAC Block can reduce up to 67.05% emission compared to clay brick. The results also showed that the recyclable steel roof truss and timber roof truss offers 48.89% and 92.56% reduction compared to steel roof truss, respectively. The recyclable steel roof truss is appropriate to be used in the building structural by taking into consideration its benefits even though timber roof trusses produce lower carbon emission compared to the steel roof truss. This is due to the recyclable steel roof truss is an eco-friendly material which significantly reduces the carbon emission and also provides a long lifespan. Finally, the clay roof tile contribute provides higher carbon emission by 76.87% in comparison to the metal roof sheet. Although clay roof tile released a higher initial carbon emission, it is more suitable to be used in a hot climate state as in Sarawak due to its ability to reduce the energy consumption for cooling in the long run.

Table 3: Summary of carbon emission between conventional materials and sustainable materials

Item	Conventional Materials	$C0_2$ Emission (Tco_2e)	Sustainable Materials	$C0_2$ Emission (Tco_2e)	Remarks
1.	Concrete grade 30	108.42	30% of BFS Concrete mixture	73.14	32.53% reduction
2.	Clay brick	18.48	AAC Block	6.09	67.05% reduction
3.	Steel roof truss	9.94	Recycled steel roof truss	5.08	48.89% reduction
4.	Metal roof sheet	2.91	Clay roof tile	12.58	76.87% increased

Cost comparison between conventional materials and sustainable materials

The results in Table 4 shows that half of the sustainable materials are more expensive than conventional materials. The substitution to BFS offers lower cost compared to concrete grade 30 with 7.88% reduction. The usage of recycled steel also is cheaper by 2.50% compared to standard steel roof. Conversely, the AAC Block is 31.08% more expensive than clay brick. Clay roof tile also is more expensive than the metal roof sheet by 10.00%.

Table 4: Summary of cost between conventional materials and sustainable materials

Item	Conventional Materials	RM	Sustainable Materials	RM	Remarks
1.	Concrete grade 30	132,956.00	30% of BFS Concrete mixture	122,479.03	7.88% reduction
2.	Clay brick	18,754.74	AAC Block	27,212.76	31.08% addition
3.	Steel roof truss	27,862.13	Recycled steel roof truss	27,168.88	2.50% reduction
4.	Metal roof sheet	24,396.12	Clay roof tile	27,106.80	10.00% addition

CONCLUSION

Conventional building in Malaysia produced higher carbon emission in comparison to the sustainable building throughout the construction phase. The substitution of sustainable materials according to the MyCREST rating tool can have the potential to reduce the carbon emission throughout the building construction. The results show that the sustainable materials such as 30% BFS concrete mixture, Aerated Autoclaved Concrete (AAC) block, and recycled steel roof truss has the potential to reduce the carbon emission throughout the process of the building construction. It also shows that some of the sustainable materials are slightly cheaper than the conventional materials except for the AAC block and clay roof tiles. Therefore, the potential of carbon emission reduction approach by using MyCREST as a guideline tool can assist in the reduction of the environmental impact of buildings.

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