M. Nazri Ahmad,*
E. N Shuhada E. Jaafar

Environment Technology Research Centre,
SIRIM Berhad, 1 Persiaran Dato Menteri,
Seksyen 2, 40700, Shah Alam, Malaysia

***mdnazri@sirim.my*

COMPARATIVE LIFE CYCLE ASSESSMENT (LCA) OF CLAY VERSUS CONCRETE ROOFING TILES PRODUCTION IN MALAYSIA

RINGKASAN: Sektor pembinaan merupakan salah satu sektor yang berkembang pesat di Malaysia dengan kadar pertumbuhan sekitar 10.7 % berdasarkan tempoh kajian semula dalam Rancangan Malaysia Ke-10 (2011-2015). Keadaan ini mendorong kepada peningkatan permintaan serta pengeluaran dalam industri bahan binaan negara. Salah satu bahan binaan utama yang diperlukan adalah atap genting. Kesedaran masyarakat terhadap konsep pembinaan hijau (*green construction*) dan permintaan terhadap produk hijau (*green product*) semakin meningkat di negara ini. Kajian ini adalah bertujuan untuk membuat perbandingan di antara atap genting tanah liat dengan atap genting konkrit dari segi kesannya terhadap alam sekitar menggunakan kaedah kajian penilaian kitar hayat (*life cycle assessment*) terhadap atap genting yang berfungsi untuk melindungi permukaan berkeluasan 1 m^2 dengan menggunakan pendekatan buaian ke pintu (cradle-to-gate). Berdasarkan hasil kajian yang dijalankan, proses pengilangan atap genting konkrit menghasilkan kurang kesan alam sekitar berbanding atap genting yang diperbuat daripada tanah liat.

ABSTRACT: The construction sector is growing rapidly in Malaysia with a growth of 10.7 % based from the review period of 10th Malaysia's Plan (2011-2015). This leads to an increase in demand and production of building materials in the country. One of the main construction materials required is roofing tiles. The public awareness on the concept of green building and the demand for green products is increasing significantly in this country. The aim of this study is to perform a comparison between the clay roofing tiles and concrete roofing tiles in terms of their impact on the environment by using Life Cycle Assessment (LCA) on the roofing tiles that serves to protect the surface area of 1 m^2 using cradle-to-gate approach. The results of the study show that the manufacturing process of concrete roofing tile has less environmental impact compared to the clay roofing tiles.

INTRODUCTION

The growth of construction industry to meet the market demand has developed concern on environmental impacts over a building's life cycle and is aiming towards sustainability (Souza *et al.*, 2015). Recent studies show that manufacturing of building materials generate 10 % of the global energy consumption (Rode *et al.*, 2011). Most developed country generates 40 % of the solid waste from construction and demolition of the buildings with the construction operation releasing almost 40 % of greenhouse emission for the entire world. This shows that construction industry is the lead sector in global energy consumption and global warming potential (Zuo *et al.*, 2012; Wong *et al.*, 2015).

In order to evaluate the environmental impact of products within its life cycle, a substantially used current methodology is product Life Cycle Assessment (LCA). According to LCA approach, there are four main phases in the product life cycle which is raw materials extraction (pre-production), production, usage and end of life (disposal). The LCA study can be carried out either partially or fully for the whole life cycle of the product depending on the requirements (Kuruppuarachchi *et al.*, 2014). International Organization for Standardization (ISO) has released the ISO 14044 "Environmental Management-Life Cycle Assessment-Requirements and Guidelines" which specifies detail requirements and provides guidelines for Life Cycle Assessment (LCA) technique that can be applied in identifying environmental performance of products at various points in their life cycle. In this quantitative analysis, calculations are based on the life cycle inventory of the product which is identified in the defined system boundary.

Roofing tiles is one type of building materials intended for use to cover the upper layer of a building that is designed mainly for shelter which provide protection from animals and weather. In the roofing industry, there are many types of roofing tiles available which differs based on its materials, architectural designed and quality. The materials of roofing tiles may range from clay, concrete, laminated glass and metals such as steel, aluminum, copper and zinc.

Based from statistical data provided by Department of Statistical Malaysia (Press Release, 4th Quarter, 2016), the performance of construction sector in 4th quarter of 2016 reached RM32.6 billion with civil engineering area valued at RM11.5 billion followed by non-residential at RM10.0 billion, residential at RM 9.6 billion, and special trades activities at RM 1.5 billion. The value of construction work also grew at 8.1 % as compared to the 4th quarter of 2015 which showed the growth of construction sector keep increasing every year. This will contribute to the increasing demand in roofing tile materials for construction sector.

Construction sector needs to change the way of operating from no concern for environmental impacts to a new mode that helps to improve environmental aspect (Nazirah, 2009). Green and sustainable construction need to be implemented in Malaysia as a way to promote green environment. Sustainable construction can be defined as the creation and responsible maintenance of a health built environment, based on ecological principles by using the resources, efficiently (Bourdeau, 1999). Malaysia needs to prove that it can follow this new approach to compete with the global market and does not slip from progressing in green and sustainable construction industry (Nazirah, 2009).

The goal of the study is to compare the environmental impacts of roofing tiles made by clay with concrete materials. The environmental hot spot is identified and further improvement can be carried out based on the LCA information of the study. At the same time, the results of the study can be used as environmental information for selection of green materials for the stake holders to enhance quality and credibility of the product.

MATERIALS AND METHOD

The functional unit defined in this study is one square meter (1 m^2) of roofing tiles intended to cover a building interior from weather events and the relevant unit of reference flow is kilogram (kg). Table 1 shows the number of tiles and total weight of tiles that were needed to cover an area of one square meter.

Table 1. Key characteristics of the studied roofing tiles

Characteristics	Clay roofing tiles	Concrete roofing tiles
Weight (kg) per piece	3.88	4.64
Roof coverage (tiles/m^2)	12.75	9.6
Total weight per m^2 (kg)	49.26	44.53

The boundaries for both product systems were defined based on cradle-to-gate approach. The cradle-to-gate is a partial assessment of a product life cycle which only focuses from resource extraction (cradle) to the factory gate (i.e. before it is transported to the consumer). The distribution, use and disposal of roofing tiles are omitted in this study due to difficulty to collect the data. The system boundary for the life cycle of clay roofing tiles is presented in Figure 1.

Clay extraction was done by the aid of excavators and transported directly to the factory. Five processes were considered in manufacturing of clay roofing tiles. The first process was the preparation of clay dough which involves crushing, grinding and milling with addition of sufficient quantity of water. This operation was followed by mechanical shaping of clay roofing tiles using extruder machine and mould. Then the process was continued for drying and firing of the clay roofing tiles in a tunnel kiln to make the tiles sturdy enough to be transported. This study only focuses on natural type of clay roofing tiles in which, pigment coating was not applied in this particular process.

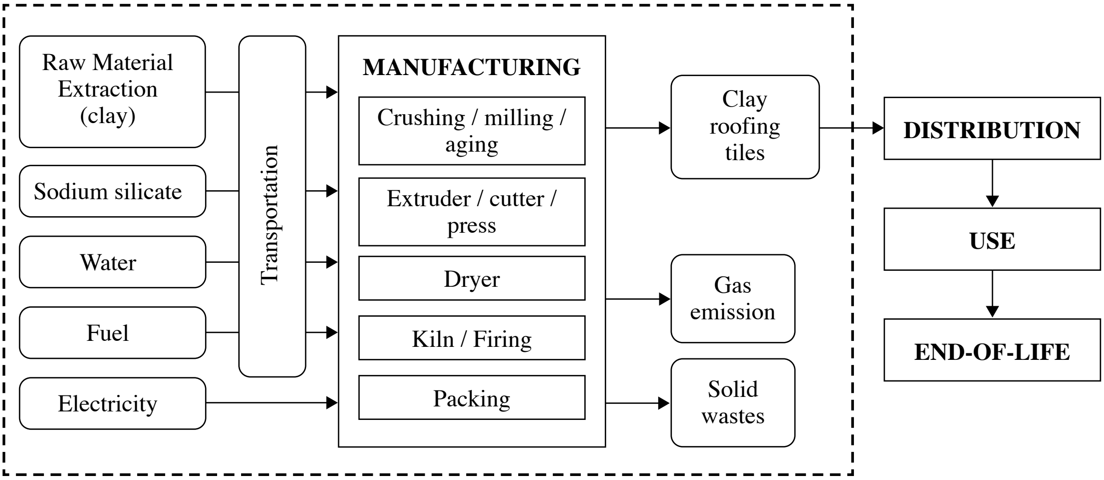

Figure 1. *Life cycle system boundary of clay roofing tiles from cradle-to-gate*

For manufacturing of concrete roofing tiles (Figure 2), the first process was to mix the raw materials (Portland cement, coarse/fine sand and water) in a mixer. Then, the mixture was discharged from the mixer through a mould to undergo extruding process that produces the tile that cut to a specific size. Iron oxide colour were added to the tiles during the production process. Sealer coating which consist of a mixture of acrylic and solvent was applied on the surface of concrete roofing tiles for providing better protection and shines to the finished product. These tiles are not fired like clay roofing tiles, but cured at a temperature of 60 °C.

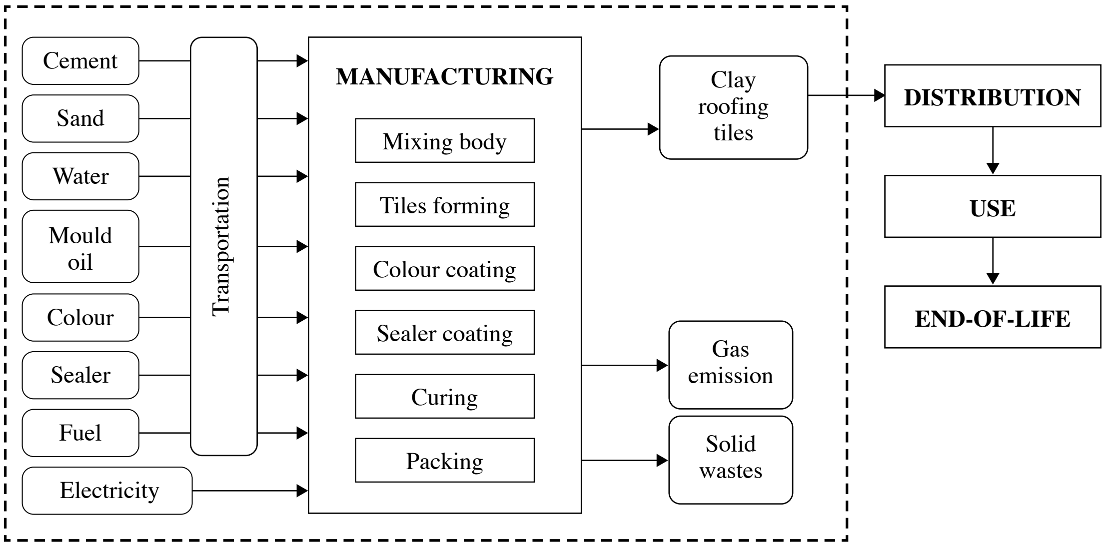

***Figure 2.** Life cycle system boundary of concrete roofing tiles from cradle-to-gate*

Life Cycle Inventory Data

Primary data for one-year production of clay roofing tiles and concrete roofing tiles which cover consumption of materials, utilities and energy, and generation of products and wastes were collected and provided by the local manufacturers. The activity data was collected based on 2014-2015 manufacturing data and the average data was taken for the profiling of the selected environmental impact assessment.

Background data for production of raw materials, fuels and utilities, generation of electricity and transportation of goods were extracted from Malaysia Life Cycle Inventory Database (MYLCID). For materials which are not available in MYLCID, data from other commercial published data i.e. Ecoinvent is used in calculations. Average Malaysian electricity grid mix was used as the background data for electricity generation, transmission and distribution which is interconnected network for delivering electricity from suppliers to consumers.

Process of roofing tiles manufacturing often produce co-product output, i.e. product that is produced along with the main product and carries equal importance as the main product. In this case, mass allocation was applied to the main product (roofing tiles) and co-product (roofing accessories) in order to get actual inventory for the production of roofing tiles. Cut-off rules are not applicable in this study because all data related to the manufacturing process including packaging are included in the calculation.

Data analysis

Gabi 6 software was used to conduct impact assessment on the roofing tiles based on life cycle inventory data provided by the manufacturer. Method TRACI 2.1 was employed during the assessment and the results were expressed according to the selected mid-point impact categories that are; Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP), and Ozone Depletion Potential (ODP).

RESULTS AND DISCUSSION

The results of impact assessment for clay and concrete roofing tiles from cradle to gate are shown in Table 2. The results show that concrete roofing tiles have less environmental impact compared to clay roofing tiles in terms of Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP) and Ozone Depletion Potential (ODP).

Table 2. Assessment impact on concrete and clay roofing tiles

Impact category	Unit	Result	
		Concrete roofing tiles	Clay roofing tiles
Global warming potential (GWP)	kg CO_2-Equiv.	11.6	17
Eutrophication potential (EP)	kg N-Equiv.	1.68E-3	4.62E-3
Acidification potential (AP)	kg SO_2-Equiv.	5.33E-2	06.95E-2
Ozone depletion potential (ODP)	kg CFC 11-Equiv.	7.08E-11	4.82E-10

The results show the summary of each impact category for concrete and clay roofing tiles are compared and illustrated in bar chart as shown in the Figure 3-10.

Global Warming Potential (GWP)

Global Warming Potential (GWP) is a relative measure of how much heat as greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. The GWP value for CO_2 is chosen as equivalence factor over a time span of 100 years.

The comparison of GWP between concrete and clay roofing tiles shows that clay roofing tiles contributes to the higher GWP compared to concrete roofing tiles as shown in Figure 3. The details contribution of GWP for both products is shown in Figure 4. The major contribution of GWP for concrete roofing tiles is mainly observed from raw material production that is Portland cement, followed with electricity consumption during manufacturing of the product. Chemical reaction during calcination process in cement production emit carbon dioxide (CO_2) which is classified as one of the Green House Gases (GHGs) that contributes to the GWP. On the other side, consumption of energy (electricity and fuel) for extrusion, pressing and firing processes are the main contributor to the GWP for clay roofing tiles and followed with plastic packaging materials i.e. polyurethane, polypropylene and low linear density polyethylene (LLDPE) for the finished product.

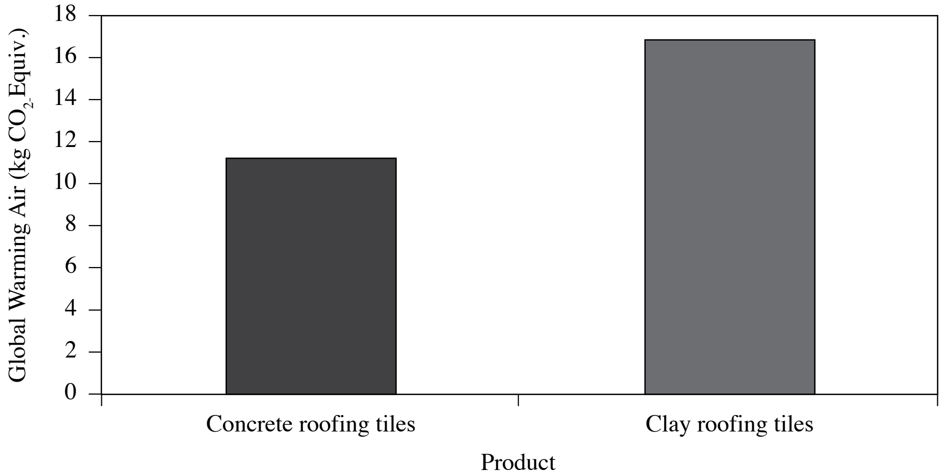

Figure 3. *Comparison of Global Warming Potential (GWP) for Concrete and Clay Roofing Tiles*

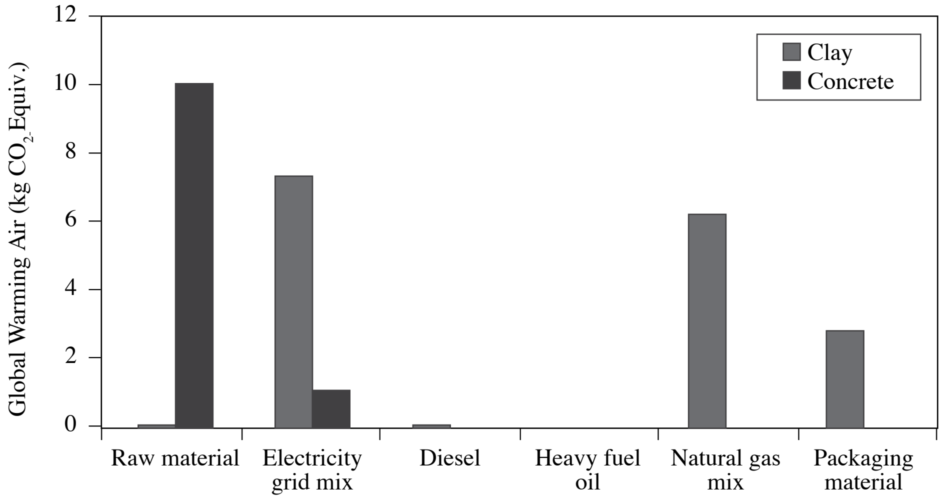

Figure 4. *Main Contribution of Global Warming Potential (GWP) for Concrete and Clay Roofing Tiles*

Acidification Potential (AP)

In order to describe the acidifying effect of substances, the acid formation potential which is known as the ability to form H^+ ions from acidifying gas emission, acidification of land and water is calculated. The result is set against a reference standard and reported as sulphur dioxide (SO_2) equivalence. The major contribution of the AP is emissions from the combustion of fossil fuels; including the electricity generation in the power station, calcination process in cement production and firing process in clay roofing tiles production as shown in Figure 6. Nitrogen oxide (NOx) and other AP substances are emitted as a result of fossil fuels combustion and electricity consumption.

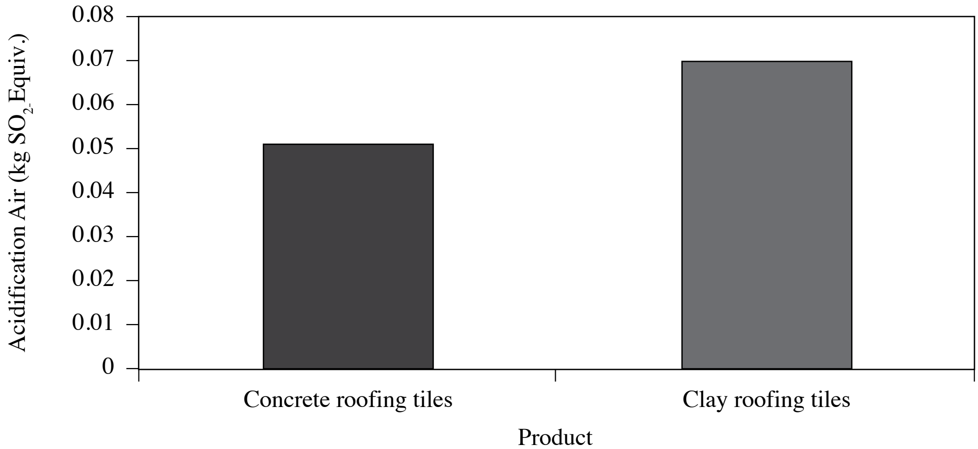

Figure 5. *Comparison of Acidification Potential (AP) for Concrete and Clay Roofing Tiles*

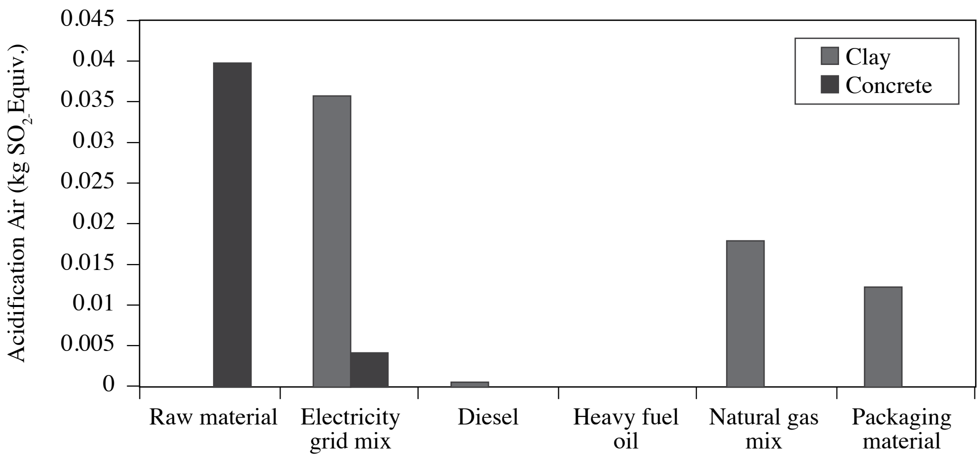

Figure 6. *Main Contribution of Acidification Potential (AP) for Concrete and Clay Roofing Tiles*

Eutrophication Potential (EP)

Additional input of plant nutrients into water can bring excessive growth of water weeds (phytobenthon), free-floating plant organisms (phytoplankton) and higher plant forms (macrophytes). This does not only represent a change in the stock of a species, but also in the balance between species. Due to the increased generation of biomass and the consequently heavier sedimentation of dead organic material, the oxygen dissolved in deep water is consumed faster, through aerobic decomposition. This can lead to serious damage in the biological populations inhabiting the sediment.

EP indicator assess the level of nutrients in a water body. The excess amount of nutrients will induce growth of plants and algae that may result in oxygen depletion. The EP assessment focused on the nitrification of land and water that is reported as Nitrogen (N) equivalence. Figure 8 shows that the main contribution to the EP for clay roofing tiles was packaging material, followed with electricity and natural gas consumption. On the other hand, raw material and electricity consumption was the main contributor of EP for concrete roofing tiles.

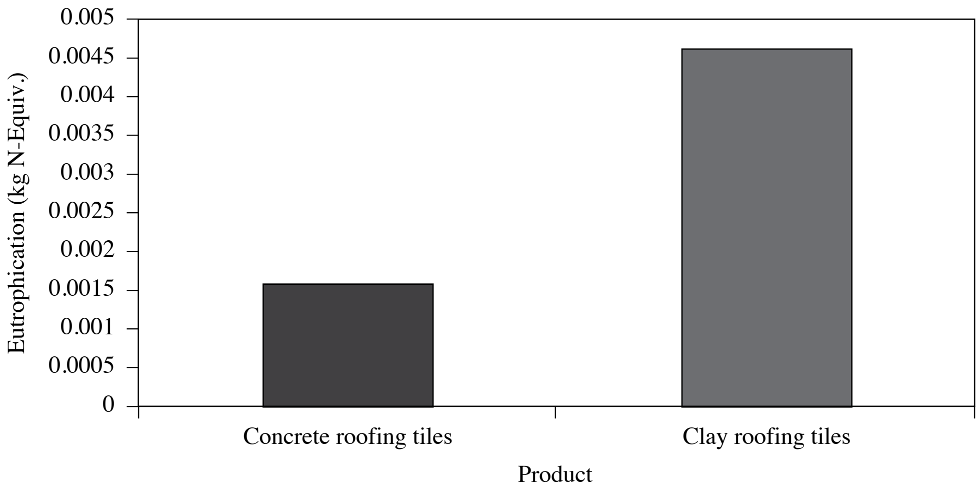

Figure 7. *Comparison of Eutrophication Potential (EP) for Concrete and Clay Roofing Tiles*

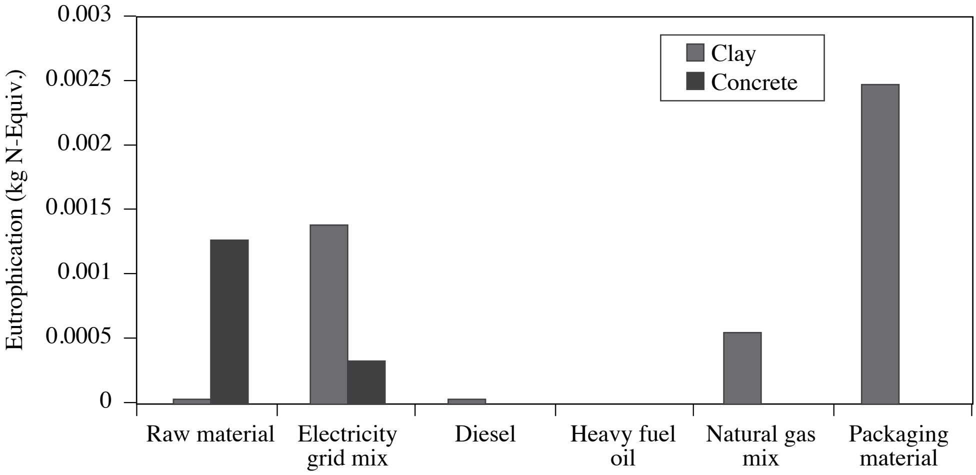

***Figure 8.** Main Contribution of Eutrophication Potential (EP) for Concrete and Clay Roofing Tiles*

Ozone Depletion Potential (ODP)

Ozone Depleting Potential (ODP) is the ratio of calculated ozone column change for each mass unit of a gas emitted into the atmosphere relative to the calculated depletion for the reference gas CFC-11. There are commonly known ozone depleting substances such as chlorofluorocarbons (CFCs), halons and other chemicals that are responsible for thinning the stratospheric ozone layer. Stratospheric ozone is a naturally-occurring gas that filters the sun's ultraviolet (UV) radiation to reach the Earth's surface. Reaction between the UV radiation and the ozone depleting substances will destruct the ozone layer and destroy the ozone molecules.

It is observed that clay roofing tiles contributed more on releasing the ozone depleting substances to the environment as illustrated in Figure 9. The electricity grid mix consumption in clay roofing tiles process has been the cause of the high contribution to the ODP. The electricity has been extensively consumed during the extrusion, pressing and firing process of clay roofing tiles as compared to concrete roofing tiles with the natural drying.

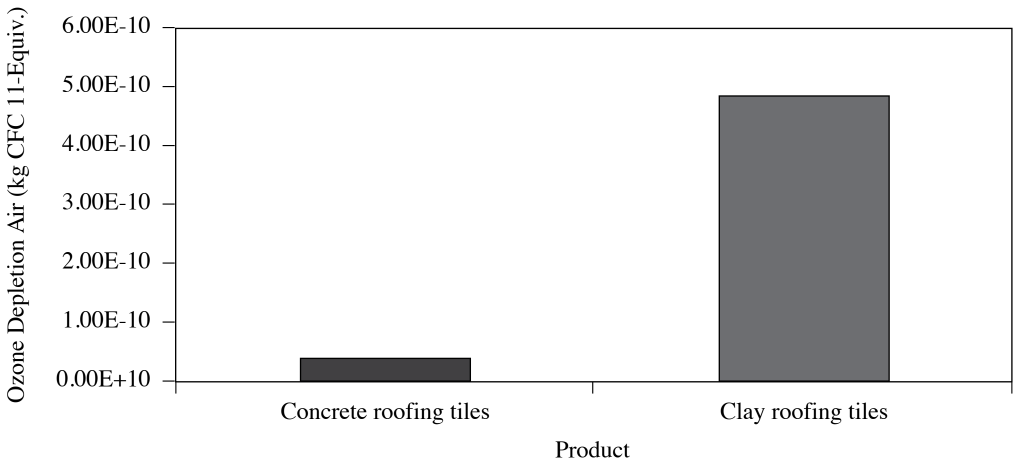

***Figure 9.** Comparison of Ozone Depletion Potential (ODP) for Concrete and Clay Roofing Tiles*

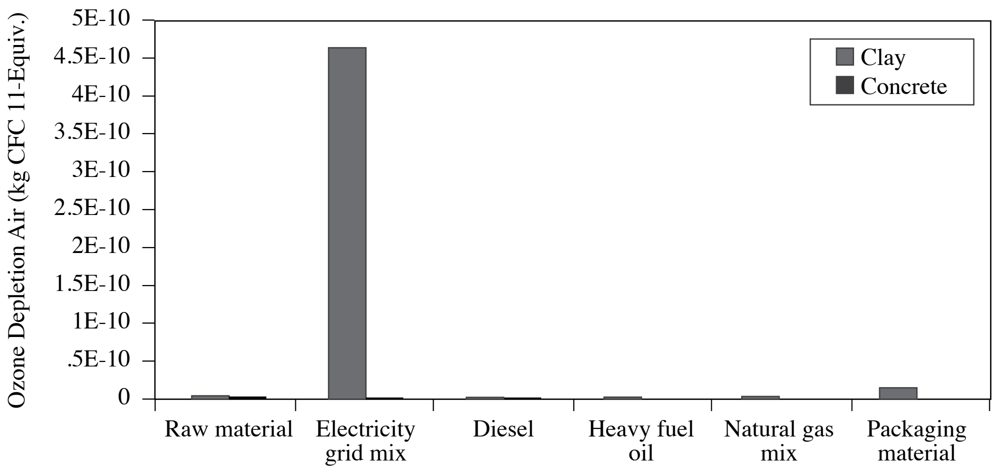

***Figure 10.** Main Contribution of Ozone Depletion Potential (ODP) for Concrete and Clay Roofing Tiles*

CONCLUSION

The main objective of this study was to compare the environmental impacts of concrete roofing tiles and clay roofing tiles over functionally equivalent covering of 1 m^2 of surface area. The results are valid for the product manufactured in Malaysia and help in identification of key parameters and hot spots in both systems together with its material categories.

The product was analyzed based on the established system boundary covering from cradle to gate in the life cycle of the product. Based on the study, the environmental hot spots for concrete roofing tiles was raw material consumption in production process. The calcination process in cement production requires extensive amount of energy and at the same time emit huge amount of greenhouse gases. This emission contributes to the high impact of GWP, AP and EP on the concrete roofing tiles. On the other hand, production of clay roofing tiles also requires extensive amount of fossil fuel for generation of energy and heat. The fossil fuels were used for generation of electricity in power station and combustion process for generation of heat in firing process. The fossil fuels consumption was considered as the environmental hot spots in production of clay roofing tiles.

In general, the results of the study show that the manufacturing process of concrete roofing tiles have less environmental impacts in terms of GWP, EP, AP and ODP compared with clay roofing tiles. However, the environmental performance of the product can be improved by reducing its environmental hot spots. Minimization of Portland cement by substitute materials i.e. fly ash, granulated blast furnace slag, silica fume, etc. during manufacturing of concrete roofing tiles will improve the environmental performance of the product. While for clay roofing tiles, reducing the consumption of fossil fuels or introducing renewable energy or biomass in the production of clay roofing tiles will contribute to improve the environmental performance of clay roofing tiles.

REFERENCES

ISO 14044, Environmental management – Life cycle assessment – Requirements and guidelines.

ISO 14040 (2006), Environmental management – Life cycle assessment – Principle and framework.

Press Release, Quarterly Construction Statistic, 4th Quarter 2016, Department of Statistics Malaysia.

Souza D., Lafontaine M., Charron-Doucet F., Bengoa X., Chappert B., Duarte F. and Lima L. (2015). "Comparative Life Cycle Assessment of ceramic versus concrete roof tiles in the Brazilian context". *Journal of Cleaner Production*, 89, 165-173.

Rode P., Burdett R. and Soares Gonçalves J. C. (2011). "Buildings: investing in energy and resource efficiency".

Zuo J., Read B., Pullen S. and Shi Q. (2012). "Achieving carbon neutrality in commercial building developments–Perceptions of the construction industry." *Habitat International*, 36(2), 278-286.

Wong J. K. W. and Zhou J. (2015). "Enhancing environmental sustainability over building life cycles through green BIM: A review." *Automation in Construction*, 57, 156-165.

Kuruppuarachchi K.A.B.N, Ihalawatta R.K., Kulatunga A.K. (2014). "Life Cycle Assessment of two different Clay Roofing Tiles". *Asia Pacific Roundtable on Sustainable Consumption and Production*, 12.

Nazirah Z. A. (2009). "Sustainable construction in Malaysia-Developers' awareness". *Proceedings of World Academy of Science, Engineering and Technology*, 41, 807-814.

Bourdeau, L., (1999)," Sustainable Development and the Future of Construction: A Comparison of Visions from Various Countries", *Building Research and Information*, 27(6), 354-366.

Zuhairi A. H., Mukhtar C. A., Kamarul Anuar, Mohamad Kamar, Maria Zura M. Z., Khairolden M. G., Hazim A. R., Natasha D., Syarizal M. N., Nurulhuda Mat Kilau and Franky Ambon (2012), "Towards a Sustainable and Green Construction in Malaysia", *Malaysian Construction Research Journal*, 11(2), 55-64.