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Carbon Emission from Buildings: An Application of Life Cycle Assessment

Pelepasan Karbon daripada Bangunan: Satu Penggunaan Penilaian Kitaran Hayat

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ABSTRACT

Buildings sector contribute to approximately 40% of carbon emissions, calling for the urge to tackle the problem. Carbon emission is mainly associated with the use of enormous amounts of energy during the operational phase in the building life cycle. Carbon emission from a building can be determined by measuring energy used starting from building material preparation until building's end of life. There is a substantial literature on determining the embodied energy (EE) of materials and carbon emission especially using Life Cycle Assessment (LCA) which considers all stages in the building life cycle. The application of LCA provides a tool for complete measurement of building effects on the environment and indirectly contributes to mitigation measures that could be applied in the whole building construction process and building life cycle that would contribute to an environment friendly and effective built environment. Thus, this paper discusses the application of LCA in building sector to determine which phases in the building life cycle that consumes more energy and releases more carbon emission. The application of LCA is very appropriate in assessing the performance of a building where effective mitigation measures could be identified to improved efficiency and helping national energy and natural resource conservation.

Keywords: Carbon emission; building; natural; life cycle assessment

ABSTRAK

Sektor bangunan menyumbang kepada lebih kurang 40% daripada pelepasan karbon, menyeru gesaan untuk menangani masalah ini. Pelepasan karbon sebahagian besarnya dikaitkan dengan penggunaan tenaga yang besar semasa fasa operasi dalam kitar hayat bangunan. Pelepasan karbon daripada bangunan boleh ditentukan dengan mengukur tenaga yang digunakan bermula daripada membina penyediaan bahan sehingga keadaan akhir bangunan. Terdapat banyak penulisan dalam menentukan 'embodied energy' (EE) bahan dan pelepasan karbon terutama menggunakan Penilaian Kitar Hayat (LCA) yang mengambil kira semua peringkat dalam kitaran hidup bangunan. Penggunaan LCA menyediakan alat untuk mengukur secara lengkap kesan-kesan bangunan terhadap alam sekitar dan secara tidak langsung menyumbang kepada langkah-langkah tebatan yang boleh digunakan dalam keseluruhan proses pembinaan bangunan dan bangunan kitaran hidup yang akan menyumbang kepada persekitaran alam bina dan berkesan. Oleh itu, kertas kerja ini akan membincangkan penggunaan LCA dalam sektor pembinaan untuk menentukan fasa dalam kitar hayat bangunan yang menggunakan lebih banyak tenaga dan melepaskan karbon secara berlebihan. Penggunaan LCA adalah sangat sesuai dalam menilai prestasi sesebuah bangunan di mana langkah-langkah tebatan yang berkesan dapat dikenal pasti untuk meningkatkan kecekapan dan membantu tenaga negara dan pemuliharaan sumber semula jadi.

Kata kunci: Pelepasan karbon; bangunan; semula jadi; penilaian kitaran kehidupan

INTRODUCTION

Building sector plays a significant function in satisfying human needs. It is designed to provide comfortable habitat and atmosphere to the occupant at the cost of huge amounts of natural resources. Building construction consume tonnes of natural resources for example energy, minerals and water while at the same time generated pollutants and waste (Dimoudi and Tompa 2008; You et al. 2011; Zuo et al 2012). Moreover, resource depletion and pollution emission derived from building sector are the main concern since more than 40% of natural resources had been consumed by the sector along with enormous emission of GHG particularly carbon dioxide (CO_2) (Arena and De Rosa 2003; Chang et al. 2012). Therefore, this sector is responsible for serious environmental problem such as waste generation, external and internal pollution, resource depletion, environmental damage, high-energy consumption and GHG emission especially CO_2 (Ortiz et al. 2009).

Globally, 30-50 % CO_2 was released by building sector, becoming one of the largest CO_2 emitter (Asif et al. 2007; Ramesh et al. 2010; Zhang et al. 2013; Jeong et al. 2012; Basbagill et al. 2013). According to IPCC (2007) and You et al. (2011), high concentration of CO_2 had been emitted to the atmosphere with concentration of 5.3 – 6.7 Gt of CO_2 per year. The emission of CO_2 is related to energy consumption throughout the building life cycle especially during operational phase (Kofoworola and Gheewala 2009; Monahan and Powell 2011). According to Jeong et al. (2012), operational energy accounts for 85 - 95 % of total energy used for dwelling type buildings. Moreover, energy consumption is not only focused during the operational of the building, it also encompasses embodied energy, which relates to resource extraction and manufacturing of building materials. For example high amount of CO_2 is released during the manufacturing of cement process and until the end-use of the building (Blengini and Di Carlo 2010; Lee et al. 2013). Thus, there is a long-term goal of CO_2 emission and energy reduction specifically to be implemented for the building industry by many countries and organization.

There are several alternatives to reduce emission from building sector. As suggested by IPCC (2007) and Zuo et al. (2012), this emission can be reduce by two main measures which are reducing operational energy and embodied energy consumption and application of renewable energy for building operation. Rising attention for environmental performance of building especially in energy saving led to several concept such as low-energy building, passive building and zero-energy building in order to reduce environmental burden from building sector (Thiers and Peuportier 2012). Adalberth (1997a) had presented a method to analyse the energy usage for dwellings with recommendation to reproduce buildings that require small amount of energy during management phases. This is because, higher energy demand is needed because of the production and placement of additional technical system especially for new and eco-friendly house such as passive house and solar house (Feist et al. 2005; Thiers and Peuportier 2012). In this context, it is important to have assessment method for whole building phases especially methods that provide complete measurement for building sector.

In order to enhance the environmental quality several methodologies had been developed to improve building environment performance such as life cycle assessment (LCA) (Ortiz et al. 2009; Zhang et al. 2013). LCA is a tool in assessing sustainability of buildings, it has always been characterised as a “cradle to grave” or also “cradle to cradle” concept which able to analyse all phases of building from material production until end on life. Many studies have been done in determining a variety of environmental impacts from many types of building. Therefore, LCA can be used as an aid to enhance the accurateness of decision making in any building sector activities towards sustainability of construction industry (Ortiz et al. 2009). This paper aims to review briefly the application of LCA in assessing building performance in consuming energy and emitting CO_2.

UNDERSTANDING LCA

Nowadays, there is growing of awareness concerning the quality of our environment, which is being worsened by anthropogenic activities and climate change. Scientific documentation regarding human activities that contribute to climate change and lessons that is learnt from industrial pollution that affects our environment leads to the introduction of sustainability concept. In order to achieve sustainability, life cycle assessment can be applied to decision making which can help in overcome the resource depletion and environmental issues (Ortiz et al. 2009; Ramesh et al. 2012). The concept of LCA has being develop since year 1970s and 1980s that focuses on the estimation of energy and materials used and waste production throughout the product life cycle from raw materials process, manufacturing, use and disposal (Dakwale and Ralegaonkar 2012; Sharma et al. 2011). This complete and complex assessment is well known as cradle to grave approach (Kofoworola and Gheewala 2009; Ortiz et al. 2009; Blengini and Di Carlo 2010; Ramesh et al. 2010).

The comprehensiveness and unified assessment in handing topics for example framework, impact assessment and data quality makes LCA being widely used (Ortiz et al. 2009). LCA method has been internationally recognized and highlighted as an international standard under ISO 14000 series on environmental management (Kofoworola and Gheewala 2009; Blengini and Di Carlo 2010; Cucek et al. 2012). As stated by Arena and De Rosa (2003), Asif et al. (2007), Hammond and Jones (2008), Sharma et al. (2011) and Thorn et al. (2011), there are four main stages of ISO LCA framework that follow logical sequences of goal definition and scoping, inventory analysis, impact assessment and interpretation (Figure 1). The most important stage in LCA is inventory analysis where it is aims to determine the magnitude and significance of the potential environmental impact of the studies by calculating the inputs which can be materials and energy and the outputs such as emissions and waste (Chang et al. 2012).

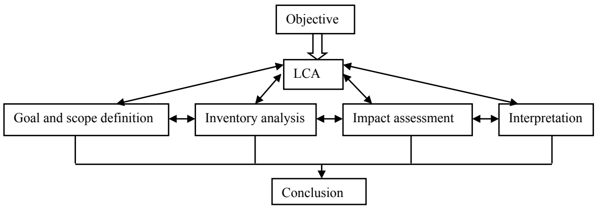

FIGURE 1. Stages in life cycle assessment

There is several methodology of LCA particularly in inventory stages which are process analysis, input-output analysis and hybrid analysis (combination of process and input-output analysis) (Kofoworola and Gheewala 2009; Heinonen et al. 2011; Sharma et al. 2011). According to Dias and Pooliyadda (2004) process analysis requires input and output data at the level of an individual industry which produces an accurate analysis but as stated by Kofoworola and Gheewala (2009), this analysis requires sufficient data requirement which makes it time consuming. Input-output analysis is based on monetary transaction which requires an input-output table (Heinonen et al. 2011). It is known as a comprehensive analysis because of the application of Leontief Inverse matrix but lacks in precision (Treloar et al. 2001) while hybrid analysis is an analysis that is designed to overcome the incompleteness of both previous analysis (Heinonen et al. 2011). The completeness of LCA makes this tools being widely use. Even though LCA is as science-based environmental assessment method, it also can be applied by several field of studies such as social studies (Weidema 2006), biological analysis (Passell et al. 2013), social-economic analysis (Iribarren and Vázquez-Rowe 2013) and human risk assessment (Ribera et al. 2014). Moreover, the methodology that represent by LCA has frequently applied to assess building system performance.

APPLICATION OF LCA IN BUILDING SECTOR

LCA is widely used in assessing embodied and operational energy in the whole life cycle of a building (Dixit et al. 2012). The studies on energy consumption estimation during the different life cycle stages: embodied, construction, operational, demolition and recycling known as life cycle energy analysis (LCEA) which is a form of LCA (Kua and Wong 2012; Buyle et al. 2013). In total life cycle energy of a building, embodied and operational energy are the important aspects to be quantified (Dixit et al. 2010). Embodied energy is the energy required for production of materials or product (Treloar et al. 2001; Cabeza et al. 2013) which includes mining process, refining, manufacturing, transportation and erection (Langston and Langston 2008) while operational energy includes all activities related to the use of the building related to operational phase, for example maintenance of indoor environment through heating and cooling; lighting and operational appliances (Ramesh et al. 2010; Cabeza et al. 2013).

High energy use always relates to high emission of CO_2. Every stage in building life cycle consumes energy and in particular produces emission. According to Williams et al. (2012), high energy consumption of a building during operational phase was due to high demand of cooling and heating in the building known as air conditioning and heater usage. Moreover, there were few literature using LCA application in building sector especially in determining embodied energy and CO_2 emission for example office building in Canada (Cole and Kernan 1996), single house dwelling in Sweden (Adalberth 1997b), low carbon building in Italy (Blengini and Di Carlo 2010), high-rise building in China (Chang et al. 2012), common residential house in United Kingdom (Cuéllar-Franca and Azapagic 2012) and commercial building in Singapore (Kua and Wong 2012). The comparison between type of building and highest emission of CO_2 among building life cycle phases are shown in Table 1.

TABLE 1. Selected studies related to energy and CO_2 emission

References	Type of analysis	Area	Type of building	Parameter studied	Note
Suzuki and Oka (1998)	LCA	Japan	Office	Energy, CO_2	Highest energy and CO_2 emission during operational phase
Blengini and Di Carlo (2010)	LCA	Italy	Low energy building compared with standard house	Energy, CO_2	Highest CO_2 emission during operational phase, low energy building contribute less CO_2 emission from standard house
You et al. (2012)	LCA	China	Residential concrete and steel structure	CO_2	Highest CO_2 emission during operational phase
Zhang et al. (2013)	LCA	Hong Kong	High commercial building	Air emission (CO_2, CH_4, SO_2, CO, NOx, N_2O)	Highest CO_2 emission among air emission analysed and during operational phase

The applications of LCA in many types of studies, areas, parameters as well as the objectives with plenty of them are more focused in assessing energy consumption rather than CO_2 emission. One of the earliest studies by Suzuki and Oka (1998) provides a significant reference by using LCA in assessing building energy consumption and CO_2 emission. The result from that study showed that, highest CO_2 emission was during operational phase of office building. Similar result determined by You et al. (2012) also shows that highest CO_2 emission from operational phases of residential building for both concrete and steel structure. The studies also find that CO_2 emission during life cycle of residential building mainly come from energy consumption and land footprint. Furthermore, a study by Blengini and Di Carlo (2010) shows that particularly low carbon energy building contributes significantly lower CO_2 emission from standard house but operational phase still is the dominant contributor. The finding by Zhang et al. (2013) reported that every phase in building life cycle generates air emission with highest CO_2 emission (compared to other air emission tested) in overall phase of building life cycle as previous studies came during operational phase.

BUILDING ASSESSMENT IN MALAYSIA

The assessment of building sector in Malaysia is limited to green building rating while the whole life cycle assessment still in progress. In fact, the limitation of initial data in terms of availability makes LCA application in Malaysia of low priority. Moreover, some of the organization tends to keep their data confidentially, which makes the compiling process difficult. According to Arena and De Rosa (2003), the difficulties of using LCA in developing countries such as Malaysia due to lack of expertise, high cost, complexity and lack of local data. However, wide use of LCA application all over the world shows that the accurateness of LCA in assessing building performance which in turn makes it recommendable to be applied in the construction industry of Malaysia.

The understanding of building embodied energy in Malaysia is still new and needs more research. Quantification of building embodied energy particularly in materials is not available compared to other country such as United Kingdom where a list of embodied energy is listed by Hammond and Jones (2008). In Asia, countries such as Taiwan also have their own database on building materials and CO_2 emission. Moreover, there is no detailed study on building energy performance exists in Malaysia compared to other country. According to Monahan and Powell (2011), the value of embodied energy and emission of carbon are different by country because of the energy mix, transformation processes, the efficiency of the industrial and economic system of the country and variability over the time. Thus, it is necessary to have detail embodied energy database. It is also very important to monitor electricity energy requirement of a product since it gives general idea of the product's environmental footprint (Thorn et al. 2011). Moreover, the effectiveness of national strategy in reducing energy consumption especially from building sector can only be done with completeness of each building materials embodied energy database. As stated by Hammond and Jones (2008), the availability of embodied energy database will help in determining the best material to be used with lowest CO_2 gas emission and impact to the environment.

CONCLUSION

As building sector is one of the major consumers of energy and main contributor of greenhouse gases particularly CO_2, the environmental impact from this sector is significant. Even though building sector is designed for human needs which good condition and cosy environment is the main priority, active action in energy reduction and energy saving needs to be taken. Highest energy usage and CO_2 emission comes from the operational phase in building life cycle and is well understood, however other life cycle phase of building at the same time could not be neglected. Thus, the application of LCA is very appropriate in assessing the performance of building where effective mitigation measures can be done. As a whole, the performance of the building can be improved while helping national energy and natural resource conservation.

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REFERENCES

Adalberth, K.1997a. Energy use during the life cycle of buildings: a method. *Building and Environment* 32(4): 317–320.

Adalberth, K. 1997b. Energy use during the life cycle of single-unit dwellings: Examples. *Building and Environment* 32(4): 321–329.

Arena, A. P. and De Rosa, C. 2003. Life cycle assessment of energy and environmental implications of the implementation of conservation technologies in school buildings in Mendoza—Argentina. *Building and Environment* 38: 359–368.

Asif, M., Muneer, T. and Kelley, R. 2007. Life cycle assessment: A case study of a dwelling home in Scotland, *Building and Environment* 42: 1391–1394.

Basbagill, J., Flager, F., Lepech, M. and Fischer, M. 2013. Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts. *Building and Environment* 60: 81–92.

Blengini, G. A. and Di Carlo, T. 2010. The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings. *Energy and Buildings* 42: 869–880.

Buyle, M., Braet, J. and Audenaert, A. 2013. Life cycle assessment in the construction sector: A review. *Renewable and Sustainable Energy Reviews* 26: 379–388.

Cabeza, L. F., Barreneche, C., Miró, L., Morera, J. M., Bartolí, E. and Fernández, A. I. 2013. Low carbon and low embodied energy materials in buildings: A review. *Renewable and Sustainable Energy Reviews* 23: 536–542.

Chang, Y., Ries, R. J. and Lei, S. 2012. The embodied energy and emissions of a high-rise education building: A quantification using process-based hybrid life cycle inventory model. *Energy and Buildings* 55: 790–798.

Cole, R. J. and Kernan, P. C. 1996. Life-cycle energy use in office buildings, *Building and Environment* 31(4): 307–317.

Cucek, L., Klemes, J. J. and Kravanja, Z. 2012. A review of footprint analysis tools for monitoring impacts on sustainability. *Journal of Cleaner Production* 34: 9–20.

Cuéllar-Franca, R. M. and Azapagic, A. 2012. Environmental impacts of the UK residential sector: Life cycle assessment of houses. *Building and Environment* 54: 86–99.

Dakwale, V. A. and Ralegaonkar, R. V. 2012. Review of carbon emission through buildings: threats, causes and solution. *International Journal of Low-Carbon Technologies* 7:143–148.

Dias, W. P. S. and Pooliyadda, S. P. 2004. Quality based energy contents and carbon coefficients for building materials: A systems approach. *Energy* 29: 561–580.

Dimoudi, A. and Tompa, C. 2008. Energy and environmental indicators related to construction of office buildings. *Resources, Conservation and Recycling* 53: 86–95.

Dixit, M. K., Fernández-Solís, J. L., Lavy, S. and Culp, C. H. 2010. Identification of parameters for embodied energy measurement: A literature review. *Energy and Buildings* 42: 1238–1247.

Dixit, M. K., Fernández-Solís, J. L., Lavy, S. and Culp, C. H. 2012. Need for an embodied energy measurement protocol for buildings: A review paper. *Renewable and Sustainable Energy Reviews* 16: 3730–3743.

Feist, W., Schnieders, J., Dorer, V. and Haas, A. 2005. Re-inventing air heating: convenient and comfortable within the frame of the passive house concept. *Energy and Buildings* 37: 1186–1203.

Hammond, G. and Jones, C. 2008. *Inventory of carbon and energy*. United Kingdom: University of Bath.

Hammond, G. P. and Jones, C. I. 2008. Embodied energy and carbon in construction materials. *Proceedings of the Institution of Civil Engineers - Energy* 161(2): 87–98.

Heinonen, J., Kyrö, R. and Junnila, S. 2011. Dense downtown living more carbon intense due to higher consumption: a case study of Helsinki. *Environmental Research Letters* 6: 034034.

IPCC. 2007. Fourth Assessment Report: Climate Change. Intergovernmental Report on Climate Change.

Iribarren, D. and Vázquez-Rowe, I. 2013. Is labor a suitable input in LCA + DEA studies? Insights on the combined use of economic, environmental and social parameters. *Social Sciences* 2:114–130.

Jeong, Y.-S., Lee, S.-E. and Huh, J.-H. 2012. Estimation of CO_2 emission of apartment buildings due to major construction materials in the Republic of Korea. *Energy and Buildings* 49: 437–442.

Kofoworola, O. F. and Gheewala, S. H. 2009. Life cycle energy assessment of a typical office building in Thailand. *Energy and Buildings* 41(10): 1076–1083.

Kua, H. W. and Wong, C. L. 2012. Analysing the life cycle greenhouse gas emission and energy consumption of a multi-storied commercial building in Singapore from an extended system boundary perspective. *Energy and Buildings* 51: 6–14.

Langston, Y. L. and Langston, C. A. 2008. Reliability of building embodied energy modeling: an analysis of 30 Melbourne case studies. *Construction Management and Economics* 26(2): 147–160.

Lee, S., Park, W. and Lee, H. 2013. Life cycle CO_2 assessment method for concrete using CO_2 balance and suggestion to decrease LCCO2 of concrete in South-Korean apartment. *Energy and Buildings* 58: 93–102.

Monahan, J. and Powell, J. C. 2011. An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. *Energy and Buildings* 43: 179–188.

Ortiz, O., Bonnet, C., Bruno, J. C. and Castells, F. 2009. Sustainability based on LCM of residential dwellings: A case study in Catalonia, Spain. *Building and Environment* 44: 584–594.

Ortiz, O., Castells, F. and Sonnemann, G. 2009. Sustainability in the construction industry: A review of recent developments based on LCA. *Construction and Building Materials* 23: 28–39.

Passell, H., Dhaliwal, H., Reno, M., Wu, B., Amotz, A. B., Ivry, E., Gay, M., Czartoski, T., Laurin, L. and Ayer, N. 2013. Algae biodiesel life cycle assessment using current commercial data. *Journal of Environmental Management* 129: 103–111.

Ramesh, T., Prakash, R. and Shukla, K. K. 2010. Life cycle energy analysis of buildings: An overview. *Energy and Buildings* 42: 1592–1600.

Ramesh, T., Prakash, R. and Shukla, K. K. 2012. Life cycle approach in evaluating energy performance of residential buildings in Indian context. *Energy and Buildings* 54: 259–265.

Ribera, G., Clarens, F., Martínez-Lladó, X., Jubany, I., Martí, V. and Rovira, M. 2014. Life cycle and human health risk assessments as tools for decision making in the design and implementation of nanofiltration in drinking water treatment plants. *The Science of the Total Environment* 466-467: 377–386.

Sharma, A., Saxena, A., Sethi, M. and Shree, V. 2011. Life cycle assessment of buildings: A review. *Renewable and Sustainable Energy Reviews* 15:871–875.

Suzuki, M. and Oka, T. 1998. Estimation of life cycle energy consumption and CO_2 emission of office buildings in Japan. *Energy and Buildings* 28: 33–41.

Thiers, S. and Peuportier, B. 2012. Energy and environmental assessment of two high energy performance residential buildings. *Building and Environment* 51: 276–284.

Thorn, M. J., Kraus, J. L. and Parker, D. R. 2011. Life-cycle assessment as a sustainability management tool: strengths, weaknesses, and other considerations. *Environmental Quality Management* Spring: 1–10.

Treloar, G. J., Love, P. E. D. and Holt, G. D. 2001. Using national input-output data for embodied energy analysis of individual residential buildings. *Construction Management and Economics* 19: 49–61.

Weidema, B. P. 2006. The integration of economic and social aspects in life cycle impact assessment. *International Journal of LCA* 11(1): 89–96.

Williams, D., Elghali, L., Wheeler, R. and France, C. 2012. Climate change influence on building lifecycle greenhouse gas emissions: Case study of a UK mixed-use development. *Energy and Buildings* 48: 112–126.

You, F., Hu, D., Zhang, H., Guo, Z., Zhao, Y., Wang, B. and Yuan, Y. 2011. Carbon emissions in the life cycle of urban building system in China—A case study of residential buildings. *Ecological Complexity* 8: 201–212.

Zhang, X., Shen, L. and Zhang, L. 2013. Life cycle assessment of the air emissions during building construction process: A case study in Hong Kong. *Renewable and Sustainable Energy Reviews* 17: 160–169.

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: 278–286.

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