Life Cycle Carbon Emissions Analysis of a Detached House in Thailand

Nattaya Sangngamratsakul[1], Kuskana Kubaha[1] and Siriluk Chiarakorn[2]

[1] Energy Management Technology Program, School of Energy, Environment and Materials,
King Mongkut's University of Technology Thonburi, 126 Pracha Uthit Rd., Bang Mod,
Thung Khru, Bangkok 10140, Thailand
[2] Environmental Technology Program, School of Energy, Environment and Materials,
King Mongkut's University of Technology Thonburi, 126 Pracha Uthit Rd., Bang Mod,
Thung Khru, Bangkok 10140, Thailand
`nattaya.s@mail.kmutt.ac.th`

Abstract. The high demand of fossil fuels used across various sectors leads to an increase of carbon emissions released into the atmosphere. This contributes to environmental issues such as global warming, air pollution, and climate change. Thailand's commitment to achieving carbon neutrality by 2050 highlights the critical need to assess carbon emissions in residential buildings. This is due to the significant contributions of both embodied and operational emissions from buildings to overall greenhouse gas (GHG) emissions throughout their lifespans. This study aims to determine the total carbon emissions of a detached house in Thailand by using the life cycle carbon emissions analysis (LCCEA) approach. The cradle-to-grave scope was employed for determining the total carbon emissions from six stages throughout the building's life cycle, i.e., initial, transportation, construction, recurrent, operational, and demolition. A detached house was broken down into 16 main building materials to quantify initial embodied emissions and recurrent embodied emission. The emission factors from the Inventory of Carbon & Energy (ICE) were employed to calculate initial embodied emissions and recurrent embodied emissions. The results from this study revealed that fiber-cement had the highest carbon emissions, accounting for 31.92% followed by steel (30.11%), and concrete (17.35%). The quantification of transportation emissions, construction emissions, operational emissions, and demolition emissions utilizes emission factors obtained from the Thailand Greenhouse Gas Management Organization (TGO). The results show that operational emissions account for the largest proportion at 54%, followed by initial embodied emissions (35%), recurrent embodied emissions (9%), and the remaining stages (2%). The total life cycle carbon emissions of a detached house was 53.97 $kgCO_2e/m^2$/year. These findings can be used to develop guidelines for reducing carbon emissions in building construction sector, ultimately contributing to achieve carbon neutrality by 2050 and fostering a sustainable future society.

Keywords: Life Cycle Carbon Emissions Analysis, Carbon Emissions, Embodied Carbon.

1 Introduction

Rapid population growth is driving an increased demand for fossil fuels across various sectors and lead to a rise in carbon emissions, contributing to environmental issues such as global warming, air pollution, and climate change. Recognizing the urgency of this situation, Thailand announced the commitment for achieving carbon neutrality by 2050 at the 26th United Nations Climate Change Conference (COP26). According to a study, construction and operation of buildings consume 35% of global energy and are responsible for nearly 40% of carbon emissions [1]. Therefore, assessing carbon emissions in residential buildings is crucial for achieving carbon neutrality by 2050. Life cycle carbon emissions analysis (LCCEA) is a subset of life cycle assessment (LCA) that focuses specifically on determining the total GHG emissions associated with a building throughout its lifespan. The results are typically reported in kilograms of carbon dioxide equivalent ($kgCO_2e$) and usually account for the three main types of GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon emissions can be categorized into two main types: embodied emissions and operational emissions [2]. Embodied emissions can be further divided into initial embodied emissions, which occur during the extraction of raw materials, transportation to the manufacturer and manufacturing of building materials. While, recurrent embodied emissions occur during maintenance and replacement of building materials throughout the building's lifespan. Moreover, embodied emissions occur during transportation of building materials to construction site, construction, and demolition process. Operational emissions, in contrast, refer to the emissions that occur during the building's use phase. This type of emission comes from running appliances, such as air-conditioning and lighting, to maintain comfortable conditions for occupants. The determination of carbon emissions through the LCCEA approach becomes increasingly important for assessing GHG emissions. This approach provides comprehensive results that reflect the environmental problems associated with climate change, a pressing global issue. This research applies LCCEA to determine the total carbon emissions of a detached house in Thailand. The cradle-to-grave scope is employed, including six stages, i.e., initial, transportation, construction, recurrent, operational, and demolition. To quantify initial and recurrent embodied emissions, a detached house was broken down into 16 main building materials. The emission factors for these carbon emissions were obtained from the Inventory of Carbon & Energy (ICE). While, the emission factors from the Thailand Greenhouse Gas Management Organization (TGO) were then utilized to quantify transportation emissions, construction emissions, operational emissions, and demolition emissions. The findings from this research can be further applied to set guidelines for achieving carbon neutrality by 2050, ultimately contributing to a more sustainable future society.

2 Methodology

This research uses a two-story detached house designed for four occupants as a case study. The house was developed by the Department of Alternative Energy Development and Efficiency (DEDE) [3]. The house has an internal floor area of 127 m^2 and a gross floor area of 215 m^2. It is assumed to have a lifespan of 50 years. The LCCEA approach with cradle-to-grave scope is employed, including six stages, i.e., initial, transportation, construction, recurrent, operational, and demolition.

2.1 Initial and Recurrent Embodied Emissions

The quantity of each building material used is multiplied by emission factors obtained from the ICE to calculate initial embodied emissions. The number of replacements for each building material is then counted to quantify recurrent embodied emissions. Service lifetimes for each building material are obtained from previous publications [6, 7]. The quantity from each building materials, service lifetime, and emission factors are presented in Table 1.

Table 1. The quantity, service lifetime, and emission factors of building materials.

No.	Building Materials	Quantity used at each stage (kg)		Service Lifetime [1]	Emission factors [2]
		Initial	Recurrent	(year)	($kgCo_2e/kg$)
1	Concrete	255,982	-	-	0.103
2	Steel	15,157	-	-	3.02
3	Autoclaved aerated blocks	7120	-	-	0.280
4	Cements	7029	-	-	0.832
5	Sand	5745	-	-	0.00747
6	Aluminum	795	-	-	6.67
7	Glass	604	-	-	1.44
8	Fiber-cement panels	18,953	18,953	30	1.28
9	Timber	10,097	165	25	0.493
10	Ceramic tiles	4331	4331	25	0.780
11	Gypsum board	1627	1627	30	0.39
12	Plywood (MDF)	349	349	25	0.856
13	Fiberglass	271	271	15	1.35
14	Paints	133	102	10	2.91
15	Plastics	80	80	25	3.31
16	Plywood	32	32	25	0.681

[1] Based on Treloar, G. [6] and Crawford, R. [7]. [2] Based on ICE [4].

2.2 Transportation Emissions

A transportation distance of 50 km is assumed. During the initial stage, building materials are transported by a six-wheeled truck with a maximum load capacity of 11 tons. Pickup trucks with a maximum load capacity of 1 ton are used for transporting building materials during the recurrent stage. Round-trip transportation is considered for calculating emissions. Emissions for the delivery trip are calculated based on a 100% load, while the return trip emissions are based on a 0% load. A six-wheeled truck releases 0.0677 $kgCO_2e/tkm$ when fully loaded and 0.4273 $kgCO_2e/km$ when empty. In comparison, a pickup truck releases 0.1411 $kgCO_2e/tkm$ when fully loaded and 0.3131 $kgCO_2e/km$ when empty. The emission factors for this calculation are obtained from the TGO [5].

2.3 Construction Emissions

The energy consumption of the construction process was obtained from the study by Sangngamratsakul, N. [8], which applied life cycle energy analysis (LCEA) to quantify the total energy consumption of an energy-conservation house in Thailand. This data was then used to determine construction emissions by allocating it evenly between diesel combustion and electricity. Emission factors for diesel combustion and electricity were obtained from TGO [5] at 2.7406 $kgCO_2e/L$ and 0.5986 $kgCO_2e/kWh$, respectively.

2.4 Operational Emissions

The operational energy data was obtained from Nitsunkit, S. [9]. This data was then multiplied by the emission factor for electricity, which was 0.5986 $kgCO_2e/kWh$, as reported by TGO [5].

2.5 Demolition Emissions

Demolition energy consumption is assumed to be 176 MJ/m^2 based on Guan, L. [10]. This value is multiplied by the gross floor area of the case study house to determine the total energy consumed during demolition. Assuming all this energy is derived from diesel combustion, demolition emissions are calculated using the emission factor for diesel combustion of 2.7406 $kgCO_2e/L$, as reported by TGO [5].

3 Results and Discussions

3.1 Embodied Emissions of Building Materials

Embodied emissions of the 16 main building materials used in a case study house were quantified for both initial and recurrent stages. Figure 1 presents the results of embodied emissions for each building material. The results reveal that fiber-cement releases the most carbon emissions, accounting for 31.92% of the total, followed by steel (30.11%), and concrete (17.35%). Notably, even though concrete is used in the highest quantity, fiber-cement and steel have a greater environmental impact due to their higher embodied emissions. Additionally, the results show that a small amount of aluminum can contribute a significant proportion of embodied emissions. These findings highlight the importance of material selection in reducing embodied emissions for buildings. Using materials with longer service lifetimes and greater durability can also reduce recurrent embodied emissions.

3.2 Life Cycle Carbon Emissions of a Case Study House

The total life cycle carbon emissions of a case study house are categorized into six stages: initial (120,786 $kgCO_2e$), transportation (1,347 $kgCO_2e$), construction (1,482 $kgCO_2e$), recurrent (31,224 $kgCO_2e$), operational (185,017 $kgCO_2e$), and demolition (2,847 $kgCO_2e$). As shown in Figure 2, operational emissions contribute the most at 54%, followed by initial embodied emissions (35%), recurrent embodied emissions (9%), and the remaining stages (2%) comprise with transportation, construction, and demolition emissions. The total life cycle emissions of a case study house was 53.97 $kgCO_2e/m^2$/year. These findings emphasize that solely focusing on operational emissions is inadequate for reducing carbon emissions. Embodied emissions from both initial and recurrent stages are growing in importance. This study's results can inform the development of guidelines to reduce carbon emissions, ultimately contributing to achieve carbon neutrality by 2050 and promoting the development of a sustainable society.

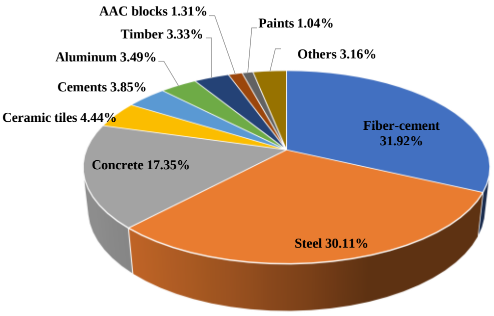

Fig. 1. The proportion of embodied emissions from different building materials.

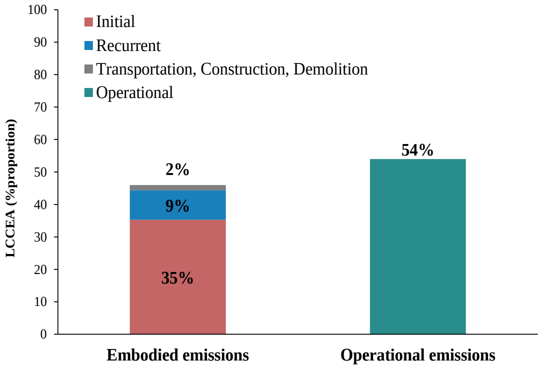

Fig. 2. The proportion of emissions throughout the building's life cycle.

4 Conclusion

These findings emphasize that reducing GHG emissions by focusing on operational emissions is inadequate. Embodied emissions from both initial and recurrent stages are growing in importance. In the context of Thailand, LCCEA throughout the building's life cycle should be emphasized and published to the public due to its crucial role in achieving the carbon neutrality goal by 2050. This study highlights the importance of selecting building materials with low embodied emissions, longer service lifetimes, and greater durability. These characteristics can significantly reduce both initial and recurrent embodied emissions. Furthermore, the results provide valuable data for future research on LCCEA of buildings. Ultimately, this research can inform the development of guidelines for achieving carbon neutrality by 2050 and supporting the development of a sustainable society for the future.

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References

1. Ajay Kumar K.C., Ghimire, A., Adhikari, B., Pant, H. R., Thapa, B., Baral, B.: Life cycle energy use and carbon emission of a modern single-family residential building in Nepal. Current Research in Environmental Sustainability 7, 1-9 (2024)
2. Huang, Z., Zhou, H., Miao, Z., Tang, H., Lin, B., Zhuang, W.: Life-cycle carbon emissions (LCCE) of buildings: implications, calculations, and reductions. Engineering 35, 115-139 (2024).
3. Study on Energy Efficiency Criteria and Prototype Development for Residential Buildings Homepage, https://www.aad.kmitl.ac.th/dede/, last accessed 2024/03/01.
4. Circular Ecology Homepage, https://circularecology.com, last accessed 2024/03/01.
5. Thailand Greenhouse Gas Management Organization Homepage, https://thaicarbonlabel.tgo.or.th, last accessed 2024/04/01.
6. Treloar, G., Fay, R., Love, P. E. D., Iyer-Raniga, U.: Analysing the life-cycle energy of an Australian residential building and its householders. Building Research and Information 28(3), 184-195 (2000).
7. Crawford, R. H., Czerniakowski, I., Fuller, R. J.: A comprehensive framework for assessing the life-cycle energy of building construction assemblies. Architectural Science Review 53(3). 288-296 (2010).
8. Sangngamratsakul, N., Kubaha, K., Chiarakorn, S.: Embodied energy coefficient quantification and implementation for an energy-conservative house in Thailand. Sustainability 16. 4045 (2024).
9. Nitsunkit, S.: Embodied energy of energy-efficient houses in Thailand. Master of Engineering, King Mongkut's University of Technology Thonburi., Bangkok Thailand (2018).
10. Guan, L., Walmsely, M., Chen, G.: Life cycle energy analysis of eight residential houses in Brisbane, Australia. In: 9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE), pp. 653-661. Procedia Engineering, Tianjin China (2015).