Life cycle energy analysis of a green building in Vietnam

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Abstract. The paper presents the life cycle energy analysis (LCEA) of an office green building in Hanoi, Vietnam to prove the advantages of green buildings regarding energy efficiency and environmental effects. The case study building is a concrete structured one, which consists of 3 basements, 17 floors, and 1 attic with a gross area of 14,112 m². In the study, the building’s embodied energy is determined based on the contained energy coefficient of the i-th material and its quantity needed. Whereas, the operating energy is computed according to the annual energy consumption of the building, which is stimulated by the EnergyPlus simulation software. Relying on the relative share of the demolition energy with the life cycle energy that has been proposed by previous publications, this category will be estimated. Results showed that the initial embodied energy contributed the largest share to the life cycle energy (61.37%), followed by operational energy (27.61%). It also indicated that the percentage share of the operational energy of a green building is much lower than that of other buildings. The primary reason for this is associated with the usage of environmentally friendly materials and energy-saving equipment in the design option of the green building. Therefore, it can be convincing evidence that may help to change the mindset of decision-makers in Vietnam about green buildings.

Keywords: green building; life cycle energy analysis (LCEA); embodied energy; operating energy; demolition energy.

1. Introduction

Vietnam is one of the nations that has been suffered severely from severe climate conditions, especially climate change and global warming. It is predicted that most areas of the Red River and Mekong River Delta are under the sea level by 2050, and this will affect more than 31 million Vietnamese people [1]. Buildings sector consumes a tremendous amount of energy, which could be one of the most primary causes of these problems [2, 3]. Some recent studies have shown that nearly 40% of the world’s produced energy was consumed by this sector [4, 5]. In Vietnam, the buildings sector used up to 36% of the total electricity expenses [6]. Moreover, because of the rapid growth of population and economic progress in Vietnam, the energy requirement in the next ten years is predicted to triple [7]. By the year 2025, it is forecasted that approximately 49% of the amount of energy needed for commercial purposes in Vietnam will need to import [7]. Therefore, reducing energy consumption in buildings is a viable solution to ensure energy security and limit the negative impacts on the environment in Vietnam.

Life cycle energy analysis (LCEA) is one of the Life Cycle Analysis (LCA) methods, which can use to analyze the energy consumption of buildings. Particularly, literature shows that LCEA can be applied...
to examine the relationship between embodied energy and operational energy of buildings [4, 5, 8]. This method also can be able to evaluate the impacts of a variety of components such as floors, walls, foundation, etc., on the total needed energy in the lifetimes of several houses in India [4, 5] and Turkey [8]. LCEA can use to analyze the energy demand of residential buildings throughout their entire life span [9] or to calculate the amount of energy per square meter on average, and evaluate the influence of buildings’ lifetimes on life cycle energy [10], then solutions for potential energy-saving can be proposed [11]. Several methods for calculating embodied energy of construction materials have been proposed in New Zealand [12] and the United Kingdom [13]. In order to assist LCEA, it is necessary to develop a database on energy consumption and embodied energy for common types of materials [14, 15].

In Vietnam, LCEA has not been widely practiced because of several different factors. There are (i) this approach has not been introduced appropriately to both scholars and practitioners nationwide, (ii) the lack of standard data as input for the calculation process such as embodied energy coefficient and service life of materials, and (iii) formulas used in other countries to estimate life-cycle energy (LCE) have not been revised to reflect the local practice. Therefore, this study with the aim to present a LCEA step by step in the Vietnam context may help to address these above issues. Moreover, by using a green building as the case study, this study will estimate its LCE and compare with standard buildings to prove the dominant of green building from the lifecycle perspective. It could be convincing evidence to change the mindset of decision-makers in Vietnam who are more familiar with the “traditional buildings” and focus more on their design functions and costs. The findings of this research also can be a good reference for policymakers and practitioners in Vietnam when developing policies or making decisions in the buildings’ design stage.

2. Life Cycle Energy Analysis Method

A building consumes a tremendous amount of energy over its entire life, which comprises of embodied energy, operating energy, and demolition energy (figure 1). Embodied energy consists of initial embodied energy and recurrent embodied energy related to the usage of materials and machinery in both construction and maintenance activities [4, 16, 17]. During the operation stage, energy is needed for operating heating, ventilation, and air conditioning (HVAC), domestic hot water (DHW), lighting systems, and household devices, etc. This type of energy is named as operational energy [4, 16, 17]. At the building’s end-of-life stage, demolition energy is needed for demolishing the building and in transporting construction waste to disposal areas and recycling factories [4, 16, 17]. When estimating energy uses, some elements of energy consumption, especially the embodied energy may be omitted due to the lack of needed data. The following sections discuss these types of energy in detail.

2.1. Embodied energy

As mentioned above, embodied energy of buildings comprises initial embodied energy and recurrent embodied energy [16].

Initial embodied energy ($E_{BE}$) includes (i) energy used to produce and transport materials to construction sites, and (ii) energy needed to operate machines during the construction phase [18]. It can be estimated using formula (1) below [16]:

$$E_{BE}=E_{MT}+E_{OS}$$  \hspace{1cm} (1)

where: $E_{OS}$ is the energy used for on-site processes; $E_{MT}$ is the embodied energy of materials, which can be calculated as the following formula:

$$E_{MT}=\sum m_i \times EC_i$$  \hspace{1cm} (2)

where: $m_i$ is the amount of the $i^{th}$ material; $EC_i$ is the embodied energy coefficients of the $i^{th}$ material per unit on average.

Recurring embodied energy ($E_{RE}$) is associated with the usage of materials and machines for renovating the building and regular annual maintenance. This type of energy can be determined by the following formula [16]:

$$E_{RE} = \sum_{i=1}^{n} m_i \times EC_{iR}$$  \hspace{1cm} (3)

where: $m_i$ is the amount of the $i^{th}$ material; $EC_{iR}$ is the recurrent embodied energy coefficients of the $i^{th}$ material per unit on average.

$$E_{OS} = \sum_{i=1}^{n} m_i \times EC_{iO}$$  \hspace{1cm} (4)

where: $m_i$ is the amount of the $i^{th}$ material; $EC_{iO}$ is the embodied energy coefficients of the $i^{th}$ material used per unit for the operation stage.
\[ E_{\text{RE}} = \sum_{i=1}^{n} m_i \times EC_i \times \left( \frac{L_{\text{building}}}{L_{\text{material}(i)}} - 1 \right) \]  

(3)

where: \( m_i \) and \( EC_i \) are similar to the formula (2); \( L_{\text{building}} \) is the lifetime of the building; \( L_{\text{material}(i)} \) is the service duration of the \( i^{th} \) material.

Figure 1. The LCEA’s system boundary (adapted from [16])

2.2. Operating energy
Operating energy (\( E_O \)) is attributed to the operation of HVAC, DHW systems, and other energy-consumed appliances during the operation stage, and it can be computed by using equation (4) as below [16]:

\[ E_O = E_{AO} \times L_{\text{building}} \]  

(4)

where: \( E_{AO} \) is the annual operating energy of buildings; \( L_{\text{building}} \) is similar to formula (3).

The annual operating energy can be estimated according to the types, quantity and wattage of energy-consumed equipment, and their average using duration. Besides, energy simulation software can also use to estimate this source of energy by simulation based on design models. In this research, the second approach will be used to simulate the annual operating energy of the case study building.
2.3. Demolition energy

This category of energy is associated with the use of machines and trucks to demolish buildings and transport waste to landfills or recycling areas, and it can be expressed as formula below [16]:

\[ E_D = E_{MD} + E_{CR} \]  

(5)

where: \( E_D \) is demolition energy; \( E_{MD} \) is the energy required to demolish the building; \( E_{CR} \) refers to the energy used to carry construction waste.

2.4. Life cycle energy (LCE)

LCE is the total of all categories of energy that a building consumed over its entire lifetime, and it can be calculated as the formula below [16]:

\[ E_{LC} = E_{IE} + E_{RE} + E_O + E_D \]  

(6)

3. The Case Study

3.1. The description of the case study building

The case study in this paper is a green high-rise building in Vietnam, which is the headquarter of the Vietnam Securities Depository Center. This building consists of 3 basements, 17 floors, and 1 attic. The building's gross floor area is 14,112m². Table 1 shows the key figures and features of the building.

| Contents          | Specifications                                      |
|-------------------|----------------------------------------------------|
| Basements         | 3 floors                                           |
| Upper floors      | 17 floors and 1 attic above ground                 |
| Service duration  | 75 years                                           |
| Total floor area  | 14,112m²                                           |
| Load-bearing structure | Reinforced concrete                             |
| Covering envelope | Combination of brick walls and glass curtain walls |
| Foundation structure | Reinforced concrete bored piles and concrete foundation slab, and walls |
| Internal walls    | Unburnt brick                                      |
| External walls    | Unburnt brick and glass curtain wall combination   |
| Floors            | Cast-in-place concrete                             |
| Floor finish      | Concrete, ceramic tiles, gypsum board              |
| Doors             | Fire-resistant steel doors, Ironwood doors, MDF doors, |
|                   | Aluminum glass doors                               |
| Roof              | Flat roof, concrete                                |

Aiming to save energy, the building uses the following architectural solutions: (i) louvers placing along the south facade as sunlight-preventing panels outside the building; (ii) reduce the window/wall area ratio to the West, North, and East sides of the building; and (iii) use Low-E glass which has two layers and wall made of unburnt materials (light concrete blocks). An energy-saving central air-conditioning system (VRF) and an effective artificial lighting system have been installed for the same purpose. Moreover, the building also uses renewable energy with 8kwp solar panels and solar hot water systems with 37kw heating capacity. Regarding the water systems, the building is equipped with saving-water toilets and faucets as well as applying the reuse of treated sewage to meet 100% of irrigation needs.

With the target to conduct a LCEA, a variety of input data is required, such as:

a. the quantity of materials each type being used to construct the building;

b. the energy embodies of materials in each type per unit;
c. the types of equipment and duration using them in the construction phase;
d. the total amount of energy using in the operating phase; and
e. data to determine demolition energy.

The data that are not available in Vietnam but are necessary for calculating LCEA will be replaced with data that has been published worldwide for the convenience of the research. Moreover, in Vietnam, there are no available sources of information for energy consumption for the workers’ living activities on the construction sites during the construction phase, and for energy used to operate construction machines in the maintenance activities. Consequently, such amount of energy will not be included in the calculation. This will not affect much on the outcomes due to the relative insignificance of the energy consumed for those activities in comparison to other types of energy uses.

3.2. Determining the initial embodied energy

3.2.1. Embodied energy of building materials (E_MT).

In this study, 20 key materials are taken into consideration for calculating this type of energy, since they are used in key components of the building such as frames, slabs, staircases, foundation, walls, and even finishing works. The quantity of these materials is estimated based on the building’s design. By using formula (2), the calculated results of this sort of energy are displayed in Table 2. The total embodied energy of building materials in this case study is 102,142 GJ.

Table 2: Embodied energy of main building materials and their relative distribution

| Materials                  | Quantity  | Unit  | EC_i (MJ/unit) | E_Mt (GJ) | Relative contribution (%) | Source |
|----------------------------|-----------|-------|----------------|-----------|---------------------------|--------|
| Ready-mixed concrete       | 21,717,356| kg    | 1.11           | 24,106    | 23.60                     | [15]   |
| Reinforcement steel        | 1,268,635 | kg    | 24.6           | 31,208    | 30.55                     | [15]   |
| Structural steel           | 255,350   | kg    | 36.8           | 9,397     | 9.20                      | [15]   |
| Sand                       | 970,777   | kg    | 0.1            | 97        | 0.10                      | [11]   |
| Aggregate                  | 454,511   | kg    | 0.083          | 38        | 0.04                      | [4]    |
| Cement                     | 363,859   | kg    | 4.6            | 1,674     | 1.64                      | [15]   |
| Cement mortar              | 422,736   | kg    | 1.4            | 592       | 0.58                      | [15]   |
| Concrete bricks            | 1,704,795 | kg    | 0.6            | 1,023     | 1.00                      | [19]   |
| Galvanized iron            | 44,552    | kg    | 38             | 1,693     | 1.66                      | [9]    |
| Plasterboard               | 56,845    | kg    | 4.4            | 250       | 0.24                      | [9]    |
| Glass                      | 106,205   | kg    | 23.5           | 2,496     | 6.38                      | [15]   |
| Paint                      | 9,810     | kg    | 30.6           | 300       | 0.29                      | [14]   |
| Ceramic tiles              | 66,842    | kg    | 10             | 668       | 0.77                      | [8]    |
| Marble stone               | 36,328    | kg    | 2              | 73        | 0.07                      | [8]    |
| Wood (work form)           | 140,979   | kg    | 8.5            | 1,198     | 1.17                      | [15]   |
| PVC pipe                   | 319,809   | kg    | 67.5           | 21,587    | 21.13                     | [14]   |
| Steel doors                | 2,213     | kg    | 48.4           | 107       | 0.10                      | [14]   |
| MDF (doors)                | 626       | kg    | 11             | 7         | 0.01                      | [14]   |
| Timber (doors)             | 3,688     | kg    | 16             | 59        | 0.06                      | [14]   |
| Doors and windows (Aluminium Framed) | 376   | m²    | 3798.6         | 1,428     | 1.40                      | [14]   |
| Total                      |           |       |                | 102,142   | 100                       |        |

3.2.2. Embodied energy in the construction phase (Ec).

Three major types of energy to be used in this phase include petrol, diesel, and electricity. To determine the energy consumption in this stage, figures on the total number of working shifts of the i_th machine, the amount of fuel consumed per shift of the i_th machine, and the heat generation capacity of
each fuel have been collected and manipulated. The number of working shifts for each machine will be determined based on the workload and the machine norms, which are issued by the Government. The amount of fuel that each machine consumes per shift on average was taken from the databook attached to the Decision 1134/QD-BXD of the Ministry of Construction of Vietnam dated October 8, 2015. These figures were put into the calculating formula and the amount of this type of energy was calculated to be 6,731 GJ.

3.2.3. Initial embodied energy...;
This category is the total of embodied energy of materials and the energy used to construct the building. Based on the equation (1), this category of energy was calculated as 108,873 GJ, which equates to 7.71 GJ/m². The analysis illustrates that reinforcement steel, ready-mixed concrete, PVC pipe, and structural steel are the most significant contributors to the initial embodied energy of the building (figure 2). Reinforcement steel displays the largest portion (30.55%), followed by ready-mixed concrete (23.6%), PVC pipe (21.13%), and structural steel (9.2%) (Table 2). The load-bearing structure as well as the water supply and drainage system are responsible for up to 84.49% of the initial embodied energy of the building.

![Figure 2. The contribution of primary materials to the embodied energy (%)](image)

3.3. Recurring embodied energy
This category of energy is related to the energy contained in materials and equipment used to maintain and refurbish the building over the entire 75-year service life. Because the case study building has just moved from the construction to operation stages, no statistics exist about the materials’ lifetime or the information about the percentage at each type of material will be replaced throughout the building’s life span. Hence, this paper has referenced the required figures from a variety of publications to estimate this kind of energy of the building.

According to equation (3) and relevant data, this sort of energy was calculated, and the results were displayed in table 3.

| Material       | Quantity | Unit | ECᵢ (MJ/unit) | Building's life span (year) | Materials' life span (year) | Eᵦᵣ (GJ) |
|----------------|----------|------|---------------|----------------------------|----------------------------|-----------|
| Plasterboard   | 56,845   | kg   | 4.4           | 75                         | 30                         | 375       |
| Paint          | 9,810    | kg   | 10.2          | 75                         | 10                         | 650       |
| Ceramic tiles  | 66,842   | kg   | 10            | 75                         | 25                         | 1,576     |
| Motar          | 422,736  | kg   | 1.4           | 75                         | 50                         | 296       |
Doors and windows (Aluminium Framed) | 376 m² | 3798.6 | 75 | 50 | 714
Timber – hardwood (doors) | 3,688 kg | 16 | 75 | 25 | 118
Glass | 277,315 kg | 23.5 | 75 | 50 | 3,258
PVC | 319,809 kg | 67.5 | 75 | 50 | 10,794
Total | | | | | 17,782

Although the HVAC, DWH systems, and lighting equipment as well as other appliances need replacements several times over the lifetime of the building, the recurring embodied energy related to these systems and appliances is excluded in this study. The primary reason for this is the unavailability of their embodied energy coefficients. Therefore, this study only considers several key finishing materials.

3.4. Operating energy
According to equation (4), the annual operation energy of the building is needed to compute the operating energy. This study uses EnergyPlus software to simulate the energy consumption of the building based on its 3D models and other information, such as (i) the climatic conditions, (ii) parameters of envelope materials, (iii) data on energy-consumed systems and appliances, etc. The simulated result is shown in figure 3. With energy equivalent to one kWh of electricity is 3.6 MJ/kWh, the total operating energy of the building was estimated as 48,989 GJ for the entire 75-year life span.

3.5. Demolition energy
At the end stage of the building’s lifetime, energy is needed in order to operate machines in the demolishing process of the building and to transport waste to dumps or recycling factories. Because of the lack of data related to the energy consumption of demolition activity in Vietnam, this type of energy cannot be calculated exactly. Based on a study by Crawford RH [21], the amount of demolishing energy required is unnoticeable in comparison with the total LCE (only under 1%). Aiming to provide a comprehensive analysis of the LCE of a green building, this paper has expected that the percentage of this energy is equal to 1% of the total of embodied energy and operation energy (175,644 GJ). Therefore, the demolition energy is equal to 1,756.44 GJ.

Figure 3. The building’s energy consumption annually simulating by EnergyPlus software

3.6. Life cycle energy
The total building’s LCE was calculated as 177,400 GJ (equal to 12.57 GJ/m²). The results show that the largest contributor to the energy demand of the building is the embodied energy (61.37%), following by the operational energy (27.61%). On the contrary, the share of recurrent embodied energy is only
10.02%, and equal to about 16.33% of the initial embodied energy of the building. In comparison with other research, this result is only about one-fourth of the figure proposed by Crawford RH [21] (60%). The main reason for this difference is that this study does not calculate the recurrent energy of HVAC, DHW, and lighting systems. The energy demand in the demolition phase is only about 1% (figure 4).

The results display that the proportion of the operational energy of the green building (27.61%) is much lower than the figures in [5] (89.06%), and [22] (62% to 77%). The primary reason for this difference is that the case study is a green building. By using environmentally friendly materials like unburnt bricks, energy-saving systems, combining with other design solutions, the building consumes less energy in the operation phase than other buildings. This finding can be proven the dominant of the green buildings compared to standard buildings. Thus, it may be a significant basis for policymakers, decision-makers, and practitioners reference when evaluating design scenarios in the design phase or developing policies regarding the energy efficiency of the buildings sector in Vietnam.

![Figure 4](image_url)

**Figure 4.** Proportion share of energy by phases over the building’s lifetime

4. Conclusion

This paper has given a holistic LCEA of a green building in Vietnam. The paper demonstrates that the proportion share of energy by phases of a green building is a big difference compared to other residential houses which have been shown in other papers. Several articles have shown that operation energy is much higher than other sorts of energy over houses’ life span, while this category of a green building only takes more than a half of the initial embodied energy. Particularly, the calculated results indicate that the initial embodied energy takes the most significant share to LCE (61.37%), whereas the operating energy is much lower than that, with only 27.61%. Recurrent embodied energy is only 10.02% of the total energy demand of the building due to this paper does not take HVAC, DHW, lighting systems, and other appliances into account since lacking needed data. In terms of initial embodied energy, reinforcement steel, ready-mixed concrete, and PVC pipe are the most significant contributors, contributing up to 84.49% of the total amount of this category of energy. The LCE consumption of the green building is estimated to be 177,400 GJ or 12.57 GJ/m².

This paper provides decision-makers a much more dependable and holistic understanding one the total amount of energy that a green building demands over its lifetime. Although this paper only focuses on a specific green building, it can give a clear indication of the significant contributors to the total energy demand of a green building over its service life. By comparing the figures of the case study green building with other residential buildings that have been taken as case studies in previous publications, the paper has discussed the reason why the operational energy could be saved. These discussions can change the public’s awareness in Vietnam about the LCE demand of a building and provides essential
information to decision-makers in order to develop strategies and make decisions in the design stage to boost the development of sustainable construction in Vietnam.

Although the LCEA plays a very important role, it could be better if the LCEA is simultaneously considered with other lifecycle assessments such as lifecycle CO$_2$ and lifecycle cost analyses. Future research should consider the combination of those assessments for a more comprehensive and effective assessment of the sustainability of green buildings.

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