Life Cycle Energy Analysis of a House in UAE

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Abstract: In the United Arab Emirates (UAE) about 70% of total energy produced is consumed by building sector, and this compares with the global average of about 40%. Energy usage in buildings has often been discussed from the standpoint of operational energy, mainly used for purposes of heating or cooling. In recent times the discussion on building energy consumption has also raised the need for investigating the energy embodied in the construction of buildings and manufacturing of their constituent materials and components. This reorientation of energy consciousness in the construction industry is of critical importance in efforts to reduce the environmental impacts of the built environment. In United Arab Emirates, significant efforts have been made in recent times to reduce the operational energy consumption; however, embodied energy consumption is nearly unaddressed. The challenge this paper addresses is the need to review not only the operational (OPE) energy of a building but also its initial (IEE) and recurrent embodied energy (REE). The aim of this paper, therefore, is to calculate the energy consumption of a residential building over its life in UAE, and to identify the significance of embodied energy. A case study residential building in the UAE was selected as a representative example of government-built homes for UAE citizens for the purpose of this investigation. Using an input-output hybrid approach to calculate the energy required at the time of its construction and REE value calculated over a period of 50 years, the study compares the IEE, OPE and REE for the case study to extrapolate comparative data. Results from this study suggest the importance of including the initial and recurrent embodied energy of buildings in building life cycle energy analyses, which in this case represented 18% and 17% of the life cycle energy of the building. The anticipated merit of this study to building professionals is an appreciation and holistic consideration of the life cycle embodied energy of building design towards promoting a reduction in total building energy consumption.

Keywords: Life Cycle Embodied Energy, Initial Embodied Energy, Recurrent Embodied Energy, Comparative Analysis, Case Study, United Arab Emirates

1. Introduction

The built environment and building industry account for over 40% of global energy consumption, 36% of all CO2 emissions [1,2], and 28% of Greenhouse gas emissions [3]. The United States Energy Information Administration (EIA) has predicted that global energy demand will increase by 50% by 2050 [4]. Buildings in the United Arab Emirates (UAE) consume about 70% the electricity produced in the country, with almost 70% used for cooling [5,6]. Reflecting on per capita energy consumption, the weighted average for GCC countries is seven times higher than the global average [7].

In recent years, the discourse on building energy consumption has sought a more intricate assessment of the critical aspect of embodied energy, in the view of total building energy consumption which has not been studied as much as operational energy. While several studies have focused on reducing the operational energy, there is a need to adopt a more holistic approach to assess the impact of energy consumption across the building life cycle [8]. The comparative lack of research on embodied energy relative to operational energy calls for a comprehensive life cycle consideration [9]. The call for embodied energy has been presented as a key component towards sustainable global energy transition [10]. Studies report that embodied energy may account for 2-38% for conventional buildings [11] but for low energy buildings this may be as high as 50% [11,12] or even recently, as high as 60% [13]. In another study, Rauf and Crawford (2013) showed by using a comprehensive embodied energy calculation method that it can be greater than the life cycle operational energy and may account for 60% of the total life cycle energy over a 50 year period building lifespan [14].

As the world shifts towards low-energy buildings, some researchers argue that although less operating energy may be being achieved through high performing buildings, more building material is being used in this process [12] leading to a rise in the embodied energy [15]. Unfortunately, the practicality of calculating embodied energy/CO^2 emissions of the envelope building elements in the United Arab Emirates (UAE) is difficult due to the absence of certain critical data [16,17]. This gap calls for further investigation which is particularly relevant in the context because the tendency is to simply shift focus on developing high-performing and low operational energy buildings. The current study is focused on UAE residential buildings where there are far less studies on embodied energy impact on life cycle building energy consumption. This paper aims to fill the knowledge gap about the embodied energy consumption of residential buildings in UAE. This paper reports part of the findings so far as a preliminary report on the on-going investigation. This paper focuses on the calculation of the total life cycle energy demand, the initial embodied energy, the recurrent embodied energy, and operational energy for a case study building in the UAE over a 50-year building lifespan.

2. Life Cycle Energy Analysis

The approach used to quantify the energy demand of a building across its lifespan is known as life cycle energy analysis (LCEA) which has recently been investigated in various residential and non-residential contexts [8,18,19]. The LCEA can be described as a simplified but more focused version of the life cycle assessment (LCA), concentrating only on the energy dimension across the building life cycle [20]. It includes both embodied energy and operational energy [21], and closely relates to the environmental aspects of building impact [22]. The LCEA is thus, the sum of embodied energy and operational energy of a building. The reliability of the calculated results is influenced by completeness and accuracy of the case study building data and, of the calculation method used for the analysis [20].

In research and practice, the methods used to evaluate operational energy are well established. However, approaches to quantify the buildings' embodied energy are still being developed and not well-understood [23]. To substantiate this claim, a recent review reported that the reduction of operational energy in buildings can cause an increase in a building's total life cycle energy use due to direct and comparative increase in its embodied energy [20]. In specific terms, LCEA focuses on the evaluation of energy inputs from different phases of the building life cycle and various processes related to manufacture, construction, operation, maintenance and demolition phases of the building [8,20], as shown in Figure 1.

Figure 1: Life cycle stages of a building (Adapted from [24])

2.1 Embodied Energy Of Buildings

Embodied energy is generally described as the energy used directly onsite and offsite during construction and related processes, as well as indirectly in relation to use of materials and equipment. While initial embodied energy (IEE) is used in construction, recurrent embodied energy (REE) refers to energy consumed in recurring maintenance, and replacement or repair of building components [25]. The total embodied energy is a summation of three components: initial, recurrent and demolition embodied energies [10,15,23,26].

There is insufficient understanding about the significance and method of recurrent embodied energy calculation [23]. One recent review noted that only 30% of studies in this area clearly explain the calculation approach [25]. The review further notes that proper evaluation of REE and IEE, as well as conversion into primary or source energy terms is necessary. In addition, the calculation method, material database, and system boundary have to be clear, consistent and valid [20,25,27]. A previous study indicates that life cycle embodied energy can be as high as 60%, and thus, significantly more than the life cycle operational energy [14]. Other studies report that EE makes up 35% of the primary energy for advanced retrofit homes [28], and 67% for NZEB compared to 32% for a conventional construction [29]. These studies suggest that embodied energy for high performing buildings may be more due to the use of more materials, when compared with standard construction [12,15].

2.2 Embodied energy assessment methods

In literature, there are specific approaches to conduct the calculation of embodied energy. Commonly used methods are the process analysis, input-output analysis, and hybrid analysis [8,25,30]. As there are significant differences noted in calculated values across each of these analysis methods [31], the call for a global standard has been made [25]. This section highlights some of those variations.

Process analysis

The procedure for this approach uses data from various processes, products and locations to evaluate environmental flows and effects based on definite information which define the embodied energy of a product [8,31], and approximate energy aspects [32]. This approach has also recently been used to track the sustainability of manufacturing practices [33]. For its limitation, researchers have argued that some data is excluded from manufacturer's databases used such as the source of these calculations, creating an incomplete definition of the system boundary [8,25,31,34]. Consequently, missing or lack of detailed data of some of the production processes as well as the attendant complexities which inherent in upstream supply chains can impinge the reliability and specificity of this approach [8,25]. Some researchers have suggested that this approach can be used in life cycle assessments to differentiate 'sub-processes' and associated environmental factors for impact valuation. However, Fan et al. [35] asserts that process analysis is a time-consuming approach, made up of countless steps, leading to selection of only major inputs; and thus, it is subject to truncation errors plus uncertainties in defining its system boundaries [34,36].

Input-output analysis

This approach uses a form of "dual tracking system" to trace and aggregate both energy and monetary flows/transactions within an entire supply chain [31,32] making it systematically complete [23]. By comparing and collating entire national economy data on energy between sectors, Baird et al. asserts that this is a significant advantage of this approach but also suggests that this may lead to a proverbial "black box". This is due to the mismatch of dissimilar products within individual sectors [32]. In a recent review, Malik et al argued that this approach provides an alternative technique to LCA as it enumerates various supply chain impacts and avoids tedious data collection [37]. Other authors, have however stated that though the approach is comprehensive, the "black box" limitation has three negative effects relating to the data and the results [14,25,38]. These are uncertain homogeneity, proportionality, and inadequate considerations of the economies of scale.

Consequently, Dixit argues that the IO model may lead to double counting of energy inputs, making the results questionable and unreliable [25].

Hybrid analysis

The unique constitution of this approach is that it seeks to adapt the advantage of previous analysis methods into one calculation approach [39], in a way that addresses their limitations [40]. This approach is the most comprehensive technique in computing life cycle inventories [31,41]. This assertion argues that it allows for the combination of bottom-up industrial process data and top-down macroeconomic input-output data. There are two variations of this approach, either a process-based hybrid analysis (PBHA), or an input-output-based hybrid analysis (IOBHA). In general, the process-based hybrid analysis as an approach, focuses on the quantification of individual products delivered in addition to energy intensities extrapolated using the input-output analysis [34,42]. This second component is mathematically computed for each material by adding process data results of the energy required to produce it, to "the difference between the total energy intensity of the input-output path of the basic material, and then multiplying it by the total price of the basic material" [42].

On the other hand, the input-output-based hybrid analysis is used to solve the limitation of the process analysis/process-based hybrid analysis [43]. Recently, it was suggested that though this approach applies an integrated system boundary its input-output data is liable to be outdated or miss new product data [30]. Other authors [41,44], have asserted that the lack of a database may limit the accuracy of an embodied energy calculation even in an input-output hybrid analysis. However, other authors [8,31], argue that embodied energy calculations using this approach combines several steps such as energy data aggregated from process analysis, with system boundary completeness improved by hybrid material energy intensity figures and input-output data. In addition, the approach makes use of integrated process and input-output data at the material level to create a define hybrid material energy coefficients" [31].

3. Research method

In order to quantify the total life cycle energy demand, the initial embodied energy, and the recurrent embodied energy were calculated for a case study of 5-bedroom villa in the UAE. The period of analysis chosen for this study was 50 years based on the assumption that a building in the UAE will be used for this period. It is also assumed that at the end of this period, the building would be at the end of its useful life and ready for demolition. Based on referenced literature in Section 2, the selected approach for calculating the embodied energy for the current investigation was the input-output hybrid approach. Also, secondary data from previous studies was used to approximate the operational energy of the building and the calculation of the life cycle energy of the building.

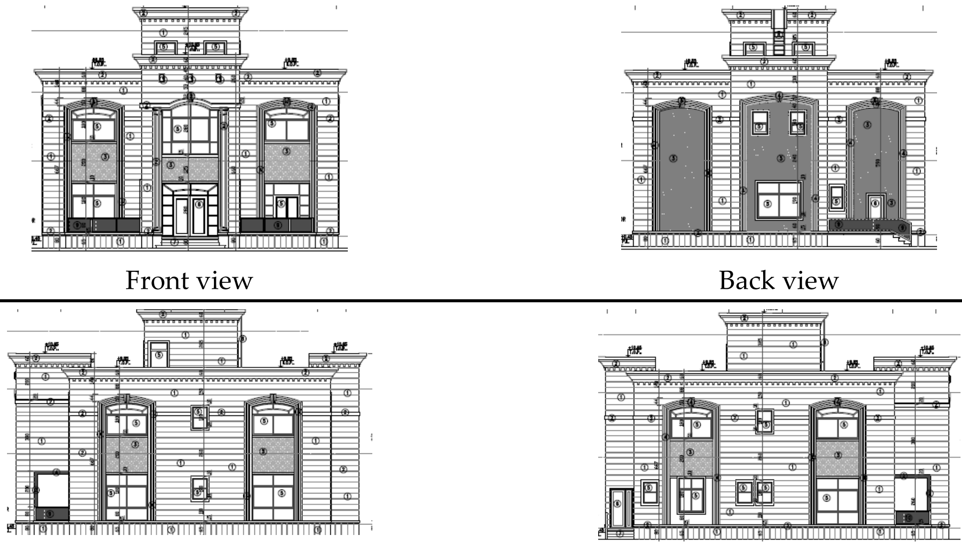
There are few comparatively related investigations with a robust material database reference in the UAE on embodied energy which define the system boundaries, embodied energy coefficients and intensities needed for this investigation. Due to the absence of a comprehensive energy intensity data for different building materials and components used in construction industry in UAE, the EPIC database compiled by University of Melbourne, Australia [45], was used in this study to calculate embodied energy.

3.1 Case study building

A two-storey 5-bedroom villa located in Al Ain with a total floor area of 532m^2 was used as the case study for this analysis (Fig.2). The house is constructed using conventional materials and construction systems including a concrete slab floor, hollow block walls, and plaster. Wall finishes include ceramic tiles, oil and acrylic paint, the ceiling was made of plasterboard and floors covered with ceramic tiles. The windows are double-glazed and aluminum-framed, and doors and their frames were made of teak wood. A full material schedule was received from the firm that designed the building and was used for the EE calculations. A few assumptions were made to clarify the parameters for calculations, these included:

1. The building was constructed with no specific green rating system requirements.
2. Standard dimensions were used for component specifications where the material schedule did not give explicit information. For example, the thickness of doors and glazing.
3. The replacement period/service life of the materials used in the EE calculations are based on Rauf (2015), and general construction and residency experience in the UAE.

Elevations



Front view | Back view

Right view | Left view

Figure 2: Case study building

3.2 Initial Embodied Energy

Using the IOBHA approach, the embodied energy of the case study building was calculated by multiplying the delivered quantities of each material by the embodied energy coefficient of the respective material which was obtained from the EPIC database. The resultant figure gives the process-based hybrid embodied energy of the house. In the next step, the energy embodied in non-material inputs was calculated to complete the system boundary and the value was added to the process-based hybrid embodied energy EE value. This *remainder* – for non-material inputs, was calculated with the use of a disaggregated energy-based input-output model. A detailed description about the use of input-output-based hybrid analysis to calculate the initial embodied energy of the case study house is available in [8].

3.3 Recurrent embodied energy

To calculate the recurrent embodied energy two values are of critical importance; firstly, the material service life (MSL) i.e. the number of years a specific material would be used before it needs to be replaced by a new one. For this, a literature review was conducted on the service life values for different materials and components. Average service life values from the available literature were used for this study. Assumptions were made where the service life value of any material or component was not available. Secondly, a period of analysis which approximates the lifespan of the building. Based on the average service life of residential buildings in available literature, a building service life of 50 years was used for this study, which the structure will be demolished. These two values will determine how many times a material or component will be replaced over the lifetime of house.

The recurrent embodied energy of the house was calculated as per the initial embodied energy of the house. The delivered material quantities associated with each replacement were multiplied by the respective material embodied energy coefficients. These values included the direct and indirect energy associated with the manufacture of materials. To complete the system boundary, the non-material inputs or remainder associated with materials being replaced, were then calculated as per the initial embodied energy calculation. The energy embodied in each material was then multiplied by the number of replacements for that material over the life of the house and summed to determine the total recurrent embodied energy associated with the house. A detailed description about the use of input-output-based hybrid analysis to calculate the recurrent embodied energy of the case study house is available in [8].

3.4 Operational energy

To compute the total life cycle energy (LCE), the operational energy (OPE) needed for heating, cooling, and running of household appliances was approximated. Electricity consumption was determined based on secondary data available in literature for UAE [46–49]. This electricity consumption data from these sources was aggregated, and average gas consumption for cooking for an average family size suitable for this villa was added to calculate the operational energy requirements.

4. Results and Discussion

In this section three specific results are presented and discussed. Firstly, the life cycle embodied energy (including initial and recurrent embodied energy) results, the operational energy approximations, and the total life cycle energy of the case study building, indicating the IEE, REE and OPE values for 50 years life span. This is followed by a discussion on the importance of these results in the context of the UAE. Secondly, the framework for a comparative analysis with previous studies in other contexts is presented.

5.1 Embodied Energy

The embodied energy calculated using IOBHA for the initial construction of the case study house was found to be 7605.68GJ (14.3GJ/m^2). In terms of initial embodied energy value per square meter, this case study house (14.3GJ/m^2) has relatively high embodied energy when compared to other studies using the same assessment method (11.7GJ/m^2 [50]; 13.GJ/m^2 in a study by [8]). One reason for this relatively high value may be due to the use of more high energy intensity materials, such as use of concrete for roof construction and concrete blocks for walls. When compared to the embodied energy results in the studies using other analysis methods (e.g. 2.86 GJ/m^2 and 5.09 GJ/m^2 for two buildings using process analysis [51]), this study has shown significantly high embodied energy demand. This is due to the much broader and complete system boundary for the input output-based hybrid analysis approach.

The recurrent embodied energy was calculated over the 50 years life span and was found to be 6894 GJ (12.96GJ/m^2). The life cycle embodied energy (LCEE) was thus, 14,908 GJ (28 GJ/m^2). Taking a closer look at LCEE, Figure 4 shows that the recurrent embodied energy made up 48% of the LCEE, while the initial embodied energy was 52% of the LCEE after 50 years. This suggests that REE would play a greater role as the building life extends and thus, the IEE would become comparatively less. As suggested in literature [8,14,25], multiple factors such as the material service life and building service life will play a significant role in defining the differences with respect to time.

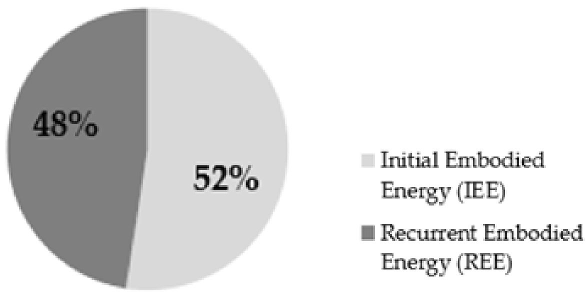


Figure 3: Proportion of initial and recurrent embodied energy for the case study building

5.2 Operational Energy

Based on secondary data found in literature [46–49], the average operational energy for villas in the UAE was calculated and found to be 273.36kWh/m²/yr. Annual energy consumption for the case study villa, with the total area of 532m² is thus, 145432.84kWh/yr. which is equivalent to 523.56 GJ/yr (0.9841GJ/m²/yr). For the 50-year period, this value rises to 26177.91GJ (49.2GJ/m²). Operational energy was found to constitute 64% of the life cycle energy of the house over a period of 50 years. This shows the importance of the operational energy in efforts to reduce energy consumption by residential buildings.

5.3 Life Cycle Energy

The life cycle energy computed over 50 years was calculated as a sum of the initial, recurrent, operational and demolition energies. The Demolition Embodied Energy (DEE) was calculated at 1% of the life cycle energy demand [52]. Thus, the LCE calculated was 41,086 GJ (77.3 GJ/m²). Figure 4 shows a comparison of the LCEE and OPE for the case study.

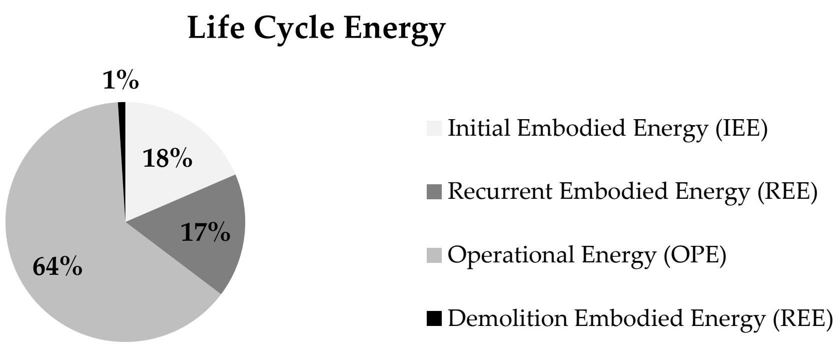


Figure 4: Life cycle energy of the case study building over 50 years

The figure shows that the total embodied energy was 36% of the life cycle energy, of which 18% was initial and 17% was recurrent embodied energy; while operational energy was 64% of the life cycle energy. In general, the results show that the embodied energy, which is often neglected in design and energy research considerations, makes a significant contribution (35%) to the total energy consumed by the building during its lifespan. Results from this study also suggest the importance of including the recurrent embodied energy in building life cycle energy analyses, which various of previous studies ignore in a life cycle analysis [23].

The life cycle embodied energy results present certain other considerations. Firstly, the LCEE is about 57% of the OPE, which a percentage that is too significant to be ignored in the building design, material specification. Operational energy requirement for a building on the other hand is expected to reduce with installation of more energy efficient energy systems and appliances in future. It is also important to note that efforts to reduce the operational energy demand of buildings are also focusing on using more materials to improve the thermal performance of building envelop. As a considerable amount of energy can be used in the manufacture of these building materials, this can result in an increase in embodied energy. This shows the importance of ensuring that energy demands are not inadvertently shifted from one area (i.e. operational) to another (i.e. embodied). The UAE also aims to increase the contribution of clean energy sources in the total capacity mix to 50% by 2050, as compared to 98% of its electricity in 2018 using natural gas-fired generation [53]. This shift towards clean energy will help further reduce the GHG emissions associated with operational energy consumption by a building. As a result, importance of embodied energy will increase further, as mining and manufacturing processes for materials production are expected to rely mainly on fossil fuels for a much longer time.

5.4 Comparative insightand future research

This section compares embodied energy values from different studies to present certain insights. Currently, our review shows that some authors who have evaluated LCEE have arrived at different percentages. Considering the context and building type as subjective variables, the interest in this section is the proportional comparison for each case as a basis for suggesting further research pathway for a detailed review. Table 1 shows a few studies on embodied energy calculations, conducted in different locations, using the same analysis method (input-output based hybrid analysis) with similar building service life.

Table 1: Comparison of LCEE and OPE

Reference	Country/ Region	Building type	Building Life	LCEE	OPEE
Current Study	UAE	Residential	50	36%	64%
[18]	UK	Office	60	10%	90%
[19]	Norway	Residential	60	50.7%	49.3%
[29]	Italy	Office	50	67%	33%
[14]	Australia	Residential	50	59%	41%

In terms of life cycle embodied energy proportion compared to life cycle operational energy, 36% embodied energy is lower than other studies which has used same embodied energy calculation method. Main reason for this relatively low proportion of embodied energy is due to the high operational energy demand to cool the buildings in long summer with extremely high temperatures in UAE. Other reasons include the difference between the scope and location of these studies, selection of materials and their service lives used as compared to this study. Improved access to process-based embodied energy data will help to minimize the errors inherent in current hybrid embodied energy data and assessments. However, authors believe that findings of this study can be applied to the residential buildings of same type in similar climatic conditions.

5.5 Limitations

A significant limitation faced during this study was the absence of UAE energy intensity data for various building materials and components; such complexities associated with EE calculations have been noted in literature [16,17]. To ensure a standardized approach in the estimation and comparison of the current study with existing studies, the EPIC database for materials and building component was used.

Another limitation this study faced was the absence or lack of localized service life data for different materials used in the construction of case study house. Due to the unavailability of such data from UAE, a literature review was conducted to find the service life values of different materials and components around the world. These values were then adjusted to reflect the local conditions and used to calculate the recurrent embodied energy.

In this study, operational energy of the case study building was considered to be unchanged over the life of building. However, in reality, it is expected that operational energy will reduce due to the more energy efficient energy systems and appliances in future as well as a change in energy mix in UAE.

6. Conclusions

This study has focused on the calculation of the life cycle embodied energy for a case study building in the UAE. A comprehensive input-output based hybrid analysis method was used for embodied energy calculations. This study has shown the significance of both the energy required to initially construct a building and the recurrent embodied energy associated with the maintenance and replacement of materials over its life. The total embodied energy calculated was found to be 36%

of the life cycle energy over a building lifespan of 50 years. The initial and recurrent embodied energy were found to constitute 52% and 48% of the life cycle embodied energy. The considerations of the impact on the total life cycle energy of the building from the embodied energy components –initial, recurrent and demolition which the study presents is part of a larger study to evaluate its importance in the UAE context. Further research is on-going to explore other parameters and factors which may influence the current findings in an effort to reduce the life cycle energy demand of the buildings.

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