Embodied Energy in Buildings Materials of Middle-Class Residential House: A Case Study

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Abstract — *while sustainability is an emerging plan in Indonesia, embodied energy is not a significant concern in West Sumatra. This study provides an insight into the embodied energy of a typical building. This study aimed to determine the average total embodied energy of middle-class residents in Padang City of West Sumatra Province, Indonesia. The methodology used included a content analysis of building design drawings and specifications and observation of six selected middle-class residents' construction activities. The floor area of the residents ranges from 312 m^2 to 638 m^2. Based on that information, the embodied energy in transportation and production stages were calculated to determine total embodied energy. It was found that the total embodied energy of middle-class residents ranges from 3.010 GJ/m^2 to 3.790 GJ/m^2, with an average of 3.38 GJ/m^2. The data, methodology, and findings are useful for future research in sustainable construction. The results could be a reference in comparing energy performance with similar residents in other developing countries.*

Keywords — *Embodied Energy, Building Materials, Transport, Energy, Residential House.*

I. INTRODUCTION

The industrial and construction sectors play an essential role in energy use around the world. They significantly influence the total use of energy and natural resources, including the resulting carbon emissions. The construction sector is one of the most significant commercial energy users in the form of electricity or heat, with the direct burning of fossil fuels [1].

Buildings are significant users of universal energy and natural resources. Building materials and building components consume nearly 40% of global energy each year, at this stage of their life cycle, such as the supply of raw materials, production of materials, transportation of materials, construction on-site, use, demolition, to end-use [2, 3].

Building materials are energy-intensive before they reach the construction site. The energy during the production of a material is known as the embodied energy. The embodied energy is a measure of the volume of life bound to the product that must be paid for the mining of raw materials and the manufacturing processes required to produce materials and products. It includes energy related to the transportation of raw materials to related industries and the distribution of ready-to-use products from industrial plants to users [13].

The manufacture of many different building materials such as cement, iron, concrete, plywood, brick, zinc roofing, floor tiles, aluminium, glass, and other building materials have been studied to determine energy and ecological costs [4]. For Indonesia, the energy used for the manufacture of building materials is mostly non-renewable materials and energy-intensive fossil fuel sources [5].

Based on data from the Ministry of Energy and Mineral Resources in 2012, the most significant percentage of energy use in Indonesia is the industrial sector, with 49.4% of the total national energy consumption value. The three types of industries that consume the most energy either for use as fuel or as raw materials are the iron industry, the cement industry, and the ceramic industry. From 2000 to 2011, energy use for the industrial sector increased by 3.05% [5]. It will have an impact on increasing energy requirements for the building materials, the manufacturing industry, especially in the housing sector.

The amount of life cycle energy of a building consists of two types of energy; the embodied energy and operating energy [1]. Embodied energy is the energy that is embedded in building materials during all the processes of material production, site construction, operation, and final-use demolition. Operating energy is the energy consumed to power electrical and mechanical equipment in buildings through processes such as charging, heating and cooling in space, and operating other equipment.

Recently, the use of energy for building operations is considered to be higher in the overall energy life cycle of the building. However, due to the emergence of energy-efficient equipment and building facade materials that are effective and high-performance, the energy limiting of potential operations has increased, and the emphasis on energy conservation in buildings has now shifted to the embodied energy in building materials [1, 6].

Several studies have estimated the energy weightiness embodied in building materials is essential, and have proven that the use of better, energy-efficient technology can reduce the embodied energy in building materials and minimize the release of CO2 carbon generated by using energy-intensive materials [2].

The embodied Energy is Energy embedded in building materials during all processes of production of materials or products, construction on-site, building operations, to the end-use of the building. The embodied energy is defined as the amount of energy used (fuel oil/electricity, materials, and human power) used to make a product [7].

The embodied energy assessment is an energy accounting method that aims to determine the total amount of energy required for a product life cycle. This energy life cycle includes mining for raw materials, manufacturing of materials or products, transportation, building on-site, building operations, building maintenance, renovation, demolition of buildings to final disposal [7].

II. MATERIALS AND METHODS

The methodology used in this study was an analysis of the building design, specifications, and material quantity. The values of the embodied energy figures in the production of materials refer to the results of research sources in the Southeast Asia region. For the analysis of the embodied energy in the calculation of transportation, refer to the embodied energy-efficient standards, source: Argonne National Laboratory of Transportation USA. The embodied energy efficiency was determined by observing construction activities at the site, knowing the type of transportation for the materials, two for each, such as the type and series of truck used, such as Ready mix concrete trucks, metal trucks, cement trucks, plywood trucks, wood, brick trucks, zinc roof trucks, and ceramic truck, and building activities [8].

A. Study Objectives and Study Areas

The purpose of this study was to determine the average amount of embodied energy in middle-class residential houses in Padang City, West Sumatra Province, Indonesia. The first objective of this study was to determine the average amount of embodied energy in each material in units (M.J. / kg/tonne) of middle-class residential houses in Padang City, West Sumatra Province. The primary materials used in the construction of houses in Indonesia include cement, iron, concrete, plywood, wood, brick, zinc roofing, and floor tiles.

The second objective was to assess the average value of the embodied energy in the body against the six studied houses, the assessment of the building in units (G.J. / m2) versus the floors in the city of Padang, West Sumatra province. The city of Padang was chosen as the study location. The city of Padang is the capital of West Sumatra province, which has a high housing development activity.

B. Building Description

The selected houses for the study object were built from 2005 to 2015, which have different building architectural styles and construction methods with almost the same building material specifications. These houses have different building floor areas - more or less different—312 m2 to 638 m2. The front view of the house of the study object is shown in Figure 3. The building components and the material specifications of the pilot study house are shown in Table 1: The quantity of building materials (tonnes) of the house R.1, the area of the building is 600 m2 shown in Table 2. Material quantity and floor area of each house building object of the building assessment study are shown in Table 3.

1a. House (R.1) 1b. House (R.2)

1c. House (R.3) 1d. House (R.4)

1e. House (R.5) 1d. House (R.6)

Fig 1. Photo of the front view of the building assessment residence

These houses are built with reinforced concrete structures consisting of three main components, concrete, formwork, and steel reinforcement. The formwork used are generally wood and plywood, and in-situ concrete Grid 20 Mpa is used to build structures. The foundation is made of local plate reinforced concrete—the inner and outer walls built with clay bricks that do not bear the burden. The roof truss is built with a wooden truss with a zinc roof. For doors and windows, they use wooden and aluminum frames where doors are made of wood and plywood. The floor finishing is with ceramic floors.

Table 1. Building components and material specifications for the case studied the house

No	Material Component	Material Specification
1	Floor Area Building	600.m^2
2	Sub Structure	Concrete (local Plat dan Stone side
3	Building Structure	0 Mpa)
4	Wall	Clay Bick Plaster
5	Frame Door and Window	Borneo Timber Level 1 (6 x 15)
6	Door and Window	Borneo Timber Level 1 (4 x 10)
7	Frame Roof	Borneo Timber Level 1 (6 x 12)
8	Roofing	Zingalume 0,5 Colour Bond
9	Frame Ceiling	Timber 5 x 7 (Meranti, Level,2)
10	Ceiling	Gypsum Board T 10.mm
11	Floor	Ceramic Tile (60 x 60)

Table 2. Quantity of building materials (tons) of houses R.1 building area 600 m^2

No	Material	Density Material (kg/m3)	Quantity Material (tons)	Materials Source
1	Cement	1,506	49.74	Local
2	Iron	7,750	20.04	Regional
3	Concrete	2,400	156.47	Local
4	Plywood	750	1.75	Regional
5	Timber	705	9.50	Local
6	Clay Brick	950	103.62	Local
7	Roof Zinc	3,330	3.51	Regional
8	Ceramic Tile	2,500	13.20	Regional

Table 3. Quantity of building materials (tons) for the studied house

No	House Study	R.1	R.2	(R.3)	(R.4)	(R.5)	(R.6)
	Floor. Area	(600m^2)	(638m2)	(312m2)	(670m2)	(545m2)	(465m2)
	Material						
1	Cement	49.74	43.40	25.60	55.50	57.25	47.50
2	Iron	25.05	30.87	12.79	30.12	27.61	25.72
3	Concrete	156.47	277.30	114.95	270.58	248.17	202.19
4	Plywood	1.75	2.03	1.40	3.00	3.36	2.20
5	Timber	14.25	21.50	15.15	26.01	30.58	16.38
6	Clay Brick	103.62	106.87	62.32	112.64	89.95	82.88
7	Roof Zinc	3.51	2.96	1.46	3.17	2.43	1.62
8	Ceramic Tile	13.20	12.76	7.48	13.40	11.50	10.23

C. Source of material for transportation distance and type of transportation

For West Sumatra, the primary source of building materials for the building of residential houses consists of two sources, namely local sources and regional sources. Local source building materials are such as cement, bricks, concrete, and wood because these types of materials are the manufacturing industry in the city of Padang, West Sumatra. For iron, zinc roofing, plywood, floor tiles are regional source materials because manufacturing plants are located on the island of Java, such as Jakarta, West Java Province, and Banten Province, which use a transportation distance of approximately 1,300 km to the city of Padang, West Sumatra.

D. Analysis of the Calculation of Embodied Energy in Transportation

For the calculation of the embodied energy in the transportation of each material, the computer analysis is to multiply the transportation distance by the embodied energy coefficient in the transport and then multiply by the quantity of the material conveyed. Then, the result of the embodied energy can be identified.

E. The Embodied Energy by Every Material

The embodied energy in each material consists of two embodied energies, namely the energy production of materials and the embodied energy in the transportation of materials. To calculate the embodied energy in each material is to add the embodied energy value in the production of each material with the embodied energy value in the transportation of each material, in units of M.J. / ton. The result of the embodied energy value in each material can be identified. The assessment results of the embodied energy value in each primary building materials of the R-1 house are shown in Table 4 below.

Table 4. The embodied energy value in each material (R-1) in the city of Padang

No	Materials	(a).Rate EmE Materials Production (M.J./tons)	(b) Rate EmE Materials Transport (M.J./tons)	(a)+(b) Total Rate EmE Materials (M.J./tons)
1	Cement	4,510	21.60	4,531
2	Iron	34,000	465.55	34,465
3	Concrete	1,700	18.00	1,718
4	Plywood	10,400	311.10	10,711
5	Timber	2.000	163.04	2,163
6	clay brick	1,300	51.00	1,351
7	Roof Zinc	53,100	427.25	53,527
8	Ceramic	5000	427.53	5,427

F. Embodied energy Analysis of Floor Area

For the assessment of the embodied energy value in the building in proportion to the floor area, first, convert the embodied energy value in the whole of each material from the Mega Joule unit (M.J. / ton) to the Giga Joule (G.J.) unit. The unit (M.J. / ton) to unit (G.J.) conversion is 1/1000, where 1000 Mega Joule (M.J.) equals 1 Giga Joules (G.J.). Second, dividing the embodied energy value in the unit (G.J.) by the floor area of each unit building (m2), then the result of the embodied energy value in the unit (G.J. / m2) compared to the floor area of the building under study can be identified.

III. RESULTS AND DISCUSSIONS

Based on the study that has been carried out on the pilothouse, the embodied energy assessment of eight main building materials at the studied houses as the study object located in the city of Padang, West Sumatra Province, and the study results are as shown in Figure 2. The embodied energy value in each of these main building materials includes transportation energy. The embodied energy value in cement material is 4.531 MJ / ton, iron 34,465 MJ / ton. Concrete 1,718 MJ / ton, Plywood 10,711 MJ / ton. Wood 2,163 MJ / ton. 1.351 MJ / ton brick. Zinc roofing 53,527 MJ / ton. The ceramic floor is 5,427 MJ / ton.

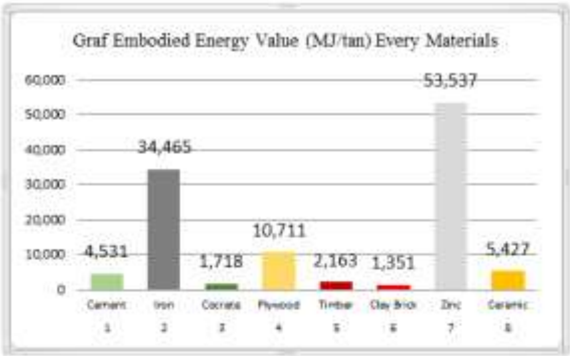

Fig. 2 The graph image results from the embodied energy values every main ingredient of the study pilot house in the city of Padang.

In Padang city, West Sumatra Province, the primary source of building materials for building residential houses consists of two sources, namely local sources and regional sources. Local source building materials such as cement, bricks, concrete, and wood, because these types of materials, the manufacturing industry is in the city of Padang, West Sumatra. Iron, zinc roofing, plywood, glass, and floor tiles use regional source materials because the manufacturing industry is on the island of Java, such as Jakarta, West Java Province, and Banten Province, which use long transportation distances, approximately 1,300 km to Padang city, West Sumatra.

From eight primary building materials studied, the highest embodied energy value was zinc roofing with a value of 53.527 MJ / ton and iron with a value of 34.465 MJ / ton. At the same time, the lowest embodied energy value is the brick material, with a value of 1.351 MJ / ton. The main factor causing the high embodied energy value in zinc and iron roofing materials is, in addition to the production of these materials being materials and energy-intensive. The source of the manufacturing industry is very far away; this will also have a high impact on energy use for transportation from the manufacturing industry to the construction site.

For comparison, the energy assessment contains building materials for residential houses in the city of Petaling Jaya, Kuala Lumpur, Malaysia, for cement the value is 2.70 MJ / ton, iron 34.00 MJ / ton, concrete 1.70 MJ / ton, Plywood 10.40 MJ / ton, wood 2.00 MJ / tons, brick 2.50 MJ / ton zinc roof 52.00 MJ / ton and ceramic floor 5.00 MJ / ton [4].

When compared to the embodied energy value in each primary material for the studied residence in the city of Padang with the primary building material in the city of Petaling Jaya Kuala Lumpur, Malaysia, especially for local source materials for the study house in the city of Padang, it is lower, such as cement, brick, concrete, and wood. In contrast, regional source materials, such as iron, zinc roofing, plywood, and floor tiles for the city of Padang, West Sumatera, are higher. The main factors causing the high value of the embodied energy figures above are in addition to the high energy production, the distance of transportation, such as iron, zinc roofing, and floor tiles from Java with a distance of more than 1,300 km. Meanwhile, residential houses in Malaysia have a transportation distance that is closer to 20 to 40 km. All materials are local sources because the material sources are available in the city of Petaling Jaya, Kuala Lumpur.

Based on the analysis of the study carried out on the piloted house is shown in Figure 2 above. The result of the embodied energy value in the building of the comparison with the floor area for each main building material of the house of the study object is for cement the value of 0.377 GJ / m2. Iron 1,438 GJ / m2. Concrete 0.446 GJ / m2. Plywood 0.031 GJ / m2. Wood 0.051 GJ / m2. Bricks 0.233 GJ / m2. Zinc roofs of 0.313 GJ / m2 and floor tiles of 0.119 GJ / m2. The results are as shown in Figure 3. The total amount of embodied energy in the floor area for the studied house is 3.010 GJ / m2.

Based on the study that was carried out on the six house buildings, the assessment study units are shown in Figure 3 below. The embodied energy value to the floor area for each house of study object is for House (R.1) with a value of 3.01 GJ / m2 (R.2) with a value of 3.41 GJ / m2. House (R.3) 3.21 GJ / m2. (R.4) 3.33 GJ / m2. (R.5) 3.57 GJ / m2. House (R.6) 3.79 GJ / m2. The total embodied energy for the five-building appraisal study houses is 20.32 GJ / m2.

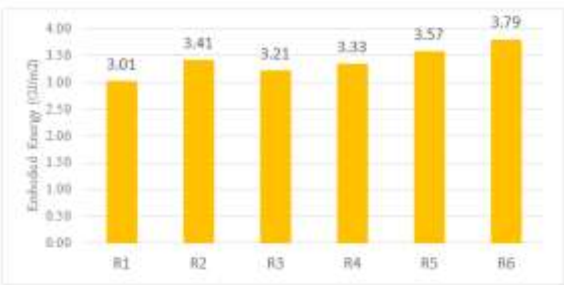

Fig. 3 The embodied energy yield is in proportion to the floor area (G.J. / m2) of six houses in the assessment of buildings.

The average value of embodied energy in the building versus the floor area of the eight primary building materials for the five study houses for building appraisal in Padang city, West Sumatra province, is 3.38 GJ / m2. The highest embodied energy value is a house (R.6) with a value of 3.79 GJ / m2, and the lowest embodied energy value is for houses (R.1) with a value of 3.01 GJ / m2.

Referring to the embodied energy assessment study of a two-tier residential house [4], in the Petaling Jaya city of Kuala Lumpur, Malaysia, the average embodied energy value in the body versus floor area is 4.46 GJ / m2. When compared with the average embodied energy value in the ratio of the floor area of the house of the study object in the city of Padang, West Sumatra with a two-level residential house in Kuala Lumpur, Malaysia, the embodied energy value for the house of the study object in the city of Padang, West Sumatra has a lower value.

It is because even though the calculation system limits are the same at the Production stage, the embodied energy assessment for residential houses in Malaysia is the calculation for all building materials, including finishing materials such as doors and windows, ceilings, glass, wall paint. And ceiling (not the main ingredient) [12]. Whereas for the house of the study object in the city of Padang, the calculation is only for the eight primary materials, so the results of the average value of the embodied energy in proportion to the floor area are different and lower, approximately 1.5 GJ / m2.

Referring to the findings of the study conducted by several researchers in Australia and New Zealand for residential houses, it is found that the embodied energy value varies. For the Sydney city area, the value of embodied energy in proportion to the floor area of a residential house is 3.6 GJ / m2 [9]. The city of Canberra is 3.9 GJ / m2. For the Gold Coast city, the value is 4.3 to 5.3 GJ / m2. For the city of Daikin, the value is 4.9 GJ / m2 (Pullen, 1995). For the city of Perth, Western Australia, the value is 5.0 GJ / m2 (Lawson, 1992 [9]. For the city of Darwin, it is 5.9 GJ / m2. The city of Tasmania is 6.6 GJ / m2.

Studies conducted by [1, 10, 11,] states that the energy results contained in the investigation of differences in the energy value contained, derived from information from different sources, and different countries [1, 10], explain that during this period, the embodied energy value obtained by several studies shows variations in the value of embodied energy figures such as typical units of residential houses and commercial buildings. The results of this study are also shown in a table of how many energy values are contained based on the floor area (G.J. / m2) obtained by various previous researchers, as shown in the following table.

The results of the embodied energy values for one square meter of building floor area in Australia are different. For the residential building, the embodied energy in the building body for one square meter of floor area is about 3.6 to 8.76 GJ / m2. While the results of the study carried out in this study, the embodied energy value in the housing body in the city of Padang, West Sumatra Province is a value of 3.38 GJ / m2, getting the embodied energy values lower than the findings of previous researchers, as shown in the table. 5.

Table 5. Variations in The Value of The Embodied energy Units (Gj / M2)

Embodied Energy (G.J./m^2)	Building Type	Source	City and Country
3.6	Residential	Hill, 1978 (cited by Pullen, 2000b)	Sidney
3.9	Residential	Edwards et al., 1994	Canberra
4.3 – 5.3	Residential	D' Cruz et al., 1990 (cited by Pullen, 2000b)	Gold Coast
4.9	Residential	Pullen, 1995	Daikin
5.0	Residential	Lawson, 1992 (cited by Pullen, 2000b)	Perth
5.9	Residential	Pullen, 2000b	Darwin
6.6	Residential	Ballantyne et al., 2000 (cited by Pullen, 2000b)	Tasmania
6.8	Residential	Treloar 1998	Adelaide
8.76	Residential	Treloar 1996b	New Zeland
4.46	Residential	Tamil Salvi Mari (2007)	K.Lumpur, Malaysia
3.38	**Residential**	**Hendrino 2017**	**Padang, Indonesia**

The main factors causing the difference in the average value of embodied energy for the studied residence in the city of Padang, West Sumatra, and the residential house in the Australian territory as shown in table 5 above are:

First, for the cities of Sidney and Canberra, the system boundaries or rank calculations are the same, namely the ratings for the main ingredients. As for the studied residence s in the cities of Gold Coast, Daikin, Perth, Darwin, Tasmania, Adelaide, and New Zealand State, the energy calculations contained are for all building materials, including materials for building, finishing, such as door frames, door frames, door frames. Windows and windows, ceiling and ceiling frames, glass, painting of walls and ceilings, and including roof and wall insulation materials. (Not the primary materials)

Second, for the studied residence in the Australian and New Zealand region, the boundary energy calculation system consists of two calculation phases. The first stage is the production of materials, including transportation energy. The two stages of energy are contained in construction. These are some of the factors causing the difference in the embodied energy value higher and different in the embodied energy value in this study.

IV. CONCLUSIONS

This study included an analysis of the embodied energy in the design of the building design and material specifications and an examination of the construction activities of six selected middle-class residential houses. The residential house floor area is from 312 m2 to 638 m2. Based on that information, the embodied energy in the material production and material transport stages is calculated to determine the amount of embodied energy. It has been found that the amount of embodied energy in middle-class houses is between 3.01 GJ / m2 to 3.79 GJ / m2, with an average of 3.38 GJ / m2. There is a difference in the average value of the embodied energy for the studied residence in the city of Padang, West Sumatra, with the residential house in the territory of Australia.

Recommendations for further research and other researchers, it is necessary to carry out a careful calculation of the energy calculation of the medium type house building material, such as referring to low-cost and energy-efficient materials for sustainable housing [17], as well as abundant alternative materials that can be used as building materials [18]. This careful calculation is influenced by many factors, ranging from geography, socioeconomic education [14], and legal aspects [15, 16] that exist in each country. It can be follow-up research with home occupancy, based on local wisdom of each country.

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