Life cycle assessment of energy and CO\textsubscript{2} emissions for residential buildings in Jakarta, Indonesia.

U Surahman\textsuperscript{1*}, T Kubota\textsuperscript{2} and A Wijaya\textsuperscript{3}

\textsuperscript{1}Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi No. 207 Bandung 40154, Indonesia.
\textsuperscript{2}Graduate School for International Development and Cooperation, Hiroshima University, 1-5-1 Kagamiyama Higashi-Hiroshima, 739-8529 Hiroshima, Japan.
\textsuperscript{3}Indonesia University of Persada, Jl. Salemba Raya No. 10 Jakarta 10440, Indonesia.

*Corresponding author. Tel.: +62-89634730153; fax: +62-22-424-6956.
E-mail address: usep@upi.edu (Usep Surahman).

Abstract. In order to develop low energy and low carbon residential buildings, it is important to understand their detailed energy profiles. This study provides the results of life cycle assessment of energy and CO\textsubscript{2} emissions for residential buildings in Jakarta, Indonesia. A survey was conducted in the city in 2012 to obtain both material inventory and household energy consumption data within the selected residential buildings (n=300), which are classified into three categories, namely simple, medium and luxurious houses. The results showed that the average embodied energy of simple, medium and luxurious houses was 58.5, 201.0, and 559.5 GJ, respectively. It was found that total embodied energy of each house can be explained by its total floor area alone with high accuracy in respective house categories. Meanwhile, it was seen that operational energy usage patterns varied largely among house categories as well as households especially in the simple and medium houses. The energy consumption for cooling was found to be the most significant factor of the increase in operational energy from simple to luxurious houses. Further, in the life cycle energy, the operational energy accounted for much larger proportions of about 86-92\% than embodied energy regardless of the house categories. The life cycle CO\textsubscript{2} emissions for medium and luxurious houses were larger than that of simple houses by 2 and 6 times on average. In the simple houses, cooking was the largest contributor to the CO\textsubscript{2} emissions (25\%), while the emissions caused by cooling increased largely with the house category and became the largest contributors in the medium (26\%) and luxurious houses (41\%).

1. Introduction
The ultimate purpose of this study is to propose low energy and low carbon residential buildings in major cities of Indonesia. Over the last few decades, Indonesia has been experiencing rapid urbanization and population growth. The total population increased from 97.1 million in 1970 to 237.6 million in 2010 [1]. As a consequence, the needs for living areas increased faster and enormous number of residential buildings have been developed especially in major cities, such as Jakarta. Due to the tremendous urbanization seen in the major cities, the present nationwide final energy consumption in Indonesia became about 14 times larger than that of 1970s [2]. This increasing consumption of energy will result in serious energy scarcity in major cities and cause further threat to the global warming.
A building consumes various natural resources, including water, materials and energy, and releases many pollutants during its life cycle [3]. Thus, any comprehensive assessment of building energy consumption and its environmental impacts, such as life cycle assessment (LCA), is essential in order to achieve a low energy and low carbon building. Several LCA methods for buildings were developed and are commonly used in many parts of the world, particularly in developed nations [3, 4, 5]. However, there are relatively few LCA studies for buildings in developing countries to date [6,7,8,9]. This is mainly because of relatively poor data availability of building, economy and environment, which are necessary for LCA analyses.

A few LCA studies were conducted in Indonesia [6,8,9], but these studies focused only on planned houses and apartments. In Indonesia, unplanned houses are typical of residences in major cities rather than the said planned houses, as discussed in the section 2.1. Nevertheless, there are few LCA studies for these unplanned houses to date. The present authors conducted a preliminary study in Bandung, Indonesia in 2011 to investigate life cycle energy and CO₂ emissions for unplanned houses [7].

This study provides the results of life cycle assessment of energy and CO₂ emissions for residential buildings comprising both planned and unplanned houses in Jakarta, Indonesia. A survey was conducted in the city from September to October in 2012 to obtain both material inventory and household energy consumption data in these buildings. This paper analyzes the life cycle energy and CO₂ emissions among different categories of houses through an input-output (I-O) analysis-based method.

2. Methodology

2.1. Case study houses

Jakarta, the capital city of Indonesia, was selected as a case study city. Its population increased from 4.4 million in 1970 to 9.6 million in 2010 [10]. The city has a hot and humid climate and the average rainfall intensity throughout the year ranges from 117.2-388.8 mm per month with the daily average outdoor relative humidity of 70-81%. The monthly average temperature varies at 27.1-28.9 ºC throughout the year [11].

Residential buildings (landed houses) in Jakarta can be grouped into two types, namely planned and unplanned houses. Originally, the unplanned houses, called ‘Kampungs’. These dwellings settled in unplanned and overcrowded urban villages. Moreover, some of them were squatters on public land and located in strategic parts of the city without being provided with basic urban infrastructure and services properly [12]. Moreover, these planned and unplanned houses can be further classified into three house categories based on its construction cost and lot size, namely simple, medium, and luxurious houses (figure 1). These houses have an approximate lifespan of 20, 35, and 50 years on average, respectively [13].

Figure 1. Views of sample residential buildings. (a) Simple house; (b) Medium house; (c) Luxurious house.
A total of 300 residential buildings were selected in the survey (table 1). As shown, the average household size was about 4-5 persons with a small variation between the three categories. The monthly average household income was also investigated by a multiple-choice question. As expected, the average income increases with house category from simple to luxurious houses. As shown, the total floor area also increases with house category. The largest percentage of total floor area was less than 50 m$^2$ (71%) for simple houses, 50 to 99 m$^2$ (51%) for medium houses and 100 to 300 m$^2$ (83%) for luxurious houses. The major building materials used were found to be almost the same among the above categories, though slight differences could be seen in terms of materials for floor and roof.

### Table 1. Brief profile of sample houses.

| Sample size (Unplanned/Planned) | Simple houses | Medium houses | Luxurious houses | Whole sample |
|---------------------------------|---------------|---------------|------------------|--------------|
| Age (%)                         | 125 (125/0)   | 115 (75/40)   | 60 (30/30)       | 300 (230/70) |
| <40                             | 32.0           | 17.4          | 10.0             | 22.0         |
| 40-49                           | 32.0           | 37.4          | 30.0             | 33.7         |
| 50-60                           | 23.2           | 30.4          | 50.0             | 32.3         |
| >60                             | 12.8           | 14.8          | 10.0             | 12.0         |
| Household size (persons)        | 4.3            | 4.5           | 5.4              | 4.6          |
| Monthly income (%)              |                |               |                  |              |
| < 100 (USD)                     | 4.8            | 1.7           | 1.6              | 4.0          |
| 100-400                         | 76.8           | 59.1          | 20.0             | 58.7         |
| 500-1000                        | 16.8           | 31.3          | 38.3             | 28.0         |
| >1000                           | 1.6            | 7.9           | 40.1             | 9.3          |
| Total floor area (%)            |                |               |                  |              |
| <50 (m$^2$)                     | 71.2           | 9.6           | 0.0              | 57.7         |
| 50 - 99                         | 20.0           | 51.3          | 0.0              | 15.7         |
| 100 - 300                       | 8.8            | 36.5          | 83.3             | 23.3         |
| > 300                           | 0.0            | 2.6           | 16.7             | 3.3          |

#### 2.2. Life cycle assessment (LCA)

LCA generally involves six phases, namely design, material production, construction, operation, maintenance, and demolition phases. However, design, construction and demolition phases were not considered in this paper. This was due to very limited possibilities to consume energy in the above three phases since most of the residential buildings in Jakarta are constructed and demolished by manual labour. Thus, the energy consumption and materials used during the above phases are considered negligible.

The design records such as building drawing are required for the analysis of embodied energy of building materials. These data can normally be obtained from the local authorities or developers, etc. Nevertheless, in the case of Jakarta, these data were available for planned houses and most of the unplanned luxurious houses only. The other houses including most of the simple and unplanned medium houses were not constructed in the formal way in practice (they are normally constructed by non-professional neighbors), and therefore the said design records could not be obtained. Thus, the actual on-site measurements by using laser distance meters and tape measures were conducted for simple and unplanned medium houses instead in order to acquire the data (figure 2a).

Meanwhile, the detailed household energy consumption data are necessary for the analysis of operational energy. Since the household energy consumption data were not available in Jakarta, the detailed interviews and measurement of appliance capacity by using watt checkers (MWC01, OSAKI) were conducted in order to obtain the data along with the above survey on building material inventory (figure 2b). The material inventory data for refurbishment were also obtained during the same interviews.
Previous studies showed that there are three main methods commonly used for analysis of energy and environmental impacts, namely process-based, economic input-output (I-O) analysis-based, and hybrid-based methods [14]. Although it is impossible to trace all the processes unlike the process-based or the hybrid-based methods, this study adopted the I-O analysis-based method to calculate the embodied energy of households and estimate their CO$_2$ emissions, which consistently followed the method described by Nansai et al. [15]. The latest Indonesian nationwide I-O table published in 2005 [16] consisting of 175 by 175 sectors was used for calculating the embodied energy and CO$_2$ emissions.

Energy used in a building is divided into two categories. The first is embodied energy for raw material extraction, material production, transportation and building construction, and maintenance. The second is energy consumption during the operation phase. The total energy of the above two categories are expressed as life cycle energy in this paper, which is given by the following equation.

\[
LCE = EE_i + EE_{rec} + (OE \times lifespan)
\]

Where $LCE$ is the life cycle energy (GJ), $EE_i$ is the initial embodied energy of materials (GJ), $EE_{rec}$ is the recurrent embodied energy of materials (maintenance) (GJ), $OE$ is the annual operational energy (GJ/year) and $lifespan$ is the time period of a building’s life (year).

The choice of energy resource is also important as type of fuel is crucial for the CO$_2$ emissions. This means that minimizing the final or purchased energy (secondary energy) does not automatically minimize the use of natural resource or the life cycle CO$_2$ emissions of a building. Thus, energy should be measured in the form of primary energy especially for a life cycle CO$_2$ assessment [17]. For the above reason, both embodied and operational energy were measured in the form of primary energy in this paper.

3. Results and discussion

3.1. Embodied energy

Figure 3 shows the average volume of each material used in respective houses, including new, reused, recycled, and maintenance materials. As shown, the sand accounted for the largest proportions in both simple and luxurious houses (28-33%), followed by stone (26-32%), clay brick (18-19%), wood (7-12%), and cement (7-9%), etc. In the case of medium houses, the stone was the largest contributor (33%), followed by sand (31%), clay brick (14%), etc. The steel contributed for about 0.2 to 0.4%. The reused and recycled materials accounted for a small amount in total (6%) for simple and medium houses. The maintenance materials were found to be 4% for medium houses and 10% for luxurious houses, respectively.

The total embodied energy was obtained by combining initial and maintenance embodied energy for respective houses (figure 4a). A shown, the average embodied energy increases with the house category from simple to luxurious houses sharply. For instance, the average value of luxurious houses
(559.5 GJ) was about 3 times larger than that of medium houses (201.0 GJ) and about 10 times than that of simple houses (58.5 GJ). This is mainly due to the differences of average building sizes among house categories (see table 1). The similar pattern was occurred for the average embodied energy per total floor area and per person. As shown in figure 4b, the embodied energy per floor area increases with house category from simple to luxurious houses. Since the total floor area was found to be the most significant explanatory variable to the embodied energy in three house categories as described before, the above per-floor area unit values can be used in predicting the embodied energy of each house category. On the other hand, as shown in figure 4c, the proportion of average embodied energy per household size showed the similar patterns with that of the original embodied energy (see figure 4). This is mainly due to the small variation of household size among different house categories (see table 1).

3.2. Operational energy

As described before, the ownership level and usage time of every appliance were investigated, while gas (LPG) and kerosene consumption were also surveyed. Figure 5 shows the average ownership levels of respective appliances in three house categories. As shown, for instance, in terms of the lighting appliances, the Compact Fluorescent Lamp (CFL) was well penetrated through the households and its ownership level gave more than 90% in all the house categories. Major appliances such as rice cooker, refrigerator, television and electric iron recorded high ownership levels of about

Figure 3. Proportion of building material volume for respective house categories.

Figure 4. Average embodied energy for respective house categories. (a) Total embodied energy; (b) Per floor area; (c) Per person.
80-100% similarly in the three house categories. In contrast, several appliances showed different ownership levels among them. This includes the blender, water dispenser, air-conditioner, laptop PC, and hair blower. In terms of the above appliances, the ownership level increases with house category from simple to luxurious houses, respectively. For instance, the ownership level of air-conditioners was found to be 6%, 30% and 90% for simple, medium and luxurious houses.

The annual average energy consumption including electricity, gas and kerosene was then calculated in primary energy terms (figure 6a). As shown, the annual average energy consumption recorded about 32.5 GJ for simple houses, 42.3 GJ for medium houses and 76.5 GJ for luxurious houses, respectively. The energy consumption for cooking accounted for the largest percentages in the simple (36%) and medium houses (29%), while that for cooling was the largest contributor in the luxurious houses (40%). (see figure 6a). The annual energy consumption per person increases with house category from simple to luxurious houses sharply (figure 6c). This is mainly due to the difference of ownership and usage levels of cooling appliances, especially air-conditioners, as described before. In contrast, the unit energy consumption per floor area decreases with house category from simple to luxurious. This is because the number of occupants per floor area is largely different among three house categories.

**Figure 5.** Ownership level of appliances.

**Figure 6.** Annual average energy consumption for respective house categories. (a) Annual average energy consumption; (b) Per floor area; (c) Per person.

We assumed that annual energy consumption patterns would continue uniformly for the whole life-span of a building in this study. Thus, the total operational energy during the whole life-span was
simply estimated through multiplying the said annual average energy consumption by its life span for respective house categories. The percentages of electricity gave higher values (83-87%) than those of gas (13-16%) particularly in the medium and luxurious houses. The average operational energy was measured at 650.4 GJ for simple houses, 1479.5 GJ for medium houses and 3826.8 GJ for luxurious houses, respectively.

3.3. Life cycle energy and CO$_2$ emissions
The life cycle energy was obtained by combining embodied energy and operational energy for respective houses (figure 7a). As shown in figure 7a, the operational energy accounted for much larger proportions of about 86-92% than embodied energy regardless of the house categories. The total life cycle energy was measured at 708.9, 1680.4 and 4386.3 GJ for simple, medium and luxurious houses, respectively. As shown in figure 7b, the CO$_2$ emissions during operation phase were larger than the embodied CO$_2$ emissions by 12 to 19 times in three house categories. The estimated total life cycle CO$_2$ emissions were 117.0, 280.2 and 743.0 tons CO$_2$-eq for simple, medium, and luxurious houses, respectively. The life cycle CO$_2$ emissions for medium and luxurious houses were larger than that of simple houses by 2 and 6 times on average.

![Figure 11. Average life cycle energy and CO$_2$ emissions for respective house categories. (a) Average life cycle energy; (b) Average life cycle CO$_2$ emissions](image)

4. Conclusion
This paper provided the detailed profiles of life cycle energy and CO$_2$ emissions in urban houses of Jakarta.

(1) The results showed that the average embodied energy for the simple, medium and luxurious houses was found to be 58.5, 201.0 and 559.5 GJ, respectively. It was found that the total embodied energy of each house can be explained by its total floor area alone with high accuracy in respective house categories. The average embodied energy per total floor area was 1.4 GJ/m$^2$ for simple houses, 2.1 GJ/m$^2$ for medium houses and 2.8 GJ/m$^2$ for luxurious houses, respectively.

(2) It was seen that operational energy usage patterns varied largely among house categories as well as households especially in the simple and medium houses. The annual average operational energy for simple, medium and luxurious houses was measured at 32.5, 42.3 and 76.5 GJ/year, respectively. The energy consumption for cooling was found to be the most significant factor of the increase in operational energy from simple to luxurious houses.

(3) In the life cycle energy, the operational energy accounted for much larger proportions of about 86-92% than embodied energy regardless of the house categories. The total life cycle energy was found to be 709.0, 1680.4 and 4386.3 GJ for simple, medium and luxurious houses, respectively.

(5) The number of air-conditioners in residential buildings is expected to rise further in the near future.
as household income increases further. It is important to find out the means to reduce usage of air-conditioning particularly for emerging middle-class houses in order to achieve low energy and low carbon residential buildings in the hot-humid climate of Jakarta.

Acknowledgements
This research was supported by a JSPS Grant-in-Aid for Young Scientist (B) (No. 23760551). We also would like to thank Mr. Yohei Ito and students of UPI and ITB who kindly supported our survey.

References
[1] Indonesia 2010 Population Census of Indonesia. Statistical Centre of Indonesia, Jakarta.
[2] Indonesia 2011 Handbook of Energy and Economic Statistics of Indonesia. Ministry of Energy and Mineral Resources of Indonesia, Jakarta.
[3] Crawford R H 2011. *Life Cycle Assessment in the Built Environment*. (New York: Spon Press).
[4] Monahan J, Powel J C, 2011 An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a life cycle assessment framework. *Energy and Buildings*. 43, p. 179–188.
[5] Mithraratne N, Vale B, 2004 Life cycle analysis for New Zealand houses, *Building and Environment*. 39, p. 483-492.
[6] Kurdi Z, 2006 Determining Factors of CO₂ Emission in Housing and Settlement of Urban Area in Indonesia. Ministry of Public Work of Indonesia and National Institute for Land, Infrastructure and Management of Japan, Bandung.
[7] Surahman U, Kubota T, 2013 Life cycle energy and CO₂ emissions of residential buildings in Bandung, Indonesia. *Advanced Materials Research*. 689, p. 54-59.
[8] Utama A, Gheewala S H, 2009 Indonesian high rise buildings: A life cycle energy assessment, *Energy and Buildings*. 41, p. 1263–1268.
[9] Utama A, Gheewala S H, 2008 Life cycle energy of single landed houses in Indonesia. Energy and Buildings. 40, p. 1911–1916.
[10] Jakarta 2010a Jakarta in figures. Statistical Centre of Jakarta, Jakarta.
[11] Jakarta 2010b Climatology Data in Jakarta from 2001-2010. Climatology and Meteorology Station of Kemayoran, Jakarta.
[12] World Bank 1995 Indonesia Impact Evaluation Report, Enhancing the Quality of Life in Urban Indonesia: The Legacy of Kampung Improvement Program. Report No. 14747-IND. Operation Evaluation Department, the World Bank, Washington, D.C., United States of America.
[13] Indonesia 2002 Planning Procedures for Developing Earthquake Resistant on Buildings. Department of Public Work (PU), Indonesia.
[14] Dixit M K, Fernandez J L, Lavy S, Culp C H, 2010 Identification of parameters for embodied energy measurement: A literature review. *Energy and Buildings*. 42, p. 1238-1247.
[15] Nansai K, Moriguchi Y, Tohno S, 2002 Embodied Energy and Emission Intensity Data for Japan Using Input-Output Table (3EID) -Inventory Data for LCA-, National Institute for Environmental Studies, Japan.
[16] Indonesia 2005 Input-Output Table of Indonesia. Statistic Centre of Indonesia, Jakarta.
[17] Gustavsson L, Joelsson A, 2010 Life cycle primary energy analysis of residential building. *Energy and Buildings*. 42, p. 210-220.