Doctoral Dissertation

Life Cycle Assessment of Energy and CO_2 Emissions for Residential Buildings in Major Cities of Indonesia

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Life Cycle Assessment of Energy and CO_2 Emissions for Residential Buildings in Major Cities of Indonesia

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Contents

Abstract

The objective of this study was to provide fundamental database of life cycle energy and CO_2 emissions for urban residential buildings in Indonesia with the aim to propose future visions for achieving low energy and carbon residential buildings in major cities of Indonesia. Two major cities, Jakarta and Bandung, were selected for case study cities, and landed urban houses focusing on unplanned houses were selected because they are typically the largest urban houses in Jakarta (74%) and Bandung (89%).

Chapter 2 reviews previous life cycle assessment (LCA) studies, focusing on their applications in buildings. In general, the use of LCA on buildings can determine environmental impacts in whole process construction (WPC) or for only building material component combinations (BMCCs), depending on the purpose of the LCA. Obtaining data for LCAs differs among countries because availability varies. Data are not so easily collected in developing countries. Process, input-output (I-O), and hybrid methods are commonly used no matter the location. In developed countries, LCA is a common analytical tool to assess environmental impacts, but relatively few LCAs are conducted in developing countries. Those conducted in Indonesia have focused on planned houses and apartments and used process-based analyses. They typically analyzed environmental impacts for BMCCs because data are lacking for buildings, the environment, and the economy, which are necessary for more complete LCAs. Therefore, it is worth to construct comprehensive database necessary for conducting LCA study for WPC in unplanned houses in major cities of Indonesia.

Chapter 3 covers statistical data for residential buildings in Indonesia in which most of the urban houses are unplanned houses. These houses, especially in urban areas, are located in *kampungs* without proper service and infrastructure because growth stimulated by rapid urbanization was not followed by urban development policy. Landed houses can be categorized based on lot size and construction cost into simple, medium, or luxurious houses. Unfortunately, the proportions between these categories were not available from Indonesian statistical data. Housing policy is primarily fulfilled by the government through the Ministry of Public Housing, which provides affordable houses. The private sector has a primary role to fulfill medium and luxurious houses. Because the need for houses has yet to be met, people construct their own houses, and these eventually become unplanned houses.

Chapter 4 describes the methodology of obtaining two necessary pieces of information for LCAs, material inventory data and household energy consumption profiles. A pilot survey was conducted in 2011 to investigate methods of obtaining this information. Two large surveys followed in Bandung in 2011 and Jakarta in 2012, to obtain consumption data for urban houses, focusing on unplanned houses. Detailed environmental and economic data were available only at the national level. On-site building measurements were taken to obtain material inventories and household energy consumption figures due to unavailability data. Estimating building material inventory and future demolition waste are

described. The input-output method was utilized to analyse embodied energy and CO_2 emissions. Embodied energy and household energy consumption were measured in primary energy unit. Scenario analysis was conducted to evaluate future demolition waste using various reuse/recycling rates of building materials.

Chapter 5 provides profiles of sample houses in each city based on house category and household cluster. A total of 297 and 247 houses were investigated in Jakarta and Bandung, respectively. In both cities, the average household size was approximately 4.5 to 5.0 persons, but in luxurious houses, it was about 5.5 persons. The average income in Jakarta was slightly higher than in Bandung. In general, household income increased as the category changed from simple to luxurious. The total area increased with house category in both cities. The major building materials used were found to be the same among the three categories, though slight differences were observed in terms of flooring and roofing materials.

To determine the socio-economic and demographic characteristics that affect embodied energy and household energy consumption patterns, an exploratory factor analysis with principal axis factoring and cluster analysis using factor scores of selected factors (wealth and household size) was carried out for combined whole samples from each city. Three household clusters were determined for each city.

Chapter 6 evaluates the current building material stock and future demolition waste for urban residential buildings based on house category. The value of η^2 (Eta square) showed that house category had larger effects (0.76) on embodied energy than household cluster (0.60). Overall, the average quantity per m^2 used for houses was less in Bandung (2.06 ton/m^2) than in Jakarta (2.14 ton/m^2). The current total material stock for urban houses in Jakarta was 232.0 million ton, while it was 77.2 million ton in Bandung. If both reuse/recycling rates are assumed to be zero, then the total demolition waste of unplanned simple houses in Jakarta will be 41.5 million ton between now and 2020; the corresponding amount is 12.6 million ton in Bandung. The difference resulted from relatively fewer simple houses in Bandung. Future expansion of unplanned residential areas by demolition and transformation of current unplanned simple houses into medium houses is expected to increase the floor area by 20.0 km^2 in Jakarta and 5.7 km^2 in Bandung by 2020. This expansion would force the cities to extend their boundaries into the surrounding suburbs, accelerating urban sprawl. Scenarios simulating minimum and maximum reuse/recycling rates of materials were applied for unplanned houses in Jakarta to examine the effect of reuse and recycled techniques on demolition waste and embodied energy and CO_2 emissions. The results showed that maximizing reuse/recycling rates would decrease material waste by 37% to 41% and embodied energy and CO_2 emissions by 27% to 28%. A combination of closed/opened-loop material flow techniques increased material recovery and reduced material waste sent to landfills. The promotion of reuse/recycling was demonstrated to effectively reduce embodied energy and CO_2 emissions of building materials.

Chapter 7 investigates detailed household energy consumption and CO_2 emissions profiles. The value of η^2 for house category indicated slightly higher effect (0.37) than that for household cluster (0.35) on household energy consumption. In general, the ownership levels of appliances increased from simple houses to luxurious houses. Overall, the average annual energy consumption of all samples in Jakarta was approximately 44.2 GJ, which was 14.9 GJ larger than that of Bandung. The difference is attributed primarily to the use of air-conditioning in Jakarta. In Bandung, energy consumption for cooking, lighting, entertainment, etc. largely affected overall energy consumption. The average annual CO_2 emissions in Jakarta were estimated to be 7.8 ton of CO_2-equivalent, while that of Bandung was 4.8 ton of CO_2-equivalent. If the CO_2 emissions from air-conditioning were excluded, the difference between the two cities would be insignificant. This clearly indicates that the use of air-conditioning dramatically increases household energy consumption and therefore, CO_2 emissions. Multiple regression analysis was carried out to further analyze the causal structure of household energy consumption. The results clearly indicated that greater household income, which had a strong relationship with category, increased building size thus increased total household energy consumption caused by major household appliances. This implies that household income increases with total household energy consumption as it will with the rise of middle class in the near future. It is important to avoid the tendency that building size increases straightforwardly simply because household income does.

Chapter 8 describes the analysis of life cycle energy and CO_2 emissions by house category. Total operational energy is much larger than the embodied energy in houses in Jakarta (80% to 90%) and Bandung (78 to 86%). In Jakarta, cooking was the largest contributor energy and CO_2 emissions (33% and 25%) in the simple houses, while it was air-conditioning that increased with house category and became the largest contributor in the medium (27% and 26%) and luxurious houses (36% and 41%). In Bandung, cooking was also the largest contributor in the simple houses (40% and 30%), but lighting increased with house category and became the largest contributor in the luxurious houses (20% and 25%).

Household energy consumption in major Indonesian cities is predicted to increase very sharply if proper energy-saving strategies are not implemented. Therefore, we recommend these potential energy-saving strategies for urban houses in Indonesia to decrease life cycle energy and CO_2 emissions, based on our analyses: (1) utilize reused/recycled building materials and increase the lifespans of buildings to reduce not only building material waste but also their embodied energy and CO_2 emissions, (2) provision of more apartments rather than landed houses that increase total floor area, to not only control urban sprawl but also avoid increasing building sizes and thus household energy consumption, (3) use natural lighting and energy-saving lighting such as LED lamps to decrease energy consumption caused by lighting, and (4) utilize passive cooling techniques wherever possible to decrease energy consumption caused by air-conditioning.

Finally, Chapter 9 summarizes the main findings of this study and recommends key areas for further study based on the limitations of this work.

Key words:

Life cycle assessment, Building materials, Building waste, Embodied energy, Input-output analysis, Household energy consumption, CO_2 emissions, Urban unplanned houses, Indonesia

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Many people and organization has made much support to accomplish this study. Therefore, I would like to express my sincerest gratitude here as follows.

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List of Acronyms

AC	Air conditioner
ADB	Asian Development Bank
AIJ	Architectural Institute of Japan
ANOVA	Analysis of variance
APERSI	Assosiasi Pengembang Rumah Sederhana Indonesia (Association of developer for simple houses in Indonesia)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAU	Business as usual
BCA	Building and Construction Authority
BLM	Direct community assistance **(**Bantuan Langsung Masyarakat)
BMCC	Building material and component combinations
BPS	Bank Papan Sejahtera
BSI	British Standards Institute
BTN	Bank Tabungan Negara
BUMN	Bada Usaha Milik Negara (State-owned Company)
C&D	Construction and demolition
CBD	Community based development
CBSWM	Community based solid waste management
CDRA	Community development resource association
CFC	Chlorofluorocarbon
CFL	Compact fluorescent lamp
CGER	Centre for Global Environmental Research

COWAM	Construction waste management
DKI	Jakarta Metropolitan Government (Daerah Khusus Ibukota)
EE	Embodied energy
EMS	Environmental management system
EPD	Environmental Protection Department
GBHN	Garis Besar Haluan Negara (Guidance Nation)
GDP	Gross domestic product
GHG	Greenhouse gasses
GPS	Globa positioning system
GWP	Global warming potential
HABITAT	Human Settlements Programme
HK EPD	Hongkong Environmental Protection Department
HT	Human toxicity
HUP	Highest unit price
HVAC	Heating, ventilating and air-conditioning
I-O	Input-output
IEA	International Energy Agency
IGES	Institute for Global Environmental Strategies
IPCC	Intergovernmental Panel on Climate Change
ISO	International organization for standardization
ISSN	International standard serial number
JETRO	Japan External Trade Organization
JICA	Japan International Cooperation Agency
Kasiba	Kawasan siap bangun (ready-for-constructed area)
Kemenpera	Ministry of Public Housing (Kementerian Perumahan Rakyat)
KIP	Kampung improvement program
KPR	Credit for house ownership (Kredit Pemilikan Rumah)
KPRS	Credit for healthy simple house ownership (Kredit Pemilikan Rumah/Kredit Pemilikan Rumah Sederhana Sehat)

Lasiba	Lahan siap bangun (ready-for-construction land)
LCA	Life cycle assessment
LCE	Life cycle energy
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LED	Light emitting diode
LPG	Liquefied petroleum gas
M&E	Mechanical and electrical
MDF	Medium density fiber board
MFA	Material flow analysis
MOC	Ministry of construction
MOE	Ministry of environment
MPA	Metropolitan priority area
MRIO	Multi regional input-output table
MSW	Municipal solid waste
NCV	Net calorific value
NGO	Non-governmental organization
PC	Personal computer
PERUMNAS	National housing (Perumahan nasional)
PVC	Polyvinyl chloride
REI	Real estate Indonesia
Repelita	Five year development planning (Rencana pembangunan lima tahun)
RSh	Healthy simple house (Rumah sehat sederhana)
Rusunawa	Rumah susun sewa (rented flat)
Rusunami	Rumah susun milik (owned flat)
RW	Rukun Warga (cluster neighborhood units)
SMF	Secondary mortgage facility
SNI	Standar Nasional Indonesia

SOD	Stratospheric ozone depletion
SRIO	Single row input-output
SW	Solid waste
TV	Television
UK	United Kingdom
UN	United Nation
UNDP	United Nation Development Program
UNEP	United Nation Environment Program
IETC	International environmental technology center
UNESCAP	United Nation Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
US EPA	Environmental protection agency
USD	United States dollars
WPC	Whole process construction

Nomenclature

A	Coefficient matrix
A	Area (m^2)
h	Height
I	Identity matrix
kg	kilogram
km	kilometer
L	Length
M	Import coefficient
M	Material quantity per unit (m^3/m^2/kg/pieces/sheet,etc)
mm	millimeter
m^2	Meter square
m^3	Meter cubic
n	Number of samples
P	Total output electricity (GWh)
q	Determining calorific value of respective energy consumed
r	Determining matrix of the net contribution rate of energy
R^2	Coefficient of determination (-)
RH	Relative humidity (%)
s	Correction factor that adjust for the amount of electricity that would have been produced in the absence of demand for heating
T	Usage time (hour(s)) per year
T_a	Air temperature (°C)

x	Independent variable in regression model (unit of the variable)
X	X-axis coordinate in the object coordinate system (-)
y	Dependent variable in regression model (unit of the variable)
Y	Y-axis coordinate in the object coordinate system (-)

List of publications

Refereed Journal Papers

Surahman, U. and T. Kubota, March, 2013: Life cycle energy and CO_2 emissions of residential buildings in Bandung, Indonesia. *Advance Material Research*, 689, 54-59.

Surahman, U. and T. Kubota, October, 2012: Development of a simplified LCA model for residential buildings in Indonesia, A pilot survey in Bandung. *AIJ Journal of Technology and Design*, 18 (40), 1003-1008.

Surahman, U., Osamu, H. and T. Kubota, June, 2014: Evaluation of current material stock and future demolition waste for urban residential buildings in Jakarta and Bandung, Indonesia. *Journal of Material Cycles and Waste Management*, (under review).

Surahman, U. and T. Kubota, September, 2013: Life cycle assessment of energy and CO_2 emissions for residential buildings in Jakarta, Indonesia. *Energy for Sustainable Development*, (under review).

Refereed Conference Papers

Surahman, U. and T. Kubota, 2012: Life cycle energy and CO_2 emissions in unplanned residential buildings of Indonesia, A case study in Bandung. In: *Proceedings of the 28th International Conference on Passive and Low Energy Architecture (PLEA 2012)*, November 7-9, Lima, Peru.

Surahman, U. and T. Kubota, 2012: Development of a life cycle assessment model for residential buildings in Indonesia: A pilot survey in Bandung. In: *Proceedings of the 5th International Building Physics Conference (IBPC)*, May 28-31, Kyoto, Japan.

Non-Refereed Conference Papers

Surahman, U., T. Kubota, and O. Higashi, 2014: Analysis of household energy consumption in major cities of Indonesia: Case studies of Jakarta and Bandung. *The Annual Meeting, AIJ,* September 12-14, Kobe, Japan.

Surahman, U. and T. Kubota, 2014: Assessment of life cycle energy and CO_2 emissions for residential buildings in Indonesia: A case study in Jakarta. In: *Proceedings of Annual Research Meeting Chugoku Chapter, AIJ,* March 29-30, Hiroshima, Japan.

Kubota, T., U. **Surahman** and Y. Ito, 2013: Assessment of life cycle energy and CO_2 emissions for urban houses in Jakarta. In: *Summaries of Technical Papers of Annual Meeting, AIJ, August 30 – September 1,* Hokkaido, Japan.

Surahman, U. and T. Kubota, 2012: A pilot survey on building materials and energy consumption: Developing a simplified life cycle assessment model for residential buildings in Indonesia. In: *Proceedings of Annual Research Meeting Chugoku Chapter, AIJ,* March 3-4, Hiroshima, Japan.

（別紙様式６）
(Attached Form 6)

学位論文の要旨（論文の内容の要旨）
Summary of the Dissertation (Summary of Dissertation Contents)

論　文　題　目
Dissertation title

Life Cycle Assessment of Energy and CO_2 Emissions for Residential Buildings in Major Cities of Indonesia

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Chapter 2 reviews previous life cycle assessment (LCA) studies, focusing on their applications in buildings. In general, the use of LCA on buildings can determine environmental impacts in whole process construction (WPC) or for only building material component combinations (BMCCs), depending on the purpose of the LCA. Obtaining data for LCAs differs among countries because availability varies. Data are not so easily collected in developing countries. Process, input-output (I-O), and hybrid methods are commonly used no matter the location. In developed countries, LCA is a common analytical tool to assess environmental impacts, but relatively few LCAs are conducted in developing countries. Those conducted in Indonesia have focused on planned houses and apartments and used process-based analyses. They typically analyzed environmental impacts for BMCCs because data are lacking for buildings, the environment, and the economy, which are necessary for more complete LCAs. Therefore, it is worth to construct comprehensive database necessary for conducting LCA study for WPC in unplanned houses in major cities of Indonesia.

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Finally, Chapter 9 summarizes the main findings of this study and recommends key areas for further study based on the limitations of this work.

Key words:

Life cycle assessment, Building materials, Building waste, Embodied energy, Input-output analysis, Household energy consumption, CO_2 emissions, Urban unplanned houses, Indonesia

1

Introduction

1.1 Background

CO_2 emissions are currently greatest in industrialized countries, although estimates suggest that developing countries will increasingly contribute to global warming in the coming decades (see Figs. 1.1-1.2). In the United States, CO_2 emissions per capita equal 20.1 tonnes, almost twice those of countries such as China and Brazil, 16 times higher than India and 50 times higher than Nigeria and Sudan (UNEP, 2007). If highly-populated developing countries follow the same unsustainable production and consumption path as developed countries, the consequence will be significant. The challenge is to determine how industrialized countries can manage their environmental impacts, while developing countries can achieve economic growth in a sustainable way.

The building sector contributes up to 30% of global annual green house gas emissions and consumes up to 40% of all energy (UNEP, 2009). The Japanese building industry is responsible for almost 30% of the nationwide CO_2 emissions (Ikaga et al., 2000). It is also reported that the British construction industry accounts for about half of UK domestic energy consumption (Howard, 2000). It is predicted if nothing is done, greenhouse gas emissions from buildings will be more than double in the next 20 years as shown in Fig. 1.2 (Levin et al., 2007). Therefore, if targets for greenhouse gas emission reduction are to be met, it is clear that mitigation of greenhouse gas emissions from buildings is necessary.

Over the last few decades, Indonesia has been experiencing high economic growth in line with rapid urbanization and population growth. The total population increased from 97.1 million in 1970 to 237.6 million in 2010 (Indonesia, 2010a). The percentage of people living in urban areas reached approximately 50% as of 2010 (UN, 2011). As a consequence, the need for living spaces increased rapidly, and an enormous number of residential buildings have been developed especially in major cities such as Jakarta, Bandung, Surabaya, Medan, Makasar, etc. At presents, most of the residential buildings in major cities are considered to be unplanned houses. These dwellings were settled in unplanned and overcrowded urban villages without being provided properly with basic urban infrastructure and services. Due to this tremendous urbanization seen in the major cities, it sees large increase in urban energy consumption.

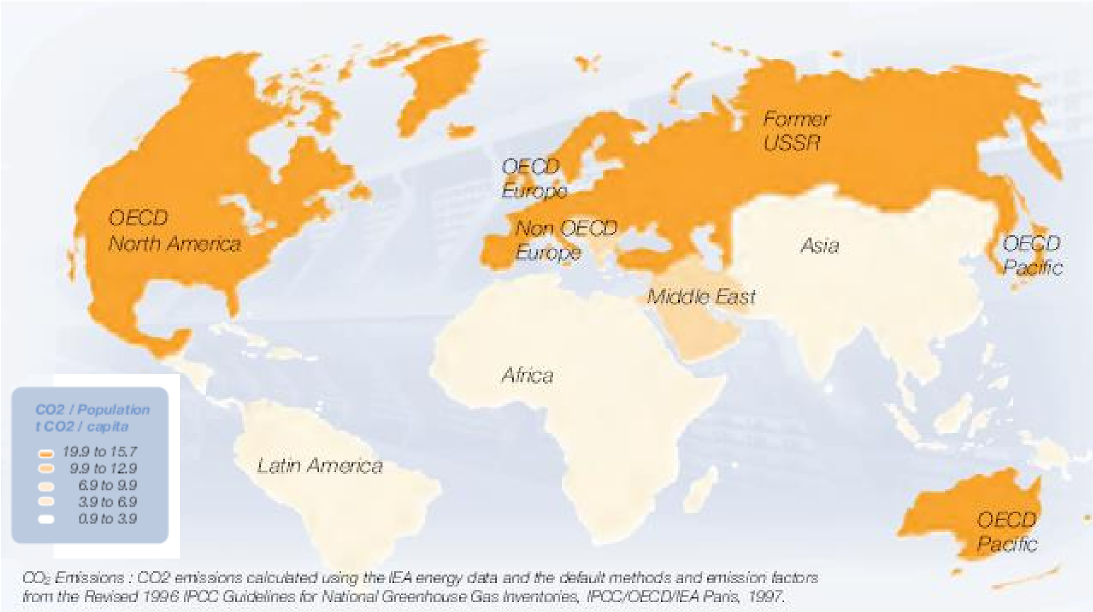


Fig. 1.1 *CO_2 emissions per capita in the world (IEA statistic, 2006 in UNEP, 2007)*

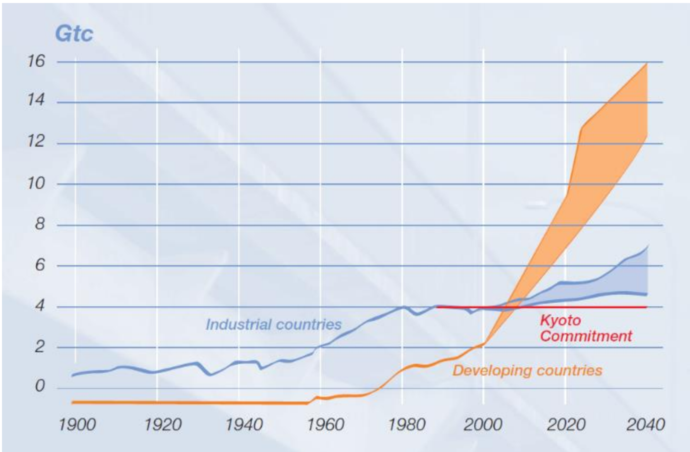


Fig. 1.2 *CO_2 emissions in the developed and developing countries (UNEP, 2007)*

The present nationwide final energy consumption in Indonesia became about 14 times larger than that of the 1970s. This increasing consumption of energy will result in greater environmental burdens. The energy sector of Indonesia accounted for 18.5% of the total CO_2 emissions as of 2005. The CO_2 emissions of the construction sector have been increasing and made up 36% of the total emissions in the energy sector as of 2005 (Dewi et al., 2010).

In Indonesia, the household sector contributes to the nationwide final energy consumption by approximately 34.7% during period 2000-2011 (Indonesia, 2012) and the household energy consumption is expected to increase dramatically as the middle class in urban areas rises in the near future (JETRO, 2011). Energy saving-strategies are, therefore, essential to be introduced further to make the cities more sustainable.

A building consumes various natural resources, including water, materials and energy, and releases many pollutants during its life cycle, i.e. from the raw material extraction to the building's final disposal (Crawford, 2011). The construction industry contributes significantly to resource consumption as well as to other environmental impacts, such as green house gas emissions, air-pollutions and solid waste generation. Thus any comprehensive assessment of building energy consumption or its environmental impacts must consider the entire life cycle of the building. Life cycle assessment (LCA) is a well-known analytical tool for assessing the environmental impacts of a product in its life span in order to achieve a low energy and low carbon building (Crawford, 2011).

This study provides the results of life cycle assessment of energy and CO_2 emissions for urban residential buildings comprising three house categories (simple, medium and luxurious houses) and focusing on unplanned houses in major cities of Indonesia. Two surveys were conducted in the city of Bandung (n=247) and Jakarta (n=297) from September to October in 2011 and 2012 to obtain both material inventory and household energy consumption profiles in these buildings. This study analyzes the life cycle energy and CO_2 emissions of landed houses comprehensively, through an Input-output (I-O) analysis-based method. The current material stock was evaluated and future demolition waste and its life cycle embodied energy/CO_2 emissions were predicted based on various reuse and recycling rates. In addition, detailed household energy consumption profiles were investigated and the causal structures on the household energy consumption were figured out. Further, potential energy-saving strategies for urban houses in Indonesia are discussed.

1.2 Research Objectives

The ultimate purpose of this study is to provide fundamental database on life cycle energy and CO_2 emissions for urban residential buildings in major cities of Indonesia with the aim to propose future visions for achieving low energy and low carbon residential buildings.

The specific objectives are as follows:

1) To construct comprehensive database on material inventory and household energy consumption in urban residential buildings of Indonesia, through case studies in Jakarta and Bandung. In these case studies, the following analyses were conducted.
    a. To evaluate current housing material stock, future demolition waste and their embodied energy and CO_2 emissions of building materials for urban residential buildings.
    b. To analyze the detailed household energy consumption patterns and CO_2 emission profiles as well as their life cycle energy and CO_2 emissions for urban residential buildings.
2) To develop a simplified LCA method based on I-O analysis that can be applied in major cities of Indonesia in which the detailed necessary database for LCA are not available.
3) To analyze the patterns of energy consumption and CO_2 emissions in the whole life spans of typical urban houses in Jakarta and Bandung.
4) To determine potential strategies for achieving low energy and low carbon residential buildings in major cities of Indonesia.

1.3 Major Contributions

The expected contributions from this study are as follows:

1. As described earlier, one of the major obstacles in implementing a LCA analysis in developing countries is often lack of data. In particular, in the case of Indonesia, there is a serious lack of data on building material inventory and household energy consumption for unplanned urban houses. The comprehensive database that will be constructed in this study would provide useful sources for LCA analyses in the future. These LCA analyses would allow researchers to estimate the life cycle energy and CO_2 emissions in urban residential buildings in detail. This will help to design the low energy and carbon residential buildings in the future.
2. There are several ways of LCA analysis, depending on the system boundaries as well as data availability. This study develops a relatively simplified LCA method based on I-O analysis through conducting two case studies (i.e. those of Jakarta and Bandung). This method was developed under the condition of relatively limited data availability environments (i.e. major cities of Indonesia). This would play a role as a LCA guideline for the following researchers who wish to do a similar analysis in Indonesia.
3. In the two case studies (i.e. Jakarta and Bandung), this study reveals the detailed patterns of energy consumption and CO_2 emissions in the whole life spans of typical urban houses. Since this study is considered to be one of the first attempts that analyzes them for unplanned urban houses of Indonesia, this would give significant insights in the subject field.

1.4 Thesis Organization

To get an overview of the structure of this thesis, contents of the individual chapters are briefly organized as listed below:

Chapter 1 introduces the background of this study. It explains the details about the study carried out including objectives, research framework and thesis organization.

Chapter 2 reviews LCA literatures comprehensively including building materials and embodied energy, household energy consumption, building wastes and life cycle assessment in buildings especially those studied in developed and developing countries.

Chapter 3 explains statistical data of Indonesia geographically, demographically, and economically. Current housing policy was explained and future prospect for housing provision in Indonesia was predicted based on reliable references. It also defines and explains two different types and three categories of residential buildings in Indonesia.

Chapter 4 describes the methodology used to obtain building material inventory data and household energy consumption profile which are two necessary data to calculate embodied energy and household energy consumption. Calculation material stock and material waste were explained. Various methods used to calculate both embodied energy and household energy consumption were discussed and the strength and the weaknesses of each method were described. The inherent errors of Input-output table were addressed. The detailed procedure of I-O analysis was explained. Scenario analysis based on reuse/recycling rates of building materials was analyzed.

Chapter 5 explains the demographic and social profile of sample houses based on house category and household cluster. Three house categories and three household clusters selected for this study were described. Embodied energy and household energy consumption are analyzed by house category and household cluster in the following chapters.

Chapter 6 analyzes flow of building material stock from material input to material output in residential buildings in Jakarta and Bandung utilizing material flow analysis (MFA). Through a pilot and main surveys, the actual on-site building measurements were carried out to acquire the inventory data. Embodied energy and CO_2 emissions of building materials were assessed using input-output analysis method. Embodied energy and CO_2 emissions of building materials in different scenarios with various reuse/recycling rates based on house category and household cluster were predicted.

Chapter 7 investigated detailed household energy consumption and CO_2 emission for residential buildings in Jakarta and Bandung, Indonesia. The detailed interviews and actual measurement of appliances' capacities were conducted to obtain the household energy consumption profiles. The samples of each city were classified into three house categories and three household clusters through the exploratory factor analysis and cluster analysis as explained in Chapter 5. These clusters well explained their household energy consumption patterns in each city. The causal structures on the household energy consumption were figured out through multiple regression analyses.

Chapter 8 assesses life cycle energy and CO_2 emissions for residential buildings in Jakarta and Bandung consisting of both embodied and operational energy as well as their CO_2 emissions. The major sources of environmental impacts of both embodied and operational energy were analyzed in order to design low energy and low carbon residential buildings in the further study. The potential energy saving strategies were discussed and recommended.

Chapter 9 concludes the research findings and outlines future prospects of this study.

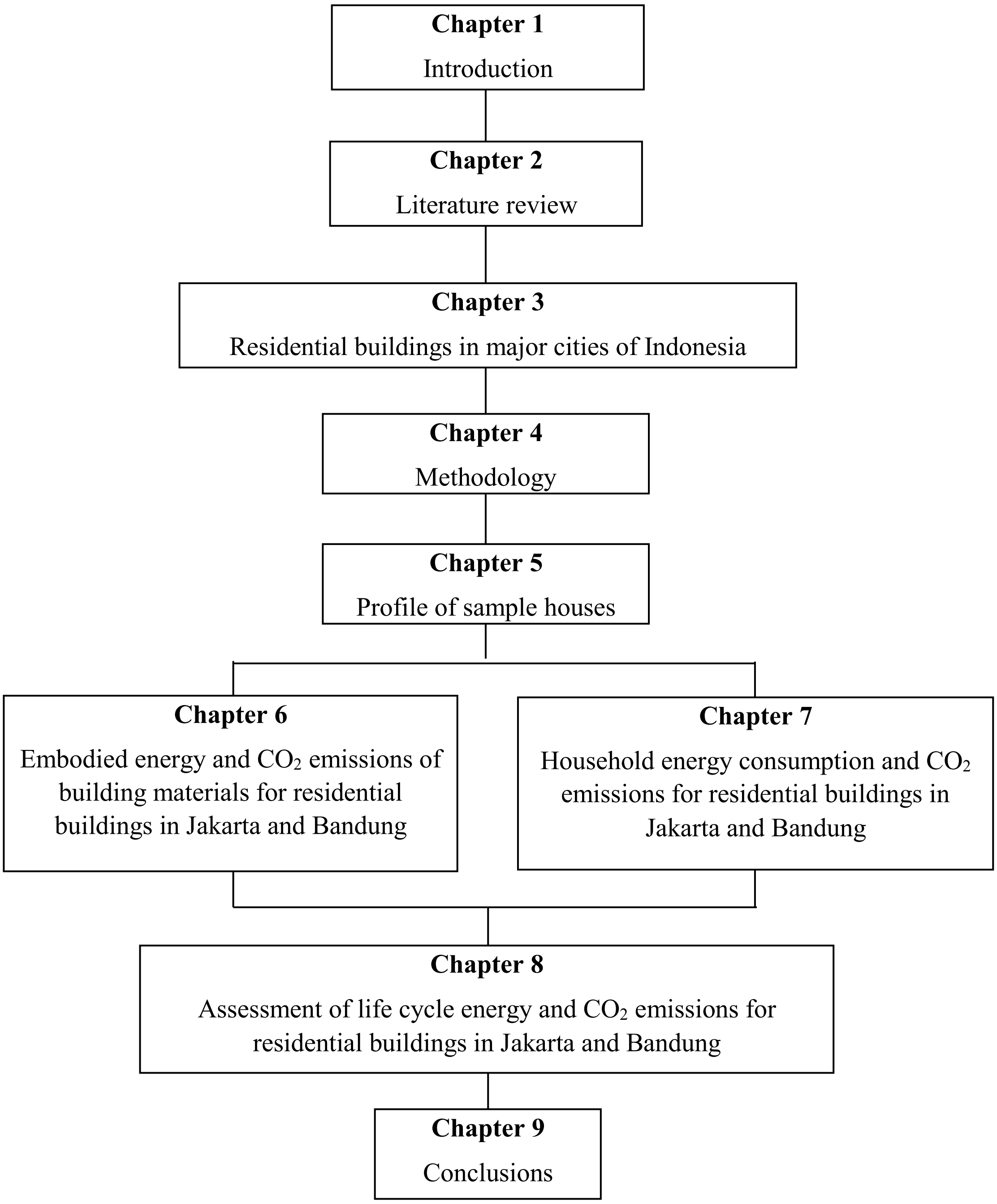


Figure 1.3 *Thesis organization of the study on life cycle assessment of energy and CO_2 emissions for residential buildings in major cities of Indonesia.*

2

Literature Review

This chapter presents the comprehensive literature review of previous studies on topics related to this thesis. The literature was reviewed to understand previous studies' accomplishments and research gaps as well as to identify the uniqueness of current research. The originality of this study can then be clarified. This chapter is divided into the following: Section 2.1 introduces the general concept of life cycle assessment. Section 2.2 describes life cycle assessments for buildings. Section 2.3 covers building materials, embodied energy and CO_2 emissions for building materials and the concept of embodied energy. Section 2.4 discusses household energy consumption and the methods used to quantify energy and CO_2 emissions. Finally, Section 2.5 discusses the role of building wastes. The focus of the literature review is on the practice of life cycle assessment and environmental impacts of buildings in developed and developing countries.

2.1 Introduction

Life Cycle Assessment (LCA) is a well-known environmental methodology to evaluate environmental impacts throughout a system (Crawford, 2011). It evaluates the environmental load of processes and products (goods and services) during their life-cycles from cradle to grave, including raw material extraction, manufacturing, construction, use, and end-of-life (disposal and recycling) (Fava, 2004; Hauschild, 2005).

The concept of life cycle studies has been developed over the years, mainly in the 70s and 80s. They focused on the quantification of energy and materials used and wastes released into the environment throughout a product's life cycle (Sharma et al, 2011).

The International Standardization Organization (ISO) standardized LCA in ISO 14040:2006 and ISO 14044:2006 (ISO, 2006). A major facet of the ISO standard is a four-stage iterative framework for conducting LCA analyses. Fig 2.1 shows the four steps of LCA analysis including: goal and scope definition, inventory analysis, life-cycle impact assessment (LCIA), and interpretation.

1) **Goal and scope definition**

Goal and scope definition identifies the specifications of the LCA, including the functional units. The scope describes the system and defines the information that will be necessary, in what categories, and to what level of detail and quality (Guinee, 2002; Curran, 1996). In general, this phase defines the purposes, audiences, and system boundaries of the proposed LCA model based on a literature review. The functional units used in the research described in this thesis were one square meter of living area of a dwelling (m^2) and one person of a household.

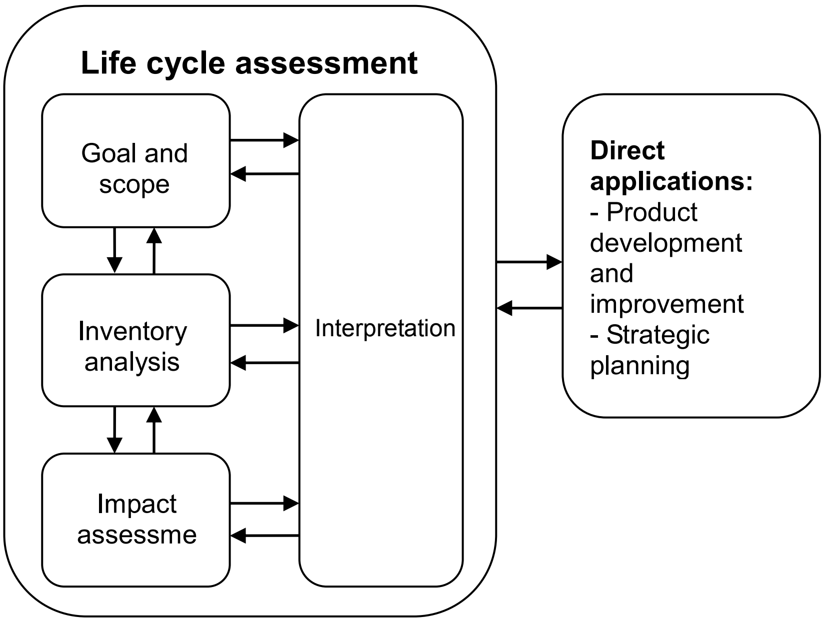


Figure 2.1. *Framework of the LCA methodology according to ISO 14040 (2006)*

2) **Life Cycle Inventory (LCI)**

This phase includes data collection and calculations to examine material and energy inputs and outputs of buildings. Sources of information and data collection will be described in further detail in Chapter 4.

3) **Life Cycle Impact Assessment (LCIA)**

This phase evaluates the significance of potential environmental impacts based on the above inventory analysis. Materials and energy inputs and outputs obtained in the previous phase are transformed into amounts of emissions of several environmental stressors such as CO_2, CFC, SO_2, etc. (Table 2.1). Environmental burdens identified in the respective phases of the building life cycle are assessed (ISO, 2006). Consequently, in this step, the LCA developer selects and defines impact categories as well as classifies, characterizes, and weights optional elements (Hauschild, 2005). The research described in this thesis used global warming potential (GWP; kg CO_2-eq) as the measure of environmental impact because global warming is the greatest environmental challenge facing the built environment (IPCC, 2007).

4) **Interpretation**

This stage identifies significant issues, evaluates findings, reaches conclusions, and formulates recommendations. The final report is the last element and completes all phases of LCA according to ISO 14040.

The construction industry has used LCAs since 1990 (Fava, 2006; Taborianski and Prado, 2004), but has assessed product development processes from cradle to grave for many years (Sharma et al, 2011; Singh et al, 2011; Ramesh et al, 2010). With the current push toward sustainable construction, LCA has gained importance as an objective method to evaluate the environmental impact of construction practices.

Table 2.1. *Environmental impacts derived from LCA.*

Indicator	Unit
Acidification (AP)	kg SO_2-eq
Global warming potential (GWP)	kg CO_2-eq
Human Toxicity (HT)	kg 1.4-DC8-eq
Stratospheric ozone depletion (SOD)	kg CFC-11-eq

Source: IPCC, 2007

2.2 Life cycle assessment in buildings

The LCA tool is important for assessing buildings and improving environmental sustainability throughout all stages of a building's life cycle from its origins (extraction of raw materials) to its end-of-life (waste disposal) (Crawford, 2011; Fava, 2004). Sartori and Hestnes (2007) stated that increased interest and improved methodologies such as LCA provide a better understanding and better estimates of the energy (and other environmental) aspects of the life cycles of all kinds of products, including buildings.

Life cycle energy analysis is an approach that accounts for all energy used during a product's life cycle (Lippiatt, 1999). Figure 2.2 shows the system boundaries of this analysis for buildings and includes energy used in the following phases (Ramesh et al., 2010): manufacture, use, and demolition. The first phase includes transportation of materials and technical installations, whether used in new buildings or renovations. Life cycle energy includes embodied and operational energy (see Fig. 2.2).

- Embodied energy is the energy content of all the materials used in the building and associated technical installations in addition to the energy incurred at the time of new construction, renovation, or demolition.
- Operating energy is the energy required to maintain comfort conditions and day-to-day maintenance of the building, such as HVAC (heating, ventilation, and air-conditioning), domestic hot water (DHW), lighting, and power for appliances.

As shown in Fig. 2.2, the system boundaries considered in an LCA for buildings consider the following life cycle phases:

1) **Manufacture and Construction** evaluates the fabrication of building materials and the energy used by building machinery from the quarry to construction areas. This phase also includes transportation, which is the movement of materials from the quarry to the factory and from the factory to the building site, as well as internal waste management and the transport of wastes generated at the building site to their final destinations.
2) **Use** includes operation and maintenance activities.
   Operation covers the full service life of HVAC and other activities such as DHW, cooking, electrical appliances, entertainment, power, etc.
   Maintenance and refurbishment include activities such as repainting, ceiling replacement, re-roofing, and changing window frames. This phase also includes transport of the associated materials.

3) **End-of-life** evaluates the energy consumed during demolition, including that used by the machinery during dismantling and that used to transport wastes to their final disposal. This phase also includes the activities of reuse and recycling materials.

Life cycle assessment of energy in buildings was studied before ISO 14040. Bekker (1982) demonstrated that in the construction industry, a life cycle approach was appropriate for analyzing consumption of critical resources and environmental impacts. When LCA is applied in this industry, it is done either at the building material and component combination (BMCC) level or the whole process of construction (WPC) level (Kotaji *et al*., 2009). Several LCA methods have been developed for both BMCC and WPC and are commonly used in many parts of the world, particularly in developed nations.

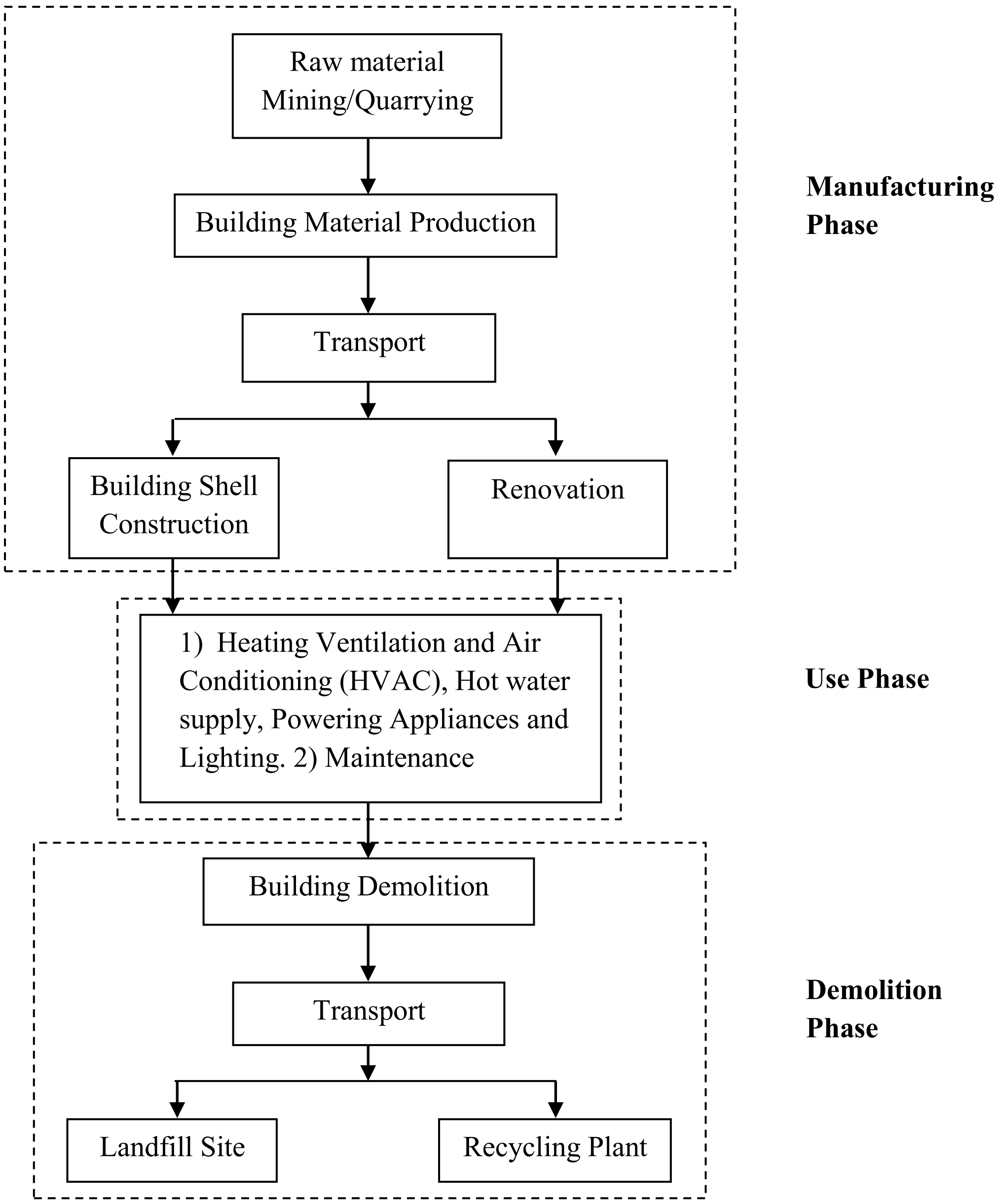


Fig. 2.2 *System boundaries for life cycle energy analysis.*

Source: Ramesh et al., 2010

Using a process-based method, Asif et al. (2007) provided detailed LCAs for five common construction materials (wood, aluminum, glass, concrete, and ceramic tile) for a home in Scotland to determine their respective embodied energies and associated environmental impacts. It was found that concrete alone consumed 65% of the total embodied energy of the home and was responsible for an even greater share of the environmental impact.

Peuportier (2001) compared three houses with different thermal conditions influenced by the building materials. He found that a wooden framed structure allowed significant storage of CO_2 over the building's life span and reduced the waste produced during the demolition phase.

Koroneos and Kottas (2007) set up a model house in the city of Thessaloniki, Greece and estimated its annual energy consumption. After comparing estimated values with actual values retrieved from annual utility bills, the accuracy of the estimation in the work described in this thesis, life cycle analysis and environmental impacts of fuel was included in addition to the GHG emissions of electricity production. It has been shown that climatic conditions and the type of building materials play crucial roles in energy savings.

Suzuki and Oka (1998) assessed an office building in Japan, utilizing the input-output analysis-based method. They found that in terms of energy consumption, operation contributed 82% of the life cycle energy consumption, while construction contributed only 15%. They argued that an effective way of reducing life cycle energy consumption for office buildings was to reduce operational energy.

Mithraratne and Vale’s (2004) research demonstrates the importance of using a process-based method to efficiently use limited resources in life cycle analysis for residential buildings. According to this research, environmental impact follows a pattern similar to that of life cycle energy use, and the use of additional insulation significantly reduces overall environmental impact.

To date, there are relatively few LCAs for buildings in developing countries (Fujita et al., 2009; Kurdi, 2006; Utama and Gheewala, 2009, 2008). This is primarily because of relatively poor availability of building, economic, and environmental data, which are necessary for LCA analyses.

A few LCAs were conducted in Indonesia. For instance, Utama and Gheewala (2009) evaluated the effects of building envelopes on the life cycle energy consumption of high rise apartments in Jakarta. They also studied the life cycle energy of a typical single landed house in Indonesia using a process-based method. They found that the initial embodied energy of typical brick- and clay-roofed enclosures was more desirable than that of enclosures made with other wall and roof materials (cement based). The effect over a life span of 40 to 50 years shows that material selection is crucial in the design phase (Utama and Gheewala, 2008). Kurdi (2006) estimated life cycle energy and CO_2 emissions of planned houses in seven large cities in Indonesia using process based methods to calculate embodied energy in several building materials.

It is difficult to find LCAs that used WPC in developing countries, particularly Indonesia. This is because it is not easy to obtain building inventory data for whole materials or household energy consumption data. However, the above studies provide rare and useful LCAs for residential buildings in Indonesia, albeit for planned houses and apartments. In Indonesia, unplanned houses are more typical of residences in major cities, but LCAs for them are rare.

2.3 Building materials and embodied energy

Buildings are constructed with a variety of building materials, and each consumes energy throughout its stages of manufacture (raw material extraction, transport, manufacture, assembly, and installation), use, and deconstruction (disassembly, deconstruction, and decomposition). Energy consumed in the production stages (in conversion and flow, as proposed by Koskela [1992]) is called the embodied energy and is concerned with energy consumption and carbon emissions. Gonzalez and Navarro (2006) assert that building materials possessing high embodied energy could result in more carbon dioxide emissions than materials with low embodied energy.

Several key materials of construction are described as follows:

1) Limestone

Perhaps the most prevalent building material obtained through mining, limestone is used as cladding and plays an important role in the production of a wide range of building products (Building Materials, 2011). Concrete and plaster are obvious examples; less obvious are steel and glass. Burning limestone creates sulfide emissions, a major contributor to acid rain (Building Materials, 2011).

2) Steel

Steel requires the mining of iron ore, coal, limestone, magnesium, and other trace elements and is produced by combining refined iron (from raw ore) with limestone and coke in a blast furnace. Hot air and flames melt the materials into pig iron, and the impurities float to the top and are removed. Controlling the amount of carbon in the iron through further smelting allows production of several varieties of steel (Allen and Iano, 2008).

3) Aluminum

Aluminum, derived from bauxite ore, requires a large amount of raw material. Up to six pounds of ore is required to yield one pound of aluminum. Bauxite is generally strip-mined from tropical rainforests, a process that requires removing vegetation and topsoil from large areas of land. After mining, the soil is replaced and the land is sometimes allowed to return to rainforest, but is more likely to be used as farmland (Allen and Iano, 2008).

4) Cement

Cement, or Portland cement, is defined as 'hydraulic cement', obtained by burning a mixture of lime and clay to form a clinker then pulverizing the clinker into powder. The greenish gray powder is composed primarily of calcium silicates, calcium aluminates, and calcium ferrites. When mixed with water (hydrated), it solidifies into an artificial rock, similar to Portland stone. The process to produce this cement consumes a large amount of energy and gives off a great deal of emissions (Allen and Iano, 2008).

5) Bricks and tiles

Made from clay and adobe soil usually found in shallow surface deposits, these are often manufactured near the source, reducing extraction and transportation cost. With the exception of adobe, bricks and tiles must be fired to be transformed into useful building materials. This can take hours or sometimes days and requires a large amount of energy (Building Materials, 2011).

6) Wood

Harvested from trees, wood is the most commonly used material in buildings and building products. Dimensional lumber is used in framing the majority of residential buildings and many commercial structures. Wood products such as plywood, particleboard, and paper are used extensively throughout the construction industry (Building Materials, 2011).

According to Miller (2001), the term embodied energy is subject to various interpretations rendered by different authors and its published measurements are found to be quite unclear. Crowther (1999) defines *embedded* energy as ‘the total energy required in the creation of a building, including the direct energy used in the construction and assembly process, and the indirect energy, that is required to manufacture the materials and components of the buildings.’ Treloar *et al.* (2001) states, “Embodied energy (EE) is the energy required to provide a product (both directly and indirectly) through all processes upstream (i.e. traceable backwards from the finished product to consideration of raw materials).” Another characterization given by Bousted and Hancock (as cited by Langston and Langston [2008]) is, “Embodied energy is defined as the energy demanded by the construction plus all the necessary upstream processes for materials such as mining, refining, manufacturing, transportation, erection and the like. . .” Likewise, a more comprehensive definition, provided by Baird (1994), Edwards and Stewart (1994), Howard and Roberts (1995), Lawson (1996), and Cole and Kernan (1996, as cited in Ding [2004]) is, “embodied energy comprises the energy consumed during the extraction and processing of raw materials, transportation of the original raw materials, manufacturing of building materials and components and energy use for various processes during the construction and demolition of the building.” These definitions represent differences of opinion about the system boundaries included in embodied energy analyses.

Overall, buildings use the following two types of energy between raw material extraction and deconstruction and disposal (Ding, 2004; Treloar, 1998):

1) Direct energy

Direct energy is consumed in various on-site and off-site operations, such as construction, prefabrication, transportation, and administration. On-site construction and assembly uses energy during the assembly of building materials and components; off-site prefabrication uses energy in assembling building components that are subsequently moved to the construction site; and transportation is any movement of goods associated with construction and assembly, and includes use of fuel, for example.

2) Indirect energy

Indirect energy is commonly used during the manufacture of building materials, whether for the main process, upstream processes, or downstream processes and during renovation, refurbishment, and demolition. For instance, electricity consumption.

Embodied energy is categorized into three kinds of energy based on the phase of the building's life cycle, namely:

- Initial embodied energy, used during production of materials and components, including raw material procurement, building material manufacturing, and final product delivery to the construction site;
- Recurrent embodied energy, used in various processes for maintenance and refurbishment (building materials and components) during the building's useful life;
- Demolition energy, necessary for deconstruction and disposition of building materials.

Methodology to measure embodied energy

Three methods are commonly used for calculating energy and environmental impacts embodied in building materials. They are process-based, economic input-output-based, and hybrid-based methods (Crawford, 2010).

Process-based methods are widely used for embodied energy analysis because they deliver more accurate (Ding, 2004) and reliable (Crawford and Treloar, 2003) results than the other methods. They start with the building material as a final product and work backward, upstream through the main process, taking into account all possible direct energy inputs or sequestered energy of each contributing material (Treloar, 1998). Some believe process analysis is impracticable and incomplete because it excludes many upstream processes as a result of system boundary truncation. This occurs because of the enormous effort required to identify and quantify each small energy and product input of a complex upstream process (Ding, 2004; Treloar, 2001). The magnitude of system incompleteness and error in process-based analyses is estimated to be as high as 50% and 10%, respectively. Even inventories based on detailed and extensive process analyses fail to attain significant completeness (Treloar, 2001). Pullen (2008) states that process analysis fails to capture not only a portion of the downstream processes, but also the capital energy inputs of plants and equipment required in the course of building material production.

Using this method, Utama et al. (2008) investigated the embodied energies in mass housing in Indonesia to find the wall-building material that minimized the energy consumed for air conditioning. Kurdi et al. (2006) used the method to calculate CO_2 emissions from material production and transportation for building mass housing in seven large cities in Indonesia. Monahan et al. (2011) used the method in the production phase of housing construction in the United Kingdom, and Thomark (2002) applied it while investigating a low energy building in Sweden. This method is specific, detailed, and reliable, even though it is generally based on incomplete system boundaries.

Input-output based methods account for most direct and indirect energy inputs in the process of material production and thus, is considered relatively complete (Fay, 1998). It uses economic data, such as the monetary flow between various industries, in the form of input/output tables made available by the national government, and converts these economic flows into energy flows by applying average energy tariffs (Ding, 2004; Fay, 1998). The method is assumed to be comprehensive and complete because it embraces nearly the entire system boundary. However, it also suffers from inherent problems, such as an assumption of homogeneity and proportionality, errors and uncertainty in economic data (e.g., energy tariffs, product costs, etc.), and aggregation of industries. These problems cause erroneous and unreliable results (Fay, 1996), and the error can range up to 50 percent (Ding, 2004).

By utilizing this method, Suzuki et al. (1998) estimated CO_2 emissions during construction that included the manufacture of building materials, Fujita et al. (2009) investigated embodied energy and calculated CO_2 emissions of Malaysian housing construction, and Norman et al. (2006) calculated GHG emissions in the construction and operation of residential buildings in United States. This method is more complete than process-based methods in system boundaries but lacks process specificity.

Hybrid-based methods are devised by unifying the benefits of both the process-based and input-output-based methods to eliminate the fundamental errors and limitations of each. However, these methods need to be compared and validated (Crawford and Treloar, 2003). A hybrid method starts with a process analysis of readily available energy input data of the final production stage and while working into more upstream processes, substitutes the input-output method when it is difficult to achieve reliable and consistent information (Lenzen, 2006).

Using this method, Mithraratne et al. (2004) investigated embodied energy and calculated CO_2 emissions for a New Zealand house and Crawford et al. (2005) did the same for commercial buildings in Australia.

Treloar (1998) categorizes the method into two types:

- Process-based hybrid analysis. This method assimilates input-output-based analyses into complex parts of upstream processes of material production, obviating incompleteness inherent in process analysis. Complex materials, those that involve more than one material, could pose problems for this method. Furthermore, overestimated prices of products could distort the results.
- Input-output-based hybrid analysis. This method incorporates identification and extraction of direct energy paths from an input-output-based analysis to integrate reliable and accurate process-based data and avoid indirect effects (Treloar, 1998). According to Treloar (as cited by Langston and Langston, 2008), the incompleteness or error in typical embodied energy calculations and analyses is approximately 20% and while no method is fully efficient, input-output-based hybrid analysis is considered complete and nearly perfect in the LCAs of buildings (Langston, 2008; Crawford, 2003).

Treloar (1998) performed a thorough study to create a comprehensive framework for embodied energy analysis that avoided the incompleteness of process-based analysis and the unreliability of input-output-based analysis. Furthermore, he asserted that process-based and input-output-based hybrid analyses have few unwanted indirect effects that influence the reliability of measurements, yet concluded that a new method of analysis is needed. An improved comprehensive framework of analysis was proposed in a doctoral thesis, which was claimed to measure embodied energy of building materials and components, accurately and completely.

The methods used for LCAs are dependent on the availability of data. In Indonesia, all building LCAs used process-based methods in the production phase for several materials, so it is difficult to assess environmental impacts. This is because a building comprises many materials. Therefore, most of the LCAs in Indonesia could not assess the whole process of construction.

Variation and inconsistency in embodied energy results

Buchanan and Honey (1994), Crowther (1999), Crawford and Treloar (2003), Ding (2004), Horvath (2004), and Langston and Langston (2008) suggested that the embodied energy results from their studies showed significant variation, but were derived from information residing in different sources and countries. Inclusion of primary and secondary energy figures brought 30% - 40% variation in their measurements. The literature suggests that determination of embodied energy is difficult, and no standard methodology is available to estimate the energy level of building materials (Crowther, 1999). The literature review revealed 10 parameters that influence the quality of embodied energy results. They are:

a. System boundaries

Boundary definition is one of the most critical issues that cause the exclusion of upstream processes that could make a considerable difference in embodied energy calculations (Horvath, 2004). Lenzen (2006) describes 'truncation errors' caused by truncating system boundaries in upstream processes. Such differing assumptions about boundaries result in differing data quality, thus making the data incomparable.

b. Methods of embodied energy analysis

Among the major processes of embodied energy analysis are process analysis, statistical analysis or input-output analysis, and hybrid analysis (Ding, 2004; Lenzen, 2006). Results from these various embodied energy and life cycle analysis methods differ widely because of the inherent limitations of each, and thus, will not agree.

c. Geographic location of study area

Countries differ from one another in not only geographic and climatic characteristics, but also in raw material quality, production processes, economic data, processes of delivered energy generation, transport distances, energy use (fuel) in transport, and labor. These differences subsequently affect the end results, causing them to vary widely (Ding, 2004; Lenzen, 2006).

d. Primary and secondary energy

Fay and Treloar (1998) and Fay et al. (2000) define primary energy as "the energy required from nature (for example, coal) embodied in the energy consumed by the purchaser (for example, electricity)" and delivered energy as "the energy used by the consumer." If information is based on primary energy consumed, the measurements are relatively consistent, but if delivered energy is used, results could prove to be misleading and ambiguous (Sartori and Hestness, 2007; Fay, 1998).

e. Age of data sources

Aged data sources have a significant impact on the comparability of the energy database because it can be derived from obsolete manufacturing technologies that are not as energy efficient as the newer technologies and thus, differ in value. Using old transportation energy data also affects energy values because newer vehicles are more fuel efficient and might use different fuels. Any study based on such flawed data sources could be misleading and doubtful (Peerebom, 1998).

f. Source of data

Researchers adopt different approaches to data acquisition. Some derive their own embodied energy coefficients and others refer to databases prepared by others. This subjective choice can influence the results significantly (Ding, 2004; Junnila, 2003). Economic information sources, such as national input/output tables, energy tariffs, and product cost, usually diverge and affect the analysis when using the input-output method. Most published figures for embodied energy in building materials are derived from a single source of information that is questioned about the accuracy and reliability of the data source (Pears, 1996). Data source is an important parameter, and its reliability, uncertainty, and transparency must be considered while performing LCAs (Pullen, 2006; Alcorn and Wood, 1998).

g. Completeness of data

Menzies *et al.* (2007) and Peereboom *et al.* (1998) argue that researchers often do not have access to primary data sources, so they rely on incomplete secondary sources. Moreover, these referenced data sources are incomplete because they either used an improper method of calculation or subjectively selected system boundaries. Menzies *et al.* (2007) suggest that accessibility of data, methodology adopted, and selection of system boundaries govern the completeness of data that eventually affects the reliability of results. According to Alcorn and Wood (1998), completeness of data is a vital quality that should be considered while choosing one material dataset over another.

h. Technology of manufacturing processes

When building materials are manufactured using different technologies, albeit in the same time frame and geographic location, dissimilar energy consumptions could arise. Use of different production technologies and types of energy in the process could bring large differences to embodied energy figures (Pears, 1996) Technological representativeness is an important data quality that should be taken into account in order to eliminate inconsistency and variability in results (Menzies, 2007; Peerebom, 1998).

i. Feedstock energy consideration

Feedstock energy is energy used as an ingredient in the production process of a material. Petrochemicals such as oil and gas are used as material inputs in the manufacturing processes of products such as plastics and rubber. Feedstock energy is included in the calculation of total embodied energy of a material (Hammond and Jonnes, 2008). Exclusion or inclusion of feedstock energy in embodied energy calculations or LCAs could result in widely variable energy figures (Pullen, 2008).

Ding (2004) states, by citing Kohler (1991), that a measurement is a function of what it includes, thus it is difficult to reach a universally applicable database of measured values. Ding (2004) observes that such deviations could be misleading and distort the results of embodied energy analysis. Therefore, it is very important to establish a set of guidelines or frameworks to monitor the measurement process. Furthermore, there is a need to accumulate all available data, then analyze and screen it against a template of criteria in order to establish a universally applicable and comparable database. Unfortunately, such a standard has not yet been established.

2.4 Household energy consumption

Household energy consumption is the use of energy required in the operation phase of a building's life cycle. It is the operational energy, which largely varies based on the level of comfort required, climatic conditions, and operating schedules (Ramesh et al, 2010). Consumption depends on various factors. For example, in sub-tropical countries, it changes seasonally (Paatero and Lund, 2006) because of the differences between seasons, particularly winter and summer. However, in tropical countries, no seasonal consumption behavior exists because there are slight differences between the seasons throughout the year.

According to Shah et al. (2008), heating and cooling systems consume the most energy and are the largest source of GHG emissions in the entire life cycle of a house in United States. In recent case studies of residential buildings, heating and cooling systems were frequently included. Prek (2004) researched the environmental impact of heating and air-conditioning systems using a simplified case study. This research showed that three heating systems with different materials of construction had different Eco-indicator values. Radiator heating had an Eco-indicator value that was far superior to floor or fan coil convection systems. Nyman and Simonson (2005) studied the LCA of a ventilation unit for a single-family home in Finland, taking into account the manufacturing process, fan energy consumption, and energy recovered by air-to-air energy exchangers. This study demonstrated that energy recovery from the exhaust air of a residential building in Helsinki, Finland is clearly an environmentally friendly solution. Shah et al. (2008) compared three residential heating and cooling systems using LCA. The three systems were studied at four locations in United States representing different climatic conditions and electricity generation mixes. They tried to determine the relative environmental performances in various regions.

Several studies of household energy consumption were conducted in tropical countries. Kubota et al. (2010) provided detailed information on household energy consumption in residential buildings in Malaysia. The results showed that air-conditioner ownership was 65% and the annual electricity consumption in air-conditioned homes was 1167 kWh/yr, the largest amount among the households studied. Le Phan and Yoshino (2010) clarified the current household energy consumption and living standards among Vietnamese in Hanoi and Ho Chi Minh City. The average energy consumption in Hanoi was lower (16.4 GJ/year) than in Ho Chi Minh (19.1 GJ/year). This difference is caused by more frequent use of air-conditioning in the Savanna climate of Ho Chi Minh, as compared to the sub-tropical climate of Hanoi. Permana and Kumar (2008) analyzed and compared the quantity of energy consumed for transport, non-cooking, and cooking purposes in households in Bandung city within three forms of urban development, namely controlled commercial residential areas, unplanned sub-urban areas, and planned satellite towns. The results showed two major findings related to household energy consumption. First, the unplanned area outweighs the other two in terms of energy consumption per unit of income. Second, those with lower incomes spend a higher percentage of their income on energy expenses than those with higher incomes. Electricity is generally used as the energy source for most household end-uses, but liquefied petroleum gas (LPG) and kerosene are used for cooking, and gas is used for DHW.

Data from the World Research Institute (2007) revealed that Indonesia has the largest average monthly household energy consumption (transport energy excluded) at 4387 MJ, followed by Brunei (3362 MJ), China (3440 MJ), India (3680 MJ), Malaysia (2428 MJ), and Thailand (2506 MJ). One reason is lower total electricity efficiency. In Indonesia, energy for household consumption comes from three sources: electricity, LPG, and kerosene. To generate electricity, Indonesia consumes several sources: coal (68114 GWh), oil (34505 GWh), natural gas (40038 GWh), geothermal (9357 GWh), hydro (17676 GWh), and biofuels (895 GWh; Indonesia, 2010). Therefore, the current energy efficiency in electricity generation in Indonesia is not as good as in other developed nations. Poor electric efficiency and transmission losses result in a 2.7-fold increase in primary energy consumption (Maruyama and Eckelman, 2009).

Methodology to measure household energy consumption

Previous studies generally measured household energy consumption by utilizing electricity, gas, and kerosene data as well as simulated values derived from surveys or other available data (secondary data). Operational energy is quantified by multiplying annual energy consumption by life span.

Takuma et al. (2006) measured the consumption of electricity, city gas, and kerosene in residences in Northern Kyusu, Japan, taking into consideration the temperature and humidity. The effects of a photovoltaic (PV) system as an energy-saving apparatus were examined. Energy consumption in winter was found to be one-half that in summer because of there was little need for hot water and air-conditioning in summer.

Adalberth (1997) presented a method to calculate energy use during the life cycle of a building. The method was applied to gain insight into the total energy use of dwellings during their life cycles. Case studies were presented in which the total energy use for three single-unit dwellings built in Sweden was 85% of the total energy used during the building's entire life cycle, including manufacturing, construction, and renovation. The transportation and process energy used during erection and demolition of the dwellings comprised approximately 1% of the total life cycle energy. Several similar studies in the literature cover residential buildings (Junnila, 2003: Treloar et al., 2000) and office buildings (Kofoworola and Gheewala, 2009).

Adalberth (1996) calculated energy use during occupation (space heating, DHW, and electricity) with the aid of the Swedish computer program Enorm. Computation did not include the accumulation on heat in the frame and furnishings of the building.

Ramesh et al. (2010) indicated that measurement of fuel and electricity use for heating, sanitary water, and lighting could utilize simulation software, annual electricity bills, household surveys on energy use, inventory data for fuel production, and electricity mix data.

Druckman (2008) utilized national and local level data on household expenditures in United Kingdom to measure household energy consumption and its CO_2 emissions. Bin and Dowlatabadi (2005) used economic data on consumer expenditures and an economic input-output matrix of energy use and CO_2 emissions to quantify household energy consumption and CO_2 emissions in United States.

Table 2.2 summarizes some published LCAs in the construction industry. The most important phases of LCA are compared and include the scope, the life span, the functional unit, the system boundaries, the location, and the building typology.

When the scope is revised, it is clear that this is the main difference between the studies. It is easy to see when the LCA focused on the materials of construction versus the whole building. Life span was specified most of the time, but few studies carried out a parametric study considering different building life spans to see if this influenced the results of the LCA. The functional unit was not mentioned in all studies; those that were LCAs of whole buildings did not identify it. The system boundaries were usually clearly identified and depended largely on the scope of the study. Those that considered whole buildings usually included every LCA phase, but those that considered only materials either had wider boundaries to include all phases of material production or considered only the manufacturing phase of the LCA. Finally, most, if not all, clearly identified the building typology and location.

After considering the LCAs presented here, it is clear that most are carried out in developed countries and few in developing countries, including Indonesia. As observed from the system boundaries of LCA studied in Indonesia, it was seen that most of them conducted LCA for BMCC in planned houses and apartment and only several materials were selected in the study through process-based analysis method. Therefore, it is necessary to construct comprehensive database on material inventory and household energy consumption for conducting LCA study for whole process construction in urban residential buildings focusing on unplanned houses in the major cities of Indonesia.

Table 2.2 *Summary of case studies of LCA in building sector*

Reference	Scope	Lifetime of the analysis	Functional unit	System boundaries	Location	Building typology
Norman et al., 2006	Compared high and low populated buildings for their energy use and GHG emissions	50-years	Living area (per m^2 basis) and number of lives in a house (per capita basis)	Three major elements of urban development: 1) all activities throughout the economy associated with resource extraction through material production for infrastructure; 2) the operational requirements for dwellings; and 3) the operational requirements of vehicles for personal transportation and public transit	Toronto, Canada	Office building and single-family dwelling
Asif et al., 2007	Comparing embodied energy/CO2 emissions of building materials	50-years	Square meter	LCA for five different building materials for a dwelling home	Scotland	Dwelling home
Koroneos and Kottas, 2007	Life cycle analysis and environmental impact for a house model	50-years	Person per year	Life cycle analysis for annual energy consumption of the house and environmental impact assessment were conducted	Greece	House model
Blengini, 2009	Contrasting the impact of the demolition phase	40-years	$1m^2$ net floor area, over a period of 1 year	All life cycle phases, with emphasis on production of construction materials and end-of-life management	Via Fratelli Garrone, Turin, Italy	Residential block of flats

Kofoworola and Gheewala, 2008	Commercial office building	50-years	60,000 m² gross floor area of building	The entire life cycle of the office building, including manufacturing of building materials, construction, operation, maintenance, and demolition	Thailand	Commercial office building
Scheuer et al., 2003	To examine differences that might arise between results from a “complete” inventory LCA of a building, and the results from partial LCAs or LCAs built on a general building model	75-years	–	All phases of life cycle	University of Michigan, Ann Arbor, Michigan, USA	University six-story building
Kofoworola and Gheewala, 2009	To determine the embodied energy coefficients of key building materials utilized in Thailand; to assess the LCE consumption of a typical office building; to study the relative importance of the different lifecycle phases and; to provide information which may be use data basis for more effective regulation of building energy efficiency policies in Thailand	50-year	60,000 m² gross floor area of building	All phases of life cycle	Central business district of Bangkok, Thailand	38-story typical office building

Treloar et al., 2001	To analysis embodied energy of individual materials, items and features within buildings	40-years	–	Embodied energy analysis	Australia	Residential building: two-story brick veneer suburban dwelling; Commercial building: typical 15 story Melbourne commercial building
Utama and Gheewala, 2008	To evaluate the effect of building envelopes on the life cycle energy consumption	40-years	–	The construction process of the building enclosure and also intermediate transportation from quarry to site	Semarang, Indonesia	Middle class single landed houses
Utama and Gheewala, 2009	To evaluate the effect of building envelopes on the life cycle energy consumption	40-years	–	The construction of the building envelope and quarrying as well as transportation of materials	Jakarta, Indonesia	Upper class high rise residential buildings
Kurdi et al.,2006	To estimate the embodied and household CO_2 emissions for planned houses	50-years	–	Analyze household energy consumption and embodied energy using process based (energy for material production only)	7 large cities of Indonesia	Planned houses
Mithraratne and Vale, 2004	To describe a method for LCA based on the embodied and operating energy requirements and LCC of buildings	100-years	MJ/m^2	Total impact of the building in terms of energy and cost	Auckland, New Zealand	Light-weight timber framed house; concrete timber house, super insulated light-weight house
Thormark. 2002	To analyze the recycling potential of a low-energy dwelling in Sweden and to	50-years	kW/m^2	Embodied energy, energy need for operation and recycling potential	Gothenburg, Sweden	20 low-energy apartments in four two-story rows

	relate the recycling potential to the energy used for production and operation of the building					
Shukla et al., 2009	To develop a simple methodology to calculate embodied energy of an adobe house	40-years	GJ per100 m^2 built-up area	Embodied energy	Solar Energy Park, Indian Institute of Techno-logy Delhi, New Delhi, India	Adobe house
Thormark, 2000	To analyze the environmental effects of the use of recycled materials in buildings	–	Whole building	All life cycle phases	Sweden	Single-family dwelling with a large proportion of reused building materials and components and recycled materials
Peuportier, 2001	To use LCA and LCEA in buildings	80-years	Whole building	All life cycle phases	France	Single family houses: the present construction standard in France (reference), a solar and a wooden frame house
Kua and Wong, 2012	Analysis of consumptions of entire buildings	30-years	–	Extends the traditional system boundary drawn for a whole-building life cycle assessment to include the management of wastes	Singapore	Multi-storied commercial building

Monahan and Powell, 2011	To conduct a partial LCA, from cradle to site of the construction, of a low energy house constructed using an offsite panelized modular timber frame system	50-years	The external, thermal envelope of a 3 bedroom, semi-detached house with a total foot print area of 45 m^2 and a total internal volume of 220.5 m^3	Cradle to site emissions from materials and products used in construction, final transport of the materials and products to site, materials waste produced on site, transportation of waste to disposal, fossil fuel energy used on site during construction and manufacture	Ling wood, Norfolk, UK	Semi-detached low energy affordable house
Gong et al., 2012	Types of framework structures of buildings	50-years	The three material building designs	All life cycle	Beijing, China	Three types of residential buildings with framework structures: concrete framework construction, light-gauge steel framework construction, and wood framework construction
Gustavsson and Joelsson, 2010	To compare buildings and their energy supply systems using a bottom-up approach, to gain a detailed understanding of production and operation energy alternatives, and facilitated comparisons between various building and supply systems	50-years	One square meter of produced and operated building area (total area inside outer walls)	Production and operation phases from a primary energy perspective	Odensala, Lindas, Vaxjo, and Karlstad, Sweden	Five buildings of different types, modified to give a total of 11 case study buildings

2.5 Building wastes

Waste management in developed and developing countries

Buildings consume material resource excessively and generate wastes, which become a significantly environmental problem. Generally, building waste consists of construction and demolition waste. Construction and demolition (C&D) waste is the waste produced during new construction, renovation and demolition of buildings and structures (Nittivatanon, 2007). Rapid urbanization and development cause increasing building construction and waste generation in the urban developing countries. However, lack of awareness of resource-efficient construction practices has resulted in excessive use of natural resources and generation of large amounts of C&D waste that is rarely reused or recycled (Macozoma, 2000 cited in UNEP, 2002: 249).

In general, C&D waste is bulky, heavy and mostly unsuitable for disposal by incineration or composting. Components of C&D waste are typically concrete, asphalt, wood, metals, gypsum wallboard, and roofing. They are most often disposed to landfills and causes waste management problems in urban areas. For example, one-third of the volume of the materials in landfills in the US is construction and demolition waste (Kibert, 2000), the amount of construction and demolition waste in Austria, Denmark, German and Netherlands were about 300, over 500, about 2600 and about 900 kg/capita, respectively (Brodersen et al., 2002). Data show that approximately 40% of the generated waste portion globally originates from construction and demolition of buildings (Holm, 2001, cited in Kulatunga et al., 2006). However, data for C&D waste is not easy to obtain in most of developing countries due to very limited record for these data and the minimal existence of regional/national policies, laws and regulation (Nitivattanon and Borongan, 2007).

A few studies for existing C&D waste of residential buildings were conducted in Indonesia. For instance, UNEP (2008) designed the guidance of debris waste generated by the Indian Ocean tsunami in Aceh. Sugiharto et al. (2002) investigated the incidence of waste within contractors companies. Suryanto et al. (2005) identified construction waste and its environmental impacts of planned houses and shop houses, respectively. The above studies focused on planned houses and commercial buildings. Meanwhile, the majority of urban housing stocks in Indonesia are unplanned houses as explained before.

Overview of current practices

National, regional and local governments in many countries now have policies relating to sustainable construction. These all include a commitment to minimize the waste generated and adopt the waste minimization strategies including 3Rs. This commitment is demonstrated from advanced countries like UK, Switzerland, Austria and the Netherlands where key reasons for the growing realization is to adopt non-renewable resources due to scarcity of landfill capacity or sites (Addis, 2006). Currently, existence of regional and national policies, laws and regulations governing 3R principles for C&D waste is minimal in Asia. Some of the policies exist and others are still in the process of formulation. In the region, development of 3R program is spearheaded by relevant international organizations (such as joint partners of ADB, UNEP, UNESCAP and others) in coordination with different Asian governments. These activities will later on contribute to the formulation of 3R policy in various sectors in the Asian region. UNEP IETC (2006) initiated the Sustainable Building and Construction Initiative (SBCI) to promote and support sustainable solutions in building and construction sector which includes the C&D waste.

IGES (2006) highlighted the promotion system for addressing the 3Rs, and noted that in almost all developing countries, legal systems regarding the 3Rs have yet to be established. It also elaborates the insufficient institutional capacity to support 3Rs measures which is a common issue for all developing countries to address. Waste management policy making is relatively decentralized in Hong Kong. The Environmental Protection Department (EPD) and the Environment and Food Bureau (EFB), are responsible for the policy formulation and implementation. Statutory non-government authorities such as the Legislative Councils, the Housing Authority and task oriented non-statutory bodies such as the Advisory Council on the Environment and Waste Reduction Committee all have a role to play in waste policy formulation and implementation. There is however, no public body with the remit to systematically formulate and implement waste and environmental education policies in Hong Kong. Other Asian countries like Malaysia, Sri Lanka, India, and China practice 3Rs principles on C&D waste but institutionalization has not been established.

Procedures for the management of C & D waste is mostly practiced in developed countries in Asia. Practitioners in developing countries in Asia need to put up initiatives in the construction industry to practice better management of C & D waste. Urban environmental management in the construction industry has been growing rapidly in some countries in Asia. Attaining towards sustainable development, some countries take efforts towards practicing environmental management system (EMS). Research in Singapore and Hong Kong SAR highlighted that C & D waste imposes an environmental burden. Construction industry has one of the highest resource uses and responsible for waste pollution. Some international and local construction industries in Singapore have already adopted the structured approach for improvement of the environmental performance of construction by ISO 14000 EMS (Ofori, 2000). Another case in Hong Kong where the local industry has been promoting measures such as establishing waste management plans, reduction and recycling of construction and demolition wastes, providing in-house training on environmental management, and legal measures on environmental protection

C&D waste management in Indonesia: current practice and problems

In Indonesia, C&D waste is classified as specific waste (Indonesia, 2008a) and has its own regulation which is not published yet. The available information indicates C&D waste recently is part of municipal solid waste (MSW) (Indonesia, 2008b). According to Indonesia (2008b), 69% of the total MSW was landfilled, 7% was treated or recycled, 5% was burnt and 10% was buried and the remaining 6% was dumped into rivers, roads, parks etc.

It was estimated that in 2008, 7% of collected MSW in Indonesia had recyclable materials which was only included formal recycling activities (Indonesia, 2008b). This is very low when compared with the recycling rates for C&D waste of other countries. In Denmark the recycling rate of materials is more than 80%. Germany and Netherlands recycle 30-50%, while the recycling rate in Luxemburg is 10% (Brodersen et al., 2002). There are many available technologies for recycling C&D wastes Tam and Tam, 2006a, 2006b). These could prolong the life of landfill sites, minimize transport needs and reduce the primary resource requirements (mineral and energy).

In Indonesia, the informal private sectors, which involved waste pickers, garbage truck helper, scavengers and etc., play main roles in material recycling activities (Sembiring and Nitivattananon, 2010). This activities occur at three points, namely the generation point, curbside collection point and at dumpsite. They collect various materials including cardboard, plastics, glass, bottles, paper and metal. These recyclable materials are sold to distributors. The distributor clean, sort and package them as the preliminary process before reselling. However, such kind of recycling reduces the quantity of wastes significantly for transportation to final disposal.

MSW management is recognized as a huge problem. The total MSW generation in Indonesia accounted 38.5 million tons/year in 2008. Meanwhile, the average per capita generation rate increased from 0.4 kg/capita/day in 1989 (UNDP, 1987) to 1.12 kg/capita/day in 2008 (Indonesia, 2008b). This indicates the quantity of generated MSW and the per capita generation rate are increasing with time, pointing to the need for a sustainable approach to disposal and management (Chiemchaisri et al.,2006). The characteristics of MSW show that putrescible, paper and plastic constitute a large proportion of MSW (Indonesia, 2008b).
Although some materials such as wood, glass and metals, which are components of MSW, are building materials, it is unclear if these materials waste were generated from C&D activities as they could also originate from activities unrelated to construction. It is interesting to note that although detail studies of MSW exist in Indonesia, there is a dearth of information on the management, reuse and recycling of C&D waste as no system to record the amount of collected construction waste exists. Thus, there is an obvious needs for a waste management system which tracks wastes from their origin (input) as well as details their composition and other relevant parameters, e.g. volume, to their final disposal (output)

2.6 Summary

This review focuses on LCAs of energy and CO_2 emissions in buildings, particularly in developed and developing countries.

- LCAs are commonly used in developed countries to assess the environmental impacts throughout a building's life cycle. On the other hand, a few LCAs were conducted in developing countries, such as Indonesia.
- A few LCAs for buildings in Indonesia used process-based analyses. Most of them focused on planned houses and apartments, and analyzed the LCA for building material component combination (BMCC).
- There is lack of LCA data that adequately describes buildings, economics, or the environment, including building materials and building waste, which are very important in analyzing embodied and operational energies for buildings.
- The review shows that case studies found in the literature are difficult to compare because of their specific properties such as building type, climate, comfort requirements, local regulations, etc.
- It is worth to construct comprehensive database on material inventory and household energy consumption for conducting LCA study for whole process construction in urban residential buildings focusing on unplanned houses in major cities of Indonesia.

3

Residential Buildings in Major Cities of Indonesia

3.1 Residential buildings in Indonesia

Indonesia is a developing country located between 6° north latitude - 11° south latitude and 95° - 141° east longitude. The area of Indonesia consists of 1, 910, 931.32 km^2 land area and 279, 322 km^2 sea area. It has 17, 504 islands, which spread out from Sabang to the Papua islands. There are five big islands, namely, Sumatera, Java, Kalimantan, Sulawesi and Irian Jaya. Groups of much smaller islands include Nusa Tenggara and Maluku (Indonesia, 2010b) (see fig. 3.1.).

Due to its location, Indonesia has a tropical climate (hot and humid) and is relatively cool in the high land areas. The climate of Indonesia is strongly influenced by the Indian and Pacific Oceans. The average rainfall intensity throughout the year ranges from 2,500-4,000 mm per year with the daily average outdoor relative humidity of 70-90%. Temperature varies little from season to season. The other regions of Indonesia have semi-arid or monsoonal climates with the driest parts found in Nusa Tenggara. The annual rainfall of these regions is about 700 mm (Indonesia, 2010b).

As a developing country with a population of 237.6 million people in 2010, Indonesia has experienced rapid economic growth especially in urban areas. This situation and condition caused rapid urbanization, which is a common phenomenon to the East Asian region. The urbanization of Indonesia began in the late 1960s and early 1970s. Between 1970 and 1980, the urban population grew from 22.6 million to 32.8 million, a 69 percent increase; by 1990, it had grown by another 59 percent, to 55.4 million persons.

The continuous growth in the country's urban areas created a high demand for housing infrastructure. Urban growth also required an urban development policy that could prioritize investment, pricing, and regulatory decisions to govern how services were delivered, and to redress disparities between wealthy immigrants and the largely poor urban population.

It was reported that 49.79 percent of Indonesia's total population lives in urban areas in 2010, and this percentage is projected to grow to 60 percent in the next several years (Indonesia, 2010a). In turn, rapid urbanization has created income disparities between higher-income areas that have been settled more recently and lower-income areas. These income disparities have been exacerbated by disparities in both living and environmental conditions.

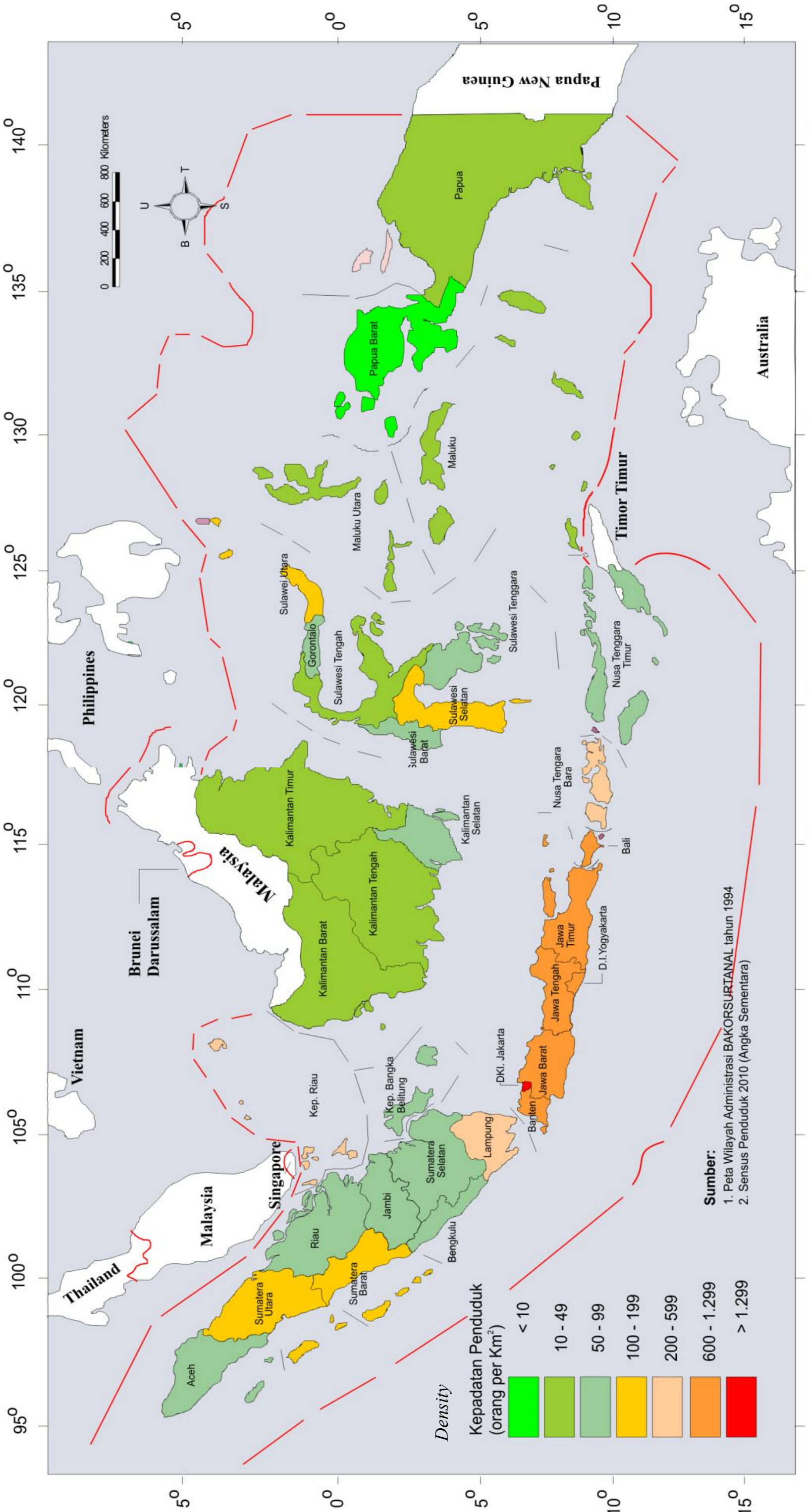


Figure 3.1 *The map of Indonesia*
Source: Indonesia, 2010a

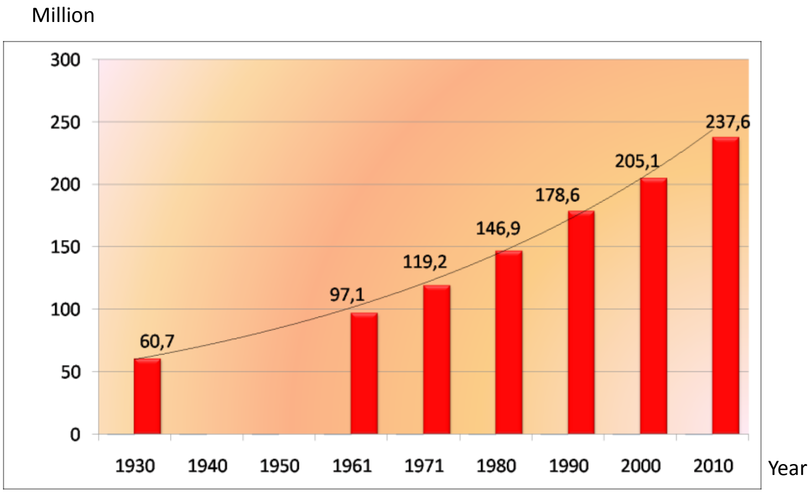


Figure 3.2 *Population of Indonesia*
Source: Indonesia, 2010a

Table 3.1 shows the percentage of households by province and the dwelling ownership status of Indonesian households (Indonesia, 2007b). As shown, the main ownership status is 'own properties', followed by 'parent relative property', 'rent houses', 'lease', etc. Status ownership of houses in Jakarta shows a lower percentage than other provinces. This may be due to the high cost of land and buildings in the city. This table also indicates that the demand for housing is still high.

Figure 3.3 indicates the households who do not own houses in 2007 (Indonesia, 2008). As shown, the households who do not own houses increase from 2004-2007. Proportion of household who do not own houses is higher in urban areas than in rural areas. The backlog of housing is 5.8 million units with a growth value per year of 0.8 and the need for improper houses is around 13 million units in 2007. This indicates clearly that most families in Indonesia need houses that are affordable in indicates clearly that most families in Indonesia need houses that are affordable in accordance with their income.

Residential buildings in Indonesia are classified by method of construction into two kinds, i.e. unplanned houses and planned houses. On the other hand, they are also categorized by lot area and construction cost into three kinds, i.e. simple houses, medium houses and luxurious houses (Indonesia, 1995) (see Table 3.2).

Residential areas in Indonesia are dominated by unplanned houses, followed by planned houses (governmental/private) and apartments (governmental /private). Unplanned houses are mostly located in rural and urban areas, while planned houses and apartments usually are constructed in sub urban and urban areas due to their economic growth. Both house types will be explained as follows.

Unplanned and planned residential buildings in major cities of Indonesia

Cultural and environmental conditions influence the urban development (Budiarto, 2003). Indonesia recognize two patterns of development, namely the implementation of formal (planned) and informal (unplanned) type. Formal development is usually conducted by middle and upper class with the ability to provide adequate capital. Meanwhile, low-income communities develop the informal systems. The pattern does not only happen in the economic sector, but also in the residential construction sector. Housing system in Indonesia has also a familiar pattern to informal (planned) and formal (unplanned) housing.

Table 3.1 *Percentage of households by province and dwelling ownership status, 2007.*

Unit: %

Province	Own property	Lease	Rent	Rent free	Official house	Parent/relative property	Others	Total
Nanggroe Aceh Darussalam	64.58	8.81	9.00	1.96	3.91	11.35	0.39	100
Sumatera Utara	59.70	14.74	6.65	3.12	4.73	10.66	0.40	100
Sumatera Barat	43.56	18.56	11.17	3.22	2.65	20.08	0.76	100
Riau	53.99	8.33	23.96	2.95	4.51	6.08	0.17	100
Jambi	71.71	15.79	1.64	1.32	0.66	8.55	0.33	100
Sumatera Selatan	60.47	16.22	5.24	2.36	2.36	13.01	0.34	100
Bengkulu	55.21	12.50	14.58	2.43	4.17	10.76	0.35	100
Lampung	69.21	11.81	3.94	2.55	1.39	10.19	0.93	100
Bangka Belitung	75.00	8.15	3.53	0.54	2.17	10.33	0.27	100
Kepulauan Riau	60.10	4.81	25.96	1.92	2.56	4.17	0.48	100
DKI Jakarta	45.80	15.10	20.61	2.67	2.90	12.43	0.49	100
Jawa Barat	69.45	6.81	6.25	2.00	0.82	14.36	0.31	100
Jawa Tengah	80.05	3.66	1.93	1.70	0.43	11.77	0.47	100
DI Yogyakarta	60.97	13.95	10.90	2.83	0.44	10.39	0.51	100
Jawa Timur	76.51	5.69	4.99	1.59	0.81	10.13	0.28	100
Banten	67.48	7.71	16.02	0.88	0.29	7.42	0.20	100
Bali	63.77	6.04	16.63	2.22	0.64	10.59	0.11	100
Nusa Tenggara Barat	76.02	4.85	2.30	1.66	0.77	13.78	0.64	100
Nusa Tenggara Timur	66.54	7.35	11.40	2.21	1.84	10.66	-	100
Kalimantaan Barat	76.08	11.21	0.86	0.65	1.08	10.13	-	100
Kalimantan Tengah	59.09	7.39	12.50	5.68	4.83	9.94	0.57	100
Kalimantan Selatan	59.30	3.49	19.33	3.78	1.60	11.19	1.31	100
Kalimantan Timur	53.81	7.77	24.24	1.83	4.42	7.62	0.30	100
Sulawesi Utara	55.77	2.16	13.70	4.09	8.41	15.87	-	100
Sulawesi Tengah	54.02	7.59	16.07	1.34	4.46	15.62	0.89	100
Sulawesi Selatan	62.80	18.45	4.12	2.74	1.98	9.76	0.15	100
Sulawesi Tenggara	46.15	13.46	10.10	4.81	12.98	12.02	0.48	100
Gorontalo	63.02	2.60	1.04	1.56	2.08	28.13	1.56	100
Sulawesi Barat	75.00	7.29	3.13	2.08	5.21	6.25	1.04	100
Maluku	61.54	7.21	8.65	4.33	8.65	9.13	0.48	100
Maluku Utara	57.14	7.14	16.07	8.04	1.79	8.93	0.89	100
Papua Barat	44.32	3.41	25.57	3.41	9.09	13.07	1.14	100
Papua	39.60	5.20	26.80	12.40	10.80	4.40	0.80	100
Indonesia	**67.02**	**8.36**	**8.81**	**2.15**	**1.68**	**11.60**	**0.38**	**100**

Source: Indonesia, 2007b.

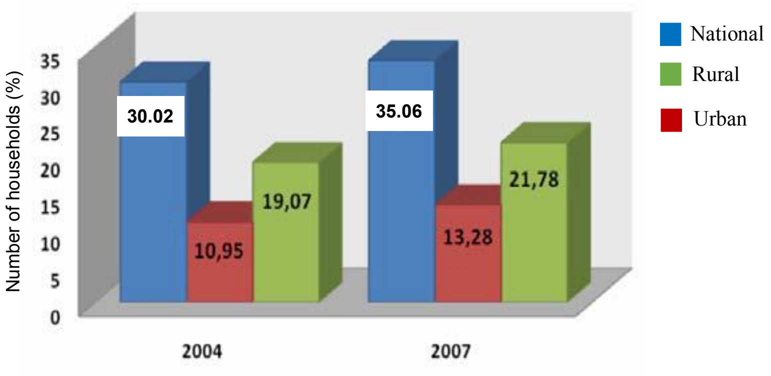


Fig. 3.3 *Households who do not own houses, 2004 and 2007. Source: Indonesia, 2008*

a) Unplanned Houses

In most developing countries such as Indonesia, many informal settlements exist with their various characteristics respective to the countries. Based on Fekade (2000) point out, informality refers to (1) illegal occupation of land (2) the non-adherence to building codes

Table 3.2 *Link matrix between house categories with lot area and construction cost per m^2*

Highest unit price (HUP) (/m^2) for house construction cost (US$)	Lot area (m^2)		
	<200	200-600	600-2000
Type A (HUP <150)	simple house	medium house	luxurious house
Type B (HUP: 150-300)	medium house	medium house	luxurious house
Type C (HUP >300)	luxurious house	luxurious house	luxurious house

Note: 1 US$ = 10,000 Rupiah

Source: Indonesia, 1995.

and infrastructure standards (3) both to the illegality of the land on which a house is built and the non-conformity of the house to building standards and codes. Informal housing could be considered a continuation of an intrinsic process of human settlement evolution on the one hand, and a response to the inadequacies of public policy intervention/guidance on the other. However, there are common characteristics described by Fekade (2000) irrespective to countries that:

- They are built by the inhabitants themselves with hardly any public assistance, often in spite of eviction threats from public authorities. The houses are built with intents of owner occupation, renting or both.
- They are built for the larger part, by low income urban dwellers for which existing formal avenues are hardly realistic options.
- They employ local building materials, skills, designs and indigenous technology.
- They do not, especially during the earlier stages of settlement establishment, adhere to formal/legal building codes and standards.
- They exhibit high variations in types and quality construction. Some housing stock is of high quality, erected with concrete blocks, corrugated iron, aluminum, zinc or tin. Others may consist of traditional rural construction materials.
- They are built incrementally, ensuring flexibility on the part of builders/owners.

Unplanned houses are the houses constructed in an improper manner. Due to the high cost of developing a house, the developers are usually non-professionals: mostly neighborhood or local contractors. The sites for constructing unplanned houses are not well-ordered and tend to have varying shapes, unlike the uniformity of mass housing projects. Most unplanned houses, especially in urban areas, are located in the areas called '*kampungs'*. In its original rural version, the word *kampung* literally means "village" – usually the home village or birthplace of an individual. In an era of unbridled urbanization, however, it has also come to mean a poorer neighborhood contained within a city. *Kampung* is not synonymous with "slum". Unplanned houses are the largest housing stock in major cities of Indonesia. As shown in Table 3.3, these houses account for 74% in Jakarta, 89% in Bandung, 98% in Surabaya, 97% in Medan and 96% in Makasar. Remain of the houses are planned houses including landed houses and apartments

Most *kampung*s actually contain a mix of lower, middle and high class - even some middle and high class families - living in mostly permanent dwellings. Squatters are relatively few.

Kampung is the word that commonly used for informal settlements (Budiarto, 2003). The ability of people to build their own housing shows great potential in solving the

Table 3.3 *Single landed houses in major cities of Indonesia*

Major cities	Houses			
	Unplanned houses		Planned houses	
	Unit(s)	%	Unit(s)	%
Jakarta	1,465,945	74	515,062	26
Bandung	579,055	89	74,722	11
Surabaya	693,689	98	16,302	2
Medan	409,660	97	12,208	3
Makasar	281,879	96	11,144	4

Source: Indonesia, 2010.

housing problem. As informal settlement, *kampungs* facing big challenges in order to survive from the activities of formal development. The vulnerability of *kampung*s become crucial to be addressed so that the *kampungs* will not be eradicated such as in Jakarta where more than 20% of kampung disappear by eviction (Budiarto and Magersari, 2005). In 1980 approximately 85% of housing development in Indonesia was constructed by residents (Struyk, 1990). *Kampung* is a form of housing that was built by the residents.

Fig. 3.4. Shows a '*kampung*' in an urban area taken in Bandung city as an example. '*Kampungs*' are densely populated, primarily low-income neighborhoods. In essence, urbanization has taken place around them. They are located in strategic parts of the city, in the midst of more affluent and expensive neighborhoods, along government centers, and near shopping areas. In many cases, they are pockets within a larger neighborhood that provides services. Most '*kampungs'* lack basic urban infrastructure and services (World Bank 1995).

It is important to understand the role of kampungs in the urban development. The existence of great number of kampungs show the limitation of the government to provide affordable housing for all. The inhabitants built informal housing in order to meet the basic needs independently (Budiarto and Magersari, 2005). The effort and ability of providing self-help housing demonstrate the potential to solve the housing problems in Indonesia.

The standard type of *kampung* house is not constructed all at once. In general, a *kampung* house is gradually completed by additions and alterations according to the needs. The structure is changed to be permanent from a temporary one.

The existence of the kampungs as a space to foster economic activity needs to be maintained. In the process of urban development that will continue to happen, as kampungs still had a chance to give better meaning of urban life better and typical in Indonesia (Setyawan, 2010). Many program have been conducting in order to improve the settlements condition. Kampung Improvement Program (KIP) was the first and successful program that was recognized globally (UNHABITAT, 2012). It was started in 1968 in order to ameliorate kampong with the upgrading of both physical and social infrastructure. This program become a model of community-led development particularly in Indonesia (Silas, 2010).

Kampung Improvement Programs (KIP)

According to Darrundono and Mulyadi (1979), initially, the city government entertained three alternative approaches to improve the situation and condition of '*kampungs*'. The first called for new buildings - single-family houses - on relatively in-expensive land in the outlying areas of the city. The problem was that the ability to pay for such housing was very limited. The second approach considered was modeled after the urban renewal

Figure 3.4 *Unplanned houses (Kampungs) in Bandung city*
Source: Pilot survey in Bandung, 2011

concept of development. Under this suggestion, the city government would acquire and raze existing '*kampungs*' and in their place it would construct new multi-story residential buildings. In theory, the use of full service, high rise buildings allows for high densities of population without the congestion and environmental degradation that so often accompanies overcrowded, tightly packed, low rise structures. In practice, however, the cost of providing such buildings on expensive urban land in the quantities needed far exceeded the expenditures anticipated for single family units on less expensive sub urban land. Although this approach addressed the problem of dealing with the existing 'kampungs', its economic and social costs proved prohibitive.

A less ambitious yet more fiscally and socially responsible solution evolved from the idea of site and services. As the name implies, site and services schemes deal with only with the provision of land and a minimum level of services, no attempt is made to provide a complete house. This is later called *Kampung Improvement Program* (KIP).

KIP was initiated by community in Indonesia became well known as a successful urban strategy for upgrading the living environment. There are a lot of lessons to be learnt from the experience of KIP to develop the method of Community Based Development (CBD).

The objective of this program was to alleviate the extremely low standard of living infrastructure and services in urban areas. The program was dealing with the improvement of the living environment covering areas which accounted for 60% of the entire area of big cities including Bandung and Jakarta. The Jakarta city government initiated an upgrading program for slum areas (*Kampungs*) called the Kampung Improvement Program (KIP) in 1969 (Darrundono and Mulyadi, 1979).

Generally, '*kampungs*' which would be improved by KIP showed similar conditions and situations, such as haphazard environment development, neglected basic sanitation needs, no drainage, no infrastructure, no social facilities and neglected physical condition. This is because most of the people occupying *'kampungs'* built their houses without any guidance and mainly following their traditional methods which they bring from the rural areas or the hinterlands. Therefore, local governments are trying to find a solution to improve the condition of '*kampungs'* through KIP.

Fig. 3.5 shows the different situation before and after KIP applied. A series of successful development initiatives, combined with economic growth in Indonesia, have helped improve the socioeconomic status and living conditions of the kampung's dwellers.

The families living in the '*kampungs*' recently are healthier, better educated, and more prosperous than they were 20 years ago. The needs and aspirations of the people have also progressed.

(a)

(b)

Figure 3.5 *Kampungs Improvement Program. (a) Before; (b) After*
Source: Darrundono and Mulyadi, 1979

b) Planned houses

Planned houses generally are those single dwellings constructed with appropriate methods and mass housing built by governmental or private developers. The housing compounds require large areas of land and therefore, sub urban areas are usually the sites of interest site due being inexpensive and extensive. In terms of the city centre, '*kampungs*' will be the main target of developers because of their low price and prospects for revitalization.

Housing policy in Indonesia is created at the national and local levels. Housing subsidies prepared by the Ministry of Public Housing is in the form of lower interest rates for people with low incomes. The Central Government also builds low-income housing, flats and supporting facilities.

In 2010-2014, the government plans to build 685,000 units of what they call ‘healthy simple houses’ (Rumah sehat sederhana - RSh) (Indonesia, 2008). These houses are constructed for low income people and subsidized by government. Table 3.3 shows simple house development planning from 2010 to 2014. 180 flats that can be owned by the dwellers and 650 twins including block residential facilities that support 836,000 poor families were built in 2012. The funds used amounted to 50 trillion IDR from the national budget. As for flats, good simple flats for sale or simple flats for rent reached 200,000 units with a value of 30 trillion IDR. The total value of market capitalization for the government-backed housing construction by the year 2014 is estimated to reach 80 trillion IDR. Besides houses, the government also builds apartments. There are 2 types of apartments: for rent and for sell to the public. Table 3.4 contains the following

Table 3.4 *Simple house development planning.*

Year	The habitable houses				
	Formal	New development	Increasing quality		Special
			KPRS	BLM	house
2010	150,000	7,500	30,000	7,500	250
2011	150,000	12,500	40,000	12,500	750
2012	210,000	16,250	50,000	16,250	1,050
2013	210,000	7,500	60,000	7,500	1,350
2014	210,000	6,250	70,000	6,250	1,600

Source: Ministry of Public Housing, 2011.

Table 3.5. *Apartments development planning*

Year	Rental apartment				Owned	
	For students and worker		In slum area		apartment	
	Tower	Unit	Tower	Unit	Tower	Unit
2010	100	9600	40	3960	60	30000
2011	100	9600	71	7041	60	30000
2012	100	9600	71	7041	60	30000
2013	40	3840	53	5200	60	30000
2014	40	3840	35	3458	60	30000

Source: Ministry of Public Housing, 2011.

Figure 3.6 *Planned houses in Jakarta city*
Source: Main survey in Jakarta, 2012

development plan for flats for the period 2010-2014.

Private real estate developers are important actors in the process of '*kampung*' renewal in Indonesia's cities. The real estate sector has become an important business. Organized private developers were practically non-existent in Indonesia in the early 1970s. Later that decade, the commercial association, Real Estate Indonesia (REI), had 33 main developers as its members. Today, membership runs to nearly 1,000 firms (Jakarta, 2012). Figure 3.6 shows some planned houses in a housing compound.

Central government dominates housing regulations in Indonesia (Indonesia, 2008). Large scale development should involve the construction of modest houses, middle class houses, and luxurious houses in balance. The Ministry for Housing and Settlement of Indonesia recently set the target of proportion for balanced residential patterns for the national housing sectors (Kemenpera, 2013). They proposed the composition of simple, medium and luxurious houses to be 3:2:1. However, the data for existing proportions of these house categories in Jakarta were not available.

3.2. Housing policy in Indonesia

Housing is one of the basic needs of human beings, on a level with food, education and health. The need for housing is therefore one of those that have to be fulfilled by the state. The Covenant is binding to Indonesia as it was ratified in 2005. Apart from that, in the Indonesian Constitution, the right to housing is one of the basic rights guaranteed by the state. Article 28H (1) of the Constitution 1945 as amended stipulates:

'All people are entitled to a healthy life, physically and mentally, and housing, as well as a good and healthy environment, and are entitled to access to health services'

The state of Indonesia is therefore responsible for providing decent and healthy (in other words, conducive to inhabitants' well-being) housing for all citizens. This is however not an easy task as Indonesia is a country with the fourth biggest population in the world. Several policies conducted by government to support the above statement as follows.

Secondary mortgage facility

In the One-Million-House Movement, the government's direct contribution was channeled through Perumnas, a government housing company, and in the form of a subsidy through House Ownership Credit (Kredit Pemilikan Rumah, KPR) for 200,000 houses. While the interest rate of KPR is 15 %, through the subsidy the recipients will only have to pay 5 to 6 % interest rate per year. However, this subsidy is provided in phases over five years. After five years, the buyers have to pay the normal interest rate (Widoyoko, 2007).

In future, the government's contribution in housing provision will be channeled through Sarana Multigriya Finansial Ltd, a Secondary Mortgage Facility established by the government of Indonesia in mid-2005. Being a new state-owned enterprise, Sarana Multigriya Finansial Ltd will get an initial capital of IDR 2.5 trillion. 1 trillion of the capital comes from the National Budget while the remainder comes from Jamsostek, the state-owned enterprise managing pension funds for private sector workers and state-owned enterprise employees. In addition, Sarana Ltd will receive technical assistance from international financial institutions, e.g. ADB and International Finance Corporation, an institution under the World Bank.

The Secondary Mortgage Facility (SMF) is an institution that is expected to be able to support housing finance. Most of funds collected by the banks from society are short-term savings, while housing finance credit is long-term credit. If the savings are suddenly withdrawn by the society, banks will face difficulty.

Ministry of People's Housing

The economic crisis taking place in 1997 not only increased the number of the poor but also decreased people's purchasing power, including the affordability for houses. Investment in the housing sector was much left behind compared to the developed countries. In Indonesia, the ratio of housing credit to GDP (Gross Domestic Product) was only 1.4 per cent in 2002, and once reached its peak at 3.2 per cent in 1997. As a comparison, Malaysia's ratio is 27.7 per cent while the USA's was 45.3 per cent in 2002.

In order to provide housing, government re-established the Ministry of People's Housing. This way, the ministry is capable of coordination, not policy implementation. Some policy implementation functions are still held by Ministry of Public Works.

In 2004, the State Ministry of People's Housing set a target to provide as many as 1,350,000 healthy simple houses, which would be developed in the five years from 2004 to 2009. Apart from that, the government would also provide rented simple flats (Rumah Susun Sederhana Sewa, Rusunawa), owned simple flats (Rumah Susun Sederhana Milik, Rusunami), self-initiated, also known as formal, housing (Perumahan Swadaya) and a facility for self-initiated housing (Fasilitas Perumahan Swadaya) and in the form of a Ready-for-Construction Area (Kawasan Siap Bangun, Kasiba) or Ready-for-Construction Land (Lahan Siap Bangun, Lasiba). Rusunawa is provided for people with fixed and not fixed income of IDR 350,000 - 1,500,000, while Rusunami for those who have fixed income of more than IDR 1.5 million and can access subsidized House Ownership Credit (KPR) (Inforum, 2005 quoted in Widoyoko, 2007).

By the end of December 2005, the target was unattainable. Development of basic housing could only be done for 68,913 as opposed to the plan of 120,000. This even included 14,133 simple homes that had not been subsidized. Similar was the development plan of Rusunawa and Rusunami: the target could not be realized. Table 3 describes the mid-term plan, target and numbers achieved by 2005 as well as 2006 target of the State Ministry of People's Housing.

Housing for the poor

The government's initiative to provide housing for the poor included the establishment of Bank Tabungan Negara (BTN), the State Saving Bank. This bank is the only one focusing on the provision of housing for the lower middle class. The large role of BTN can be seen from the credit the Bank has channelled. Indeed, apart from BTN whose shares are owned by the government, there was Papan Sejahtera Bank (BPS) which also focused on housing finance. However, unlike BTN, BPS provided credit for housing finance for the upper middle class. When the economic crisis hit Indonesia, BPS was one of the liquidated banks.

Another role played by the government was the establishment of the company of National Housing Development (Perusahaan Pembangunan Perumahan Nasional, Perumnas). Perumnas is a government-owned company working in housing construction, particularly simple housing. One of the achievements of Perumnas to note as the pioneer of development companies is its success in introducing housing complexes in big cities.

3.3 Future prospect for housing provision in Indonesia

Housing provision challenge in Indonesia has started after the Independence Day. Freek Colombijn (2011) analyzed how Indonesian public housing policy change during

1930-1960 underlining the difference of Dutch collonialization approach and new leaders of Indonesia after independence. Issues that raised during the era such as competition between civil and military authorities to control available housing; the exasperation of urban dwellers about the residential permits issued; public building programmes appropriated by self-serving civil servants; the cat-and-mouse games between the kampong population and the urban administration; and the shifting balance of power between landlords and tenants. Housing plans during post-independence era facing the hard economic and demographic reality that there were not enough funds to build a home for all the people.

Indonesia housing provision condition after Colombijn period of analysis is not really changing nowadays, few resources for too many people create relatively unclear policy of housing provision. Looking on Indonesia demography, with average age of 29 years old in 2012, with lower dependency ratio compare to European area, Indonesia currently experiencing a demographic bonus, a good sign for the economy in one side, but also a challenge of housing provisions on the other sides.

(a)

(b)

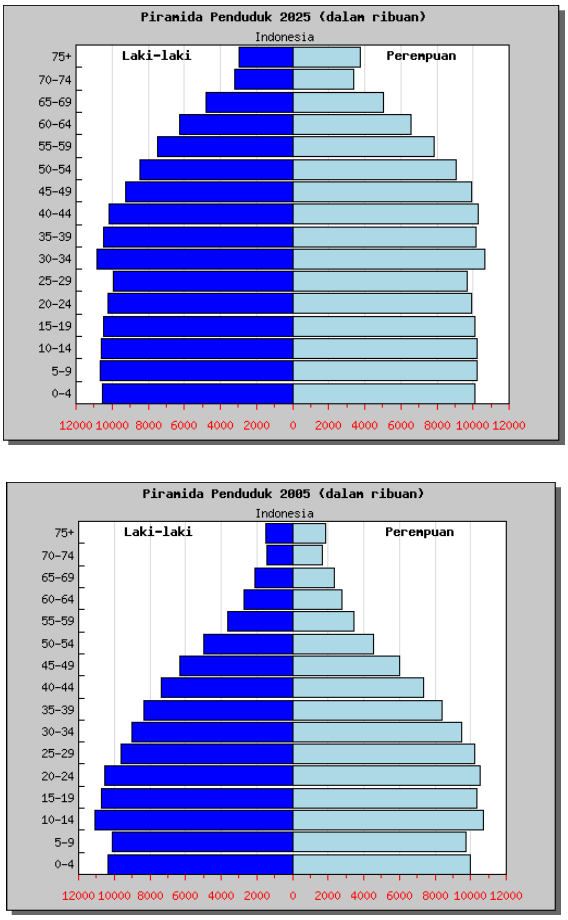


Fig. 3.7 *Indonesia demography in (a) 2005- (b) 2025*
Source: Indonesia, 2010a

There are five key players who involved in Indonesia housing provisions. First, central government which represent by Ministry of People Housing, whom create housing regulations and incentives. Second, banks which through its mortgage product help the housing buyers achieve their goals in having house through credit term. Third, developers which create housing products for housing buyers. Fourth, the buyers which range from affluent middle class to less affluent middle-low class. Fifth, local government whom actually exercise the policies and to some extent land-bank owners for public housing.

First, Ministry of People Housing. This entity is responsible for the regulation of housing provision especially for the middle to lower income segment. Due to external factors complexities (land price, building price materials spikes, loan interest rates), there are approaches changes within relatively short period of administration.

Second, participating banks. All four of the bank involved for Ministry of people housing program, are state owned bank. Three of them are top 5 Indonesian bank (Mandiri, BNI, BRI) and listed as the top 2000 companies worldwide. To remind that the state owned enterprise function is not only creating profit but also supporting less profitable but crucial in fulfilling people welfare needs.

Third, the developers. There are two types of housing developer which serves different type of consumers. First, high capital developers like Agung Podomoro, Ciputra and Metland which associated with REI (Real Estate Indonesia) network. This group of developers possess high capital, land-banks and serving wider range of consumers from business building, high-end housing to affordable high rise housing project. Second, low capital developers like Elang Gumilang and APERSI member. This second type of developers are focusing on affordable landed house provisions in outskirt area of big cities.

Fourth, house buyers. Challenge on young/first time house buyers are housing inflation is higher compare to the average salary increase.

Last but not least, Municipal/local government. Providing land combined with proper urban planning are the challenge to provide the basic human rights, housing with good environments. Several existing rusunawa problems, still need to be address such as land provision for new rusunawa project as well as better tenant recruitment and management. How big is the need for housing in Indonesia? The Ministry for Settlement and Regional Infrastructure predicts that the need for housing in Indonesia will soon reach 800,000 units per year. This prediction is in addition to the backlog or gap in provision of housing that has not been met before: 5.93 million houses in 2003. If the government provides 1,150,000 houses per year, the need for housing for the whole population of Indonesia will be fulfilled in 17 years.

The Asian Development Bank (ADB) makes an estimation of housing need in detail as illustrated in Table 3.5. As can be seen in Table 3.5, ADB estimates that over the 10-year period between 2000 and 2010 the urban population will become 50 per cent of the total population of Indonesia. By the end of 2020, the percentage of urban residents will become 60 percent or 217.47 million. The population growth in urban areas will in turn increase the demand for housing.

The increasing population of Indonesia are driven by the increasing of population in its major cities, such as Jakarta and Bandung as predicted by UN (2011). It was predicted that by 2020, the population of Jakarta would increase of 11.6 million and keep increasing in 2030 (14.0 million). The increasing population is also shown for the population in Bandung from 2.4 million in 2010 to 2.9 million by 2020 and 3.6 million by 2030.

Table 3.6 *Estimation of housing need (in thousands)*

Year	1990	2000	2000 –2010	2011 –2020
Total population	179.379	212.739	277.684	362.457
Urban population, in percentage of total		40.3%	50%	60%
Urban population	55.428	85.734	138.842	217.474
Size of household		4.3	4.2	4.1
Rate of population growth		2.7%	2.7%	
Total households	12.890	19.938	33.058	53.042
Increase in number of households			13.120	19.985
Ratio household/house		0.9	0.9	0.9
Housing needed			11.808	17.986
Annual rate of mobility		0.01	0.01	0.01
Increase of annual rate of mobility			2.650	4.305
Total new houses			15.769	24.290
Gap/backlog	7.7%			
Figure to close the gap		1.382		
Average need for housing/year			1.646	2.498
Most needy group	8%		132	200
Needy group	27%		444	674
Very low income	23%		379	575
Low income	35%		576	874
Middle and upper income	7%		115	175
Total	**100%**		**1.646**	**2.498**

Source: ADB, 2001.

In 2000, there were almost 20 million households in Indonesia and this will increase by the end of the decade to 33 million and to 53 in the next decade. The increased number of households will boost the demand for housing. With the assumption that the ratio of household/house is 0.9 at the end of 2010 it is estimated that 15.77 million houses will be needed and 24.29 million more at the end of 2020. Calculated annually, between 2000 and 2010 there will be a demand for 1.646 million houses per year, and this increases in the decade of 2011-2020 to 2.498 million houses annually.

Looking at the projection, despite the government's success in launching the project of one million houses per year, the real demand is not yet fulfilled when the population who do not own a house are taken into account. ADB notes that 1.38 million houses were needed in 2000 to cover backlog. The figure has gone up and Ministry of Settlement and Public Infrastructure calculated in 2003 that the backlog reached a figure of 5.93 million houses.

When the need for housing is put into detail of demand for each segment of society, the demand of upper and middle class is only 7 per cent. This means that the market share of upper-middle class housing that does not require subsidy and government's intervention is only 115 million/year in the period of 2000-2010 and 175 million/year in the following decade. Meanwhile, the remaining 93 is the lower-middle income group who needs government's assistance.

It is to be noted that the estimates released by ADB do not included the category of unhealthy houses and slum settlement, while these constitute an urgent issue to overcome, both by the national and local governments. Given the facts, the government – with an obligation to provide decent housing for the people – faces a serious problem. This is even so if we consider the impact of economic crises and the large amount of fuel subsidy the government has to finance. Along with the pressure of the debt repayments, domestic or foreign, all these make the Indonesian government unable to secure funding for provision of housing.

As a strategy to overcome the gap between actual and ideal conditions, the government launched the National Movement of One Million House Construction in 2003. However, the government has failed to complete it. 600,000 houses were constructed independently by the community and 200,000 underwent quality enhancement. The government only provided technical assistance such as provision of drawings of a 'healthy, simple house' [homes that use simple construction technologies and are conducive to the health of those living in them] that can be used by the community. This contribution is very small and insignificant as the government is unable to reduce other costs paid by the community, such as land and licensing cost.

3.4. Summary

Indonesia is a developing country which is an extensive archipelago and has a large population. Due to increased economic and population growth, numerous residential buildings are being constructed, especially in urban areas.

- Residential buildings in Indonesia can be categorized in to three types based on lot size and construction cost, namely simple houses, medium houses and luxurious houses. Meanwhile, they are divided into two types based on how they are constructed. i.e., unplanned houses and planned houses.
- Unplanned houses are those constructed by the owner or a local informal developer (non-professional developer). These form the largest portion of the housing stock in Indonesia. The unplanned houses integrated in one compound called *Kampungs*. A *kampung* usually has poor infrastructure and utility services. The Government has attempted to improve these poor conditions with a program called the *Kampung Improvement Program* (KIP). The objectives of this program are to improve the infrastructure and physical condition of a *kampung*, through such means as road repair, creation of disposal sites, improving washing and bathing areas, etc. This program has already been conducted in several major cities from the end of 1969 through to the 1990s under a grant of the World Bank. Recently, non-governmental organization or local societies are trying to widen the areas impacted by that program.
- Unlike unplanned houses, planned houses are constructed by formal developers such as governmental and private developers. Governmental developers through the National Company for Public Housing (PERUMNAS) only develop simple houses to provide low cost housing for low income people. In addition, private companies can develop all housing categories. i.e., simple, medium and luxurious houses.
- Housing policy in Indonesia is conducted at national and local levels. Housing subsidies which prepared by the ministry of public housing is in the form of lower interest rates for people with low income. Central government builds low-income housing, flats and supporting facilities. While local governments build housing for people affected by the program, such as evictions due to the government infrastructure buildings.
- The future prospect of housing provision in Indonesia are determined by several stakeholders, for instance, government through Ministry of Public Housing, private sectors represented by developers and by the people themselves. The backlog of house in Indonesia is very big (13.6 million housing backlog units). Since private sectors can supply only around 20% of annual new housing demand, Ministry of Public Housing cannot fulfill these housing need. Therefore, Most of housing in Indonesia are provided by people themselves which are called informal houses or unplanned houses.

4

Methodology

In the previous chapter, we explained historical background and statistical data of residential buildings, housing policy and future prospect of housing provision for all people. This chapter provides the methodology how to obtain two necessary data for life cycle assessment in buildings, i.e. material inventory and household energy consumption data. Section 4.1 explains a pilot survey conducted in Bandung city as initial survey to investigate the methods which would be used to obtain building material inventory data and household energy consumption. Then, through these methods, two main surveys were conducted in Bandung and Jakarta to investigate both data. Section 4.2 explains methods to analyze building material inventory and building waste. Section 4.3 describes embodied energy and input-output analysis methods. Section 4.4 describes methods to quantify household energy consumption. Summary (section 4.5) concludes the methodology used in this study.

4.1 Surveys

One of the obstacles to conducting life cycle assessment (LCA) in developing countries is considered to be relatively poor availability of building, environmental and economic data. This study aims to analyze life cycle energy and CO_2 emission profiles for residential buildings in Indonesia, which can be developed under relatively poor data availability conditions. As the initial step, a pilot survey comprising a small number of samples (n=11) was carried out in Bandung city in March 2011 to initiate the assessment of life cycle energy and CO_2 emissions profiles using an input-output analysis. This study discusses the possibility of assessment the said profiles while investigating the availability of required data through the pilot survey. Then, two main surveys were carried out in Bandung city (September-October 2011) and in Jakarta city (September-October 2012) to investigate building material inventory data and household energy consumption profiles which are necessary to analyze embodied energy and household energy consumption.

4.1.1. Case study cities

Bandung

Bandung city was selected as a representative city of rapidly developing cities. The city is located in region of West Java and constitutes as the Capital of West Java. It is lied between 107° 36 east longitudes and 6° 55 south latitudes. Topographically, the city is located on 791 m above the sea level; the highest point area in the north is 1050 m and the lowest point in the south, which is around 675 m above the sea level. The climate of Bandung has humid and relatively cool climate (Fig. 4.1). The average rainfall intensity throughout the year ranges from 40.6-324.2 mm per month with the daily average outdoor relative humidity of 73.3-82.2%. As a highland city, the daily variation of temperature is relatively small. The monthly average temperature varies at 22.9-23.9 ºC throughout the year with the average minimum temperature of 18.3-20.0 ºC and the average maximum temperature of 27.5-30.1 ºC (Bandung, 2010b).

The area of the city is 167.29 km^2. It is divided into 26 districts (kecamatan), 139 sub-district (kelurahan), 1509 cluster neighborhood units (RW), and 9378 neighborhood unit (RT). Its population increased from 2.2 million in 2005 to 2.4 million in 2010 (Bandung, 2010a) and 2.45 million in 2012. It consists of 1.25 men and 1.20 women, Therefore, Bandung is one of the populated city and the population density increased from 14,450 persons/km^2 in 2010 to be 14,680 persons/km^2, with Bojongloa Kaler Sub District as a densely area which its density is 39,280 persons/km^2. The number of household in Bandung is 653,572 households with an average of 3.8 persons of each household. The population growth rate was 1.15% in the period of 1990–2000 (BPS, 2007).

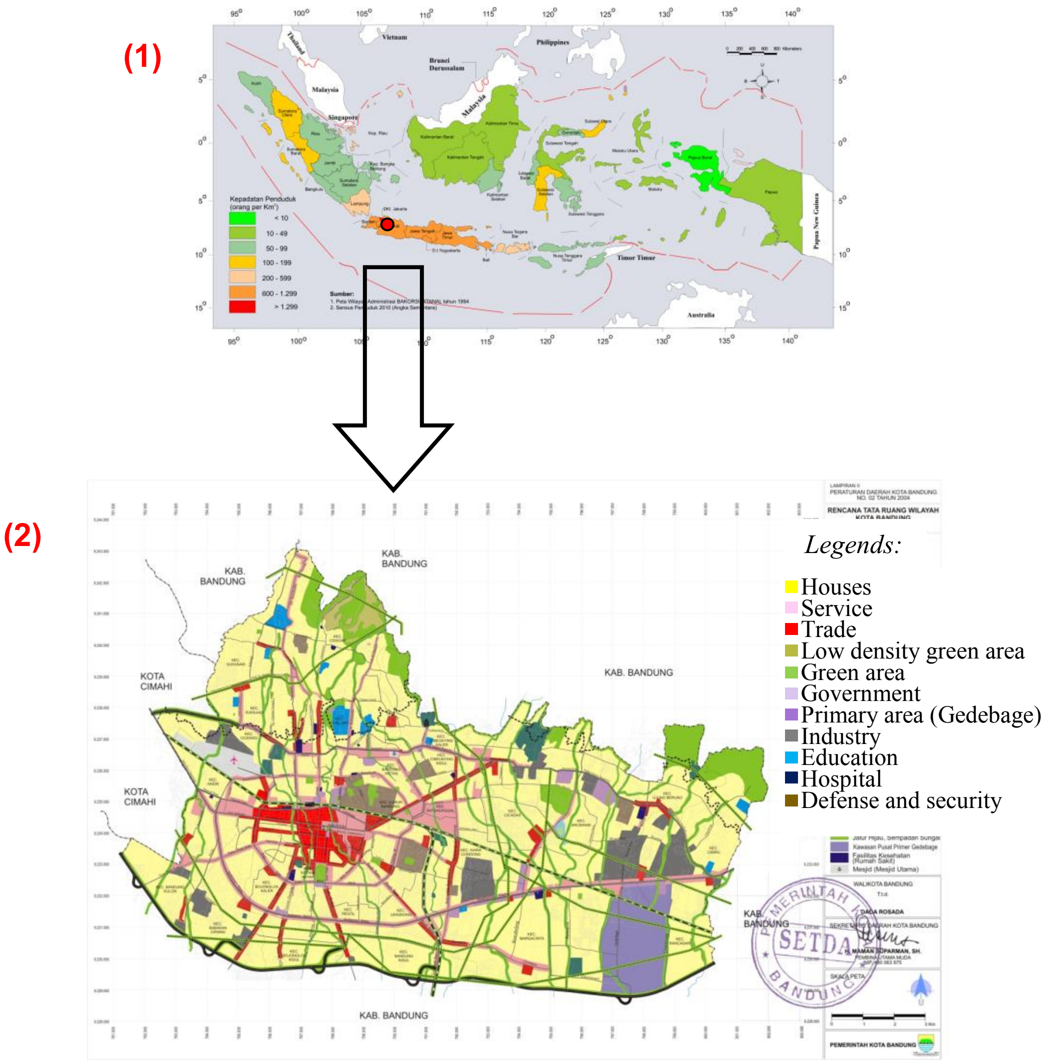


Fig. 4.1 *Map of (1) Indonesia; (2) Bandung. (Source: City planning of Bandung, 2010.*

GDP (gross domestic product) based on current prices from year 2010 to 2012 showed a significant increase. The absolute value of Bandung's GDP at current prices in 2012 accounted 111.1 million IDR and increased in nominal GDP at current prices amounted to 16.22%.

Jakarta

Jakarta, the capital city of Indonesia, was selected as a case study city. Jakarta, as oriented in Figure 4.2 is a city located in the western part of Java Island. Positioned at the southern shore of the intensely navigated Java Sea, the city has been greatly influenced by its strategic position since centuries ago. Its population increased from 4.4 million in 1970 to 9.6 million in 2010 (Indonesia, 2010a). The city has a hot and humid climate, which is dominated by the north monsoon (November to March) and the south monsoon (May to September). 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%. As a coastal city, the daily variation of temperature is relatively small. The monthly average temperature varies at 27.1-28.9 ºC throughout the year with the average minimum temperature of 24.6-25.4 ºC and the average maximum temperature of 30.7-33.3 ºC (Jakarta, 2010a, 2010b).

City of Jakarta is a lowland area with an average altitude of 7 m above the sea level. The total area of Jakarta is a land area of 662.33 km^2 and a sea area of 6.98 km^2. Administration region of Jakarta is divided into 5 areas of the city administration and one administration agency, namely: the city administration Jakarta Selatan, Jakata Timur, Jakarta Pusat, Jakarta Barat and Jakarta Utara and an administration Regency of Kepulauan Seribu.

Industrial activities take place mostly in the northern and eastern part, while business and trade is more concentrated in the western, central, and southern part. Most of the land is nevertheless dominated by residential areas, occupying about 66% of the total area. Being the central of the national government and commercials activities, Jakarta city is given a special autonomy, equivalent with a province. Administratively its large region consists of 5 municipalities, 44 districts, 267 villages, and 2657 sub-villages.

During the period 1969 – 1983, trade was very important and comprised a big share of GDP, while agriculture decreased on the other hand. Manufacture developed slowly increasing from 9.8 to 17% during that period. Jakarta's contribution to the 1996 National GDP was 7%, in which was included 17% of domestic industrial production and 61% of financial activities. GRDP at current market price in 2012 accounted 1,103 million IDR which increased from 757.6 million in 2009.

4.1.2. Sampling methods

Since the data for proportion of among house categories is not available in Indonesia, the study assumed that proportion of simple houses is the largest and that of luxurious houses is the smallest number of house category. Therefore, the disproportional stratified sampling was used to obtain the samples.

This study assumed that the population of each house category is homogenous. Statistically, in most cases, a sample size of less than about 30 respondents will provide too little certainty. Usually, experienced researchers regard a sample of about 100 respondents as the minimum sample size for large populations. It is seldom to sample more than 10% of the population to obtain adequate confidence (Bryant and Yarnold, 2001).

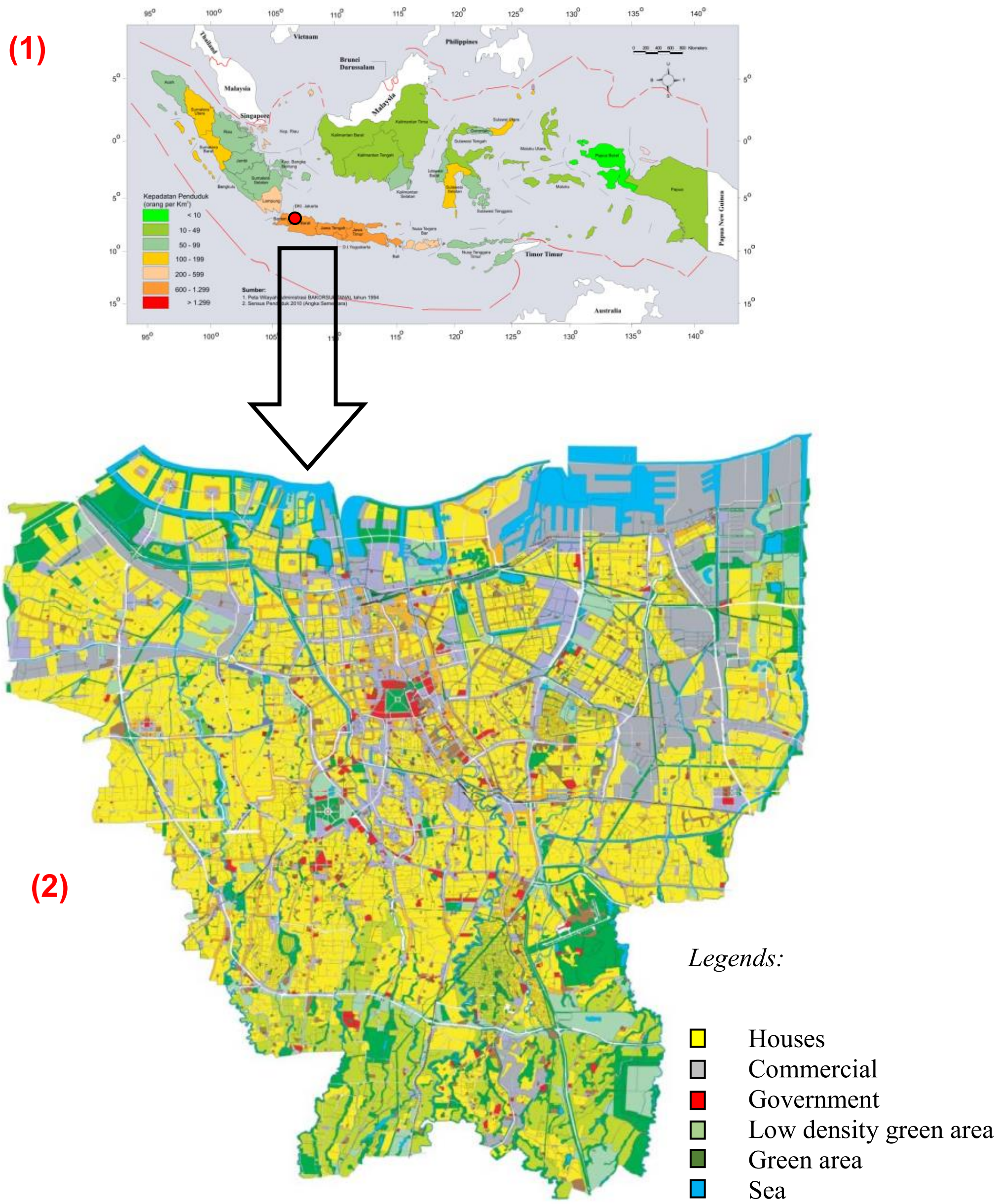


Fig. 4.2 *Map of Jakarta City. (1) Indonesia; (2) Land use of Jakarta.*
Source: Jakarta, 2010a.

- Unplanned houses accounted 89% of total landed houses in Bandung. A total 247 samples were selected by considering establishment year and location (city center and sub urban). Existing proportion of house categories was not available. Therefore, the proportion of house categories of the sample do not represent those of target population.
- The total unplanned houses in Jakarta accounted for about 74% of total houses in Jakarta. On the other hand, planned houses accounted for another 26% in Jakarta. The total samples (n=297) were selected by considering the above mentioned existing ratio.

However, the data for existing proportions for house categories were not available. Therefore, the proportions of these house categories of the sample do not represent those of the target population too.

- The housing areas in the city of Jakarta were classified into several categories based on their establishment years and distances from the city center, and more than one study areas were selected from each of the categories randomly. As a result, the study areas were taken out from each municipality of Jakarta, i.e. Centre Jakarta, North Jakarta, South Jakarta, West Jakarta and East Jakarta, except for planned houses in the Centre Jakarta. Since land prices in Jakarta were relatively expensive, the category of planned simple houses was not existent in the city

Bandung

In most of the major cities in Indonesia, unplanned houses account for the largest proportion of the existing housing stocks, which is about 89% in case of Bandung (Bandung, 2010a). Hence, this study focuses on these unplanned houses. These houses are classified into three categories based on construction costs and lot area namely simple houses, medium houses and luxurious houses, having a life span of 20, 35 and 50 years respectively (Indonesia, 2007a). Three areas were selected to represent near city centre (Cipaganti (a), Tamansari (b)) and sub urban (Batununggal (d)) (see Fig. 4.3). The pilot survey was conducted in six simple houses (No. 1-6), three medium houses (No. 7-9) and two luxurious houses (No. 10-11) in March 2011.

Meanwhile, in main survey, six typical residential neighborhoods were selected from the city by considering the distance from the city centre and their establishment years as shown in Fig. 4.3, namely Braga (c) (city centre); Tamansari and Cipaganti (a and b) (near city centre); Batununggal, Antapani and Sukapada (d,e and f) (far from city centre/sub

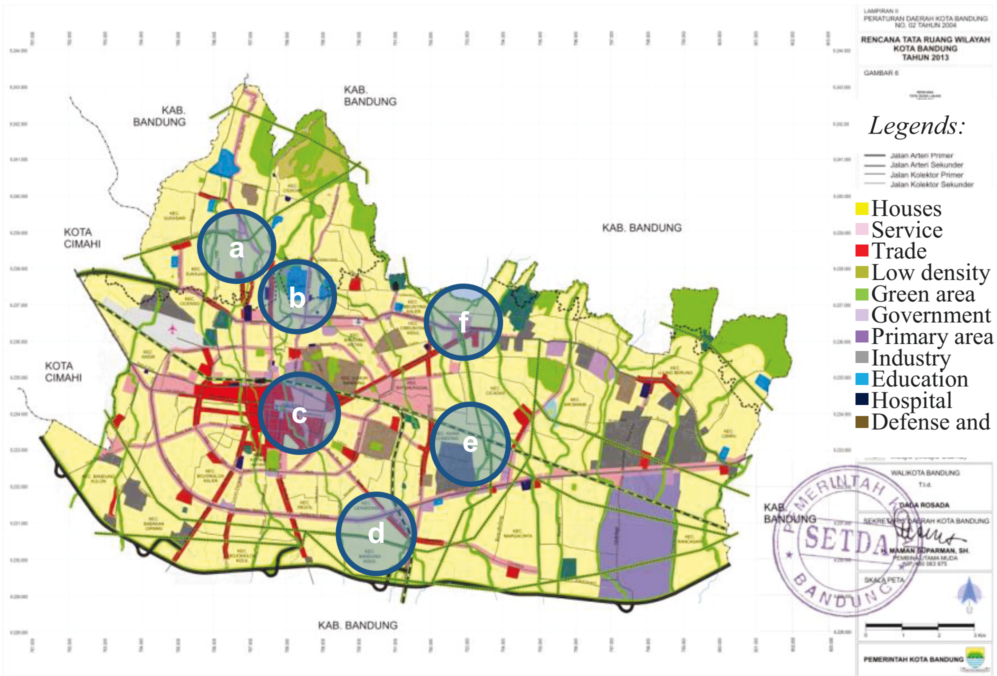


Fig. 4.3 *Map of Bandung. (a) Cipaganti; (b) Tamansari; (c)Braga; (d) Batununggal; (e) Antapani and (f) Sukapada.*

urban). Household income and floor area were expected to be the key factors affecting embodied and household energy consumption and therefore the above areas were chosen in order to cover a wide range of building area and income groups. One of the sites was located in the city centre and two of them were situated within the radius of about 3.5 km from the centre. The other three areas were located in the suburb of the city, which is about 5.5 km away from the city centre.

Jakarta

Residential buildings (landed houses) in Jakarta can be grouped into two types, namely planned and unplanned houses. Originally, the unplanned houses, called '*Kampungs*', were urban dwellings built by the earliest inhabitants of a city or by city government during colonial period to provide cheap labor to wealthy areas. 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 (World Bank, 1995). These unplanned houses are scattered across the city as pockets of low income settlements and accounted for about 74% of the total housing stocks in Jakarta as of 2010 (Jakarta , 2010a). In contrast, planned houses are defined as houses constructed in a proper modern urban planning. The recent mass developments comprising terraced houses are included in this type. This accounted for another 26% in Jakarta (Jakarta, 2012). 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. These houses have an approximate lifespan of 20, 35, and 50 years on average, respectively (Indonesia, 2007).

A total of 297 residential buildings were selected in the survey. These samples were selected by considering the above mentioned existing ratio of unplanned and planned

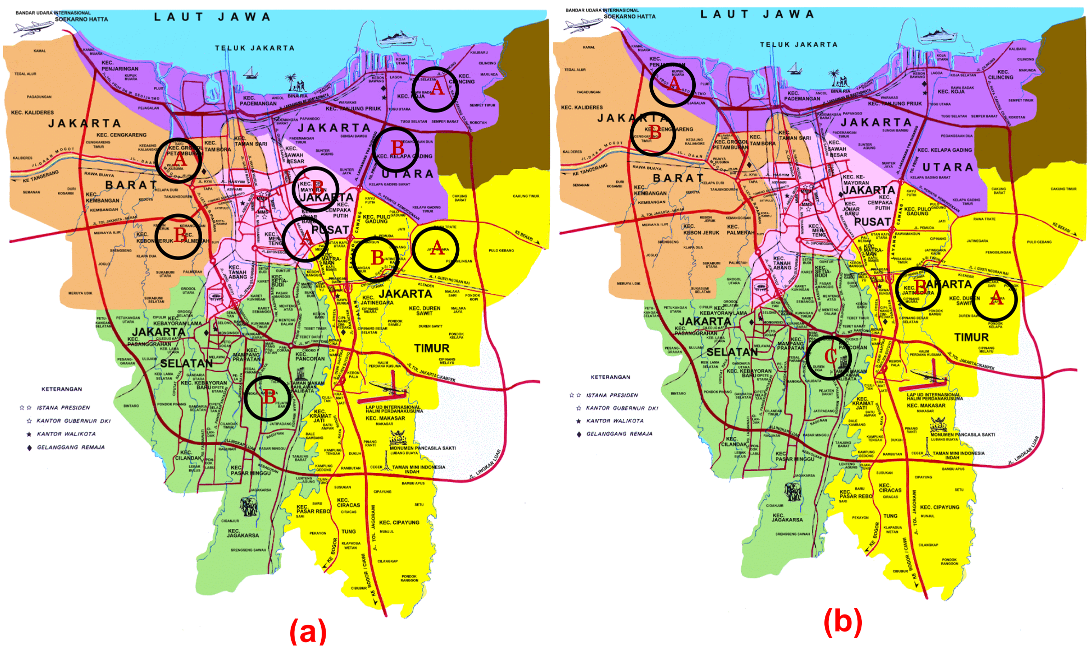


Fig. 4.4 Map of Jakarta City. (a) Selected unplanned housing areas; (b) Selected planned housing areas.
Source: Jakarta, 2010a.

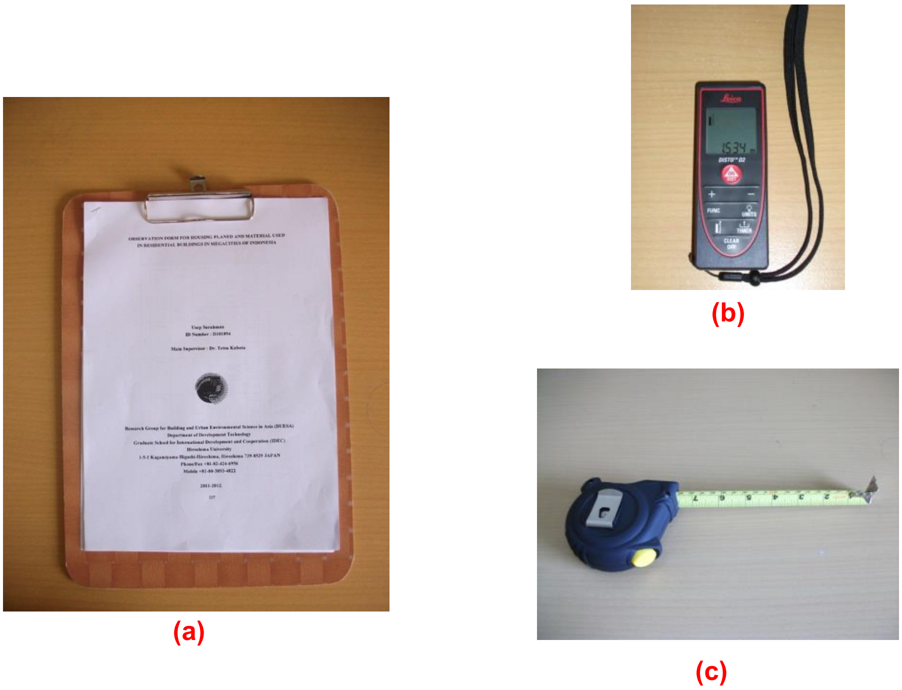
houses in Jakarta. The whole sample consisted of planned houses of 23% and unplanned houses of 77%. The Ministry for Housing and Settlement of Indonesia recently set the target of proportion for balanced residential patterns for the national housing sectors (Kemenpera, 2013). They proposed the composition of simple, medium and luxurious houses to be 3:2:1. However, the data for existing proportions of these house categories in Jakarta were not available. Therefore, this study obtained a certain number of samples from respective categories with the aim to make comparisons among these three house categories. This means that the proportions of these house categories of the sample do not necessarily represent those of the target population, i.e. all the landed residential buildings of Jakarta.

The housing areas in the city of Jakarta were classified into several categories based on their establishment years and distances from the city center, and more than one study areas were selected from each of the categories randomly. As a result, the study areas were taken out from each municipality of Jakarta, i.e. Centre Jakarta, North Jakarta, South Jakarta, West Jakarta and East Jakarta, except for planned houses in the Centre Jakarta. Since land prices in Jakarta were relatively expensive, the category of planned simple houses was not existent in the city.

4.2 Building material and waste analyses

4.2.1. Building material inventory data

LCA in buildings generally involves six phases, namely design, material production, construction, operation, maintenance, and demolition phases. However, design and construction 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



(a) (b) (c)

Fig. 4.5 *Measurement equipment;*
(a) Questionnaire of building material inventory survey; (b Laser distance); (c) Tape meter

Fig. 4.6 *On-site measurements; Building material inventory*

buildings in Bandung are constructed and demolished by manual labor. Moreover, some of the demolished materials will be reused and some will be landfilled around the sites (Utama and Gheewala, 2008, 2009). Reuse/recycling rates will be assumed in this study. Thus, the energy consumption and materials used during the above phases, i.e. design and construction phases, are considered negligible.

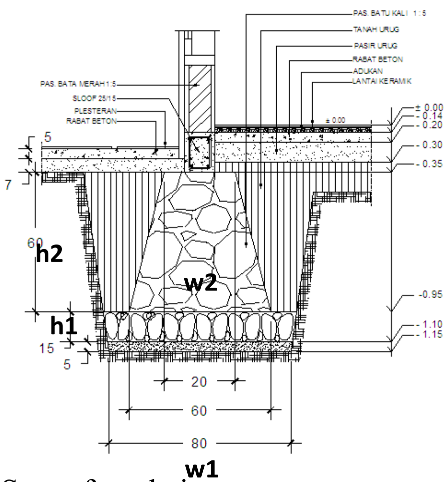
The design records such as building drawing are required for the analysis of embodied energy of building materials. These data can normally be obtained from the local authorities or developers, etc. (Kurdi, 2006; Monahan and Powel, 2011; Thormark, 2002). Some developed countries provide the data in the literatures (Mithraratne and Vale, 2004; Tove, et al., 2010). Nevertheless, in the case of Bandung, 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 tape measures and laser distance meters (Fig 4.5) were conducted for simple and unplanned medium houses instead in order to acquire the data (Fig. 4.6).

Procedure to calculate material quantity and intensity of building material inventory data are as follows.

1) The building material inventory data derived from on-site building measurement were calculated to obtained volume (m^3) of each building materials using Eqs (4.1)-(4.29).
2) Then, these building material volumes were converted into material quantity per average floor area (kg/m^2) by multiplying the obtained volume and density of each building materials (Eq. (4.30)) (Indonesia (SNI), 1989).
3) In order to obtain embodied energy, the building material quantity (volumes or areas) were then converted in to material intensities (material unit/million IDR) by dividing with the price of each material unit for respective cities following Indonesia (2010).

Table 4.1 shows the equations to calculate material quantity of each material used in a residential building.

Table 4.1 *Equations of material components in a residential building*

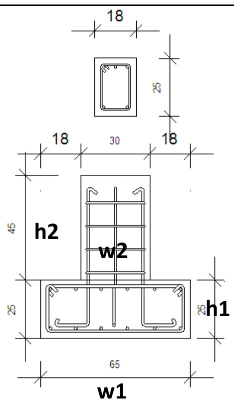
<table>
<tr><th>Materials</th><th>Figures of material components</th><th>Equation</th></tr>
<tr><td>1. Stone foundation</td><td>


Stone foundation</td><td>$V_{fb} = w1\ .\ h1\ .\ L$ ………………….(4.1)

Where:
V_{fb} = Volume of stone foundation base (m^3)
$w1$ = wide 1 (m)
$h1$ = height 1 (m)
L = length (m)

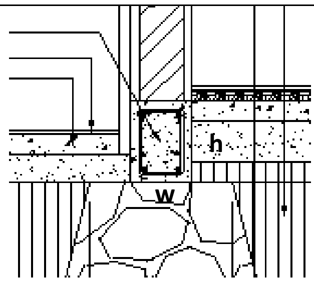
$V_{mf} = 0.5\ .\ (w2 + h2\ )\ .\ L$ ………….(4.2)

Where:
V_{mf} = Volume of main stone foundation (m^3)
$w2$ = width of down side (m)
$h2$ = width of upper side (m)
L = length (m)

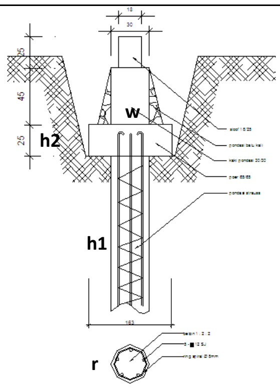
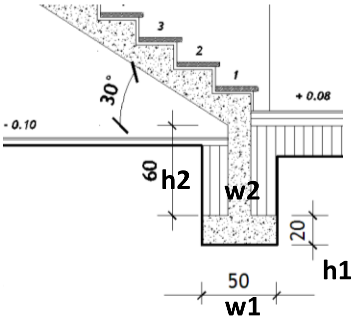
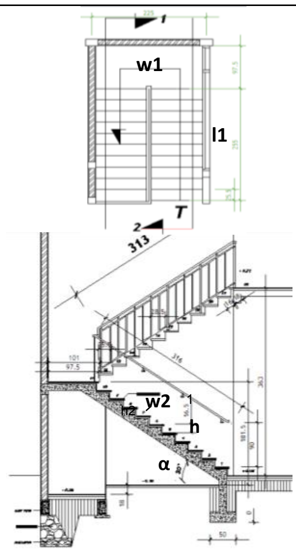
V total = $V_{fb} + V_{mf}$ ………………... (4.3)</td></tr>
<tr><td>2. Concrete foundation</td><td>


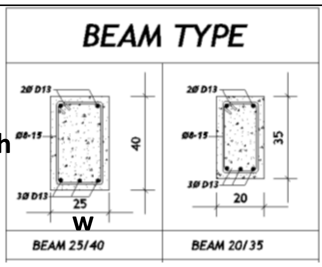
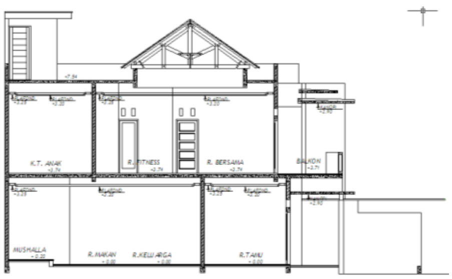
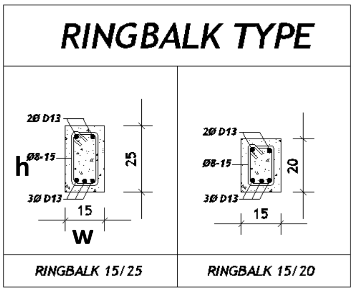
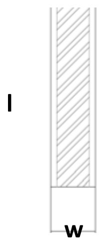
Foot plat foundation</td><td>$V_{fp1} = w1\ .\ h1\ .\ L$ ………………... (4.4)
Where:
$V1$ = volume of foot plat1 (m^3)
$w1$ = wide1 (m)
$h1$ = height1 (m)
L = Length (m)

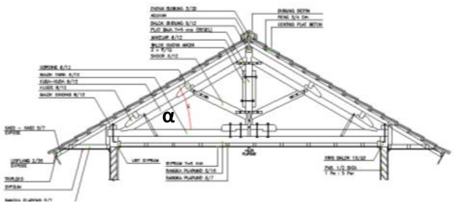
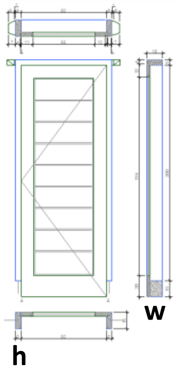
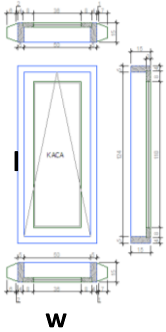
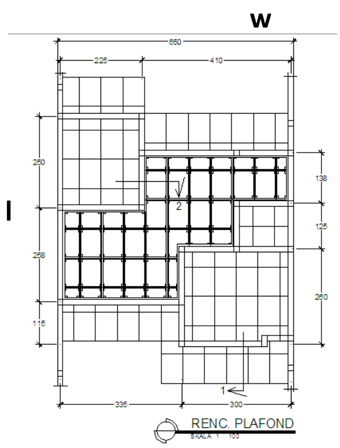
$V_{fp2} = w2\ .\ h2\ .\ L$ ………………....(4.5)
Where:
$V2$ = foot plat volume2 (m^3)
$w2$ = wide2 (m)
$h2$ = height2 (m)
L = length (m)

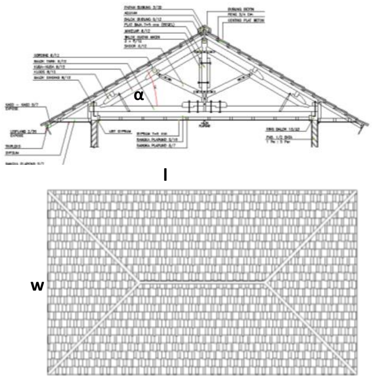
V total = $V_{fp1} + V_{fp2}$ ……………..…(4.6)</td></tr>
<tr><td></td><td>


Sloof</td><td>$V_s = w\ .\ h\ .\ L$…………………….... (4.7)
Where:
V_s = Volume of sloof (m^3)
w = wide (m)
h = height (m)
L = length (m)</td></tr>
</table>

	 Strauss foundation and its poer	$V_{st} = (\mu \cdot r^2) \cdot h1$ …………….... (4.8) Where: V_{st} = volume of strauss (m^3) μ = 3.14 r = radius of strauss (m) $h1$ = height of strauss (m) $V_p = w \cdot h2 \cdot L$ ………………... (4.9) V_p = volume of poer (m^3) w = wide (m) $h2$ = height (m) L = length (m) V total = $V_{st} + V_p$ ……………… (4.10)
	 Stair foundation	$V_{sfb1} = w1 \cdot h1 \cdot L$ ………………..(4.11) Where: V_{sfb1} = volume of stair's foundation base 1(m^3) $w1$ = wide1 (m) $h1$ = height1 (m) L = Length (m) $V_{sfb2} = w2 \cdot h2 \cdot L$ ………………..(4.12) V_{sfb2} = volume of stair's foundation base 2(m^3) $W2$ = wide2 (m) $H2$ = height2 (m) L = Length (m) $V\ total = V_{sfb1} + V_{sfb2}$
	 Stair step	$V_{ssl} = ((w1 \cdot L) / \cos \alpha) \cdot h$ ……. .(4.13) Where: V_{ss} = volume of stair's slope (m^3) $w1$ = wide (m) α = angle of stair's slope $h1$ = height of concrete (m) L = Length (m) $V_{sst} = 0.5 \cdot w2 \cdot h2 \cdot L$ ………… (4.14) Where: $V2$ = volume of stair's steps (m^3) $w2$ = wide (m) $h2$ = height of step (m) $V\ total = V_{ss} + V_{sst}$ ……………… (4.15)
	Concrete of kitchen table	$V = w \cdot L \cdot h$ ……………..…….(4.16) Where: V = volume of kitchen table (m^3) W = wide (m) L = length (m) h = height of concrete (m)

	 Floor beam	$V = w\ .\ h\ .\ L$ …………………. (4.17) Where: V = Volume of floor beam (m^3) w = wide (m) h = height (m) L = length (m)
	 Slab concrete	$V = w\ .\ L\ .\ h$ ………..………. (4.18) Where: V = slab concrete volume (m^3) w = wide (m) L = length (m) h = height of slab (m)
	 Ring balk	$V = w\ .\ h\ .\ L$ ………………… (4.19) Where: V = volume of rig balk (m^3) w = wide (m) h = height (m) L = length of ring balk (m)
	Plat roof (concrete)	$V = w\ .\ L \times h$ ………………..…(4.20) Where: V = concrete roof volume (m^3) w = wide (m) L = length (m) h = height (m)
3. Clay or concrete brick	 Wall	$V = L\ .\ h\ .\ w$ ………………..…(4.21) Where: V = volume of clay brick wall (m^3) L = length (m) h = height (m) w = width of clay brick (m)
	Plaster	$V = L \times h \times w$……………..……..(4.22) Where: V = volume of plaster (m^3) L = length (m) h = height (m) w = width of plaster (m)

4. Ceramic	Ceramic for floor, for kitchen table, for kitchen wall	$V = L \times h \times w$ ………………….....(4.23) Where: V = volume of ceramic (m^3) L= long (m) h = height (m) w = width of ceramic (m)
5. Wood	 Wood of roof structure frame	$V = w \, . \, h \, . \, L \, . \, n$ ……………….(4.24) Where: V = volume of wood structure (m^3) w = wide (m) h = height (m) L = length of wood (m) n = number of wood (unit)
	 Door/window frame	$V = w \, . \, h \, . \, L$ ……………..……..(4.25) Where: V = volume of door/window frame (m^3) w = wide (m) h = height (m) L= length of door and window frame (m)
6. Clear glass	 Clear glass	$V = L \, . \, h \, . \, w$ ………………..….(4.26) Where: V = volume of clear glass (m^3) L = length (m) h = height (m) w = width of clear glass (m)
7. Gypsum	 Ceiling gypsum	$V = L \, . \, h \, . \, w$ ………………….…..(4.27) Where: V = volume of gypsum (m^3) L = length (m) h = height (m) w = width of gypsum (m)

8. Paint		$V = L \cdot h \cdot w$ ....,,....(4.28) Where: V = volume of paint (m^3) L = length (m) h = height (m) w = width (m)
9. Clay/concrete roof		$V = ((w \cdot L)/ \cos \alpha) \cdot h$...............(4.29) Where: V = volume of clay/concrete roof (m^3) $A = (w \times L) : \cos \alpha$ w = wide (m) L = length (m) α = angle of roof's slope

Source: Irawan et al., 2010.

To obtain material quantity per m^2, building material volume above (m^3) was multiplied by building material density (kg/m^3) (see Table 4.2) of each material following SNI (1989) utilizing the following equation (4.30).

***Table 4.2** Building material density*

Materials	Density (kg/m^3)
1. Stone	1450
2. Clay brick	950
3. Concrete brick	2300
4. Cement	1506
5. Sand	1400
6. Steel	7750
7. Ceramic tile	2500
8. Clear glass	2579
9. Wood	705
10. Gypsum	1100
11. Paint	700
12. Clay roof	2300
13. Concrete roof	2500
14. Asbestos roof	2200
15. Zinc roof	3330

Source: SNI, 1989.

$M = (V \cdot d) / A$ ....(4.30)

Where:
M = Material quantity per m^2
V = Material volume (m^3)
d = material density (kg/m^3)
A = Total floor area (m^2)

Unit of each material is required to obtain material intensity. This is because, each material was sold in different unit at the market. Therefore, a coefficient of building material per working unit obtained from Indonesia as shown in Table 3 (2010c) was used to convert material volume or area to be unit of each material (see Tables 4.4-4.5) as following equation (4.31).

$U = V$ or $A \cdot CoM$ ....(4.31)

Where:
U= unit of each material
V= Material volume (m^3)
A= Material area (m^2)
CoM= coefficient of material (unit of each material)

Table 4.3 *Coefficient of building material per working unit*

Simple houses			**Medium house**			**Luxurious houses**		
1 m^3 Stone foundation (1:5)			1 m^3 Stone foundation (1:4)			1 m^3 Stone foundation (1:3)		
Stone	1.2	m^3	Stone	1.2	m^3	Stone	1.2	m^3
cement	136	kg	cement	163	kg	cement	202	kg
Sand	0.544	m^3	Sand	0.52	m^3	Sand	0.485	m^3
1m^2 clay brick wall (1:5)			1m^2 clay brick wall (1:5)			1m^2 clay brick wall (1:4)		
clay brick	70	pieces	clay brick	70	pieces	clay brick	70	pieces
Cement	9.68	kg	Cement	9.68	kg	Cement	11.5	kg
Sand	0.045	m^3	Sand	0.045	m^3	Sand	0.043	m^3
1 m^2 plaster (1:5)			1 m^2 plaster (1:5)			1 m^2 plaster (1:4)		
Cement	5.184	kg	Cement	5.184	kg	Cement	6.24	kg
Sand	0.026	m^3	Sand	0.026	m^3	Sand	0.024	m^3
1 m^3 concrete K175			1 m^3 concrete K225			1 m^3 concrete K225		
Steel	135	kg	Steel	143	kg	Steel	143	kg
cement	326	kg	cement	371	kg	cement	371	kg
Sand	0.5	m^3	Sand	0.49	m^3	Sand	0.49	m^3
Stone	0.83	m^3	Stone	0.8	m^3	Stone	0.8	m^3
1m^2 paint of wall and ceiling			1m^2 paint of wall and ceiling			1m^2 paint of wall and ceiling		
paint	0.175	kg	paint	0.275	kg	paint	0.275	kg
1 m^2 clay roof			1 m^2 clay roof			1 m^2 Flat concrete roof tile		
clay roof	25	pieces	clay roof	25	pieces	concrete roof	18	pieces
1 m^2 gypsum			1 m^2 Gypsum ceiling			1 m^2 Gypsum ceiling		
gypsum	0.364	sheet	gypsum	0.364	sheet	gypsum	0.364	sheet
1 m^2 ceramic tile 30x30 cm			1 m^2 ceramic tile 30x30 cm			1 m^2 granite tile		
ceramic tile	11.87	unit	ceramic tile	11.87	unit	ceramic tile	1	m^2
cement	10	kg	cement	10	kg	cement	13	kg
Sand	0.045	m^3	Sand	0.045	m^3	Sand	0.03	kg
1 m^2 Cement (acian)			1 m^2 Cement (acian)			1 m^2 Cement (acian)		
cement	3.25	kg	cement	3.25	kg	cement	3.25	kg
1 m^2 ceiling wood			1 m^2 ceiling wood			1 m^2 ceiling wood		
wood	0.375	sheets	wood	0.375	sheets	wood	0.375	sheets

Source: Indonesia, 2010c; Building material inventory survey, 2012.

Table 4.3 shows the coefficient of building material per working unit. Building materials were converted to be units of each material utilizing these coefficients.

Table 4.4 *Material intensity for building material in Jakarta*

Materials	Unit	Simple houses		Medium houses		Luxurious houses	
		IDR/unit	Unit/million IDR	IDR/unit	Unit/million IDR	IDR/unit	Unit/million IDR
1. Stone	m^3	175000	5.71	175000	5.71	175000	5.71
2. Clay brick	pieces	325	307692	425	2352.94	425	2352.94
3. Concrete brick	pieces	1650	606.06	1650	606.06	2365	422.83
4. Cement	kg	1012	988.14	1060	943.40	1100	909.09
5. Sand	m^3	185000	5.41	185000	5.41	185000	5.41
6. Steel	kg	8800	113.64	8800	113.64	8800	113.64
7. Ceramic tile	m^2	31000	32.26	99000	10.10	166050	6.02
8. Clear glass	m^2	58000	17.24	58000	17.24	58000	17.24
9. Wood	m^3	2437995	0.41	3482850	0.29	4788250	0.21
10. Gypsum	sheets	74200	13.48	74200	13.48	74200	13.48
11. Paint	kg	10557	94.72	14208	70.38	15160	65.96
12. Clay roof	pieces	2500	400.00	2500	400.00	2500	400.00
13. Concrete roof	m^2	61534	16.25	61534	16.25	61534	16.25
14. Asbestos roof	pieces	44039	22.71	44039	22.71	44039	22.71
15. Zinc roof	pieces	50000	20.00	50000	20.00	50000	20.00

Table 4.5 *Material intensity for building material in Bandung*

Materials	Unit	Simple houses		Medium houses		Luxurious houses	
		IDR/unit	Unit/million IDR	IDR/unit	Unit/million IDR	IDR/unit	Unit/million IDR
1. Stone	m^3	142500	7.02	142500	7.02	142500	7.02
2. Clay brick	pieces	450	2222.22	450	2222.22	450	2222.22
3. Concrete brick	pieces	500	2000.00	500	2000.00	500	2000.00
4. Cement	kg	1075	930.23	1075	930.23	1075	930.23
5. Sand	m^3	157500	6.35	157500	6.35	157500	6.35
6. Steel	kg	9250	108.11	9250	108.11	9450	105.82
7. Ceramic tile	m^2	25500	39.22	96500	10.36	141500	7.07
8. Clear glass	m^2	62500	16.00	62500	16.00	62500	16.00
9. Wood	m^3	1275000	0.78	2450000	0.41	3850000	0.26
10. Gypsum	sheets	58500	17.09	58500	17.09	58500	17.09
11. Paint	kg	10750	93.02	14500	68.97	14500	68.97
12. Clay roof	pieces	1075	930.23	1075	930.23	1075	930.23
13. Concrete roof	m^2	71250	14.04	71250	14.04	71250	14.04
14. Asbestos roof	pieces	37250	26.85	37250	26.85	37250	26.85
15. Zinc roof	pieces	42500	23.53	42500	26.85	42500	26.85

Source: Indonesia, 2010c.

Then, unit of each material obtained from Table 4.3 was divided by price of each material obtained from Indonesia (2010) to calculate material intensity (Tables 4.4-4.5) as the following equation (4.32).

$$Mi = M / \text{million IDR} \qquad (4.32)$$

where:
Mi= material intensity (unit/1,000,000 IDR)
M= quantity of material for each unit (m^3/m^2/kg/pieces/sheet, etc)

During operation period, the relevant materials are exchanged (number of times) due to maintenance period according to the following formula:

$$\mathrm{M} = \frac{Ls_b}{Ls_m} - 1 \qquad (4.33)$$

Where:
M : maintenance (times)
Ls_b : Life span of building (years)
Ls_b : Life span of material (years)

The exact meaning of the concept 'life-span' in relation to product varies. Sometimes a product will be exchanged because it has expired or become worn out. In such case, the lifespan may be the technical life span, for instance the lifespan of white goods. In another case, a product might be replaced due to altered fashions (aesthetic lifespan). The building materials' life spans in this study were the combined lifespans of materials obtained from the surveys as follows

Table 4.6 *Lifespan of building materials for maintenance* (Main surveys, 2011 and 2012)

No	Material	Life-span (years)		
		Simple houses	Medium houses	Luxurious houses
1	Ceramic	15.6	25.0	20.2
2	Paint	6.4	4.7	4.2
3	Wood	26.9	23.7	24.6
4	Gypsum	0.0	0.0	21.6
5	Glass	17.0	29.9	24.0
6	Clay roof	27.6	21.8	23.9

The mathematical equations used to estimate material stock for urban houses are described below (example for Jakarta)

1) Current material stock in unplanned residential area

$$TS = \sum_i \sum_j S_{i,j} \times H_j \qquad (4.34)$$

Where:
TS: current total material stock of unplanned residential area (kg)
$S_{i,j}$: stock of material i, included in the house type j (kg)
i: shown in Table 1 shown in Table 4.4
j: house type (simple, medium and luxurious) shown in figures 5.23 and 5.30

H_j: number of household of house type j

$$S_{i,j} = \gamma_i\left(PI_{i,j} + MI_{i,j}\right) \tag{4.35}$$

Where:
γ_i: the density of material i (kg/m^3)
$PI_{i,j}$: volume of primary material i input for each type of house (m^3)
$MI_{i,j}$: maintenance volume of material i for each type of house (m^3)

$$H_j = \alpha \times \beta_j \frac{TP}{HS_j} \tag{4.36}$$

Where:
α: share of population live in unplanned residential area among the total population (Jakarta: 0.74, Bandung: 0.89)
β_j: current income distribution (low income (live in simple house): 0.75, medium income (live in medium house): 0.20, high income (live in luxurious house): 0.05)
TP: total population in 2010
HS_j: Averaged household size for each type of house

$$SA_{i,j} = S_{i,j} / F_j \tag{4.37}$$

Where:
$SA_{i,j}$: stock of material i per unit gross floor area in house type j (kg/m^2)
F_j: averaged gross floor area in house type j (m^2)

4.2.2. Building waste analysis

Buildings do not consume only material resources, water and energy but also generate waste and emitted CO_2 emissions, which become a significantly environmental problem in the whole building lifespan, from material extraction to the building's final disposal.

Generally, building waste consists of construction and demolition waste. Construction and demolition (C&D) waste is the waste produced during new construction, renovation and demolition of buildings and structures (HQ Air Force Center, 2006). The mathematical equation to estimate material waste as following equations.

1) Demolition waste of an each type of house
(100% waste versus promoting reused and recycled material use)

$$TWH_j = \sum_i W_{i,j} \tag{4.38}$$

Where:
TWH_j: total demolition waste of a house type j (kg)
$W_{i,j}$: demolition waste of material i from a house type j (kg)

$$W_{i,j} = S_{i,j}\left(1 - RU_{i,j} - RC_{i,j} - TR_{i,j}\right) \tag{4.39}$$

Where:
$S_{i,j}$: stock of material i, included in a house type j (kg)

$RU_{i,j}$: reuse ratio of material i, included in a house type j (scenario)
$RC_{i,j}$: recycle ratio of material i, included in a house type j (scenario)
$TR_{i,j}$: treatment ratio of material i, included in a house type j (scenario)

$$WA_{i,j} = W_{i,j} / F_j \tag{4.40}$$

Where:
$WA_{i,j}$: demolition waste i per unit gross floor area of a house type j (kg/m^2)
F_{simple}: averaged gross floor area of a house type j (m^2)

2) Virgin materials

(100% virgin material input versus promoting reused and recycled material use)

$$S^R_{i,j} = \sum_i \left\{ PI_{i,j}\left(1 - RU^P_{i,j} - RC^P_{i,j}\right) + MI_{i,j}\left(1 - RU^M_{i,j} - RC^M_{i,j}\right) \right\} \tag{4.41}$$

Where:
$S_{i,j}^R$: Stock of virgin material i in a house type j (kg)
$RU_{i,j}^P$: reuse ratio of primary input (construction)
$RC_{i,j}^P$: recycle ratio of primary input (construction)
$RU_{i,j}^M$: reuse ratio of secondary input (maintenance)
$RC_{i,j}^M$: recycle ratio of secondary input (maintenance)

By using the above equation, embodied energy and CO_2 emissions of an each type of house can be calculated.

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.

$$LCE = EE_i + EE_{rec} + (OE \times lifespan) \tag{4.42}$$

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 (Gustavsson and Joelsson, 2010). For the above reason, both embodied and operational energy were measured in the form of primary energy in this study

4.3 Embodied energy and input-output analyses

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 (Dixit et al., 2010). The process-based method models different activities associated with a product or a service using process flow diagrams from downstream to upstream. The previous studies using this method include Kurdi (2006), Monahan and Powel (2011), Thomark (2002), and Utama and Gheewala (2009, 2008). All materials and energy used in the process are identified. Thus, the environmental impacts and emissions can be estimated accounting for production of the materials and consumption of the energy. Therefore, this method is considered to be specific, detailed, and reliable, while generally based on incomplete system boundaries.

The economic I-O analysis-based method is, literally, the means using the I-O table, which presents the exchange of goods and services among industrial sectors in matrix form. There are also a number of researches using this method, such as Fujita et al. (2009), Norman et al. (2006), and Suzuki and Oka (1998). This method is more complete in system boundaries but lacks of process specificity. Further, the hybrid-based method attempts to overcome the disadvantages of the above two methods while combining their advantages (Crawford and Treloar, 2005; Mithraratne and Vale, 2004).

Since it is impossible to trace all the processes unlike the process-based or the hybrid-based methods, mainly due to difficulties in obtaining necessary data, some studies adopted the I-O analysis-based method to calculate the embodied energy and estimate their CO_2 emissions. This is because this method is considered more appropriate and effective under relatively poor data availability condition such as in Indonesia.

However, when applied in LCA, input-output analysis exhibits various errors that are a consequence of data aggregation, or related to methodological aspects such as underlying linearity and proportionality assumptions. For example, the results of previous LCA study (Surahman and Kubota, 2012) using national I-O table 2005 for analysis of I-O table in order to calculate embodied energy of building materials in Jakarta and Bandung, Indonesia, showed different values and big gap compared with values derived from I-O analyses using inter-regional and local I-O tables. These different results may be caused by the inherent aggregation errors of I-O tables itself.

4.3.1. Procedure of input-output analysis

Fig. 4.7 illustrates the procedure of the embodied energy analysis employed in this dissertation.

a. Embodied energy intensity of domestic product:

$$E_{dm} = e_{dm}(I - (I-M)A)^{-1} \tag{4.43}$$

where:

E_{dm} : embodied energy intensity sector n (GJ/million IDR)
e_{dm} : direct environmental burden per unit production in sector n (GJ/million IDR)
M : import matrix
$(I-(I-M)A)^{-1}$: domestic Leontief inverse matrix of I-O table

b. Embodied energy intensity of imported product:

$$E_{im} = e_{im}(I-A)^{-1} \tag{4.44}$$

where:
E_{im} : embodied energy intensity sector n (GJ/million IDR.)
e_{im} : direct environmental burden per unit production in sector n (GJ/million IDR)
I : Identity matrix
A : input-coefficient matrix
$(I\text{-}A)^{-1}$: imported Leontief inverse matrix of I-O table

Calculation procedure for leontief imported and domestic inverse matrixes:
1. Preparing I-O table of Indonesia 2005 comprising 175 x 175 sectors.
2. Determining Identity matrix (I)
3. Determining Input-coefficient matrix (A) by dividing sector unit by total input
4. Determining (I-A) matrix
5. Determining Leontief Inverse matrix $(I\text{-}A)^{-1}$
6. Determining Import ratio (m) by dividing total import by total domestic demand
7. Determining Import matrix (M)
8. Determining (I-M) matrix
9. Determining (I-M) A matrix
10. Determining (I-(I-M) A) matrix
11. Determining $(I\text{-}(I\text{-}M)\,A)^{-1}$ matrix

Calculation procedure for direct environmental burdens per unit production in sector *n*:
12. Determining matrix of Indonesian fuel consumption (m)
13. Determining matrix of the net contribution rate of energy (r)
14. Determining calorific value of respective energy consumed (q)
15a. Determining direct environmental burden by multiplying energy consumed with net contribution rate and calorific value each sector (GJ)
15b. Converting secondary energy of electricity to primary energy
16. Total direct environmental burden each sector (h) is the sum of energy consumed each sector, which is calculated by multiplying consumption of fuels (m) by the net contribution rate (r) and calorific value (q) each sector. By dividing the above results with total input or output each sector, we will find direct environmental burden per million IDR (GJ/million IDR).

$$\text{h/million IDR} = \Sigma\,(m\ .\ r\ .\ q)\ /\ \text{Total input} \qquad (4.45)$$

Calculation procedure to estimate imported and domestic embodied energy intensity
17. Determining imported embodied energy intensity by multiplying direct environmental burden per million IDR (16) by imported Leontief invers matrix (5) (GJ/million IDR).
18. Determining domestic embodied energy intensity by multiplying direct environmental burden per million IDR (16) by domestic Leontief invers matrix (11) (GJ/million IDR).

Calculation procedure to estimate domestic/imported CO_2 emission intensity
19. Determining CO_2 emissions factor for respective energy sources used
20. Determining emission amounts of CO_2 for each sector by multiplying the direct environmental burden (h) with the emission factors above (kg). Total CO_2 emissions intensity each sector (h) is obtain by summing CO_2 emissions intensity each sector and divided by total input or output (kg/million IDR)

21. Determining the imported CO_2 emissions intensity by multiplying the emission amounts of CO_2 intensity each sector (20) by imported Leontief inverse matrix (5) (kg/million IDR).
22. Determining the domestic CO_2 emissions intensity by multiplying the emission amounts of CO_2 intensity each sector (20) by domestic Leontief inverse matrix (11) (kg/million IDR

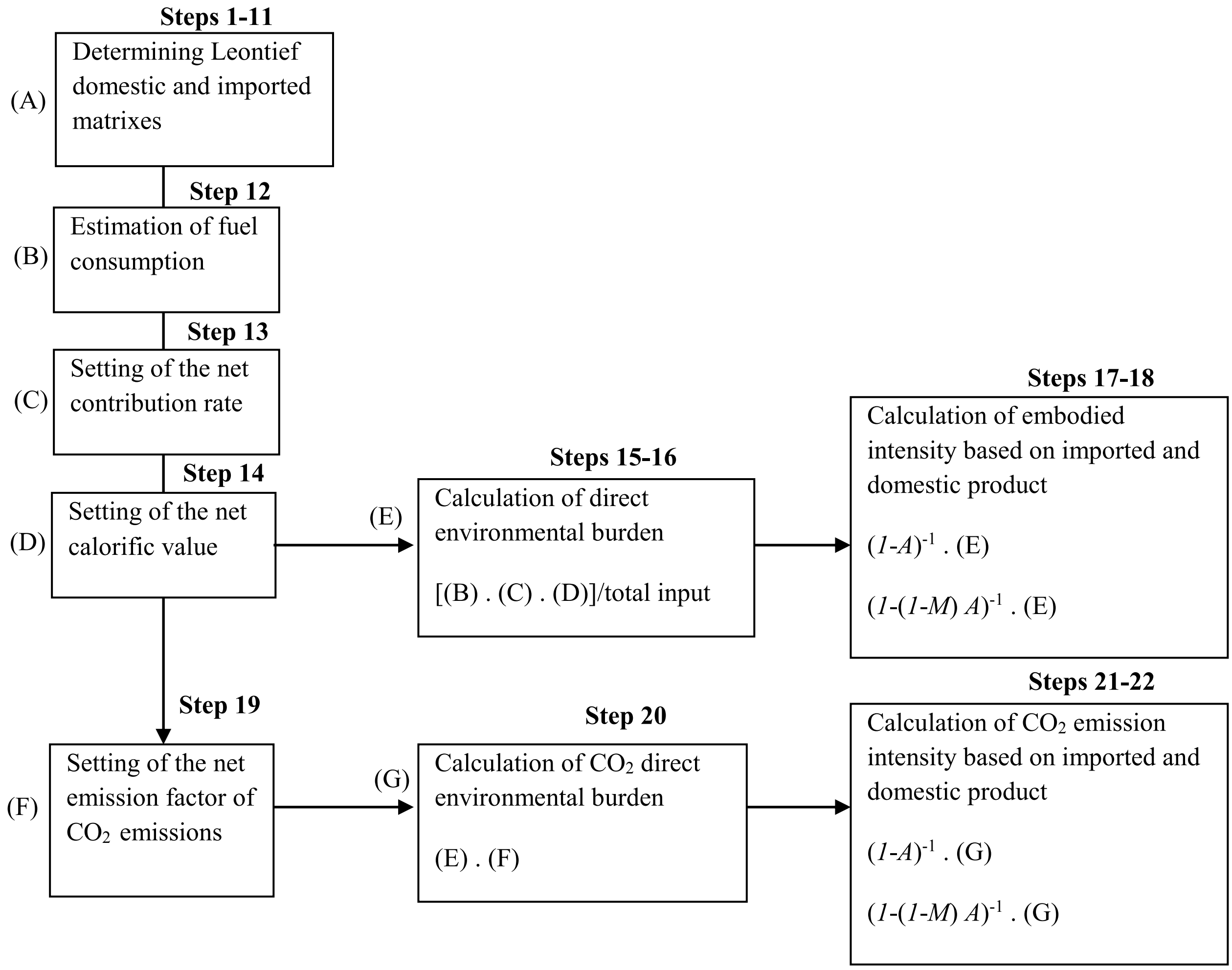


Fig. 4.7 *Detailed flow chart of calculation procedure for estimating embodied energy and emission intensities by using I-O analysis-based method*
Source: Nansai K., Moriguchi Y., and Tohno S., 2002, Embodied Energy and Emission Intensity Data for Japan Using I-O Tables, CGER Report, ISSN 1341-4356, Japan.

The embodied energy was obtained by integrating energy intensity derived from I-O analysis with material intensity derived from data obtained from the building inventory survey. The mathematical equations used to estimate embodied energy and CO_2 emissions of building materials are described below

$$E_{total} = \sum_{i}^{n} \left(E_{dm_{category}} + E_{im_{category}}\right) \quad (4.46)$$

$$E_{dm_{category}} = \sum_{i}^{n} \left[\left(\frac{e.(I-(I-M).A)^{-1}}{M_{category}} \right)_i . U_i \right] \quad (4.47)$$

$$E_{im_{category}} = \sum_{i}^{n} \left[\left(\frac{e.(I-A)^{-1}}{M_{category}} \right)_i . U_i \right] \quad (4.48)$$

where E_{total} is the total embodied energy of unplanned houses (GJ), $E_{im_{category}}$ is the total imported embodied energy of each house category(GJ) derived from Eq. 10. $E_{dm_{category}}$ is the total domestic embodied energy of each house category (GJ) derived from Eq. 11. e_i is the direct energy consumption of material *i* (GJ/million IDR), $(I-A)^{-1}{}_i$ is the imported Leontief inverse matrix of material *i*, $(I-(I-M).A)^{-1}{}_i$ is the domestic Leontief inverse matrix of material *i*. *I* is the identity matrix, *A* is the coefficient matrix and *M* is the total import coefficient matrix. $M_{category\,i}$ is the material intensity of material *i* of each house category (unit/million IDR) and U_i is the unit of materials used. Meanwhile, the estimation of CO_2 emission was calculated by the following equation

$$ECO_{2_{total}} = \sum_{i}^{n} \left(ECO_{2_{dm\ category}} + ECO_{2_{im\ category}}\right) \quad (4.49)$$

$$ECO_{2dm_{category}} = \sum_{i}^{n} \left[\left(\frac{eCO_2.(I-(I-M)\times A)^{-1}}{M_{category}} \right)_i . U_i \right] \quad (4.50)$$

$$ECO_{2_{im\ category}} = \sum_{i}^{n} \left[\left(\frac{eCO_2.(I-A)^{-1}}{M_{category}} \right)_i . U_i \right] \quad (4.51)$$

Where $ECO_{2_{total}}$ is the total embodied CO_2 emissions of unplanned houses (ton CO_2-eq). $ECO_{2_{im\,category}}$ is the imported embodied CO_2 emissions of each house category (ton CO_2-eq) derived from Eq. 13. $ECO_{2dm_{category}}$ is the domestic embodied CO_2 emissions of each house category (ton CO_2-eq) derived from Eq. 14. eCO_{2_i} is the direct CO_2 emissions of material *i* (ton CO_2-eq/million IDR).

4.3.2 Input-output tables in Indonesia

Input-Output Analysis was introduced by Wassily Leontief in 1973 and since then has become a powerful tool for economic planning. Input-output Analysis is based on Input-output tables which are useful tools for the projection of emissions, or analysis of emission structure, and economic planning (Miller and Blair, 1985). Input-output tables present economic exchanges of goods and services among industrial sectors in matrix form. Most of the tables actually available are specified in monetary units. For example, energy and resource flows among industries can be analyzed on the assumption that goods are transferred in direct proportion to their monetary value. Methods for calculating the energy that is consumed to produce a final product, including indirect consumption by upstream industries such as the component and material industries, are known as energy analyses (Pan and Kraines, 2001; Lenzen, 1998). Input-output tables have been frequently applied to analyses of environmental issues. Liang et al. (2006) developed a multi-regional input–

output model for regional energy requirements and used it to estimate CO2 emissions in China. Another study assessed the "Life cycle GHG emission analysis of power generation systems in the Japanese context" (Honda, 2005). The embodied carbon emissions from the material content have also been estimated using the Japanese Input-Output Table (Nishimura et al., 1997). Researchers in other nations have also carried out similar studies for their national economies (Crawford et al., 2006; Eddie et al., 2006; Peters and Hertwich, 2006). However, only one such similar study in which the embedded energy and CO2 emissions of residential building materials within Indonesia using I-O analysis method was assessed exists for Indonesia (Surahman and Kubota, 2012). The study only evaluated energy and emission of CO2 for residential building materials in Bandung.

Generally, Indonesia has three forms of I-O table, namely national I-O table, local I-O table and inter-regional I-O table. Two first are single row input-output table (SRIO) and the third is multi-regional input-output table (MRIO). National I-O table is represented by Indonesia I-O table 2005 having 175 sectors of products and services (Indonesia, 2010). Local I-O tables include Jakarta and Bandung I-O tables. Jakarta I-O table is presented by Jakarta I-O table 2006 having 87 sectors of product and services (Jakarta, 2010). Meanwhile, Bandung I-O table 2008 has 54 sectors of product and services (Bandung, 2010). MRIO is presented by Inter-Regional I-O table 2005 comprising 35 sectors of product and services for five regions, namely Sumatera, Java-Bali, Kalimantan, Sulawesi and East Indonesia (Resosudarmo, 2010). However, some errors inherent in the I-O table are often significant to effect the values of embodied energy.

In the past, researchers have used a number of techniques to evaluate the various method of embodied energy analysis. These have included error analysis, gap analysis and comparative analysis (Treloar, 1998; Lenzen, 2001). Error analysis is used to assess the error associated with the use of input-output data (Lenzen, 2001,2000).

4.3.3 Inherent errors of I-O table

Although able to cover an infinite number of production stages in an elegant way, input-output analysis suffers from uncertainties arising from the following sources: (1) uncertainties of basic source data due to sampling, reporting and imputation errors, and uncertainties resulting from, (2) the assumption made in single-region input-output models that foreign industries producing competing imports exhibit the same factor multipliers as domestic industries, (3) the assumption that foreign industries are perfectly homogeneous, (4) the estimation of flow tables for domestically produced and imported capital commodities, (5) the assumption of proportionality between monetary and physical flows, (6) the aggregation of input-output data over different producers, (7) the aggregation of input-output data over different products supplied by one industry, and (8) the truncation of the "gate to grave" component of the full life cycle (Lenzen, 2001).

Source Data Uncertainty

National Accounts and input-output tables are compiled from data collected in industry surveys. Although standard errors exist for survey data, it is generally not possible to provide exact information on the accuracy of national accounts and input-output tables, because the initial survey data undergo a number of transformations.

Imports Assumption Uncertainty

Commodities produced by foreign industries can exhibit factor inputs that differ significantly from those of domestically produced commodities. For example, the output of the motor vehicles industry consists partly of assembly work undertaken in Indonesia, whereas imports consist only of vehicles and vehicle parts. Thus, by assuming equal energy multipliers for foreign and domestic motor vehicle industries, the energy embodied in motor vehicle imports is, in this case, underestimated. A lack of available information makes it necessary to assume that foreign industries are perfectly homogeneous; that is, that they produce only one (the primary) commodity type.

Estimation Uncertainty for Capital Flow

The Indonesian Statistical Centre does not compile capital flow tables, so these have to be constructed by reconciling aggregates and industry totals of gross fixed capital expenditure from disparate sources (Indonesia, 2010). The uncertainties associated with constructing a flow table purely from totals can be approximated as follows. Industry totals are a sum over about n=175 row or column entries, and have standard errors of about Δ =5%. The standard error of the row or column entries is at minimum when all entries are of the same magnitude. The standard error is then about $\sqrt{n} \times \Delta$=50%, which can be taken as a lower limit for standard errors of capital flow estimates

Proportionality Assumption Uncertainty

Using monetary input-output tables for the calculation of multipliers of physical quantities implies that the physical flow of commodities between industries can be represented by the monetary values of the corresponding inter-industrial transactions. For example, the content of 100 A IDR of electricity supplied to aluminum smelters is assumed to be equal to the energy in 100 A IDR of electricity supplied to travel agencies. Electricity prices vary considerably among industries, however, which violates the proportionality assumption. The associated uncertainty can in principle be overcome by replacing monetary entries in all basic input-output tables with entries in physical units.

Aggregation Uncertainty

Input-output and factor data are generally aggregated over a number of producers within one industry. The fact that the number and identity of producers involved in a particular inter-industrial transaction is generally unknown leads to uncertainties in factor multipliers. In general, this uncertainty depends on the geographical and technological variability of production in the respective industry sector. Production scale may also influence factor multipliers, but this could not be confirmed by Hanssen and Asbjornsen (1996), who found "only minor differences between small and large pulp and paper plants in environmental efficiency." Consider the case of energy as a factor to be analyzed. One path contributing to the total energy multiplier of iron-ore mining, for example, is the amount of energy required for the railway transport of iron ores.

Allocation Uncertainty

Entries in input-output tables represent transactions of whole industry classes, and are aggregated over the product range in the respective class. This aggregation is equivalent to assuming that each industry class is perfectly homogeneous with regard to its product range, that is, it produces only one type of commodity. This assumption clearly ignores product diversity and joint production between industries, and leads to an *allocation uncertainty* in input-output data, if the corresponding inter-industrial transaction involves only a few product types out of the whole output range of the supplying industry.

Gate-to-Grave Truncation Error

Input-output analysis considers only factor requirements for the provision of commodities (the "cradle-to-gate" period), but not for downstream components of the full life cycle, including use of maintenance, decommissioning, demolition, disposal, or recycling (the "gate-to-grave" period). This omission causes a systematic *gate-to-grave truncation error*, which can, however, easily be avoided. If the use or end-of-life of a commodity is associated with a significant life-cycle impact (the use of a motor vehicle, for example), the corresponding inputs (fuel, lubricants, spare parts, servicing, insurance, registration, road construction and maintenance, street lighting, scrapping) can be assessed separately using input-output–based multipliers (Joshi, 2000).

Determining selected I-O table used for I-O analysis method

As explained above, Generally, Indonesia has three forms of I-O table, namely national I-O table, local I-O table and inter-regional I-O table. Two first are single row input-output table (SRIO) and the third is multi-regional input-output table (MRIO). National I-O table is represented by Indonesia I-O table 2005 having 175 sectors of products and services (Indonesia, 2010). Local I-O tables include Jakarta and Bandung I-O tables. Jakarta I-O table is presented by Jakarta I-O table 2006 having 87 sectors of product and services (Jakarta, 2010). Meanwhile, Bandung I-O table 2008 has 54 sectors of product and services (Bandung, 2010). MRIO is presented by Inter-Regional I-O table 2005 comprising 35 sectors of product and services for five regions, namely Sumatera, Java-Bali, Kalimantan, Sulawesi and East Indonesia (Resosudarmo, 2010).

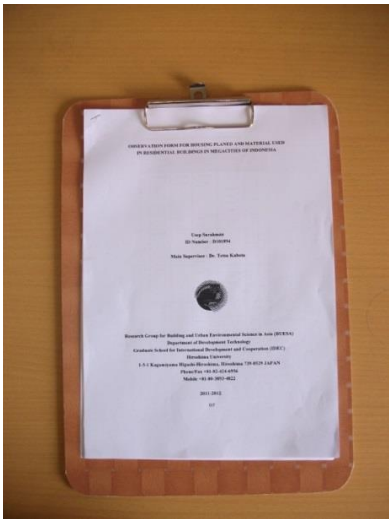
SRIO which is comprised Indonesia and Jakarta/Bandung I-O table is used to assess energy intensity of product or services in particular region. In contrast, MRIO is used to assess energy intensity of product or services in different region in order to find out which region has higher/lower energy intensity. The essence of MRIO model is that it includes impacts in one region that are caused by changes in another region. Therefore, MRIO is more appropriate to be applied for investment analysis. Since Bandung and Jakarta are located in the same region, Java, MRIO is not appropriate to be applied in the analysis of embodied energy for building materials of residential buildings in Jakarta and Bandung.

However, energy intensity derived from Jakarta/Bandung I-O analysis is higher that energy intensity derived from Indonesia I-O table. Therefore this study investigated the energy intensity difference by aggregating both SRIO in the same number of sector, 82 sectors. It was found that most of energy intensity of each product and services derived from Jakarta/Bandung I-O analysis were much higher that energy intensities derived from Indonesia I-O analysis. This investigation obviously show that the big difference of energy intensities between two I-O analysis is caused by aggregation error/bias. Thus, this study selected Indonesia I-O table 2005 more appropriate to apply as a method to analyze embodied energy/CO2 emissions for building materials of residential buildings in Jakarta and Bandung.

4.4 Analysis of household energy consumption

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 (Figs. 4.8-4.9). The material inventory data for refurbishment were also obtained during the same interviews

Energy consumption for respective household appliances was estimated through multiplying the number of appliances by their usage time and electric capacity, which were acquired through the said interviews and measurements.



(a)

(b)

(c)

Fig. 4.8 *Measurement equipment;*
(b) Questionnaire of household energy consumption survey; (b) Watt checker; (c) Data logger (thermo recorder)

Fig. 4.9 *On-site measurements for household energy consumption survey.*

$$aE = N \cdot t \cdot C \quad \text{……………………………………………………………..(4.52)}$$

aE= annual energy consumption (kWh)
N = number of appliances (unit)
t = usage time (hour(s)) per year
C = Capacity of appliance (kW)

Then operational energy is energy consumed in the whole building's life-span as following equation.

$OE = aE \cdot ls$ ………………………………………………..…………(4.53)

OE= operational energy (kWh)
aE = annual energy consumption (kWh)
ls = life-span of building (years)

The primary energy used for electricity in Indonesia comprised 42% of coal, 17% of oil, 28% of natural gas, 10% of hydro and 3% of geothermal as of 2010 (Indonesia, 2010b; IEA, 2012a). The electricity consumption was converted into primary energy by considering the above energy mix, electric efficiencies and transmission losses. The annual average household energy consumption was then calculated by combining consumption for all the appliances. As described earlier, the seasonal variation in climatic conditions is not large in Bandung. Therefore, the usage time of appliances was assumed to be constant throughout the year. Nevertheless, the small seasonal changes of air temperature and humidity were considered in the estimation of energy consumption caused by air-conditioners and refrigerators, though the resultant changes were found to be negligible.

Calculation of effective electric efficiency and conversion factor of CO2 emissions for primary energy in Indonesia based on data in 2010

$$\varepsilon_{EE} = \frac{P + (H \cdot s)}{I} \qquad \text{…………………………………………………….(4.54)}$$

Where:
ε_{EE}: effective electric efficiency (%)
P : total output electricity (GWh)
H : heat output of CHP plants (GWh)
s : correction factor that adjust for the amount of electricity that would have been produced in the absence of demand for heating
I : total primary energy input (GWh)
Source: Maruyama and Eckelman, 2009

H and s is negligible because Indonesia does not use combined heat and power (CHP) plants to generate electricity. Therefore, we obtained P and I (IEA, 2012)
Electricity in Indonesia is generated from several sources, i.e. coal, oil, natural gas, hydro, geothermal and biofuels
1 Mtoe = 11630 GWh .
Energy wasted when electricity is transferred from electricity generation plant to end user is 9.89% (Indonesia (PLN), 2010)
We obtained that total electricity efficiency for real energy share received by end user is 0.3655. Therefore,

$Es = 0.3655 \cdot Ep$ ……………………………………………………..……(4.55)
Where:
Es= Secondary energy (kWh)
Ep= primary energy (kWh)

Validation of household energy consumption data

The quality of household energy consumption data especially derived from electricity source was determined by comparing data obtained from measurement with data obtained from monthly electricity bill in secondary energy form. This study also compare the household energy consumption obtained with the energy consumption of other studies.

4.5 Scenario analysis

The current reused and recycled building material data were not used in this study. This is because the data were obtained from interview activities, which were highly dependent on respondents' remembrance and considered inaccurate. Therefore, two scenarios by minimum and maximum reuse/recycling rate of materials were applied to evaluate future demolition waste, embodied energy/CO_2 emissions.

The common method to analyze future demolition waste is to use building cohort analysis. Unfortunately, the demolished building data were not available. Therefore, this study designed scenarios to predict future demolition waste and total floor area by various reuse/recycling rate of materials by 2020, which will be discussed in the next chapter. The mathematical equations used to estimate future demolition waste for urban houses by 2020 are described below.

1) Future demolition waste in unplanned residential area in 2020

$$TW = \sum_{i} W_{i,simple} \times H_{simple} \times \eta_{simple} \tag{4.56}$$

TW: total demolition waste of unplanned residential area in 2020 (kg)
(assumption: medium and luxurious houses will not be demolished by 2020.)
$W_{i,simple}$: demolition waste of material i from a simple house (kg)
η_{simple}: demolition ratio of simple house by 2020

$$W_{i,simple} = S_{i,simple} \tag{4.57}$$

Where:
$S_{i,simple}$: stock of material i, included in a simple house (kg)

$$\eta_{simple} = \frac{\beta_{simple} - \beta^{F}_{simple}}{\beta_{simple}} \tag{4.58}$$

$\beta_{simple}{}^{F}$: income distribution in 2020 (low income: 0.23)

$$WA_{i,simple} = W_{i,simple} / F_{simple} \tag{4.59}$$

Where:
$WA_{i,simple}$: demolition waste i per unit gross floor area in a simple house (kg/m^2)
F_{simple} : averaged gross floor area of a simple house (m^2)

2) Future expansion of unplanned residential area

The mathematical equation used to estimate urban expansion due to demolition of unplanned houses in 2020 are described as follows.

$$FE = \left(F_{medium} \square F_{simple}\right) \times H_{simple} \times \square_{simple} \qquad (4.60)$$

Where:
FE: future urban expansion in 2020 (m^2)
F_{medium}: averaged gross floor area of a medium house (m^2)
In this analysis, it is assumed that:
1) a demolished simple house will be a medium house in unplanned residential area by 2020
2) increasing households from 2010 to 2020 will live in planned residential area

4.6 Summary

- The pilot survey was conducted in the city of Bandung in order to initiate the development of LCA model, which can be used under relatively poor data availability conditions. Then two main surveys were conducted in Bandung (n=247) in 2011 and in Jakarta (n=297) in 2012.
- It was found that generally, the detailed environmental and economic data were only available at the national level in Indonesia.
- The actual on-site building measurement was conducted to obtain building material inventory data because most of the residential buildings in Bandung were constructed not in formal way. Moreover, household energy consumption data were acquired by the actual survey because of the unavailability of the energy consumption data record.
- Unit of building materials were calculated for each materials and converted using density or coefficient of working unit. Material intensity was obtained by dividing unit materials with its price.
- Embodied energy of building materials was obtained by integrating embodied energy intensity derived from I-O analysis with material intensity derived from the results of building material inventory survey.
- Annual household energy consumption was obtained by multiplying number of appliances by their capacities and time usage of appliances.
- Embodied energy and household energy consumption were measured in primary energy unit.
- Both embodied energy and household energy consumption were compared with the values of other studies.
- Scenario analysis were conducted to evaluate future demolition waste including future total floor area for residential buildings by various reuse/recycling rates of building materials.

5

Profiles of sample houses

In the previous chapter, the study explained the methods how to obtain two necessary data for life cycle assessment in buildings, i.e. building material inventory data and household energy consumption profiles through a pilot survey in Bandung. Through these methods, two main surveys were conducted to obtain the above both data in order to analyze life cycle energy and CO_2 emissions profiles in the major cities of Indonesia, in Bandung and Jakarta. This chapter describes profiles of sample houses in Jakarta and Bandung comprising demographic and social profiles as well as residential building types. The samples can be grouped by house category and household clusters based on their socio-economic and demographic characteristics. Section 5.1 describes profiles of sample houses by house category and section 5.2 explains classification of household utilizing factor analysis and cluster analysis (household clusters).

5.1 Profiles of sample by house category

5.1.1 Demographic and social profiles

Demographic and social factors obtained in the main surveys in Jakarta and Bandung encompassed gender, age, relationship to the household, ethnic group, civil status, occupation, highest educational attainment, monthly income and average daily staying in the house (see appendixes 1 and 2).

Jakarta city

A total of 300 residential buildings were selected in the survey. Three samples were selected as outliers. Therefore they were excluded from the analysis and became 297 samples. The samples of Jakarta were classified in to three categories namely, simple (125 samples), medium (115 samples) and luxurious (57 samples) households. These samples were analyzed their demographic and social profiles as explained below

As shown in Table 5.1, 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 5.1** Summary of brief profile of sample houses in Jakarta.*

	Simple house	Medium house	Luxurious house	Whole sample
Sample size	125	115	57	297
(Unplanned/planned)	(125/0)	(75/40)	(29/28)	(230/67)
Gender (%)				
Female	40.0	53.9	61.4	49.5
Male	60.0	46.1	38.6	50.5
Age (%)				
<40 (years)	31.2	17.4	10.5	21.9
40-49	32.0	37.4	29.8	33.7
50-60	26.4	30.4	49.2	32.3
>60	10.4	14.8	10.5	12.1
Household size (persons)	4.3	4.5	5.3	4.5
Monthly household income (%)				
< 1 million (IDR)	4.8	1.7	1.8	3.0
1-4 million	76.8	59.1	19.2	58.9
5-10 million	16.8	31.3	38.6	26.6
>10 million	1.6	7.9	40.4	11.5
Total floor area (%)				
<50 (m^2)	71.2	9.6	0.0	33.7
50 - 99	20.0	51.3	0.0	28.3
100 - 300	8.8	36.5	84.2	34.0
> 300	0.0	2.6	15.8	4.0
Major building materials				
Structure	Concrete (100%)	Concrete (100%)	Concrete (100%)	Concrete (100%)
Foundation	Stone (76%) Concrete (24%)	Stone (37%) Concrete (53%)	Stone (22%) Concrete (78%)	Stone (54%) Concrete (46%)
Floor	Cement (80%) Ceramic (20%)	Cement (0%) Ceramic (100%)	Cement (0%) Ceramic (100%)	Cement (33%) Ceramic (77%)
Walls	Clay brick (100%)	Clay brick (100%)	Clay brick (100%)	Clay brick (100%)
Roof	Clay tile (48%) Concrete tile (0%) Zinc roof (6%) Asbestos (46%)	Clay tile (79%) Concrete tile (0%) Zinc roof (1%) Asbestos (20%)	Clay tile (0%) Concrete tile (97%) Zinc roof (0%) Asbestos (3%)	Clay tile (51%) Concrete tile (19%) Zinc roof (3%) Asbestos (27%)

As shown in Table 5.1, 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.

The detail statistical data of demographic and social factor of samples are as follows:

1) Household size

Fig. 5.1 show household size by house category. As shown, the average of household member in simple house was 4.3 persons (Fig. 5.1a) comprising 2.7 elderly and 1.6 children (Fig. 5.2). The biggest was 10 persons (0.8%) and the smallest was 2 persons (6.4%). Most of the households had 4 persons (32.8%). The average of household member in medium house was 4.5 persons comprising 2.9 elderly and 1.6 children. The biggest was 15 persons (0.9%) and the smallest 1 persons (0.9%). Most of the households have 4 persons (31.3%). The average of household member in luxurious houses was 5.3 persons comprising 3.7 elderly and 1.6 children (Fig. 5.2). The biggest was 10 persons (1.8%) and the smallest 2 persons (1.8%). Most of the households have 6 persons (24.6%).

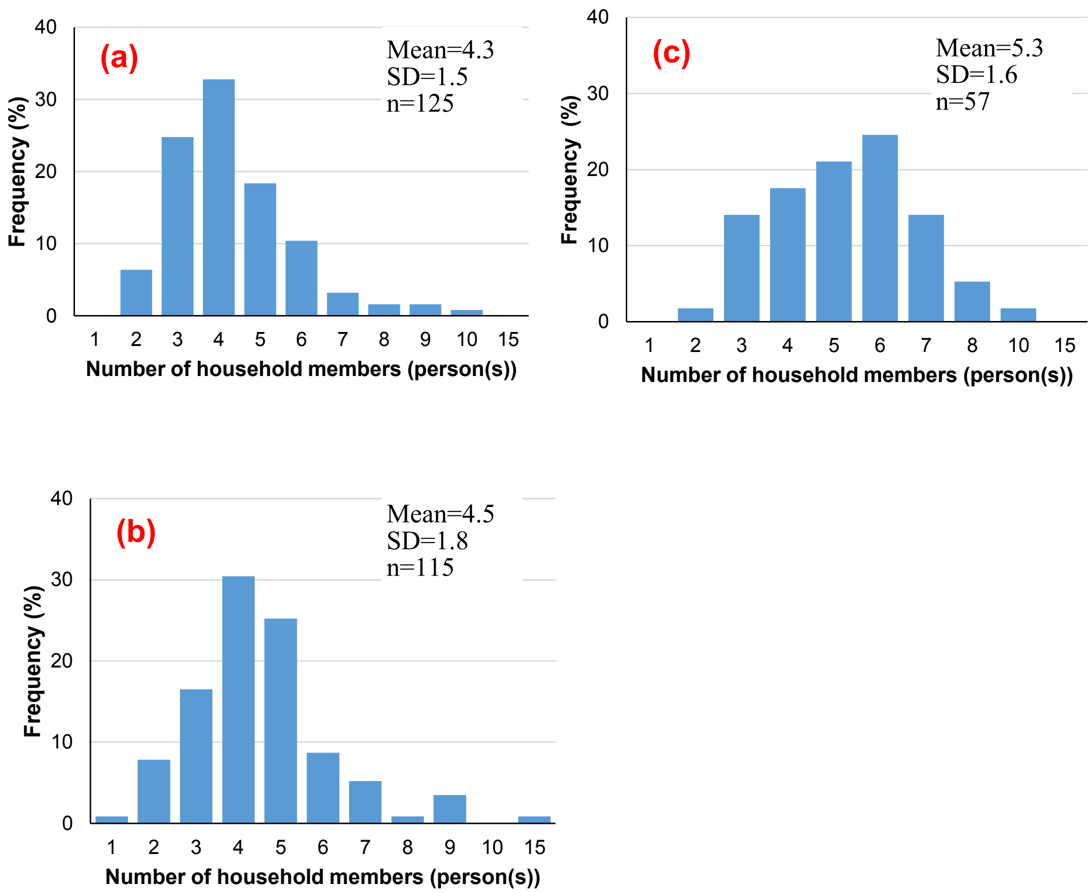


Fig. 5.1 *Household size by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

2) Elderly and children

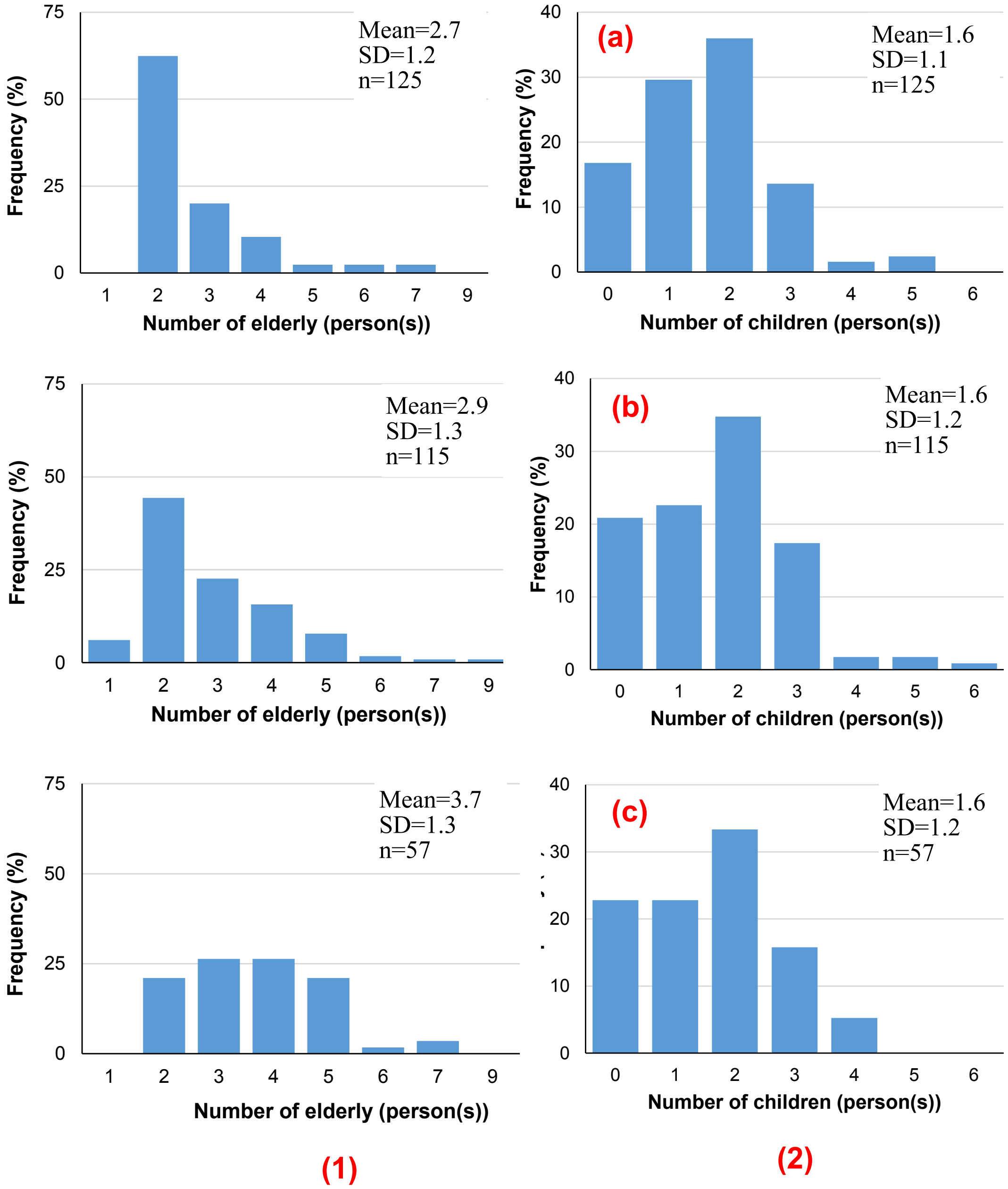


Fig. 5.2 *Number of (1) elderly; (2) children by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

.

3) Ethnic

4) As shown in Fig. 5.3, most of the simple households were Betawi ethnic (47.2%), followed by Javanese (32%) and Sundanese (20.8%). Meanwhile, most of the medium households were Betawi ethnic (54.8%), followed by Javanese (32.2%) and Sundanese (13.0%). In the luxurious households Betawi ethnic were the largest (63.2%), followed by Javanese (24.6%) and Sundanese (12.3%).

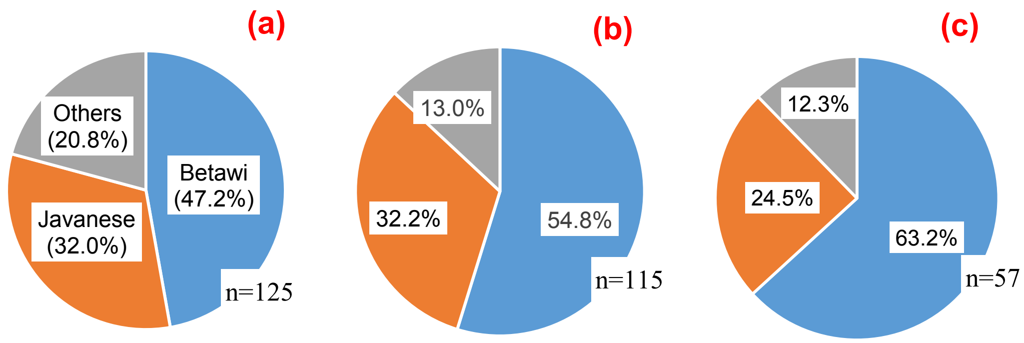


Fig. 5.3 *Ethnic by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

5) Number of households

Most of the sample of simple houses has 1 households in one house (86.4%) and two households was the rest (13.6%) with the average 1.1 households. Most of the sample of medium houses has 1 households in one house (79.1%) and two households was the rest (20.9%) with the average 1.2 households. Most of the sample of luxurious houses has 1 households in one house (82.5%) and two households was the rest (15.8%) with the average 1.2 households (see Fig. 5.4).

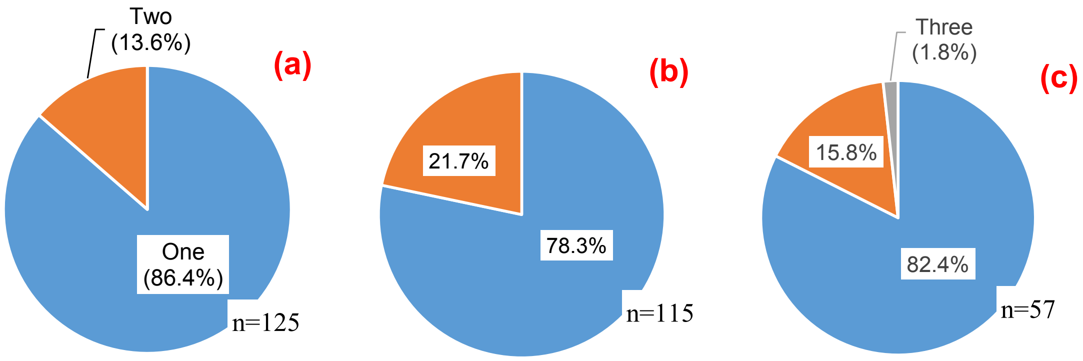


Fig. 5.4 *Number of household by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

6) Head's occupation

Fig. 5.5 shows head's occupation by house category. Private employee accounted the most of kind occupations (53.6/39.1%) which belong to the head's family followed by private temporary employee (24/21.7%), etc. for simple/medium houses, respectively. On the other hand, for luxurious houses, government employee accounted 35.1% followed by private employee (26.3%), private temporary employee (17.5%), etc.

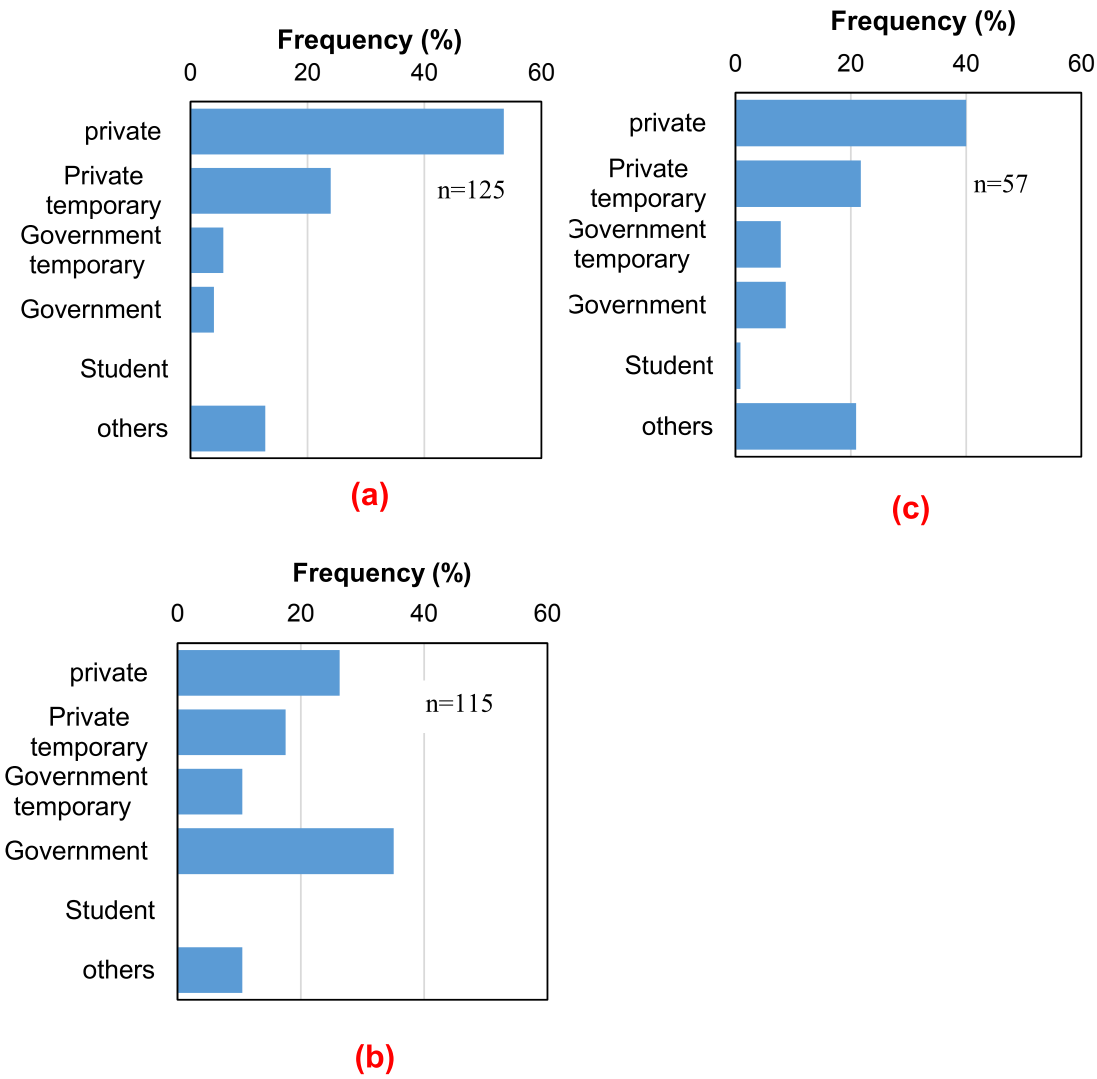


Fig. 5.5 *Head's occupation by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

7) Head's highest education attainment

Most of the head's highest educational attainment was senior high school (47.2%), followed by Junior high school (21.6%), etc. for simple houses. In medium houses, most of the head's highest educational attainment was senior high school (37.4%), followed by graduate (27.8%), etc. For luxurious houses, Graduate accounted the largest (57.9%), followed by senior high school (14.0%), etc. (see Fig. 5.6).

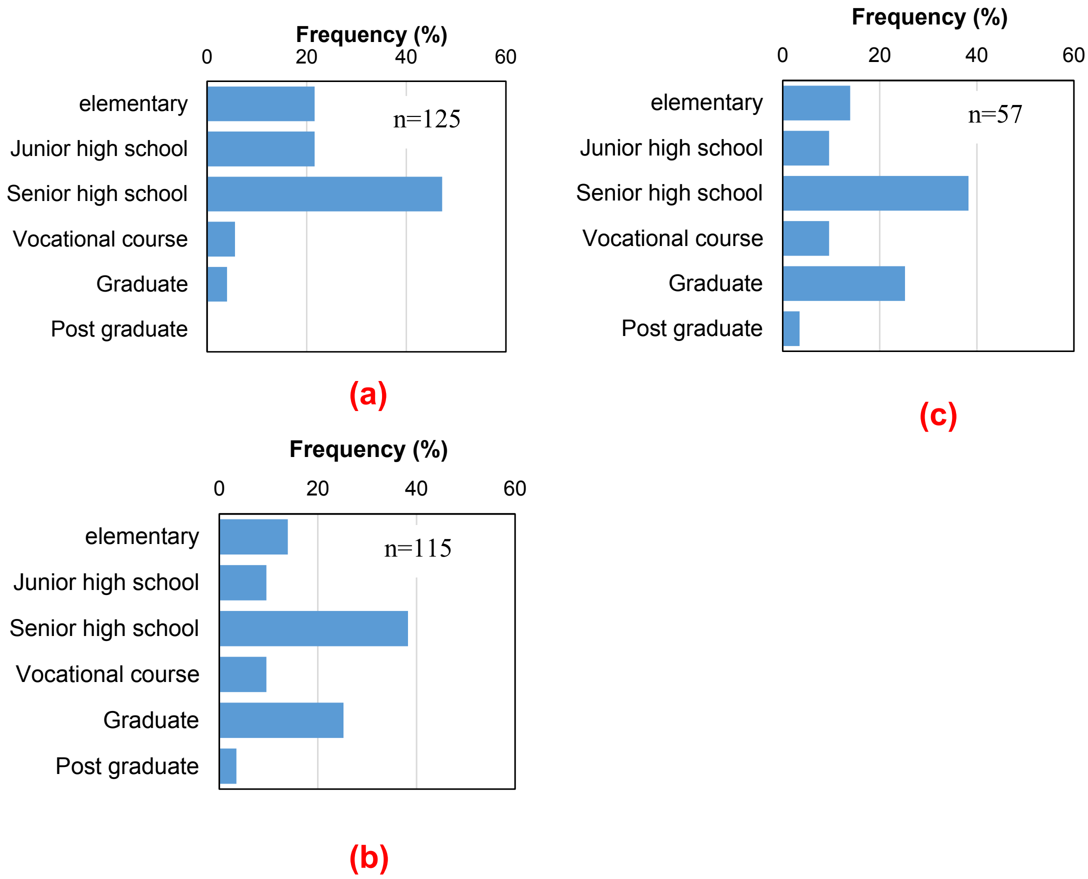


Fig. 5.6 *Highest education attainment by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

8) Period time to stay

Duration time to stay at home was 18.5 hours for simple households, 18.9 hours for medium households and 17.5 hours for luxurious households (see Fig. 5.7).

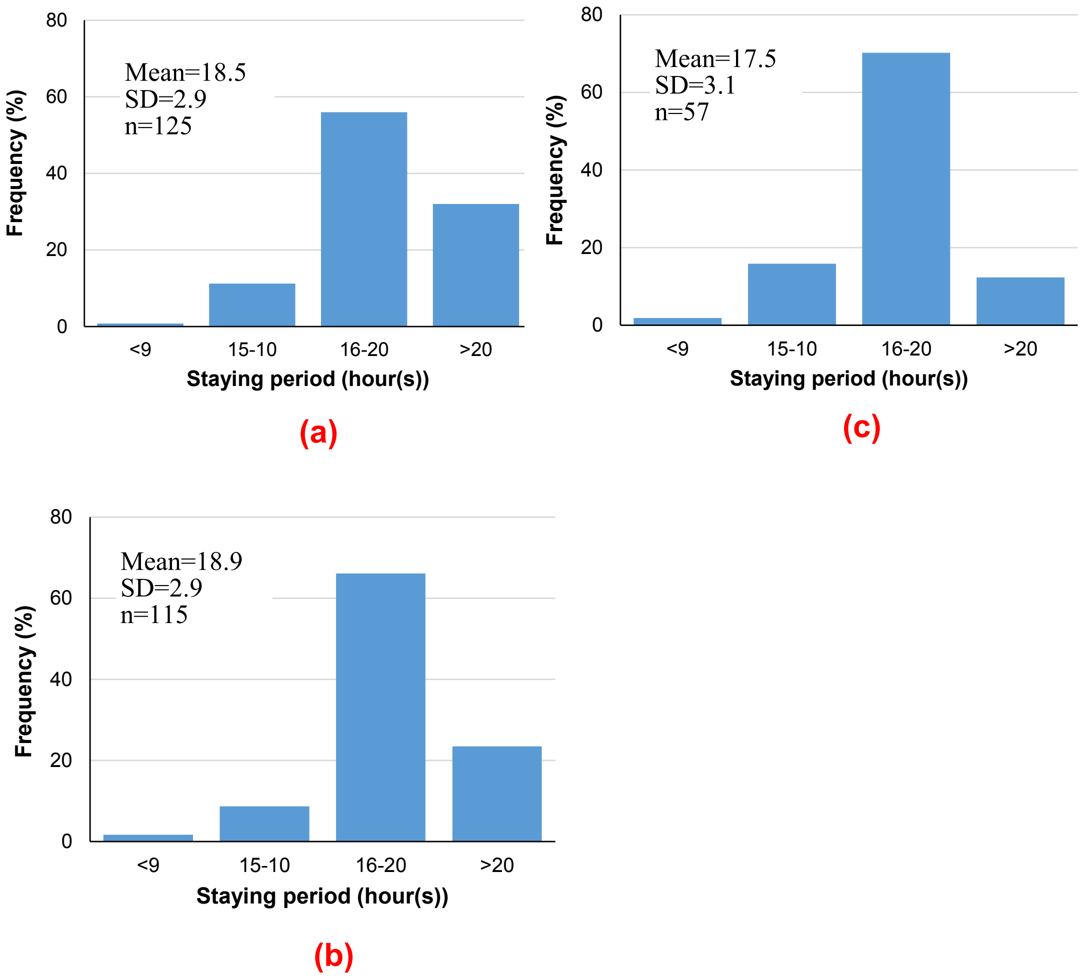


Fig. 5.7 *Period time to stay by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

Bandung city

In most of the major cities in Indonesia, unplanned houses account for the largest proportion of the existing housing stocks, which is about 89% in case of Bandung (Bandung, 2010). Hence, this study focuses on these unplanned houses. These houses are classified into three categories based on construction costs and lot area, namely simple houses, medium houses and luxurious houses, having a life span of 20, 35 and 50 years respectively (Indonesia, 2007).

A brief profile of respondents is shown in Table 5.2. A total of 250 unplanned houses were investigated in the survey. Three samples were selected as outliers and therefore they excluded from the analysis and became 247 samples. The samples of Bandung were classified in to three categories namely, simple (120 samples), medium (99 samples) and luxurious (28 samples) households. These samples were analyzed their demographic and social profiles as explained below

As shown, the total floor area also increases with house category. The largest percentage of total floor area was less than 50 m^2 (50.8%) for simple houses, 100 to 300 m^2 (58.6%) for medium houses and 100 to 300 m^2 (64.3%) for luxurious houses. The major building materials used were found to be almost the same among the above three categories, though a slight difference can be seen in terms of materials for floor and roof.

As shown, the average household size of the sample was 4.7 persons in simple houses, 4.7 persons in medium houses and 5.6 persons in luxurious houses. The average monthly household income was also investigated by a multiple-choice question. As shown, the households in luxurious houses have higher monthly incomes than the others as expected

Table 5.2. *Brief profile of sample houses.*

	Simple houses	Medium houses	Luxurious houses	Whole sample
Sample size	120	99	28	247
(Unplanned/planned)	(120/0)	(99/0)	(28/0)	(247/0)
Gender (%)				
Male	27.4	45.5	67.9	39.3
Female	72.6	54.5	32.1	60.7
Age (%)				
<40	15.0	18.2	21.4	17.0
40-49	30.8	27.3	17.9	27.9
50-60	32.5	33.3	25.0	32.0
>60	21.7	21.2	35.7	23.1
Household size (persons)	4.7	4.7	5.6	4.8
Household income (%)				
< 100 (USD)	10.0	0.0	0.0	4.5
100-400	75.8	58.6	7.1	61.5
500-1000	14.2	38.4	57.2	28.7
>1000	0.0	3.0	35.7	5.3
Total floor area (%)				
<50 (m^2)	50.8	6.1	0.0	25.9
50 - 99	39.2	34.3	3.6	32.4
100 - 300	10.0	58.6	64.3	37.7
> 300	0.0	1.0	32.1	4.0
Major building materials				
Structure	Concrete (100%)	Concrete (100%)	Concrete (100%)	Concrete (100%)
Foundation	Stone (36%) Concrete (64%)	Stone (30%) Concrete (70%)	Stone (13%) Concrete (87%)	Stone (31%) Concrete (69%)
Floor	Cement (75%) Ceramic (25%)	Cement (0%) Ceramic (100%)	Cement (0%) Ceramic (100%)	Cement (36%) Ceramic (64%)
Walls	Clay brick (98%) Con-block (2%)	Clay brick (100%) Con- block (0%)	Clay brick (97%) Con-block (3%)	Clay brick (99%) Con- block (1%)
Roof	Clay tile (74%) Concrete tile (0%) Zinc roof (14%) Asbestos (12%)	Clay tile (94%) Concrete tile (0%) Zinc roof (1%) Asbestos (5%)	Clay tile (0%) Concrete tile (100%) Zinc roof (0%) Asbestos (0%)	Clay tile (73%) Concrete tile (12% Zinc roof (7%) Asbestos (8%)

1) Household size

The average of household member in simple house was 4.7 persons comprising 3.6 elderly and 1.2 children, as shown in Fig. 5.8a and Fig 5.9 (1a and 2a). The biggest was 11 persons (3.3%) and the smallest 1 persons (0.8%). Most of the households have 4 persons (30.0%). The average of household member in medium house was 4.7 persons comprising 3.6 elderly and 1.2 children. The biggest was 13 persons (1.0%) and the smallest 1 persons (1.0%). Most of the households have 4 persons (27.3%) (see Fig. 5.8b and Fig 5.9 (1b and 2b). The average of household member in luxurious houses was 5.6 persons comprising 4.5 elderly and 1.1 children. The biggest was 15 persons (3.6%) and the smallest 2 persons (7.1%). Most of the households have 5 persons (28.6%) (see Fig. 5.8c and Fig 5.9 (1c and 2c).

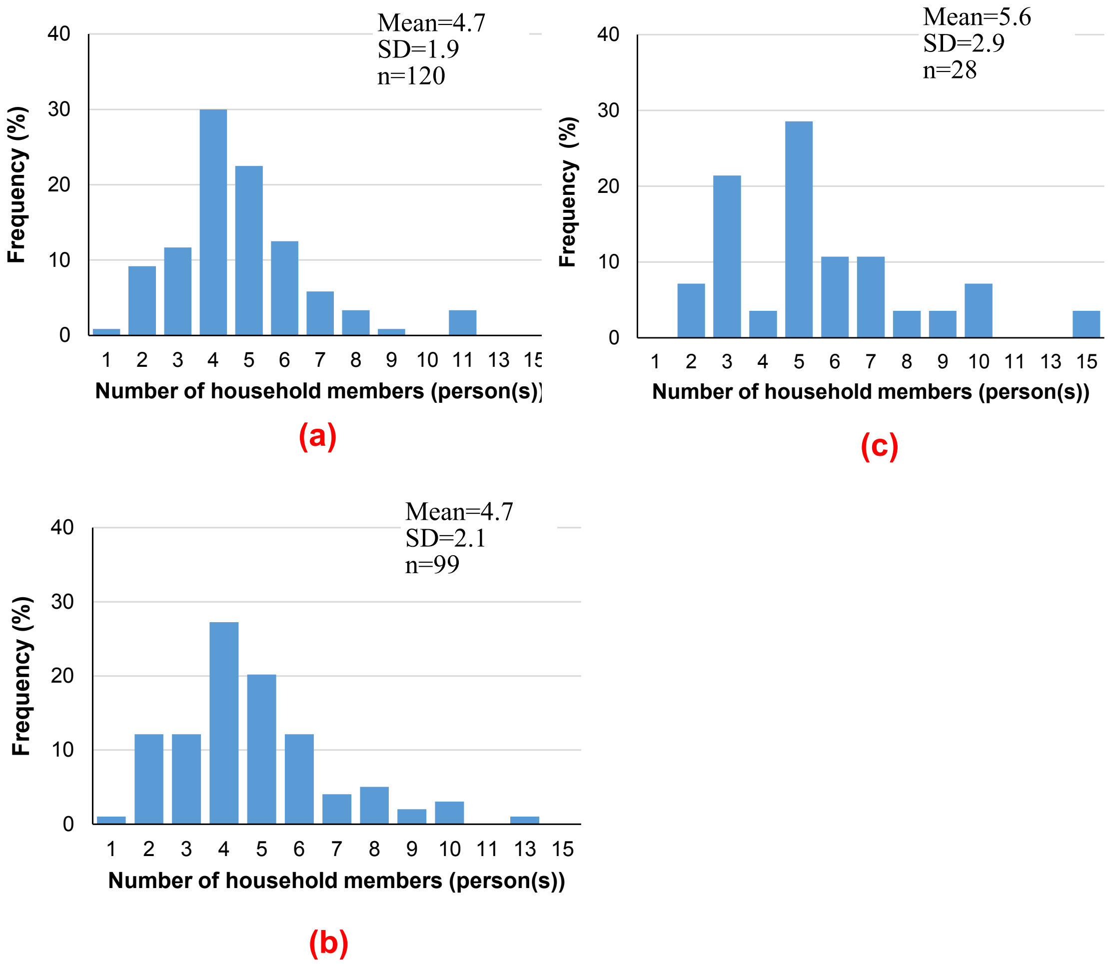


Fig. 5.8 *Household size by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

2) Elderly and children

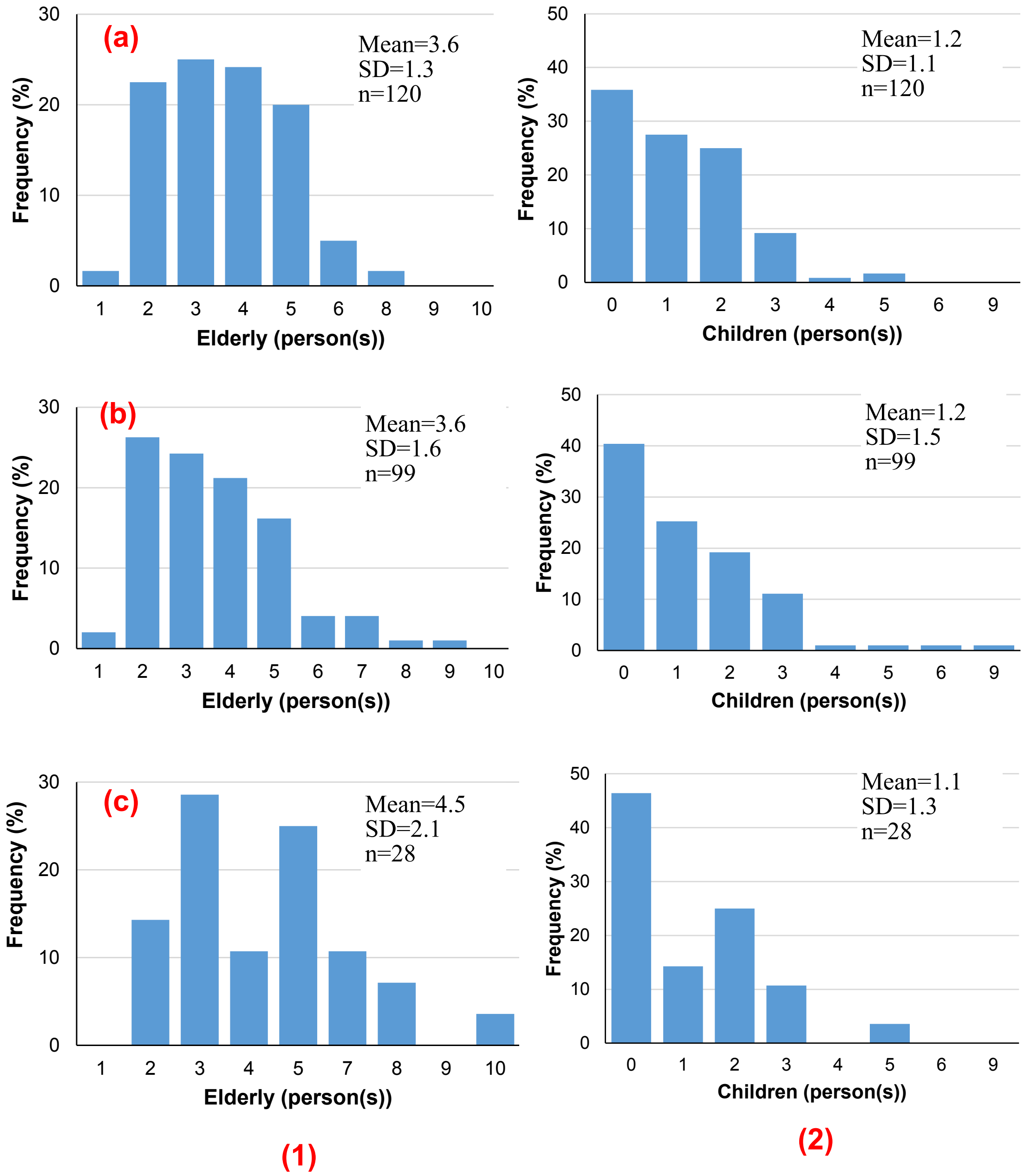


Fig. 5.9 *Number of (1) elderly; (2) children by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

3) Ethnic

Most of the simple households were Sundanese ethnic (94.2%), followed by Javanese (7.5%) and others (2,5%). Most of the medium households were Sundanese ethnic (76.8%), followed by Javanese (18.2%) and others (5.1%). Most of the luxurious households were Sundanese ethnic (53.6%), followed by Javanese (28.6%) and others (17.9%) (Fig. 5.10).

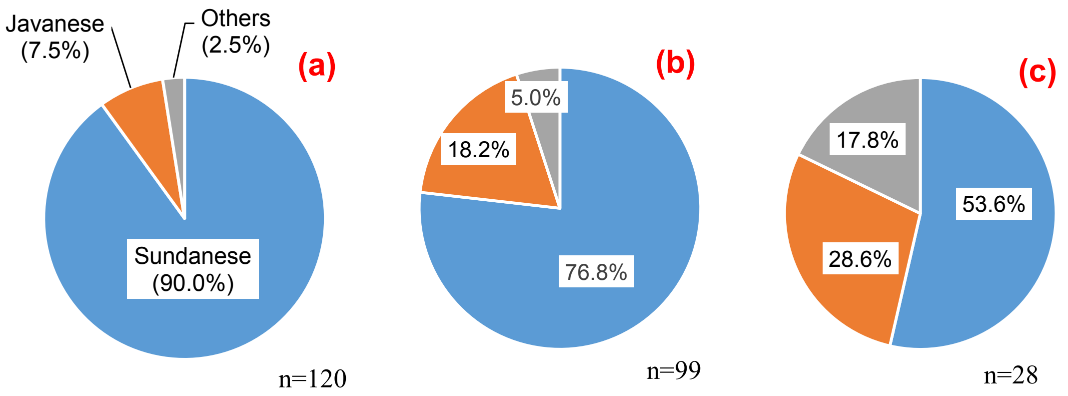


***Fig. 5.10** Ethnic by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

4) Number of households

Most of the sample of simple houses has 1 households in one house (84.8%) and two households was 12.1% and three households was 3.0% with the average 1.1 households. Most of the sample of medium houses has 1 households in one house (79.1%) and two households was the rest (20.9%) with the average 1.2 households. Most of the sample of luxurious houses has 1 households in one house (92.9%) and two households was the rest (7.1%) (see Fig. 5.11).

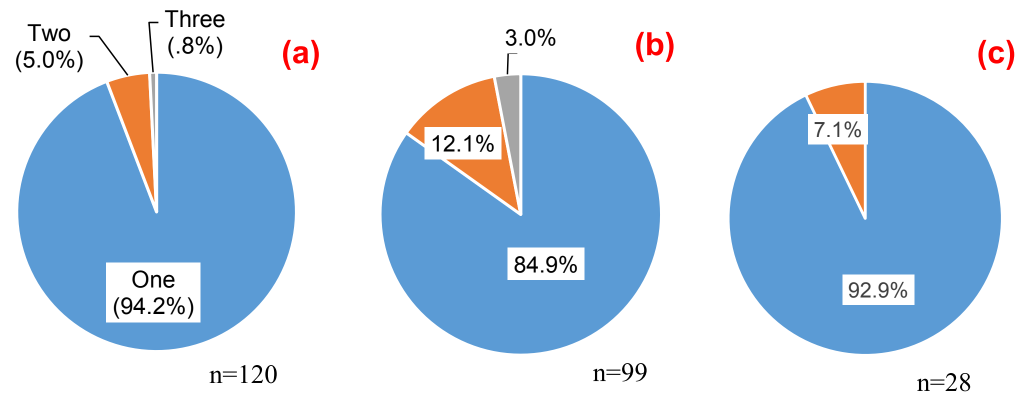


***Fig. 5.11** Number of household by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

5) Head's occupation

Private employee accounted the most of kind occupations (37.5/36.4%) which belong to the head's family followed by private temporary employee/government employee (29.2/18.2%), etc. for simple/medium houses, respectively. On the other hand, for luxurious houses, Private employee accounted 39.3% followed by government employee (25.0%), etc. (see Fig. 5.12).

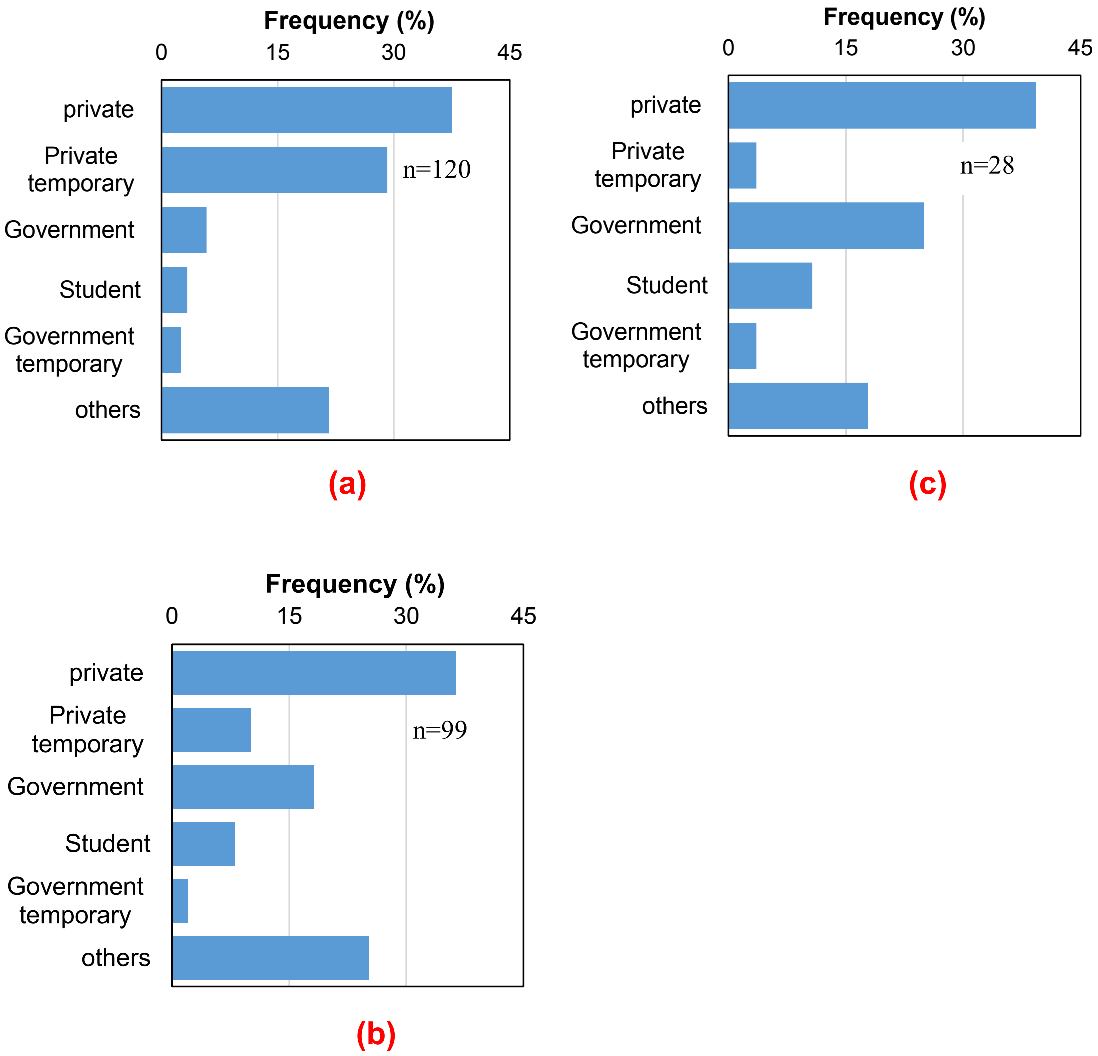


Fig. 5.12 *Head's occupation by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

6) Head's highest education attainment

Most of the head's highest educational attainment was senior high school (43.3%), followed by Elementary school (25.0%), etc. for simple houses. In medium houses, most of the head's highest educational attainment was senior high school (31.3%), followed by graduate (28.3%), etc. For luxurious houses, Graduate accounted the largest (50.0%), followed by post graduate (35.7%), etc. (see Fig. 5.13).

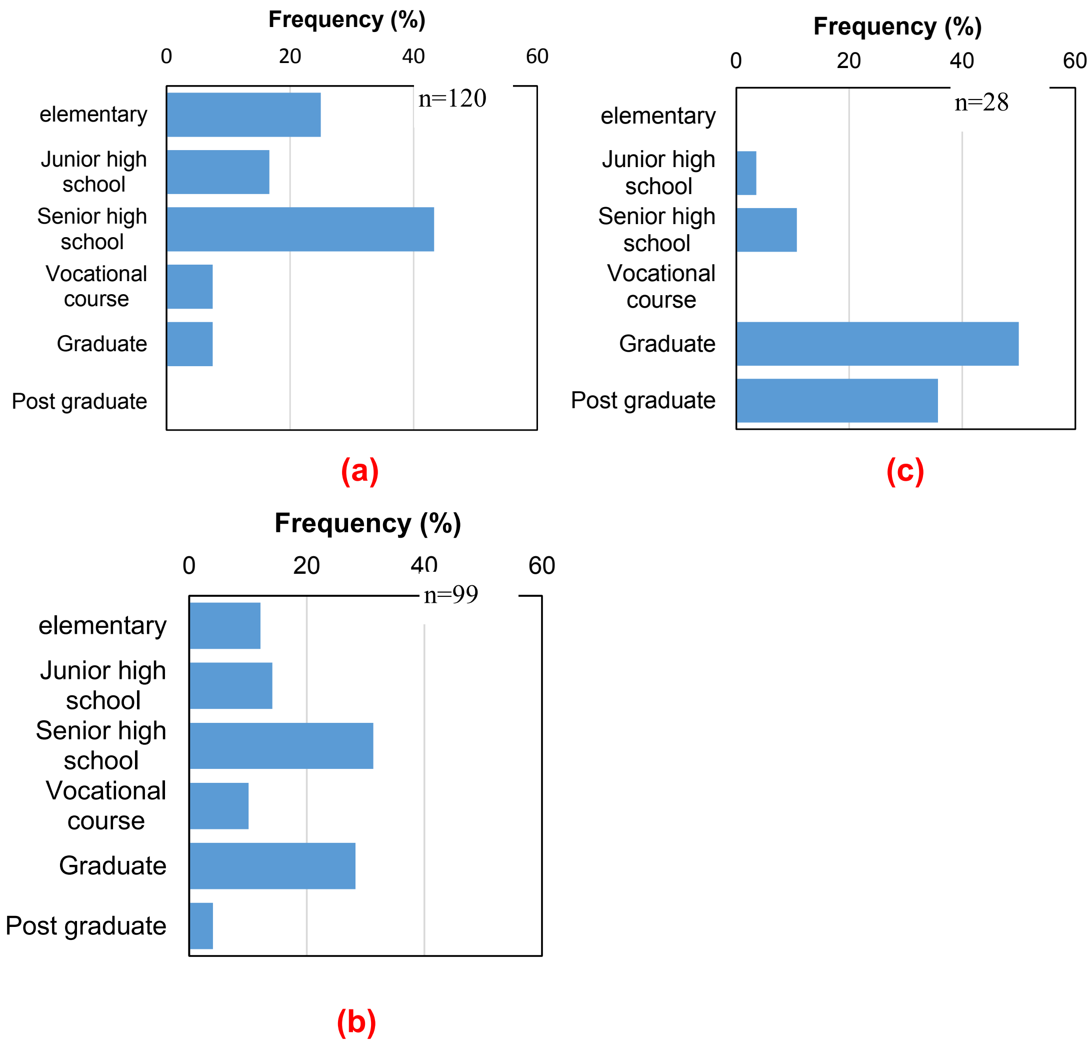


Fig. 5.13 *Highest education attainment by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

7) Period time to stay

Fig. 5.14 shows period time to stay by house category. As shown, duration time to stay at home was 19.3 hours for simple households, 19.0 hours for medium households and 17.5 hours for luxurious households.

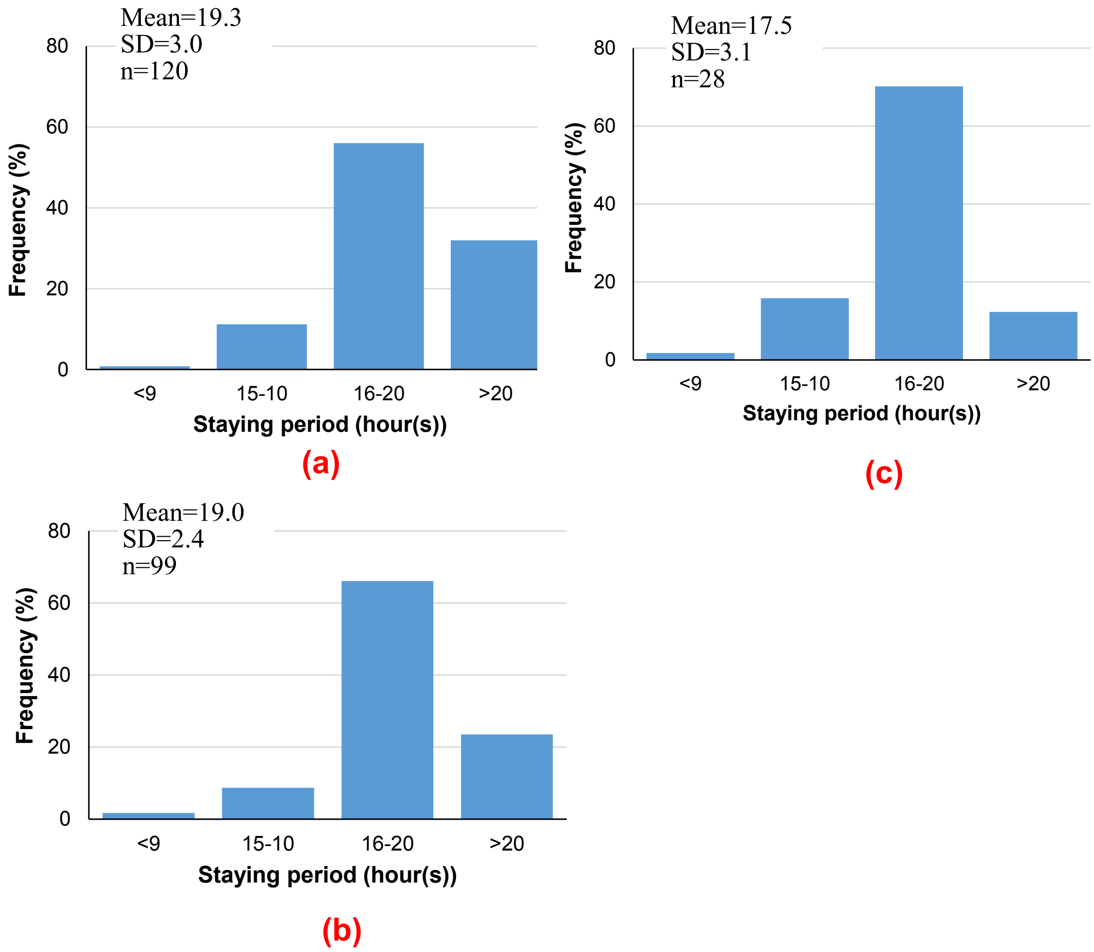


Fig. 5.14 *Period time to stay by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

5.2.2 Building types

Jakarta city

The samples of Jakarta were classified in to three house categories namely, simple (125 samples), medium (115 samples) and luxurious (57 samples) households. The houses were classified in to two house types, namely unplanned houses (229 houses) and planned houses (68 houses) as shown in Fig. 5.15. The detailed description describe in the

(a)

(b)

(c)

Fig. 5.15 *Views of sample residential buildings. (a) Simple house; (b) Medium house; (c) Luxurious house.*

1) House types

All the simple houses were unplanned houses (100%). Medium houses comprised 75 unplanned houses and 40 planned houses. Meanwhile, luxurious houses consists of 29 unplanned houses and 28 planned houses.

2) House storey

Most of the simple houses have one storey (76.8%). On the other hand, most of the medium houses had two storeys (56.5%). Luxurious houses' storey accounted 82.5% for two storeys (see Fig. 5.16).

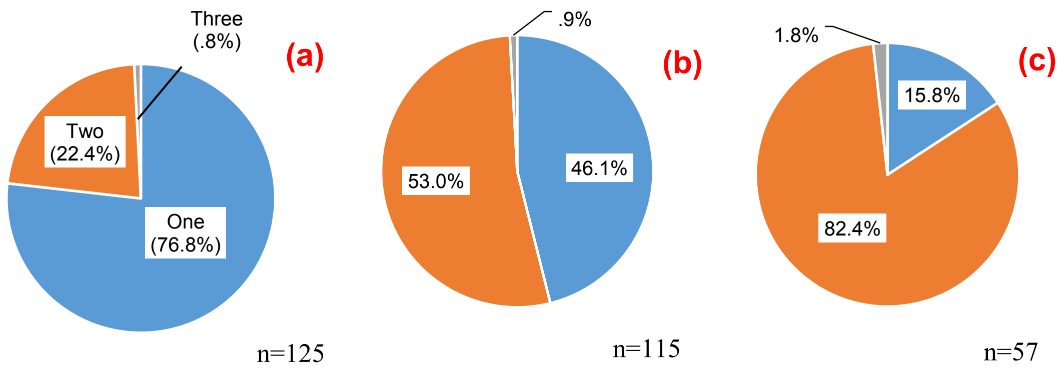


Fig. 5.16 *House's storey by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

3) Location of the house

Most of the simple/medium/luxurious houses were located in the middle (74.4/73/70.2%) followed by in the corner (25.6/27/29.8%) (Fig. 17).

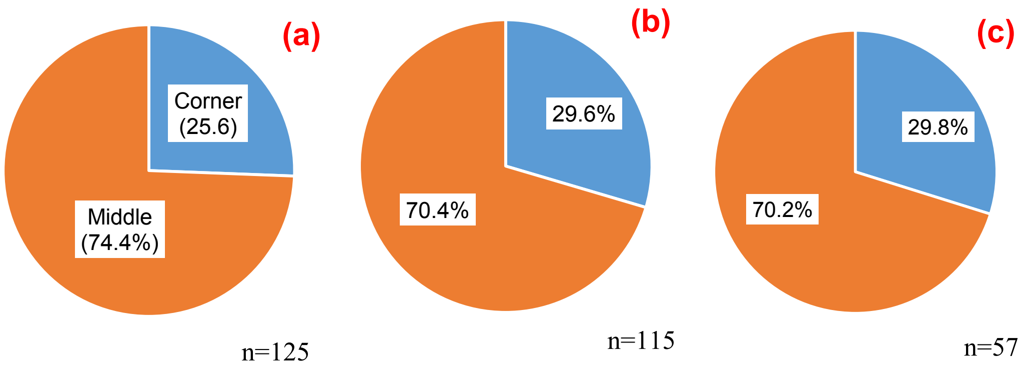


Fig. 5.17 *Location of the house by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

4) Building age

The average of building age for simple houses was 19.6 years, 23.2 years for medium houses and 24.6 years for luxurious houses (Fig. 5.18).

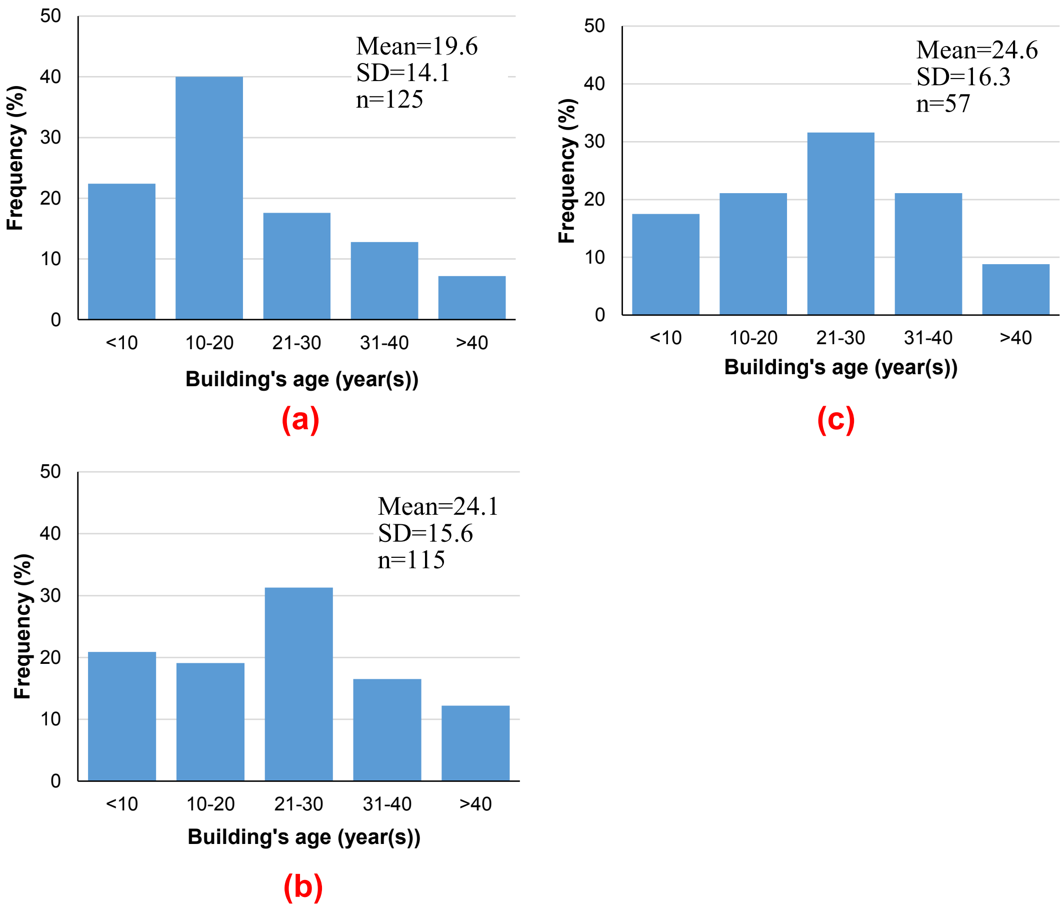


***Fig. 5.18** Building age by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

5) Duration of living

The average of duration of living for simple households was 16.2 years, 21.5 years for medium houses and 22.6% for luxurious houses (see Fig. 5.19).

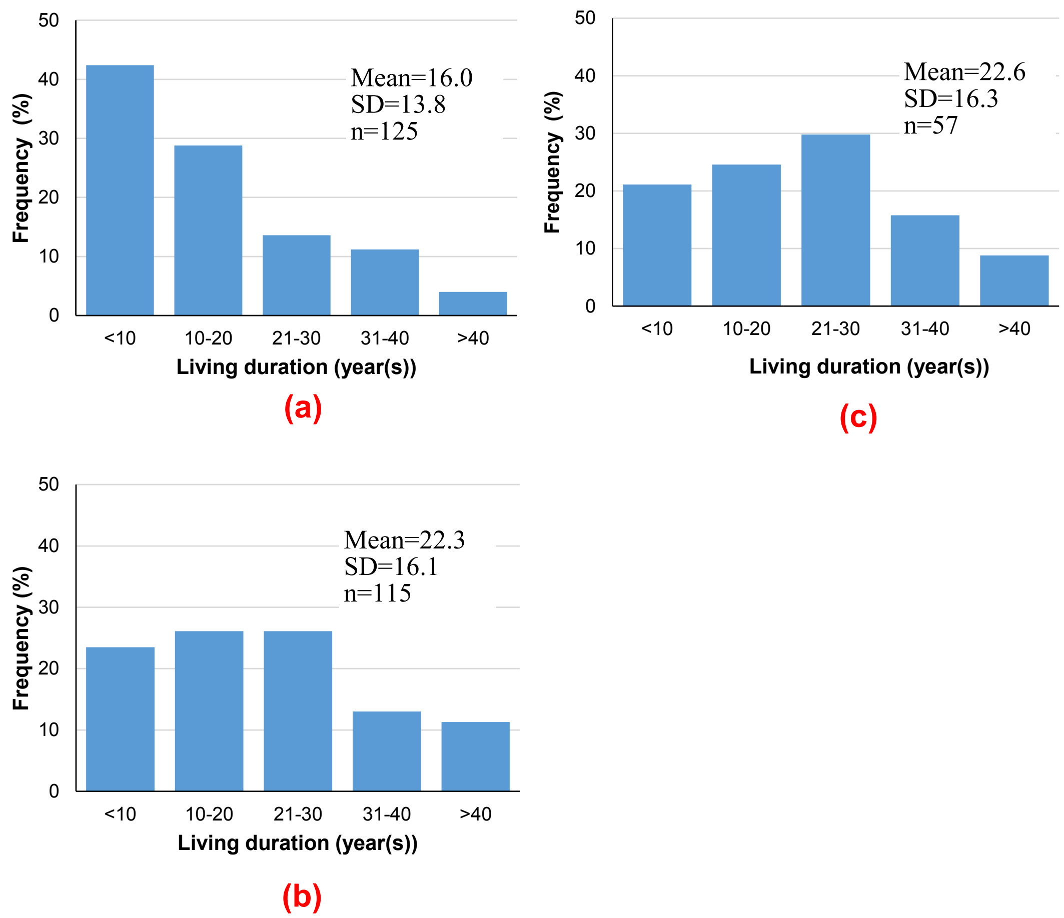


Fig. 5.19 *Duration of living by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

6) Lot area

The average of lot area for simple houses was 43.1 m^2 and 194.6 m^2 for medium house. Luxurious houses accounted 177.7 m^2 (Fig. 5.20).

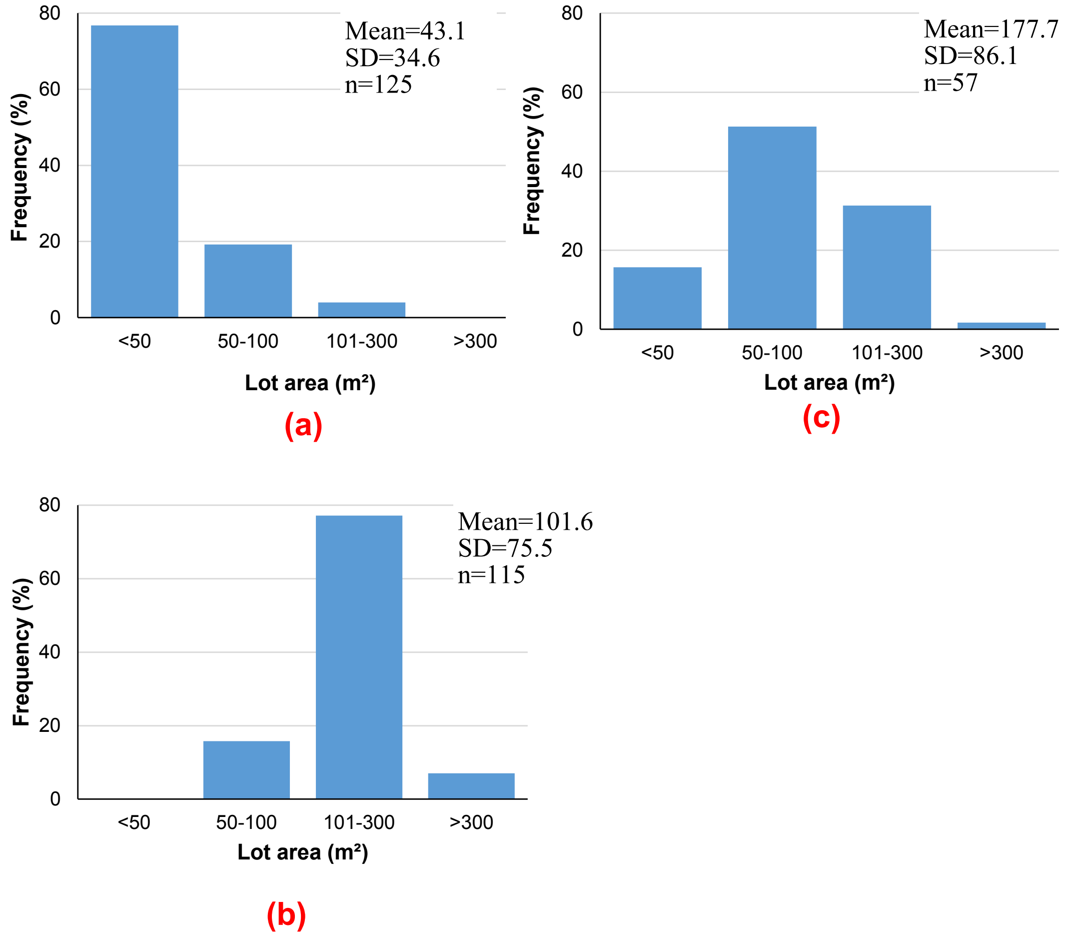


Fig. 5.20 *Lot area by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

Bandung city

In most of the major cities in Indonesia, unplanned houses account for the largest proportion of the existing housing stocks, which is about 89% in case of Bandung (Bandung, 2010). Hence, this study focuses on these unplanned houses. These houses are classified into three categories based on construction costs and lot area (Fig. 5.21), namely simple houses, medium houses and luxurious houses, having a life span of 20, 35 and 50 years respectively (Indonesia, 2007) as explained before.

Fig. 5.21 *Views of sample residential buildings (Bandung). (a) Simple house; (b) Medium house; (c) Luxurious house.*

House types

All the simple, medium and luxurious houses were unplanned houses (100%).

1) House storey

Most of the simple houses have one storey (76.8%). On the other hand, most of the medium houses had two storeys (77.8%). Luxurious houses' storey accounted 71.4% for two storeys and 14.3% for one and three storeys respectively (Fig. 5.22).

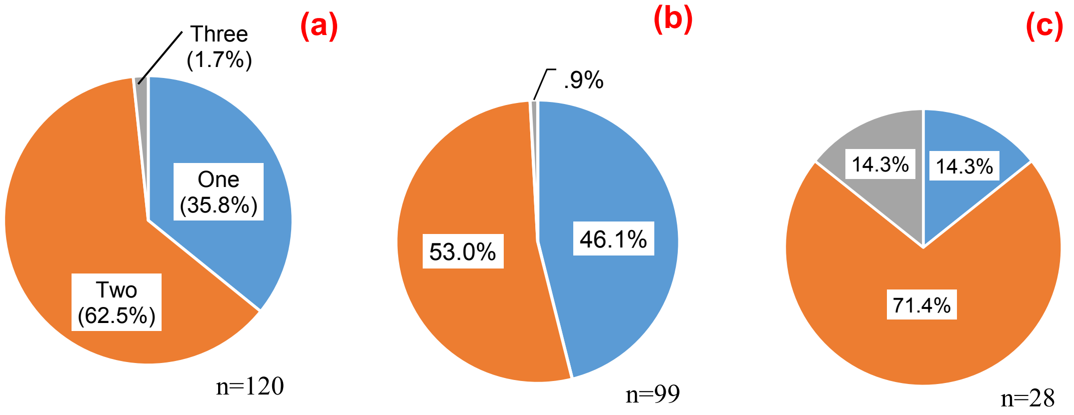


Fig. 5.22 *House's storey by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

2) Location of the house

Most of the simple/medium/luxurious houses were located in the middle (56.7/58.6/78.6%) followed by in the corner (43.3/41.4/21.4%) (Fig. 5.23).

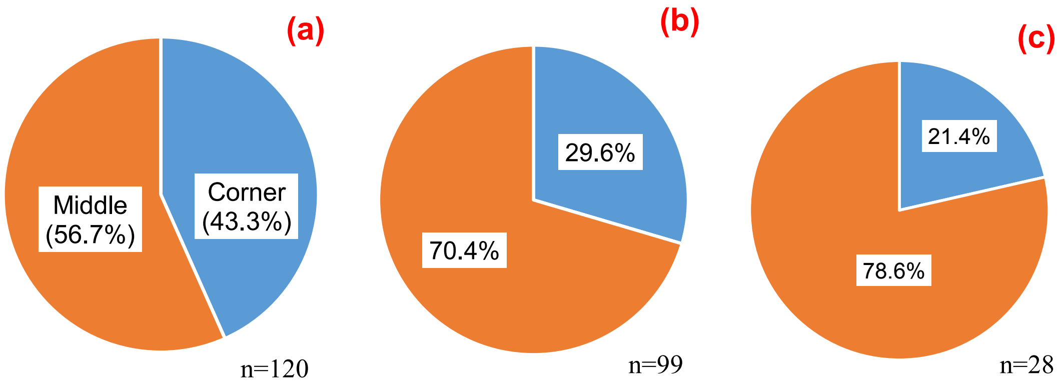


Fig. 5.23 *Location of the house by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

3) Building age

The average of building age for simple houses was 34.5 years, 23.8 years for medium houses and 10 years for luxurious houses (Fig. 5.24).

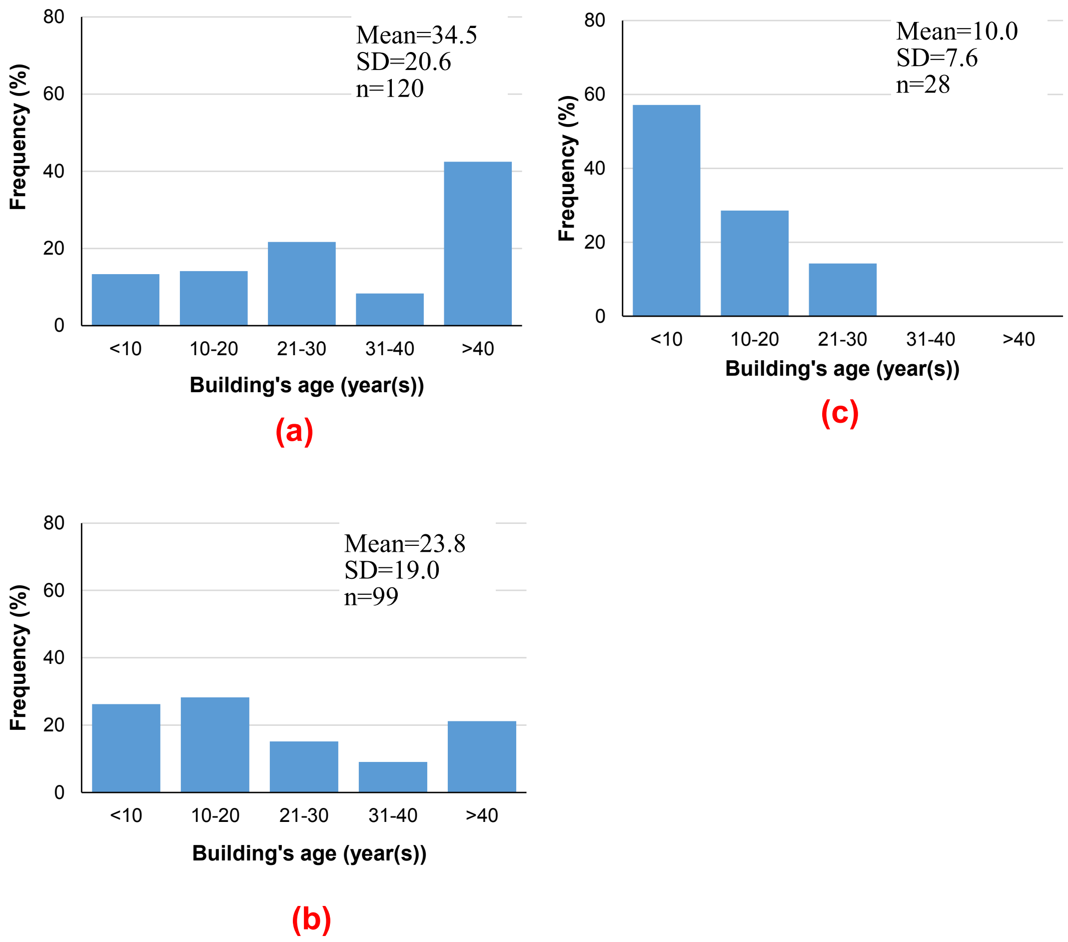


Fig. 5.24 *Building age by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

4) Duration of living

The average of duration of living for simple households was 16.2 years, 19.2 years for medium houses and 8.7 years for luxurious houses (Fig. 5.25).

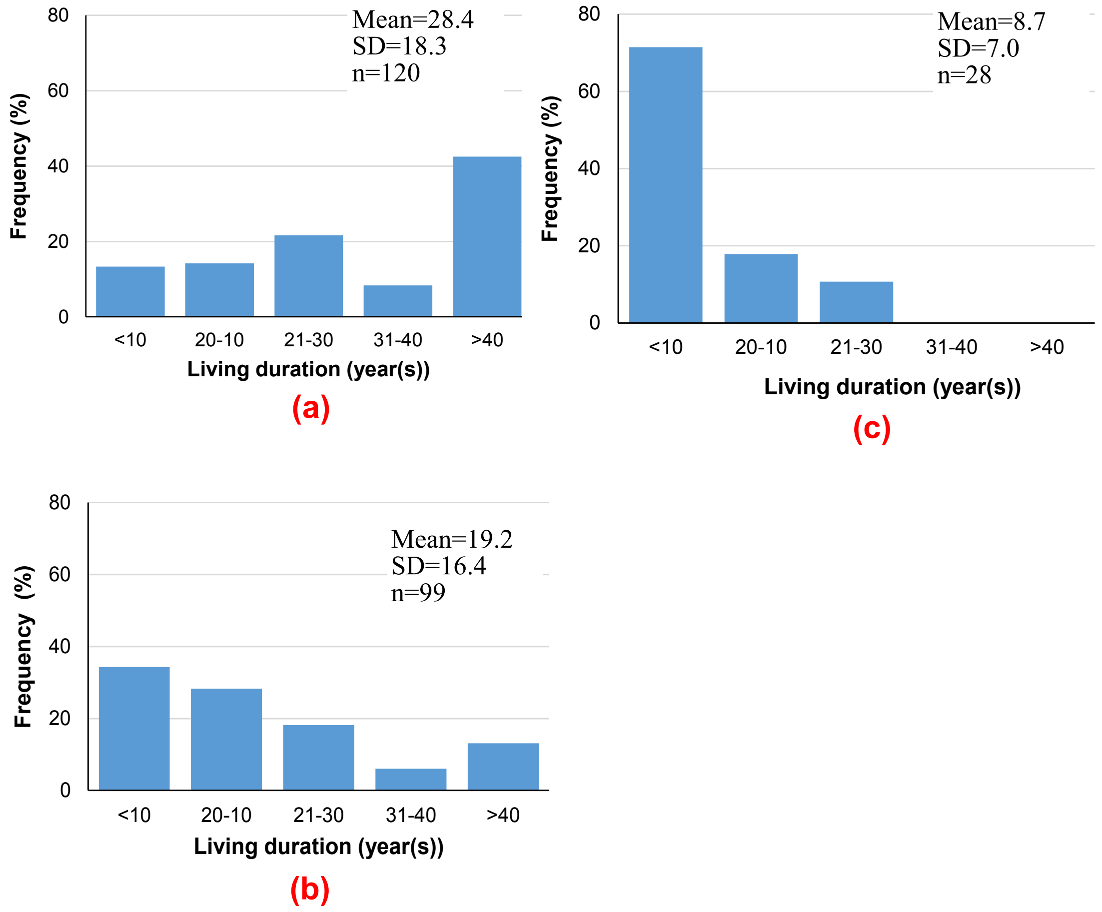


Fig. 5.25 *Duration of living by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

5) Lot area

The average of lot area for simple houses was 503.1 m^2 and 119.0 m^2 for medium house. Luxurious houses accounted 490.5 m^2 (Fig. 5.26).

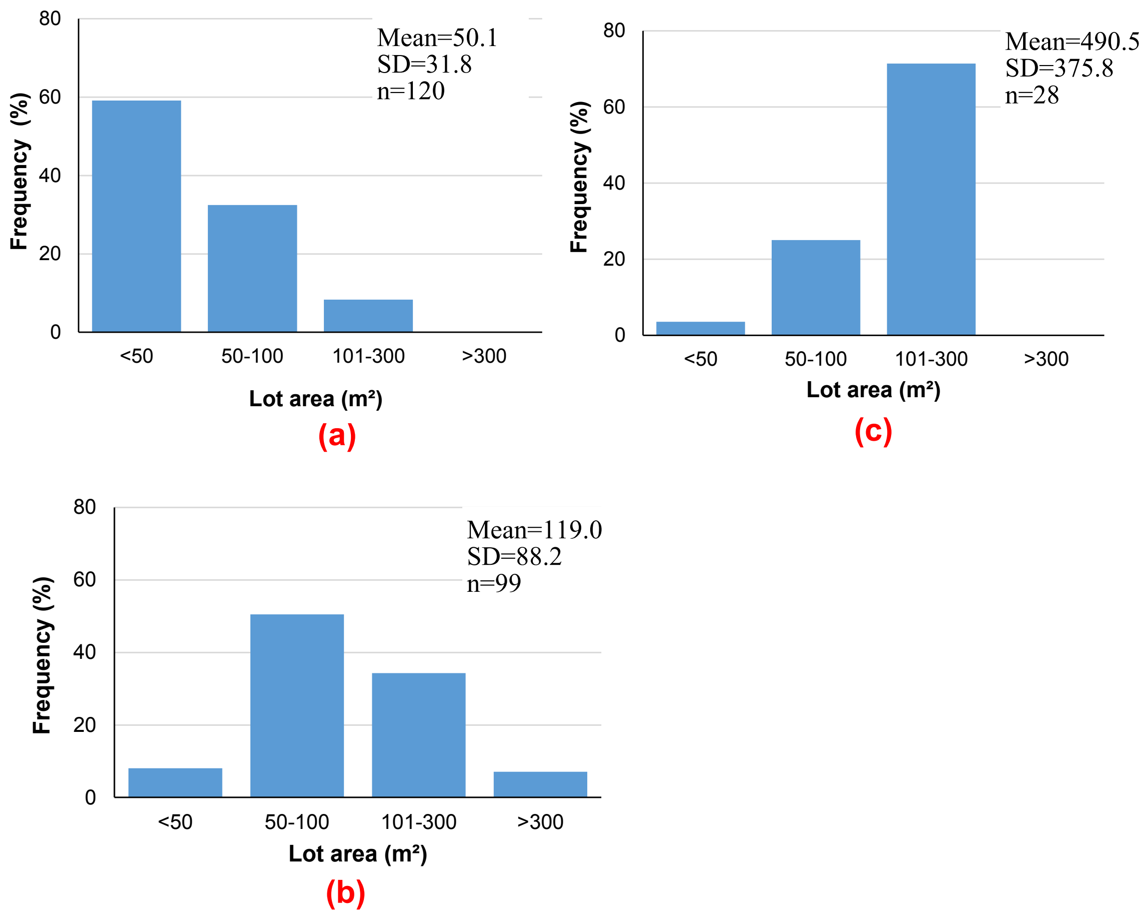


***Fig. 5.26** Lot area by house category. (a) Simple house; (b) Medium house; (c) Luxurious house.*

5.2 Household clusters

5.2.1 Classification of household: Factor analysis and cluster analysis

In order to figure out the socio-economic and demographic characteristics that affect their embodied energy and household energy consumption patterns, exploratory factor analyses with principal axis factoring and a cluster analysis were carried out for the combined whole samples of the two cities (n=544). The orthogonal varimax rotation was employed and the factors were determined based on the eigenvalues (>1). As shown in Tables 5.3, three factors were extracted from the combined samples. The variables with rotated factor loads of more than 0.4 were grouped into the same groups for each factor. These three factors were named equally in the two cities as follows: 'Factor 1: Wealth', 'Factor 2: Building age', and 'Factor 3: Household size'.

It was found that both Factor 1 (wealth) and 3 (household size) have significant relationships with embodied energy and household energy consumption respectively in both of the cities. Then, cluster analyses were conducted by using factor scores of the selected two factors (i.e. 'wealth' and 'household size') for respective cities (Figure 5.28). Since sample sizes of respective cities were relatively large, the *K*-means nonhierarchical clustering technique was adopted. By considering the resulting average household energy consumption values, three clusters were determined for respective cities (Figure 5.28). In both cities, the factor score of Factor 1 (wealth) consisting of house category, total floor area, lot area, household income, and educational attainment increases from Cluster 1 to 3. However, the wealth levels are almost the same between Cluster 1 and 2 in both cities. Instead, the households in Cluster 2 have larger household size than those of Cluster 1 as shown in Figure 5.27.

Table 5.3 *Rotated factor matrix (Jakarta and Bandung)*

Variable	Factor 1	Factor 2	Factor 3
Total floor area	0.822	0.003	0.079
House category	0.820	-0.093	0.074
Household income	0.673	-0.081	0.262
Lot area	0.659	0.004	-0.024
Educational attainment	0.582	-0.061	-0.057
No. of building story	0.338	0.065	0.150
Building age	-0.060	0.928	0.034
Living duration	-0.021	0.910	0.099
Household size	0.182	0.090	0.658
No. of household	-0.013	0.019	0.607
% of variance	27.24	17.22	9.18

Note: Factor 1, Wealth; Factor 2, Building age; Factor 3, Household size. n = 544.

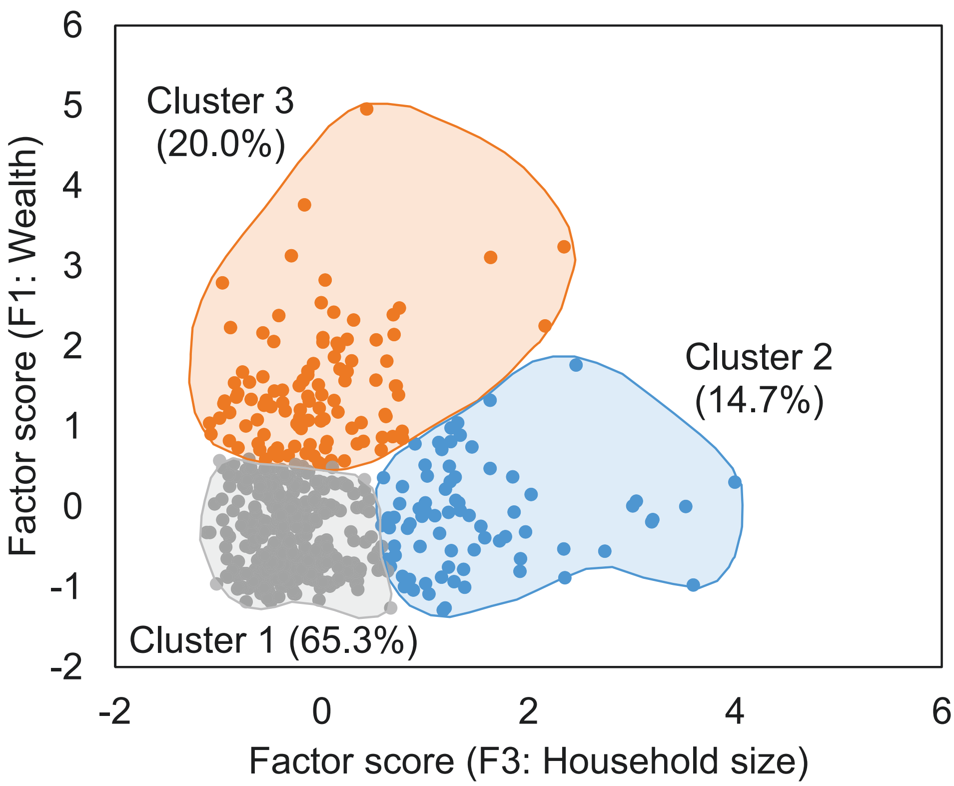


Figure 5.27 *Results of cluster analyses using Factors 1 and 3.*

Sample size by household clusters

Each household cluster in both cities was comprising mixed house category. Fig 5.28 shows sample size by household clusters. As shown in Fig 5.28a, household clusters in Jakarta were comprising mixed house categories except for Cluster 1 (without luxurious houses) and Cluster 3 (without simple houses). Meanwhile, household clusters in Bandung who are comprising mixed three house categories only Cluster 3 without simple houses. Clusters 1 has only one member of simple house and Cluster 2 were occupied by only simple and medium houses (see Fig 5.28b.)

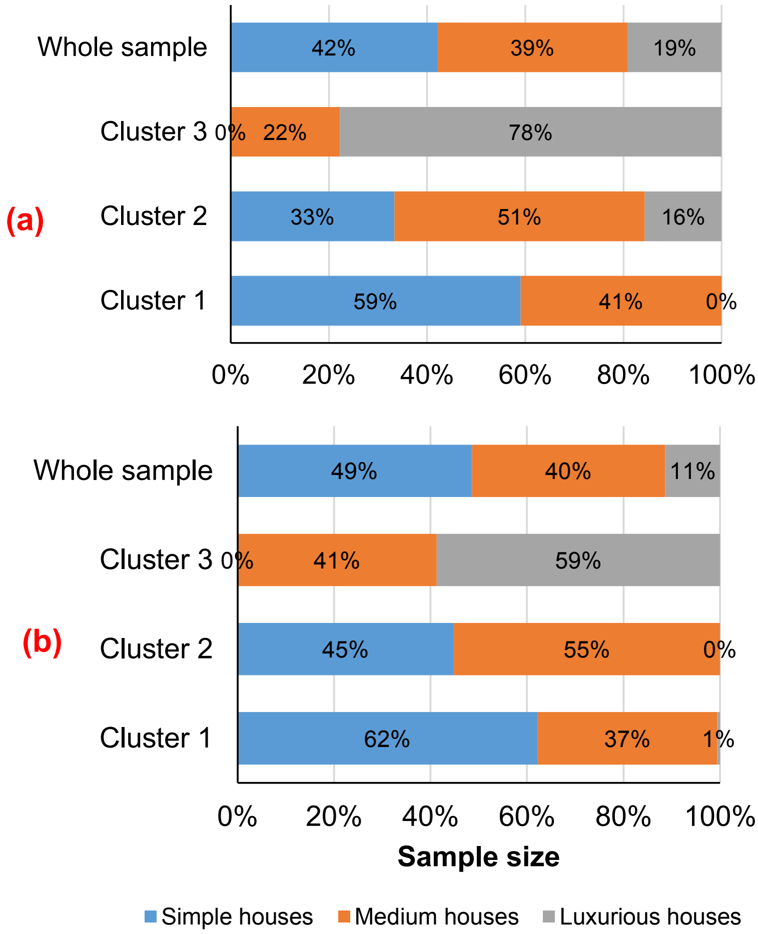


Fig. 5.28 *Sample size (percentage) by household clusters. (a) Jakarta (n=297); (b) Bandung (n=247)*

5.3 Summary

Two main surveys were conducted in Bandung (2011) and Jakarta (2012) to obtain building material inventory and household energy consumption.

- A total 247 samples were obtained from the main survey in Bandung, while 297 samples were obtained from the survey in Jakarta.
- Demography and social data were obtained comprising gender, age, relationship to the household, ethnic group, civil status, occupation, highest educational attainment, monthly income and average daily staying in the house
- Most of housing stock in major cities of Indonesia including Bandung and Jakarta were unplanned houses. These houses accounted 74% in Jakarta and 89% in Bandung.
- Unplanned houses were categorized in to three categories, namely simple, medium and luxurious houses.
- The average household size was about 4-5 persons with a small variation between the three categories. The average income increases with house category from simple to luxurious houses.

- The proportions of household income strata are almost the same between the two cities, although average income in Jakarta is slightly higher than that of Bandung. In general, household income increases with the house category from simple to luxurious houses.
- The total floor area also increases with house category. 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.
- Cluster analyses were conducted by using factor scores of the selected two factors (i.e. 'wealth' and 'household size') for respective cities and three clusters were determined by considering the resulting average embodied energy and household energy consumption values.

6

Embodied Energy and CO_2 Emissions of Building Materials for Residential Buildings in Jakarta and Bandung

In the previous chapter, the study explained the methods how to obtain two necessary data for life cycle assessment in buildings, i.e. building material inventory data and household energy consumption profiles through a pilot survey in Bandung. Utilizing these methods, two main surveys were conducted to obtain building material inventory and household energy consumption data in order to analyze life cycle energy and CO_2 emissions profiles in the major cities of Indonesia, in Bandung and Jakarta. This chapter analyzes life cycle materials and their embodied energy and CO_2 emissions of building materials for residential buildings in Jakarta and Bandung by house category and household cluster through following sections. Section 6.1 outlines the introduction and objectives. Section 6.2 describes potential reuse/recycling rates of materials based on literatures. Sections 6.3 presents the current building material stock and section 6.4 analyzes the scenario of building material stocks, demolition waste, their embodied energy and CO_2 emissions of building materials using various reuse/recycling rates of building materials. The results of the study are summarized in Chapter 6.5.

6.1 Introduction

The ultimate purpose of this study is to provide fundamental data of life cycle building materials, their embodied energy and CO_2 emissions for residential buildings in major cities of Indonesia. As a country experiencing economic growth and rapid urbanization, the proportion of the total population living in urban areas was growing from 42.2% in 2000 to 49.8% by 2010, and expected to continue increasing (Indonesia, 2010). The rapid urbanisation of Indonesia has generated an increased demand for housing and infrastructure, particularly in major cities such as Jakarta and Bandung, which in turn leads to the consumption of material resources, water and energy and generates enormous quantities of material waste throughout their entire life-spans, from material extraction to final disposal.

Buildings consume material resources, water, and energy as well as generate waste, which become a significantly environmental problem in the whole building lifespan, from material extraction to the building's final disposal. Therefore, the comprehensive assessment of building materials, energy and their environmental impacts such as material-flow analysis (MFA) (Brunner and Rechberger, 2003) and life cycle assessment (LCA) (Kotaji et al., 2003), is necessary in order to provide comprehensive data on material inventory, embodied energy and CO_2 emissions for residential buildings.

The construction industry, along with its support industries, is one of the largest exploiters of natural resources, both renewable and non-renewable, that is adversely altering the environment of the earth (Horvath, 2004). It depletes two-fifths of global raw stone, gravel, sand and one-fourth of virgin wood, and consumes 40 percent of total energy and 16 percent of water annually (Horvath, 2004). Data show that approximately 40% of the generated waste portion globally originates from construction and demolition waste (Kulatanga et al., 2006).

Construction and demolition (C&D) waste is the waste produced during new construction, renovation and demolition of buildings and structures HQ Air Force Center, 2006). These structures include buildings of all types in residential and non-residential as well as roads and bridges. Components of C&D waste are typically concrete, asphalt, wood, metals, gypsum wallboard, and roofing. In general, C&D waste is bulky, heavy and mostly unsuitable for disposal by incineration or composting. Such waste is often disposed of in landfills and causes waste management problems in urban areas. Several researchers have attempted to estimate the amount of construction and demolition waste in various countries. For instance, about one-third of the volume of materials in landfills in the United States (US) is C&D waste (Kibert, 2000), the amount of C&D waste in Austria, Denmark, Germany and Netherlands were about 300, over 500, about 2600 and about 900 kg/person, respectively (Brodersen et al., 2002) and 65% of Hong Kong's landfill space was filled by C&D waste in 1994-1995 (Stokoe, et al., 1999). However, data for C&D waste is not easy to obtain in most of developing countries due to very limited records and the minimal existence of regional/national policies, laws and regulation pertaining to the management of this waste (Nitivattananon and Borongan, 2007).

In Indonesia, available information indicates that C&D waste is currently regarded as part of municipal solid waste (MSW) (Aprilia et al., 2012; Meidiana and Gamse, 2010). A few studies for existing C&D waste of residential buildings have been conducted in Indonesia. For instance, UNEP (2008) designed a system for managing debris waste generated by the Indian Ocean tsunami in Aceh. Sugiharto et al. (2002) investigated the incidence of waste within construction companies. Suryanto et al. (2005) identified construction waste generated by planned houses and shop houses and their environmental impacts. In fact, all of the above mentioned studies focused on planned houses and commercial buildings. However, the majority of urban housing stocks in Indonesia are unplanned houses, as described in the following section. These houses are not designed and constructed in a formal way. Therefore, there is a serious lack of building material inventory data that are required for the analysis of material flow and the corresponding embodied energy/CO_2 emissions.

This study analyses the flow of building materials and their embodied energy/CO_2 emissions for urban houses in Indonesia, focusing especially on unplanned houses, through a material-flow analysis and an input-output analysis. Actual on-site building measurements were conducted in the cities of Jakarta (2012) and Bandung (2011) to investigate building material inventory. The current status of material stock was evaluated. Furthermore, life-cycle material flows focusing on future demolition waste and the embodied energy/CO_2 emissions of urban unplanned houses are predicted for different scenarios using various reuse/recycling rates.

C&D waste management in Indonesia: current practice and problems

In Indonesia, C&D waste is classified as specific waste (Indonesia, 2008c) and has its own regulation which is not published yet. The available information indicates that C&D waste recently is part of municipal solid waste (MSW) (Indonesia, 2008a). According to Indonesia (2008b), 69% of the total MSW was landfilled, 7% was treated or recycled, 5% was burnt and 10% was buried and the remaining 6% was dumped into rivers, roads, parks etc.

It was estimated that in 2008, 7% of collected MSW in Indonesia had recyclable materials which were only included formal recycling activities (Indonesia, 2008b). This is very low when compared with the recycling rates for C&D waste of other countries. In Denmark the recycling rates of materials is more than 80%. Germany and Netherlands recycle 30-50% of materials, while the recycling rates in Luxemburg is 10% (Brodersen et al., 2002). There are many available technologies for recycling C&D wastes (Tam and Tam, 2006a, 2006b). These could prolong the life of landfill sites, minimize transport needs and reduce the primary resource requirements (mineral and energy).

In Indonesia, the informal private sectors, which involved waste pickers, garbage truck helper, scavengers and etc., play main roles in material recycling activities (Sembiring and Nitivattananon, 2010; Dhokhikah and Trihadiningrum, 2012). This activities occur at three points, namely the generation point, curbside collection point and at dumpsite. They collect various materials including cardboard, plastics, glass, bottles, paper and metal. These recyclable materials are sold to distributors. The distributor clean, sort and package them as the preliminary process before reselling. However, such kind of recycling reduces the quantity of wastes significantly for transportation to final disposal.

MSW management is recognized as a huge problem. The total MSW generation in Indonesia accounted 38.5 million ton/year in 2008. Meanwhile, the average per capita generation rate increased from 0.4 kg/capita/day in 1989 (UNDP, 1987) to 1.12 kg/capita/day in 2008 (Indonesia, 2008b). This indicates the quantity of generated MSW and the per capita generation rate are increasing with time, pointing to the need for a sustainable approach to disposal and management (Chiemchaisri et al., 2006). The characteristics of MSW as summarized in Fig. 6.1 show that putrescible, paper and plastic constitute a large proportion of MSW (Indonesia, 2008b).

Although some materials such as wood, glass and metals, which are components of

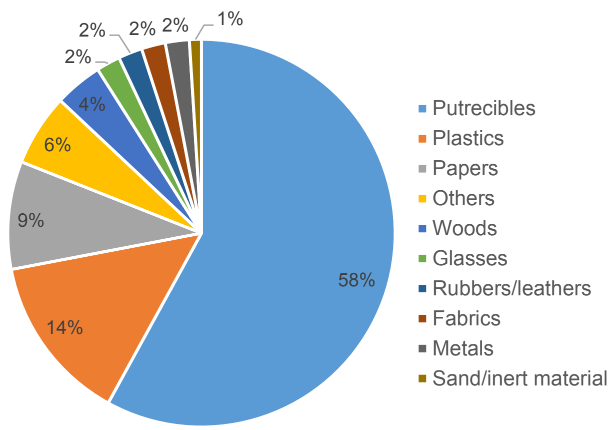


Fig. 6.1 *Composition of municipal solid waste (MSW) in Indonesia (2008b)*

MSW, are building materials, it is unclear if these materials waste were generated from C&D activities as they could also originate from activities unrelated to construction. It is interesting to note that although detail studies of MSW exist in Indonesia, there is a dearth of information on the management, reuse and recycling of C&D waste as no system to record the amount of collected construction waste exists. Thus, there is an obvious needs for a waste management system which tracks wastes from their origin (input) as well as details their composition and other relevant parameters, e.g. volume, to their final disposal (output).

Current material stock and future demolition waste in urban residential buildings

In Indonesia, limitations of data, such as those for population, number of households, household expenditure, and building life cycle of each type of house, make it difficult to clarify the current material stock in urban residential buildings and to design and implement concrete policies to address issues of C&D waste management. In this study, we first attempt to evaluate (a) the current material stock in urban residential buildings in Jakarta and Bandung at the city level, (b) the future demolition waste in unplanned urban houses, and (c) future urban expansion due to the demolition of unplanned houses in both of the cities, based on the survey results. The results of these analyses would emphasise the importance of housing policy for promoting planned houses (instead of unplanned houses, which currently constitute the majority), as described in the MPA Master Plan toward 2020 (JICA, 2012).

The mathematical equations used to estimate the current material stock for urban houses at the city level are described in Chapter 4 (Eqs. (4.34)-(4.37)). In this analysis, it is assumed that (1) the number of housing stocks are determined by the population and number of households, (2) the income distribution in unplanned settlement areas of Jakarta and Bandung is the same as the that throughout the entire city of Jakarta, further assuming that low-, middle- and high-income people live in simple, medium and luxurious houses, respectively.

The mathematical equations used to estimate the amount of demolition waste generated by unplanned residential buildings until 2020 are described in Eqs. (4.56)-(4.59). In this analysis, we only focus on the demolition waste generated from the current material stock, estimated by Eq. (4.34). The following assumptions are made. (1) The predicted population of Jakarta in 2020 (11.6 million people) will follow the population projection of the UN (2011). (2) The share of each type of house in unplanned residential buildings will vary in proportion to the significant change in income level (the projected income distribution in 2020 shows that the middle-income class is expected to grow rapidly; 4% for high-income class, 73% for middle-income class and 23% for low-income class (JETRO, 2011)). This projection is supported by the forecasted growth in GDP from 6.1% in 2010 to 8% in 2020 (BPPT, 2012). (3) Medium and luxurious houses will not be demolished until 2020, based on assumption (2) and the buildings' life-spans (i.e., medium houses: 35 years; luxurious houses: 50 years). (4) The reuse and recycling rates of each material are zero.

The mathematical equations used to estimate the urban expansion caused by the demolition of unplanned simple houses and the transformation of these simple houses into larger medium houses by 2020 are described in Eq. (4.60). In this analysis, it is assumed that all of the demolished simple houses will be reconstructed to be medium houses in the same cities.

Flow of materials and the embodied energy/CO_2 emissions for each type of house

Second, this paper analyses the per-house flow of building materials for each type of house by using Jakarta as an example. Material-flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in a certain domain and time (Brunner and Rechberger, 2003). Fig. 6.2 shows the framework of the MFA model for urban houses adopted in this study. As shown, housing growth is driven by population, number of households and per-capita income. Moreover, material input is driven by total floor area and material intensity. Demolition waste is determined by buildings' life-spans. The material input and output in a building system cover various house categories, which will be discussed in the next section. MFA defines terms and procedures for establishing material balances between the input of material stock and the output of material waste.

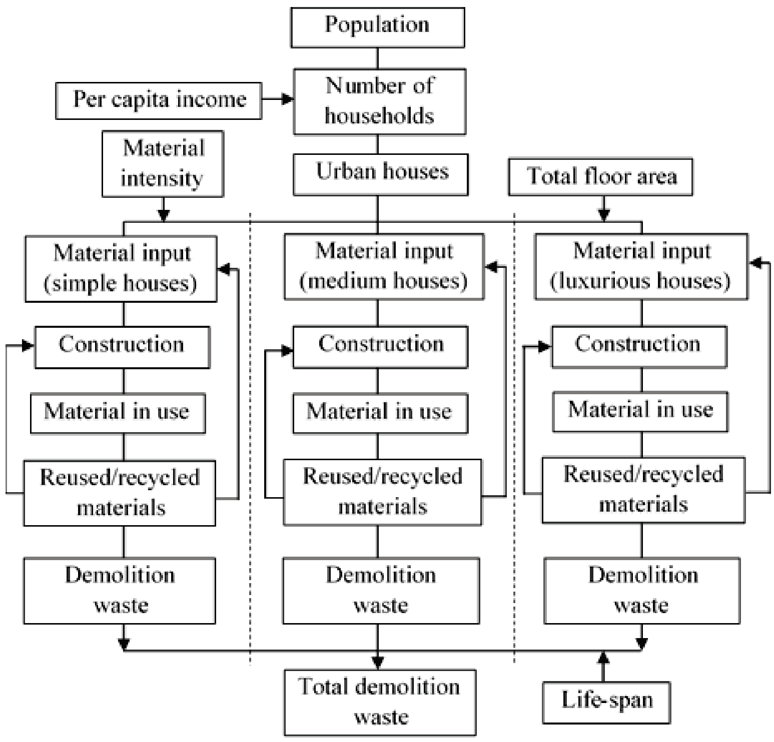


Fig. 6.2 *Framework of MFA model for urban houses*

Embodied energy and CO_2 emissions

The embodied energy of building materials generally includes energy for production in several phases, including material extraction, production, construction, maintenance, and demolition (Dixit et al., 2010). However, the construction and demolition phases are not considered in this paper due to the very limited possibilities of consuming materials in these two phases in the case of Indonesia.

Design records such as building drawings are required for the analysis of the embodied energy of building materials. These data can normally be obtained from local authorities, developers, etc. (Utama and Ghewala, 2009; Mithraratne et al., 2004). Some developed countries provide the data in the literature (Dixit et al., 2010; Nansai et al., 2002). Nevertheless, these data are available for most planned houses or unplanned luxurious houses only. Because the other types of houses are not constructed in a formal way (they are normally constructed by non-professional neighbours), the required design records could not be obtained in the surveys. Thus, actual on-site measurements using laser-distance meters and tape measures were conducted for the other types of houses (i.e., unplanned simple and medium houses) to acquire the required data.

Previous studies showed that there are three main methods commonly used for analysis of energy and CO_2 emissions, namely process-based, economic input-output (I-O) analysis-based and hybrid-based methods (Dixit et al., 2010). Because it was impossible to trace all of the production processes for most of the building materials due to the unavailability of design records in the surveys, this study adopted the I-O analysis-based method to calculate the embodied energy of building materials and estimate the materials' CO_2 emissions; the method described by Nansai et al. (2002) was consistently followed in this respect.

The procedure of the embodied energy analysis employed in this paper was explained in Chapter 4. Firstly, the combination of averaged fuel consumption in industrial and transportation sectors during 2010 based on the nationwide data (Indonesia, 2011) was calculated. Secondly, the net contribution rate was determined by giving the figure 0 or 1 for each combination between the fuel type and the sectors indicated in the I-O table, in order to exclude fuel consumption that was converted into another fuel type or used as feedstock. Thirdly, the Net Calorific Value (NCV) was obtained from IEA (2012a) and IPCC (2006), and fuel consumption was converted into calorific values through multiplying the gross fuel consumption by the net contribution rate and the said NCV for each fuel type in respective sectors.

The latest Indonesian nationwide I-O table published in 2005 (Indonesia, 2005) consisting of 175 by 175 sectors was used to calculate the embodied energy and CO_2 emissions. Meanwhile, the building material inventory data were investigated as described earlier. Each material was classified into domestic material and imported material respectively, based on the site observation. Then embodied energy intensities for respective materials were calculated using the above I-O table. Embodied energy intensity is divided into two kinds. The first is domestic embodied energy intensity (Eq. (4.47)) and the second is imported embodied energy intensity (Eq. (4.48)). The total embodied energy of respective houses was computed by combining all the energy consumption for respective building materials (Eq. (4.46)).

On the other hand, the CO_2 emissions caused by the embodied energy were estimated through multiplying the energy consumption for each fuel type by its corresponding CO_2 emission factor obtained from IEA (2012b) and IPCC (2006). The CO_2 emissions released during the combustion of biomass was assumed to be balanced by the CO_2 removed from the atmosphere during growth of new biomass (Gustavsson and Joelsson, 2010). The total CO_2 emissions of respective houses were calculated by adding the emissions for each of the building materials.

In this analysis, we assess the effects of policy promoting reuse and recycled material use through a scenario analysis. The first scenario (Scenario 1) assumes that both recycling and reuse rates are set to be zero (minimum), and the second scenario (Scenario 2) is designed under the assumption that both recycle and reuse rates for respective building materials are increased to the maximum values (Table 2). The effects of the promotion of reused and recycled building material use are evaluated through a comparison between the two scenarios. The per-house material stock and demolition waste for the respective house categories are estimated based on the equations in Chapter 4 (Eqs. (4.38)-(4.40)).

6.2 Potential reuse and recycling rates of building materials

Most materials can be reused and recycled as long as their condition and properties are known and judged to be adequate for the purpose intended or can be treated to improve them to an adequate level. The opportunities to reuse materials in the form of components will depend on two main factors (Addis, 2006): (1) how easily the properties, performance, condition and quality of the reused materials can be assessed in order to design a component using the material and/or establish the life or durability of a component made with the material; (2) the nature of remedial work or reconditioning that can be done to improve the properties, performance, condition or quality, to a level that enables it to be reused (e.g. removing nails from a timber floorboard) .The term 'reuse' tends to imply that the material or product is being used for the same purpose as it was used in its former life. The opportunities to recycle materials depends on two main factors; (1) Whether the material can easily be separated from other materials – iron and steel, for instance, can be separated magnetically; copper and tin cannot. (2) The suitability of the recycled material to be manufactured into a useful product, for example recycled plastic bottles used to make garden furniture.

The potential reuse and recycling rate of building materials are described as elaborated and shown in Table 6.1. As shown, Considerable quantities of soil waste used as fill and topsoil, are excavated during construction work and much of this is often reused for construction reclamation. In addition, there remain many occasions where such material can be reused completely for landscaping or as fill. Meanwhile, stone for foundation as a material which has long durability are reusable material for the same purpose in building construction (Addis, 2006). Therefore, we assumed that soil and stone can be reused completely.

Bricks and blocks work is usually constructed using a mortar to provide good bedding between units and, to an extent that varies with the type of mortar, to bind the units together. The ease with which bricks and blocks can be separated for reuse depends on the type of mortar used. Modern cement mortars are highly tenacious and make separating the units both mechanically difficult and likely to cause damage to the units. Although bricks are usually made from virgin clay it is possible to make bricks with recycled content using a variety of post-industrial waste materials, including colliery spoil, dredged silt, pulverized fuel ash. Reused bricks may lack of the strength and durability of new bricks. The reuse of bricks is not appropriate for all brick structures. Clay bricks are sometimes reused in such decorative applications as brick fireplaces, hearths, patios, etc. The percentage recycled content mixed with virgin clay varies considerably according to the material being used and type of brick, but can exceed 90% and the remain is reused dependent on the quality of material (Addis, 2006). Meanwhile, clay and concrete roof are easily reused due to their long durability. On the other hand, recycling ratio of concrete brick and roof are zero due to difficult to be separated from other materials (Becker, 1982).

When structure are demolished, the waste of concrete can be crushed and reused in place of virgin aggregate. Virgin aggregates, which include crushed stone, gravel, and sand, are used in a wide variety of infrastructure construction applications, such as road base, fill, and as an ingredient in concrete and asphalt pavement. Meanwhile, recycling of ceramic materials is almost impossible because at the moment, these products cannot be transformed into their pure materials (Luiz et al., 2013).

Timber is used in a wide variety of construction components and building elements and the material is used in many different forms, varying from substantial structural timbers that may be many hundreds of years old to modern products such as chipboard and medium-density fiber board (MDF), which are made from small particles of timber bonded with a resin glue. The opportunities to reuse timber in construction vary greatly according to the type of timber product and its intended use. Nevertheless, reclaimed timber does present many opportunities for reuse and recycling, depending on its form. The wood fraction of C&D waste is only partly recyclable. Clean and de-nailed timber and boards can be reused for new construction, and uncontaminated wood can be shredded and used for gardening, farming, etc. (Kartam et al., 2004). There are several potential of recycled wood, such as for erosion control/groundcover, organic soil amendment, chipboard, export as fuel wood, animal bedding, etc. Therefore, this study assumed timber has reuse and recycling ratio 50%, respectively.

Metals, including steel, are easy to separate from mixed waste – iron and steel can be removed with electromagnets and aluminum and copper can be removed using other electromagnetic processes. The resulting metal is effectively new material and this means that metals can be recycled almost indefinitely. The recycling ratio of steel profiles is theoretically almost one (Becker, 1982).

Glass is one of the easiest materials to reuse/recycle, though remelting it is an energy-intensive process. Also, there are many different uses for recycled glass. Today the majority of glass that is recycled is crushed and used in the manufacture of new glass containers or fiber glass insulation (Addis, 2006). Meanwhile, the recycling system for gypsum assures that gypsum and plasterboard waste become 100% recyclable. Nothing goes to the landfill (Nielsen, 2014).

Asbestos was commonly used in many asphalt roofing materials. It was rarely used in the shingles themselves. Some manufactures did use asbestos in the fiber mat of shingles. Therefore, asbestos shingle is potential to be reused as aggregate road base, temporary roads, driveways, parking lots and erosion control at construction site and rural roads (CDRA, 2014). Meanwhile, at present, approximately 75% of the zinc consumed

Table 6.1 *Potential reuse and recycling rates*

Materials	Potential rate (%)	
	Reuse	Recycling
Soil	100 (Addis, 2006)	0 (Addis, 2006)
Stone	100 (Addis, 2006)	0 (Addis, 2006)
Clay brick	10 (Addis, 2006)	90 (Addis, 2006)
Concrete brick	0	0 (Becker, 1982)
Cement	0	0
Sand	0	0
Steel	0	100 (Becker, 1982)
Ceramic tile	0 (Luiz et al., 2013)	0 (Luiz et al., 2013)
Clear glass	100 (Addis, 2006)	100 (Addis, 2006)
Wood	50 (Kartam, 2004)	50 (Nielsen, 2014)
Gypsum	0	100 (Nielsen, 2014)
Paint	0	0
Clay roof	100 (Addis, 2006)	100 (Addis, 2006)
Concrete roof	100 (Damanhuri, 2010)	0 (Becker, 1982)
Asbestos roof	0	100 (CDRA, 2014)
Zinc roof	10 (Damanhuri, 2010)	90 (IZA, 2014)

worldwide originates from mined ores and 25% from recycled or secondary zinc. The level of recycling is increasing each year, in step with progress in the technology of zinc production and zinc recycling. While the recycling rate of zinc depends mainly on the collection rate of zinc-containing products at their end of life, over 90% of these collected products are recycled (IZA, 2014). Damanhuri (2010) stated that a few zinc roofs were reused by informal sectors recently.

6.3 Current building material stock

.Number of housing stocks are related with number of populations and households. The current population in Jakarta increased from 9,607,787 in 2010 to 9,991,788 people in 2012. The households number also increased from 2,509.096 in 2010 to 2,579,953 in 2012 (Jakarta, 2013). The distribution of income level in Jakarta comprises 5% for high, 25% for medium and 70% for low income levels, respectively (Mizuho Research Institute, 2010). This study assumed that income distribution in unplanned settlement area is same with the status of Jakarta that low, middle and high income people live in simple, medium and luxurious houses, respectively. Meanwhile, population in Bandung increased from 2,394,673 people in 2010 to 2,455,517 people in 2012. Number of household in Bandung reached 653,572 units in 2012 (Bandung, 2013). The distribution of income level is estimated to be the same with Jakarta.

This section discusses the current total material stock and future demolition waste in urban residential buildings at the city level in Jakarta and Bandung by house category and household's cluster. The current building material stocks in urban unplanned houses in the two cities in 2012 were calculated utilising Eqs. (4.34)-(4.37). Table 6.2 shows the composition for current housing material stock, including materials for maintenance by house category, in Jakarta and Bandung. As shown, overall, the average material quantity per m^2 is 2.14 ton/m^2 in Jakarta and 2.06 ton/m^2 in Bandung. The average material quantity slightly varies among the different house categories in the two cities: 2.26, 2.06 and 2.05 ton/m^2 for simple, medium and luxurious houses in Jakarta, respectively, whereas the corresponding quantities are 1.88, 2.23 and 2.26 ton/m^2 for simple, medium and luxurious houses in Bandung, respectively. Overall, stone accounts for the largest percentage in Jakarta and Bandung (32% and 31%), followed by sand (31% and 30%), clay brick (19% and 19%), and cement (8% and 8%), etc. As indicated, the average material quantity of wood per m^2 for luxurious houses in Bandung is much smaller than that in Jakarta. This discrepancy arises because the houses in Bandung are relatively newer and tend to use steel more, particularly for roof structures and window frames, instead of wood than those in Jakarta (Fig. 6.3). The current total material stock in urban houses of Jakarta is measured at 232.0 million ton, whereas that of Bandung is 77.2 million ton. The difference between the two cities is mainly due to the difference in the number of houses.

Table 6.2 *Current building material inventory by house category*

(unit: kg/m^2)

Materials	Density (kg/m^3) *	Simple house		Medium house		Luxurious house		Whole sample	
		Jakarta	Bandung	Jakarta	Bandung	Jakarta	Bandung	Jakarta	Bandung
1. Stone	1450	729.8	623.1	696.5	682.6	529.0	603.9	678.4	644.7
2. Sand	1400	717.5	561.0	623.1	674.4	583.8	740.2	655.3	626.8
3. Clay brick	950	494.9	371.7	309.2	414.0	413.3	451.2	407.4	397.7
4. Cement	1506	142.9	118.8	175.7	185.0	187.4	227.2	164.1	157.6
5. Wood	705	105.0	143.1	131.0	161.5	159.8	43.2	125.6	139.2
6. Ceramic tile	2500	30.8	15.5	33.9	34.2	59.5	77.4	37.5	30.0
7. Steel	7750	16.6	17.3	36.6	37.7	30.5	34.0	27.0	27.4
8. Clay roof	2300	16.6	20.7	40.9	30.2	0.0	0.0	22.8	22.2
9. Concrete roof	2500	0.0	0.0	0.0	0.0	49.9	39.2	9.6	4.4
10. Gypsum	1100	0.0	0.3	7.0	1.3	23.0	24.4	7.1	3.4
11. Paint	700	2.0	1.6	5.4	4.4	10.0	12.4	4.9	4.0
12. Asbestos roof	2200	5.6	0.6	2.1	0.3	0.3	0.0	3.2	0.4
13. Concrete brick	2300	0.0	7.5	0.0	0.0	0.0	0.0	0.0	3.6
14. Clear glass	2579	0.8	1.2	0.8	1.3	1.3	6.2	0.9	1.8
15. Zinc roof	3330	1.2	0.8	0.1	0.1	0.0	0.0	0.5	0.4
Total		2,263.7	1,883.2	2,062.3	2,227.0	2,047.8	2,259.3	2,144.3	2,063.6

*SNI, 1989

The composition for current housing material stock, including materials for maintenance by household's cluster in Jakarta and Bandung showed in Appendix 3. As shown, overall, the average material quantity per m^2 same as the average material quantity per m^2 by house category. The average material quantity slightly varies among the different household clusters in the two cities: 2.25, 2.01 and 1.96 ton/m^2 for simple, medium and luxurious houses in Jakarta, respectively, whereas the corresponding quantities are 2.08, 1.98 and 2.06 ton/m^2 for simple, medium and luxurious houses in Bandung, respectively.

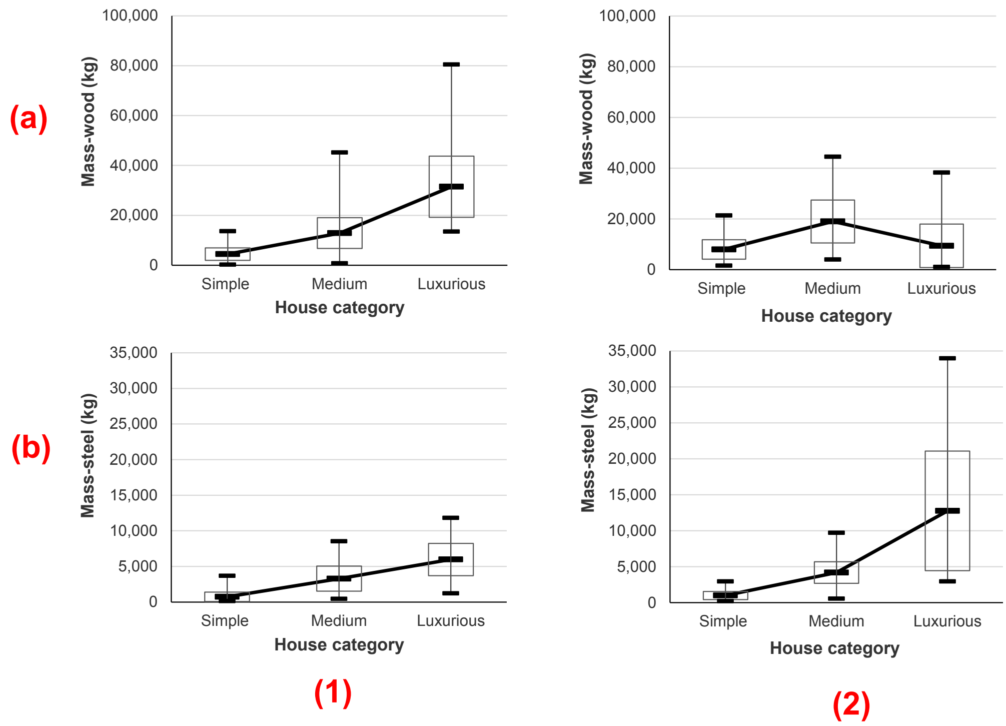


***Fig. 6.3** Statistical summary (5th and 95th percentiles, mean and ± one standard deviations) of building materials in (1) Jakarta and (2) Bandung. (a) Wood; (b) Steel*

Future demolition waste from unplanned residential buildings until 2020

If both the reuse and recycling ratios are assumed to be zero, then the total demolition waste of unplanned houses (i.e., only simple houses) in Jakarta is determined to be 41.5 million ton/m^2 until 2020, all of which goes to landfills (Eqs. (4.56)-(4.59)). The corresponding amount of waste in Bandung is predicted to be lower (12.6 million ton/m^2) than that in Jakarta due to the smaller number of simple houses in Bandung. This scenario will cause a severe situation in which the amount of waste sent to landfills would be very large, thus resulting in the overloading of landfills. As a consequence, this scenario anticipates that both Jakarta and Bandung would be forced to construct new landfills to address the increased amount of waste in the near future.

Urban sprawl caused by the transformation of simple houses into medium houses

The future demolition of unplanned houses and the transformation of these houses into larger, medium houses by 2020 would cause the further urban expansion of both cities: at least, additional areas of 20.0 km^2 and 5.7 km^2 would be required for new constructions in Jakarta and Bandung, respectively, (Eq. (4.60)). These expansions would force the cities to extend their boundaries further to the surrounding suburbs and accelerate urban sprawl. In addition, the increased number of landed houses would also exert negative effects on water reserves and food production (e.g., paddy fields) in cities, as indicated by Shirakawa et al. (2014) for the case of Bandung.

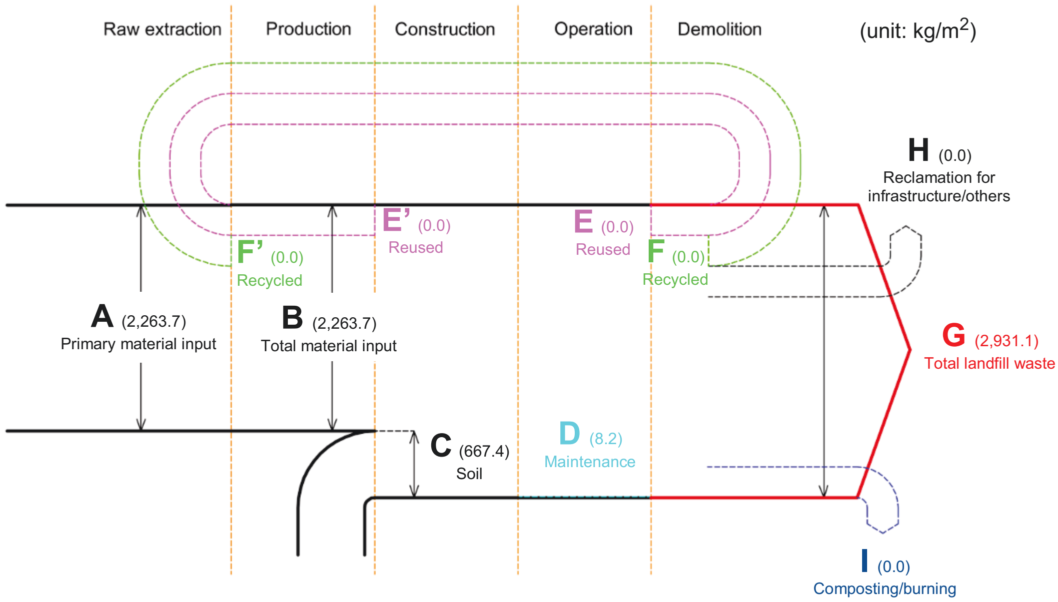
6.4 Scenario Analysis: Policy effects of promoting reused/recycled material use on reduction of building waste and embodied energy and CO_2 emissions

Scenario 1: Zero reuse and recycling rates

The following sections analyse the flow of building materials per house for each of the house categories by taking Jakarta as an example. As described previously, we assess the effects of policy promoting reused and recycled material use through a scenario analysis. In this scenario (Scenario 1), the zero reuse/recycling rates are applied to all building materials used for a house. Figs. 6.4-6.7 show the results of flow analysis for the average material input and output of urban unplanned houses in Jakarta utilising zero reuse/recycling rates for simple, medium, and luxurious houses and the whole sample. As shown, the total average material inputs, including those for maintenance, for the respective house categories ('B' in the figures) are derived from Table 6.2. A few materials are imported, such as ceramics (37.5 kg/m^2) in the case of luxurious houses. There are no materials reused/recycled for other buildings or other products ('E' and 'F') in this scenario. Thus, all of the materials go to landfills. Eqs. (4.38)-(4.40) were used to calculate the demolition waste for each of the house categories. The total average amount of waste sent to landfills is greater than the average material input due to the additional waste of soil derived from the surplus soil extracted in the construction phase ('C'), accounting for 2,931.1, 2,521.3, 2,371.5 and 2,665.1 kg/m^2 for simple, medium, and luxurious houses and the whole sample, respectively ('G'). Overall, mortar accounts for the largest proportion of material waste (23%), followed by soil (19%), stone foundation (17%), concrete (16%), and clay brick (15%).

Scenario 2: Maximum reuse and recycling rates

In this scenario (Scenario 2), we apply the maximum potential reuse/recycling rates (see Table 1). Figs. 6.8-6.11 show the results of the flow analysis of building material inputs and outputs for urban unplanned houses in Jakarta in Scenario 2 for the respective house categories. As shown, the total average material inputs, including those for maintenance, for the respective houses in Jakarta are still the same as those in Scenario 1 ('B' in the figures). However, some materials (700.1, 537.5, 454.2 and 590.0 kg/m^2) are reused for other buildings ('E'). For instance, the reused materials include stone (83%), clay brick (7%), and wood (8%) in the case of simple houses (Fig. 6.8). In addition, several materials (515.7 kg/m^2) are recycled, including clay brick (86%), wood (10%), steel (3%), and zinc roofing material (0.2%) ('F' in Fig. 6.8). No material is composted/burned. The rest of the materials (soil, mortar, concrete, ceramic and asbestos) are assumed to be reclaimed for other products or for infrastructure. The total amount of waste used for reclamation accounts for 1,715.3; 1,596.3; 1,412.0 and 1,611.1 kg/m^2 for simple, medium and luxurious houses and the whole sample, respectively ('H'). Overall, mortar accounts for the largest proportion of material waste (39%), followed by soil (32%), concrete (27%), ceramic tile (2%) and asbestos roofing material (0.3%) ('H' in Fig. 6.11). These materials cannot be reused/recycled for other building constructions due to the difficulty of separating them from mixed materials. Thus, it is observed that a closed-loop material flow is not sufficient to fully reclaim building materials and eliminate building material waste sent to landfills. Nevertheless, these materials can be reused/recycled by crushing them and reclaimed for building infrastructure such as roads and for creating materials for building sites. In this case, the total waste sent to landfills would become zero.



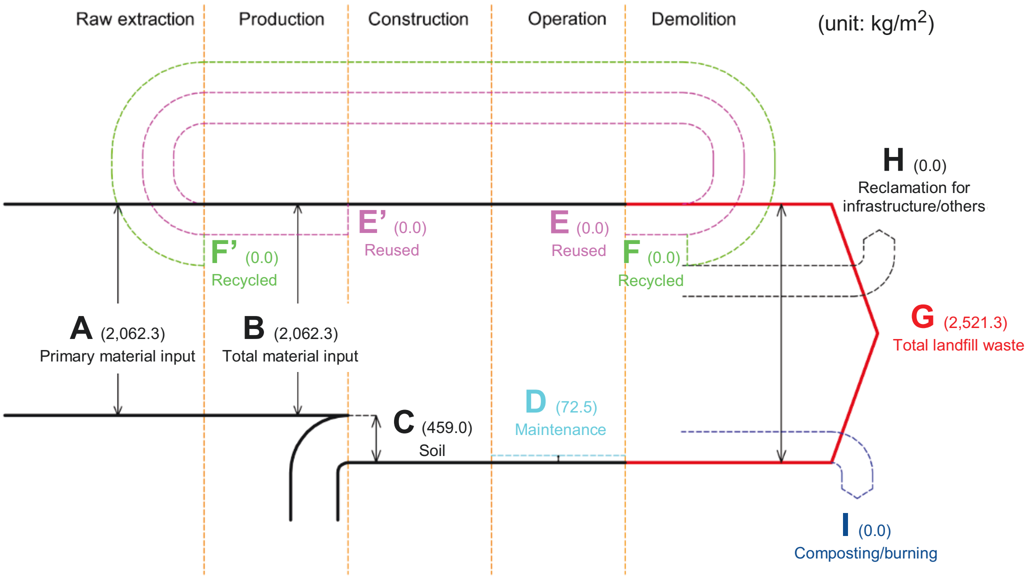
Legends:

Materials	Quantity kg/m^2	%
A (primary material input) = B (total material input)		
Stone foundation	580.6	25.6
Gravel	149.2	6.6
Clay brick	494.9	21.9
Concrete brick	0.0	0.0
Cement	142.9	6.3
Sand	717.4	31.7
Steel	16.7	0.7
Ceramic tile	30.8	1.4
Clear glass	0.8	0.0
Wood	105.0	4.6
Gypsum	0.0	0.0
Paint	2.0	0.1
Clay roof	16.6	0.7
Concrete roof	0.0	0.0
Asbestos roof	5.6	0.3
Zinc roof	1.2	0.1
Total	2,263.7	100

Materials	Quantity kg/m^2	%
C (soil generation)		
Soil	667.4	100.0
D (Maintenance)		
Ceramic tile	6.8	82.9
Clear glass	0.1	1.2
Paint	1.3	15.9
Total	8.2	100.0
E = E' (reused materials)		
-	-	-
F= F' (recycled materials)		
-	-	-

Materials	Quantity kg/m^2	%
G (total landfill waste)		
Soil	667.4	22.8
Stone foundation	580.6	19.8
Clay brick	494.9	16.9
Concrete brick	0.0	0.0
Mortar;	735.2	25.1
Cement	102.5	13.9
Sand	630.7	85.8
paint	2.0	0.3
Concrete;	276.3	9.4
Cement	40.4	14.6
Sand	86.7	31.4
Gravel	149.2	54.0
Steel	16.7	0.6
Ceramic tile	30.8	1.0
Clear glass	0.8	0.0
Wood	105.0	3.6
Gypsum	0.0	0.0
Clay roof	16.6	0.6
Concrete roof	0.0	0.0
Asbestos roof	5.6	0.2
Zinc roof	1.2	0.0
Total	2,931.1	100.0
H (reclamation for infrastructure)		
-	-	-
I (composting/burning)		
-	-	-

Fig. 6.4 Flow of building materials for simple house in Jakarta (Scenario 1)



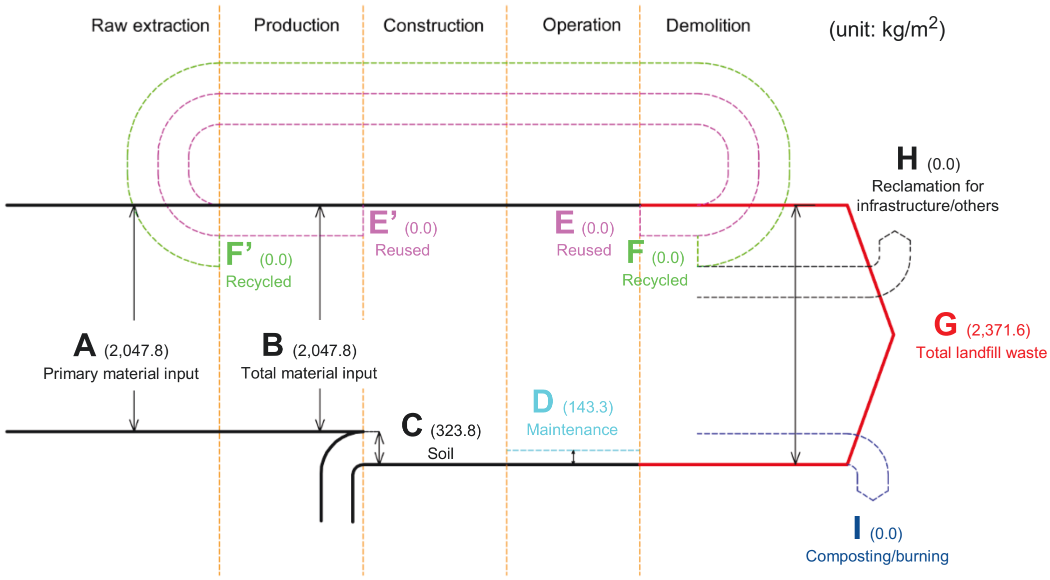
Legends:

Materials	Quantity kg/m²	%
A (primary material input) = B (total material input)		
Stone foundation	399.4	19.4
Gravel	297.1	14.4
Clay brick	309.2	15.0
Concrete brick	0.0	0.0
Cement	175.7	8.5
Sand	623.1	30.2
Steel	36.6	1.8
Ceramic tile	33.9	1.6
Clear glass	0.8	0.0
Wood	131.0	6.4
Gypsum	7.0	0.3
Paint	5.4	0.3
Clay roof	40.9	2.0
Concrete roof	0.0	0.0
Asbestos roof	2.1	0.1
Zinc roof	0.1	0.0
Total	2,062.3	100.0

Materials	Quantity kg/m²	%
C (soil generation)		
Soil	459.0	100.0
D (Maintenance)		
Ceramic tile	9.7	13.4
Clear glass	0.1	0.1
Wood	42.5	58.6
Paint	4.7	6.5
Clay roof	15.5	21.4
Total	72.5	100.0
E = E' (reused materials)		
-	-	-
F= F' (recycled materials)		
-	-	-

Materials	Quantity kg/m²	%
G (total landfill waste)		
Soil	459.0	18.2
Stone foundation	399.4	15.8
Clay brick	309.2	12.3
Concrete brick	0.0	0.0
Mortar;	533.5	21.2
Cement	80.7	15.1
Sand	447.4	83.9
paint	5.4	1.0
Concrete;	567.8	22.5
Cement	95.0	16.7
Sand	175.7	30.9
Gravel	297.1	52.4
Steel	36.6	1.5
Ceramic tile	33.9	1.3
Clear glass	0.8	0.0
Wood	131.0	5.2
Gypsum	7.0	0.3
Clay roof	40.9	1.6
Concrete roof	0.0	0.0
Asbestos roof	2.1	0.1
Zinc roof	0.1	0.0
Total	2,521.3	100.0
H (reclamation for infrastructure)		
-	-	-
I (composting/burning)		
-	-	-

Fig. 6.5 *Flow of building materials for medium house in Jakarta (Scenario 1)*



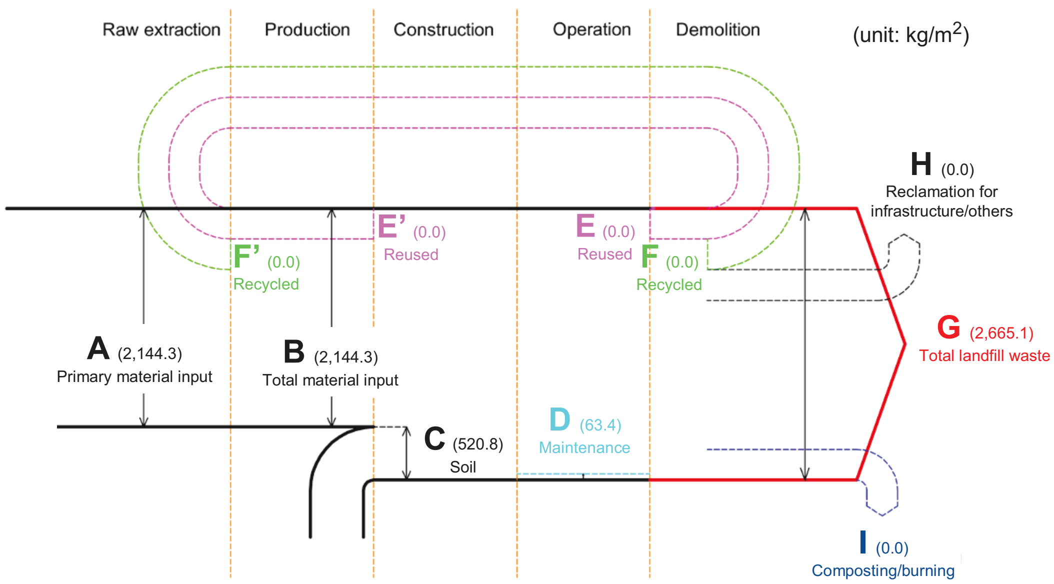
Legends:

Materials	Quantity kg/m²	%
A (primary material input) = B (total material input)		
Stone foundation	281.7	13.8
Gravel	247.3	12.1
Clay brick	413.3	20.2
Cement	187.4	9.2
Sand	583.8	28.5
Steel	30.5	1.5
Ceramic tile	59.5	2.9
Clear glass	1.3	0.1
Wood	159.8	7.8
Gypsum	23.0	1.1
Paint	10.0	0.5
Clay roof	0.0	0.0
Concrete roof	49.9	2.4
Asbestos roof	0.3	0.0
Zinc roof	0.0	0.0
Total	2,047.8	100.0

Materials	Quantity kg/m²	%
C (soil generation)		
Soil	323.8	100.0
D (Maintenance)		
Ceramic tile	36.9	25.8
Clear glass	0.7	0.5
Wood	57.3	40.0
Gypsum	13.1	9.1
Paint	9.2	6.4
Concrete roof	26.1	18.2
Total	143.3	100.0
E = E' (reused materials)		
-	-	-
F= F' (recycled materials)		
-	-	-

Materials	Quantity kg/m²	%
G (total landfill waste)		
Soil	323.8	13.7
Stone foundation	281.7	11.9
Clay brick	413.3	17.4
Mortar;	555.8	23.4
Cement	108.3	19.5
Sand	437.5	78.7
paint	10.0	1.8
Concrete;	472.7	19.9
Cement	79.1	16.7
Sand	146.3	30.9
Gravel	247.3	52.4
Steel	30.5	1.3
Ceramic tile	59.5	2.5
Clear glass	1.3	0.1
Wood	159.8	6.7
Gypsum	23.0	1.0
Clay roof	0.0	0.0
Concrete roof	49.9	2.1
Asbestos roof	0.3	0.0
Zinc roof	0.0	0.0
Total	2,371.6	100.0
H (reclamation for infrastructure)		
-	-	-
I (composting/burning)		
-	-	-

Fig. 6.6 *Flow of building materials for luxurious house in Jakarta (Scenario 1)*



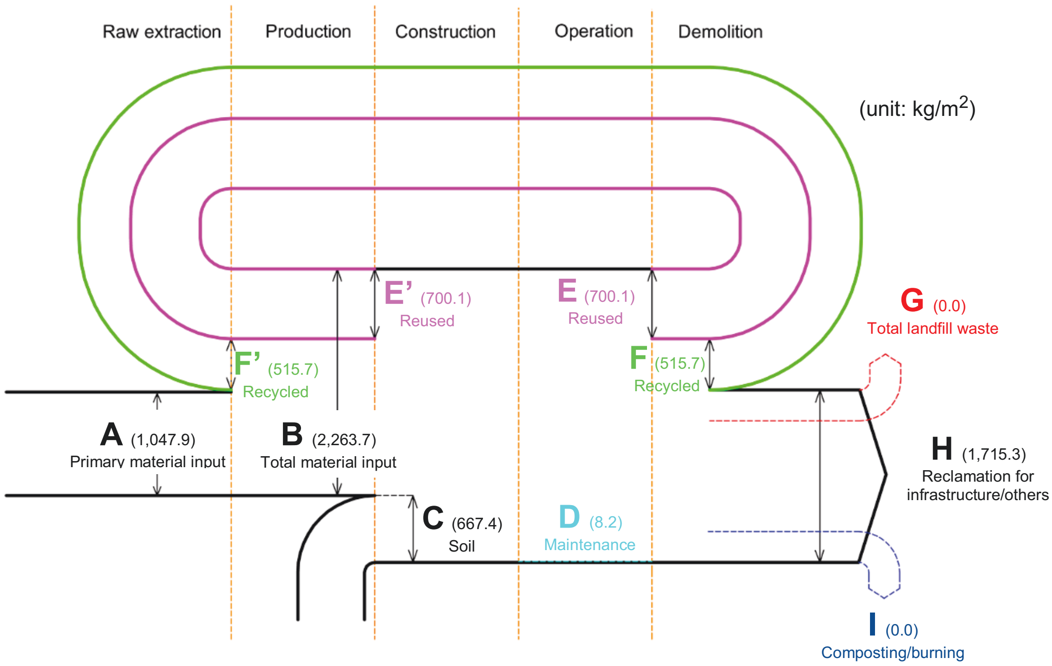
Legends:

Materials	Quantity	
	kg/m^2	%
A (primary material input) = B (total material input)		
Stone foundation	453.1	21.1
Gravel	225.3	10.5
Clay brick	407.4	19.0
Concrete brick	0.0	0.0
Cement	164.1	7.7
Sand	655.3	30.6
Steel	27.0	1.3
Ceramic tile	37.5	1.7
Clear glass	0.9	0.0
Wood	125.6	5.9
Gypsum	7.1	0.3
Paint	4.9	0.2
Clay roof	22.8	1.1
Concrete roof	9.6	0.4
Asbestos roof	3.2	0.2
Zinc roof	0.5	0.0
Total	2,144.3	100.0

Materials	Quantity	
	kg/m^2	%
C (soil generation)		
Soil	520.8	100.0
D (Maintenance)		
Ceramic tile	13.4	21.1
Clear glass	0.2	0.3
Wood	32.1	50.6
Gypsum	2.5	3.9
Paint	4.2	6.6
Clay roof	6.0	9.5
Concrete roof	5.0	8.0
Total	63.4	100.0
E = E' (reused materials)		
-	-	-
F= F' (recycled materials)		
-	-	-

Materials	Quantity			
	kg/m^2			%
G (total landfill waste)				
Soil	520.8			19.5
Stone foundation	453.1			17.0
Clay brick	407.4			15.3
Concrete brick	0.0			0.0
Mortar;	622.7			23.4
Cement		95.1	15.3	
Sand		522.7	83.9	
paint		4.9	0.8	
Concrete;	426.9			16.0
Cement		69.0	16.2	
Sand		132.6	31.1	
Gravel		225.3	52.7	
Steel	27.0			1.0
Ceramic tile	37.5			1.4
Clear glass	0.9			0.0
Wood	125.6			4.7
Gypsum	7.1			0.3
Clay roof	22.8			0.9
Concrete roof	9.6			0.4
Asbestos roof	3.2			0.1
Zinc roof	0.5			0.0
Total	2,665.1			100
H (reclamation for infrastructure)				
-	-			-
I (composting/burning)				
-	-			-

***Fig. 6.7** Flow of building materials for whole sample in Jakarta (Scenario 1)*



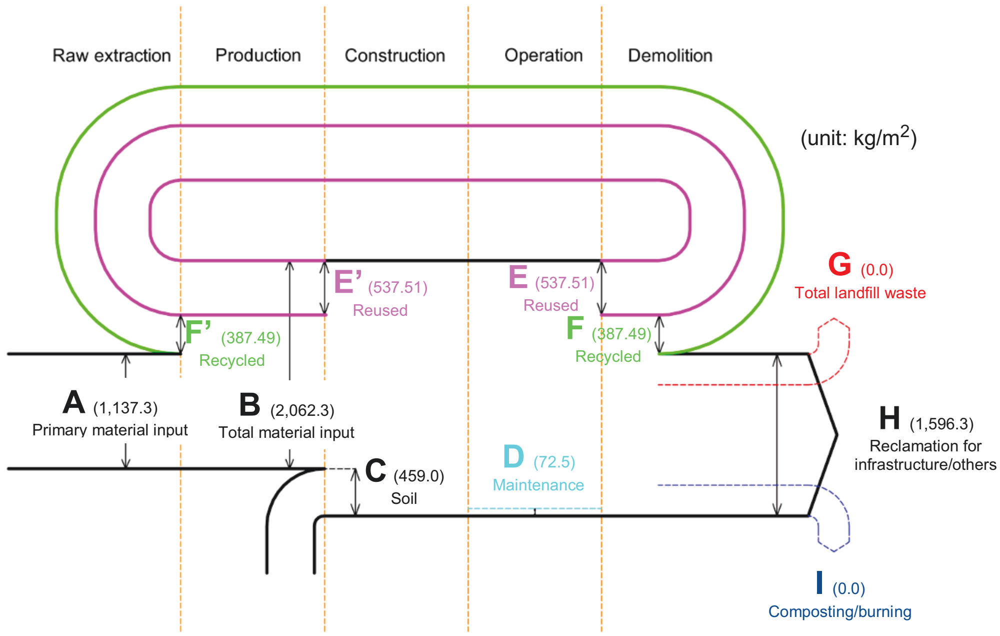
Legends:

Materials	Quantity kg/m²	Quantity %
A (primary material input)		
Gravel	149.2	14.2
Cement	142.9	13.6
Sand	717.4	68.5
Ceramic tile	30.8	2.9
Paint	2.0	0.2
Asbestos roof	5.6	0.6
Total	1,047.9	100.0
B (total material input)		
Stone foundation	580.6	25.6
Gravel	149.2	6.6
Clay brick	494.9	21.9
Concrete brick	0.0	0.0
Cement	142.9	6.3
Sand	717.4	31.7
Steel	16.7	0.7
Ceramic tile	30.8	1.4
Clear glass	0.8	0.0
Wood	105.0	4.6
Gypsum	0.0	0.0
Paint	2.0	0.1
Clay roof	16.6	0.7
Concrete roof	0.0	0.0
Asbestos roof	5.6	0.3
Zinc roof	1.2	0.1
Total	2,263.7	100

Materials	Quantity kg/m²	Quantity %
C (soil generation)		
Soil	667.4	100.0
D (Maintenance)		
Ceramic tile	6.8	82.9
Clear glass	0.1	1.2
Paint	1.3	15.9
Total	8.2	100.0
E = E' (reused materials)		
Stone foundation	580.6	82.9
Clay brick	49.5	7.1
Clear glass	0.8	0.1
Concrete brick	0.0	0.0
Wood	52.5	7.5
Clay roof	16.6	2.4
Zinc roof	0.1	0.0
Total	700.1	100.0

Materials	Quantity kg/m²	Quantity %
F = F' (recycled materials)		
Clay brick	445.4	86.4
Steel	16.7	3.2
Wood	52.5	10.2
Zinc roof	1.1	0.2
Total	515.7	100.0
G (total landfill waste)		
-	-	-
H (reclamation for infrastructure)		
Soil	667.4	38.9
Mortar;	735.2	42.9
Cement	102.5	13.9
Sand	630.7	85.8
paint	2.0	0.3
Concrete;	276.3	16.1
Cement	40.4	14.6
Sand	86.7	31.4
Gravel	149.2	54.0
Ceramic tile	30.8	1.8
Asbestos roof	5.6	0.3
Total	1,715.3	100.0
I (composting/burning)		
-	-	-

Fig. 6.8 *Flow of building materials for simple house in Jakarta (Scenario 2)*



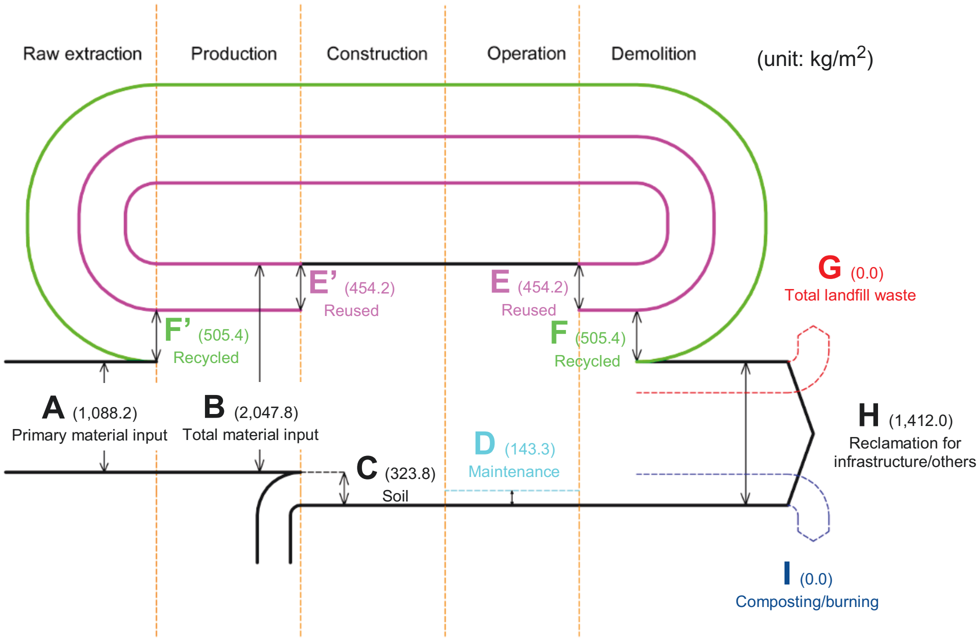
Legends:

Materials	Quantity kg/m²	%
A (primary material input)		
Gravel	297.1	26.1
Cement	175.7	15.4
Sand	623.1	54.8
Ceramic tile	33.9	3.0
Paint	5.4	0.5
Asbestos roof	2.1	0.2
Total	1,137.3	100
B (total material input)		
Stone foundation	399.4	19.4
Gravel	297.1	14.4
Clay brick	309.2	15.0
Concrete brick	0.0	0.0
Cement	175.7	8.5
Sand	623.1	30.2
Steel	36.6	1.8
Ceramic tile	33.9	1.6
Clear glass	0.8	0.0
Wood	131.0	6.4
Gypsum	7.0	0.3
Paint	5.4	0.3
Clay roof	40.9	2.0
Concrete roof	0.0	0.0
Asbestos roof	2.1	0.1
Zinc roof	0.1	0.0
Total	2,062.3	100.0

Materials	Quantity kg/m²	%
C (soil generation)		
Soil	459.0	100.0
D (Maintenance)		
Ceramic tile	9.7	13.4
Clear glass	0.1	0.1
Wood	42.5	58.6
Paint	4.7	6.5
Clay roof	15.5	21.4
Total	72.5	100.0
E = E' (reused materials)		
Stone foundation	399.4	74.3
Clay brick	30.9	5.8
Clear glass	0.8	0.1
Concrete brick	0.0	0.0
Wood	65.5	12.2
Clay roof	40.9	7.6
Zinc roof	0.01	0.0
Total	537.51	100

Materials	Quantity kg/m²	%
F = F' (recycled materials)		
Clay brick	278.3	71.8
Steel	36.6	9.5
Wood	65.5	16.9
Gypsum	7.0	1.8
Zinc roof	0.09	0.0
Total	387.49	100.0
G (total landfill waste)		
-	-	-
H (reclamation)		
Soil	459.0	28.8
Mortar;	533.5	33.4
Cement	80.7	15.1
Sand	447.4	83.9
paint	5.4	1.0
Concrete;	567.8	35.6
Cement	95.0	16.7
Sand	175.7	30.9
Gravel	297.1	52.4
Ceramic tile	33.9	2.1
Asbestos roof	2.1	0.1
Total	1,596.3	100.0
I (composting/burning)		
-	-	-

Fig. 6.9 *Flow of building materials for medium house in Jakarta (Scenario 2)*



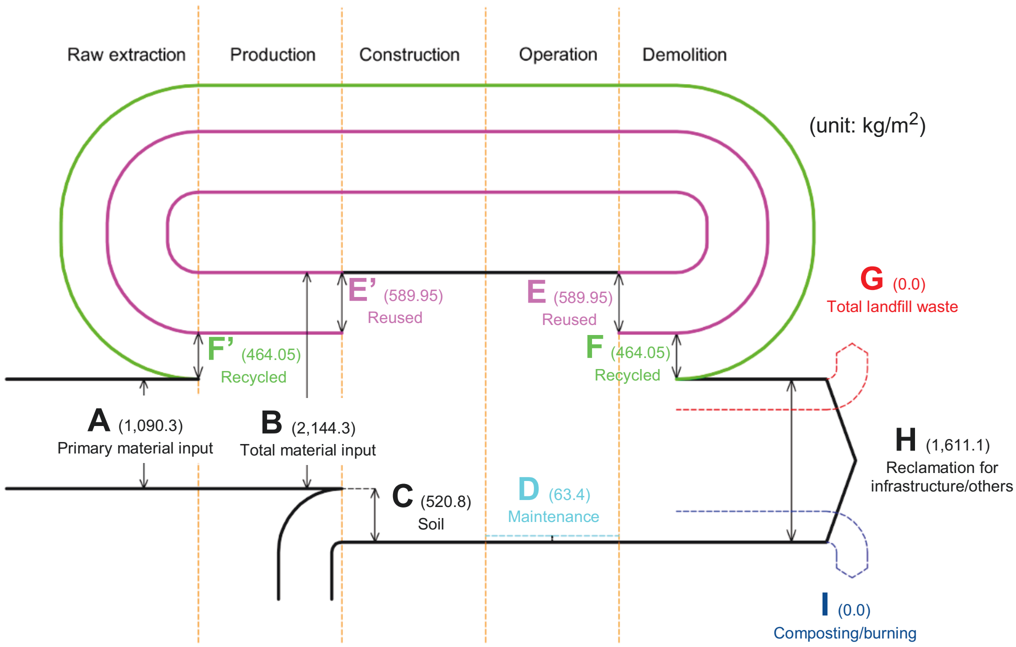
Legends:

Materials	Quantity	
	kg/m^2	%
A (primary material input)		
Gravel	247.3	22.7
Cement	187.4	17.2
Sand	583.7	53.7
Ceramic tile	59.5	5.5
Paint	10.0	0.9
Asbestos roof	0.3	0.0
Total	1,088.2	100.0
B (total material input)		
Stone foundation	281.7	13.8
Gravel	247.3	12.1
Clay brick	413.3	20.2
Cement	187.4	9.2
Sand	583.8	28.5
Steel	30.5	1.5
Ceramic tile	59.5	2.9
Clear glass	1.3	0.1
Wood	159.8	7.8
Gypsum	23.0	1.1
Paint	10.0	0.5
Clay roof	0.0	0.0
Concrete roof	49.9	2.4
Asbestos roof	0.3	0.0
Zinc roof	0.0	0.0
Total	2,047.8	100.0

Materials	Quantity	
	kg/m^2	%
C (soil generation)		
Soil	323.8	100.0
D (Maintenance)		
Ceramic tile	36.9	25.8
Clear glass	0.7	0.5
Wood	57.3	40.0
Gypsum	13.1	9.1
Paint	9.2	6.4
Concrete roof	26.1	18.2
Total	143.3	100.0
E = E' (reused materials)		
Stone foundation	281.7	62.0
Clay brick	41.3	9.1
Clear glass	1.3	0.3
Concrete brick	0.0	0.0
Wood	79.9	17.6
Concrete roof	49.9	11.0
Zinc roof	0.0	0.0
Total	454.2	100.0

Materials	Quantity			
	kg/m^2		%	
F = F' (recycled materials)				
Clay brick	372.0		73.6	
Steel	30.5		6.0	
Wood	79.9		15.8	
Gypsum	23.0		4.6	
Zinc roof	0.0		0.0	
Total	505.4		100.0	
G (total landfill waste)				
-	-		-	
H (reclamation for infrastructure)				
Soil	323.8		22.9	
Mortar;	555.7		39.4	
Cement		108.3		19.5
Sand		437.4		78.7
paint		10.0		1.8
Concrete;	472.7		33.5	
Cement		79.1		16.7
Sand		146.3		30.9
Gravel		247.3		52.4
Ceramic tile	59.5		4.2	
Asbestos roof	0.3		0.0	
Total	1,412.0		100.0	
I (composting/burning)				
-	-		-	

Fig. 6.10 Flow of building materials for luxurious house in Jakarta (Scenario 2)



Legends:

Materials	Quantity kg/m²	%
A (primary material input)		
Gravel	225.3	20.7
Cement	164.1	15.1
Sand	655.3	60.1
Ceramic tile	37.5	3.4
Paint	4.9	0.4
Asbestos roof	3.2	0.3
Total	1,090.3	100.0
B (total material input)		
Stone foundation	453.1	21.1
Gravel	225.3	10.5
Clay brick	407.4	19.0
Concrete brick	0.0	0.0
Cement	164.1	7.7
Sand	655.3	30.6
Steel	27.0	1.3
Ceramic tile	37.5	1.7
Clear glass	0.9	0.0
Wood	125.6	5.9
Gypsum	7.1	0.3
Paint	4.9	0.2
Clay roof	22.8	1.1
Concrete roof	9.6	0.4
Asbestos roof	3.2	0.2
Zinc roof	0.5	0.0
Total	2,144.3	100.0

Materials	Quantity kg/m²	%
C (soil generation)		
Soil	520.8	100.0
D (Maintenance)		
Ceramic tile	13.4	21.1
Clear glass	0.2	0.3
Wood	32.1	50.6
Gypsum	2.5	3.9
Paint	4.2	6.6
Clay roof	6.0	9.5
Concrete roof	5.0	8.0
Total	63.4	100.0
E = E' (reused materials)		
Stone foundation	453.1	76.8
Clay brick	40.7	6.9
Clear glass	0.9	0.2
Concrete brick	0.0	0.0
Wood	62.8	10.6
Clay roof	22.8	3.9
Concrete roof	9.6	1.6
Zinc roof	0.05	0.0
Total	589.95	100.0

Materials	Quantity kg/m²	%
F = F' (recycled materials)		
Clay brick	366.7	79.0
Steel	27.0	5.8
Wood	62.8	13.5
Gypsum	7.1	1.5
Zinc roof	0.45	0.2
Total	464.05	100.0
G (total landfill waste)		
-	-	-
H (reclamation for infrastructure)		
Soil	520.8	32.3
Mortar;	622.7	38.6
Cement	95.1	15.3
Sand	522.7	83.9
paint	4.9	0.8
Concrete;	426.9	26.5
Cement	69.0	16.2
Sand	132.6	31.1
Gravel	225.3	52.7
Ceramic tile	37.5	2.3
Asbestos roof	3.2	0.3
Total	1,611.1	100.0
I (composting/burning)		
-	-	-

***Fig. 6.11** Flow of building materials for whole sample in Jakarta (Scenario 2)*

Fig. 6.12 shows the average amount of material waste for the respective house types for both scenarios. As shown, maximising the reuse/recycling rates would decrease the average amount of material waste dramatically by 41% for simple houses, 37% for medium houses and 40% for luxurious houses. As previously discussed, the remaining waste still has potential for being reused/recycled as infrastructure materials or other products. The amount of mortar waste generated by the construction of simple houses is observed to be greater than that generated by the construction of the other types of houses. This discrepancy arises because the per-house floor area of simple houses is generally much smaller than the per-house floor areas of medium (2.5 times) and luxurious houses (5.0 times). The average amount of material waste for the respective household clusters for both scenarios has the similar pattern with that of material waste for the respective house categories (see Index 3)

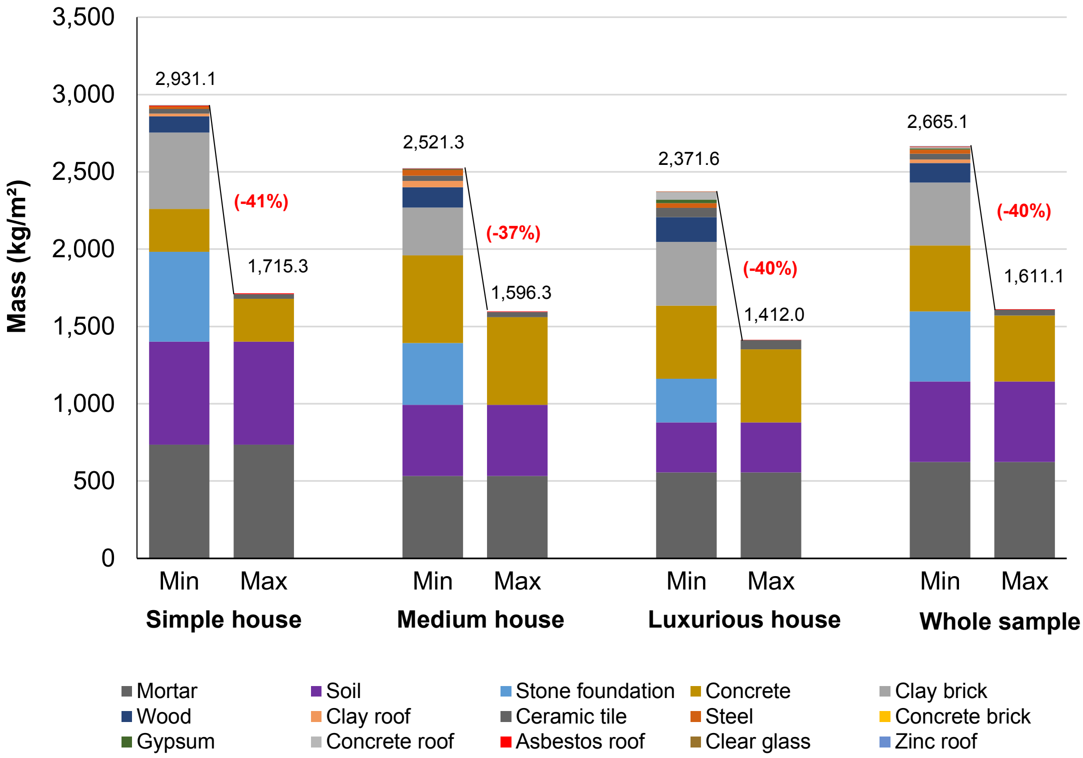


Fig. 6.12 *Average material waste for respective house categories in the two scenarios in Jakarta*

Embodied energy and CO_2 emissions

Primary building material inputs were obtained by utilising Eq. (4.41) to analyse the materials' embodied energy and CO_2 emissions. The total embodied energy and CO_2 emissions were estimated by combining initial, maintenance and recycling embodied energy/CO_2 emissions for the respective house categories through the previously described I-O analysis-based method (Surahman and Kubota, 2012). Figs. 6.13-6.14 show the total embodied energy and CO_2 emissions for the two scenarios considered (i.e., zero and maximum reuse and recycling rates). The results indicate that the reuse and recycling materials reduce not only the amount of material waste generated but also diminish embodied energy/CO_2 emissions. The maximum reuse/recycling rates are expected to decrease embodied energy by 19.8 (32%), 49.2 (24%), 78.1 (14%) and 49.0 GJ (18%) for simple, medium, and luxurious houses and the whole sample, respectively (Fig. 6.13). Moreover, the decreasing trends observed for embodied CO_2 emissions are similar to those observed for embodied energy (Fig. 6.14). The value of Eta squared showed that house category has larger effects (0.76) on embodied energy than household cluster (0.60).

Meanwhile, the pattern of material waste, embodied energy and CO_2 emissions for the respective household clusters are similar with those for the respective house categories as shown in Appendices 4-6.

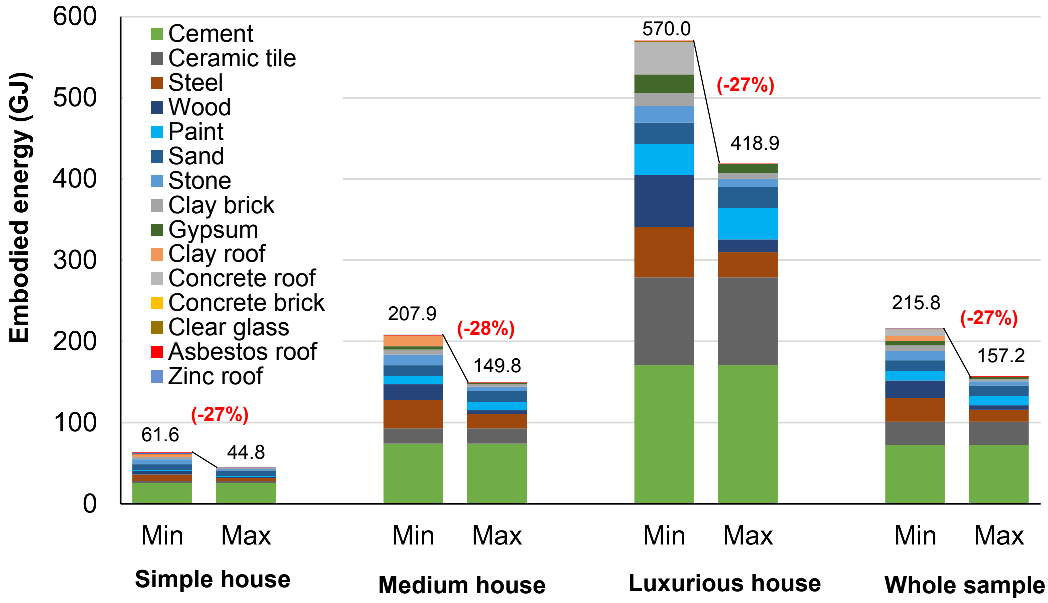


Fig. 6.13 *Embodied energy for respective house categories in the two scenarios in Jakarta.*

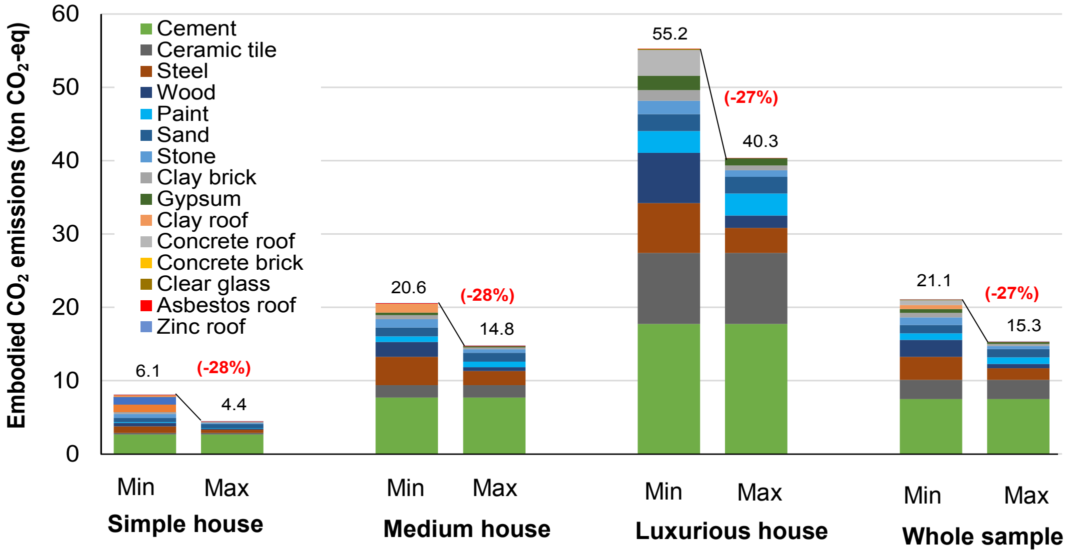


Fig. 6.14 *CO_2 emissions for respective house categories in the two scenarios in Jakarta*

The results of the foregoing scenario analysis prove that the promotion of reuse/recycling is important to ensure the availability of building material stocks and to reduce not only material waste but also their corresponding embodied energy/CO_2 emissions.

Tables 6.4-6.6 summarized the value of building material inventory, building waste and their embodied energy/CO_2 emissions for Jakarta, Bandung and combination of Jakarta and Bandung.

__Table 6.3__ Building materials inventory and their embodied energy/CO_2 emissions for urban houses in Jakarta

	Unit	House category			
		Simple house	Medium house	Luxurious house	Whole sample
Material input	kg/m^2	2,263.7	2,062.3	2,047.8	2,144.3
Maintenance materials	kg/m^2	8.2	72.5	143.3	63.4
Material waste	kg/m^2	2,931.1	2,521.3	2,371.6	2,665.1
Initial embodied energy	GJ	57.3	176.0	380.6	165.3
Maintenance embodied energy	GJ	4.3	31.9	189.4	50.5
Embodied energy	GJ	61.6	207.9	570.0	215.8
Annual embodied energy	GJ/year	3.1	5.9	11.4	5.8
Unit annual embodied energy per floor area	GJ/m^2 year	0.07	0.06	0.06	0.07
Unit annual embodied energy per person	GJ/person year	0.75	1.53	2.40	1.37
Initial embodied CO_2 emissions	ton CO_2-eq	5.99	18.28	37.18	17.31
Maintenance embodied CO_2 emissions	ton CO_2-eq	0.11	2.27	18.05	3.81
Embodied CO_2 emissions	ton CO_2-eq	6.1	20.6	55.2	21.12
Annual embodied CO_2 emissions	ton CO_2-eq/year	0.30	0.59	1.10	0.57
Unit annual embodied CO_2 emissions per floor area	ton CO_2-eq/m^2. year	0.01	0.01	0.01	0.01
Unit annual embodied CO_2 emissions per person	ton CO_2-eq/person year	0.07	0.15	0.23	0.13

Table 6.4 *Building materials inventory and their embodied energy/CO_2 emissions for urban houses in Bandung*

	Unit	House category			
		Simple house	Medium house	Luxurious house	Whole sample
Material input	kg/m^2	1,883.2	2,227.0	2,259.3	2,063.6
Maintenance materials	kg/m^2	4.9	77.6	115.4	46.6
Material waste	kg/m^2	2,418.4	2,656.0	2,636.5	2,538.3
Initial embodied energy	GJ	65.2	213.3	582.5	183.2
Maintenance embodied energy	GJ	2.0	26.8	234.5	7.8
Embodied energy	GJ	67.1	240.1	817.1	191.0
Annual embodied energy	GJ/year	3.36	6.86	16.34	6.23
Unit annual embodied energy per floor area	GJ/m^2 year	0.06	0.06	0.06	0.06
Unit annual embodied energy per person	GJ/person year	0.83	1.79	3.25	1.49
Initial embodied CO_2 emissions	ton CO_2-eq	6.61	21.90	61.61	18.97
Maintenance embodied CO_2 emissions	ton CO_2-eq	0.10	2.10	17.51	2.87
Embodied CO_2 emissions	ton CO_2-eq	6.71	24.00	79.12	16.10
Annual embodied CO_2 emissions	ton CO_2-eq/year	0.36	6.86	16.34	6.23
Unit annual embodied CO_2 emissions per floor area	ton CO_2-eq/m^2. year	0.01	0.01	0.01	0.01
Unit annual embodied CO_2 emissions per person	ton CO_2-eq/person year	0.08	0.18	0.31	0.15

Table 6.5 *Building materials inventory and their embodied energy/CO_2 emissions for urban houses in both cities*

	Unit	House category			
		Simple house	Medium house	Luxurious house	Whole sample
Material input	kg/m^2	2,077.3	2,138.5	2,117.3	2,107.7
Maintenance materials	kg/m^2	6.6	74.8	149.2	55.7
Material waste	kg/m^2	2,680.0	2,583.7	2,458.8	2,607.5
Initial embodied energy	GJ	63.0	198.4	473.1	180.4
Maintenance embodied energy	GJ	1.2	24.3	178.3	38.0
Embodied energy	GJ	64.3	222.8	651.4	218.4
Annual embodied energy	GJ/year	3.21	6.37	13.03	5.99
Unit annual embodied energy per floor area	GJ/m^2 year	0.07	0.06	0.06	0.06
Unit annual embodied energy per person	GJ/person year	0.79	1.65	2.68	1.42
Initial embodied CO_2 emissions	ton CO_2-eq	6.29	19.96	47.25	18.07
Maintenance embodied CO_2 emissions	ton CO_2-eq	0.10	2.19	15.85	3.38
Embodied CO_2 emissions	ton CO_2-eq	6.39	22.09	63.10	21.43
Annual embodied CO_2 emissions	ton CO_2-eq/year	0.32	0.63	1.26	0.59
Unit annual embodied CO_2 emissions per floor area	ton CO_2-eq/m^2. year	0.01	0.01	0.01	0.01
Unit annual embodied CO_2 emissions per person	ton CO_2-eq/person year	0.08	0.16	0.26	0.14

6.5 Summary

The objective of this study was to analyse the flow of building materials and their embodied energy/CO_2 emissions for urban houses in Indonesia, focusing particularly on unplanned houses. Actual on-site building measurements were conducted in Jakarta (n=297) and Bandung (n=247) to investigate the building material inventories of the two cities. The key findings are summarised as follows:

- The average amounts and the detailed compositions of the current building material stocks for urban houses in the cities of Jakarta and Bandung were revealed through on-site measurements. Overall, the average material quantity per m^2 was 2.14 ton/m^2 in Jakarta and 2.06 ton/m^2 in Bandung. The average material quantity slightly varied among the different house categories in the two cities: 2.26, 2.06 and 2.05 ton/m^2 for simple, medium and luxurious houses in Jakarta, respectively, and 1.88, 2.23 and 2.26 ton/m^2 in Bandung, respectively. The compositions of building materials were similar between the two cities. On average, stone accounted for the largest percentage for all houses (32% and 31%), followed by sand (31% and 30%), clay brick (19% and 19%), and cement (8% and 8%). The current total material stock of urban houses in Jakarta was measured to be 4.3 million ton, while that of urban houses in Bandung was measured to be 0.9 million ton.
- If both reuse and recycling rates are assumed to be zero, then the total demolition waste of unplanned simple houses in Jakarta is determined to be 41.5 million ton/m^2 until 2020, all of which goes to landfills; the corresponding amount of waste in Bandung is predicted to be lower (12.6 million ton/m^2). Moreover, the transformation of these simple houses in larger, medium houses by 2020 would cause further urban expansion in both of the cities: at least, an additional area of 20.0 km^2 would be required for new constructions in Jakarta, whereas an area of 5.7 km^2 would be required in Bandung. These expansions would force the cities to extend their boundaries further to the surrounding suburbs and would accelerate urban sprawl.
- A scenario analysis was conducted for Jakarta to assess the effects of policy promoting reuse and recycled material use. Two scenarios—zero and maximum reuse/recycling rates—were compared in the analysis. The results showed that maximising reuse/recycling rates would decrease the average amount of material waste dramatically by 41% for simple houses, 37% for medium houses and 40% for luxurious houses. Moreover, the results suggest that the remaining waste still has the potential to be reused/recycled as infrastructure materials or other products. The promotion of reuse/recycling was demonstrated to effectively reduce the embodied energy/CO_2 emissions of building materials.

- The analyses of building material inventory, demolition waste and their embodied energy/CO_2 emissions by household cluster showed similar patterns with those of ones by house category. The value of Eta squared showed that house category has larger effects (0.76) on embodied energy than household cluster (0.60).

The Indonesian government has been promoting the 3Rs (reduce, reuse and recycling) since 2007 to increase material recovery and to reduce waste disposal to landfills (Indonesia, 2008b). However, these promotion efforts are aimed at general municipal solid waste and do not specifically target C&D waste. The lack of specific policies for C&D waste at the national level is considered to be one of the most critical problems faced by Indonesia.

Major cities in Indonesia such as Jakarta are expected to receive more in-migrants accounting for further urbanisation in the near future. Moreover, it is expected that the current low-income population will shift to the middle class over the next few decades and demand larger houses than it currently does. As demonstrated in the previous sections, the increase in the number of large landed houses will directly result in the rapid horizontal expansion of cities, thus accelerating urban sprawl. The provision of mid-to-high-rise apartments to the growing middle class in cities would be one effective housing policy for the already highly crowded cities of Indonesia.

7

Household Energy Consumption and CO_2 emissions in Jakarta and Bandung

In the previous chapters, this study investigated building material inventory data, their embodied energy and CO_2 emissions profiles for two case studies, in consideration of climate and income differences, in two main cities of Indonesia, Bandung and Jakarta, by using methods explained in Chapter 4. Since the total value of η^2 for house category has higher effect (0.37) than that for household cluster (0.37) on household energy consumption, further analyses to investigate household energy consumption for residential buildings in Jakarta and Bandung cities are investigated and explained by house category in this chapter. The similar figures and tables explaining household energy consumption analysis by household cluster are provided in the appendix. The introduction and objectives of the analysis of household energy consumption and CO_2 emissions are explained first in Section 7.1. Section 7.2 explains the ownership levels of household appliances used. Operational energy and CO_2 emissions are analyzed in Section 7.3. The causal structures on household energy consumption are analyzed utilizing multiple regression analyses and potential energy-saving strategies for urban houses in Indonesia are discussed based on the results of the above analyses in Section 7.4. Section 7.5 summarizes the detailed household energy consumption and CO_2 emissions in Jakarta and Bandung.

7.1 Introduction

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 (Indonesia, 2010a). 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. At present, Indonesia has a population of 240 million and the percentage of people living in urban areas reached approximately 50% as of 2010 (UN, 2011). It has been reported that approximately 60% of the total population are distributed in the relatively small island, Java, which accounts for only 6% of the total national land. As a consequence, major cities in the Java Island are highly densely populated, such as Jakarta, Bandung and Surabaya, etc.

The present nationwide final energy consumption in Indonesia became about 14 times larger than that of 1970s due to the tremendous urbanization seen in the major cities. This increasing consumption of energy will result in serious energy scarcity in major cities and cause further threat to the global warming. The energy sector of Indonesia accounted for

18.5% of the total CO_2 emissions as of 2005. The CO_2 emissions in the building sector have been increasing and made up 36% of the total emissions in the energy sector as of 2005 (Dewi et al., 2010). The household sector contributes to the nationwide final energy consumption by approximately 29% in 2011 (Indonesia, 2011) and the household energy consumption is expected to increase dramatically as the middle class in urban areas rises in the near future (JETRO, 2011). Therefore sees large increase in urban energy consumption. Energy-saving strategies are, therefore, essential to be introduced further to make the cities more sustainable.

The objective of this study is to reveal the detailed household operational energy consumption patterns in major cities of Indonesia. A total of 297 households were surveyed in Jakarta, while 247 households were investigated in Bandung, focusing especially on unplanned landed houses. Firstly, the samples of each city are classified into several groups through cluster analyses in order to analyze their household energy consumption patterns in each of the cities. Secondly, multiple regression analyses are carried out for respective cities to figure out the causal structures on the household energy consumption. Potential energy-saving strategies for urban houses in Indonesia are discussed based on the results of the above analyses.

Data of household energy consumption

The household energy consumption survey obtained necessary data to calculate household energy consumption such as electricity bills, capacity of appliances, time usage of appliances, etc. as shown in appendixes 1 and 2. The content of the questionnaire covers the following items: (a) socio-economic profile, (b) building information, (c) monthly energy bills (electricity, water, gas (LPG), and kerosene), and (d) number and usage time of household appliances. Meanwhile, on-site measurements using watt meters (MWC01, OSAKI) were carried out to investigate the electric capacity of respective household appliances. Then, the monthly average household electricity consumption was estimated based on the data of (a) number of appliances, (b) usage time, and (c) measured electric capacities. These measured electricity consumption was validated by the data obtained through the electricity bills (see Figs 8.1-8.4). The monthly gas (LPG) and kerosene consumption was estimated simply based on the data from their bills.

The primary energy used for generating electricity in Indonesia comprised 42% of coal, 17% of oil, 28% of natural gas, 10% of hydro and 3% of geothermal as of 2010 (Indonesia, 2010; IEA, 2012). The electricity consumption was converted into primary energy by considering the above energy mix, electric efficiencies and transmission losses. The annual average household energy consumption was then calculated by combining consumption for all the household appliances. As shown before, the seasonal variation in climate conditions is not large in both Jakarta and Bandung. Therefore, the usage time of appliances was assumed to be constant throughout the year. Nevertheless, the small seasonal changes of air temperature and humidity were considered in the estimation of energy consumption caused by air-conditioners and refrigerators, though the resulting changes were found to be negligible.

Fig. 7.1-7.4 show regression analyses between average monthly electricity bills, remembrance and measured electricity consumption in Jakarta and Bandung, respectively. The measured electricity consumption obtain from on-site measurement of electricity appliances was then recalculated based on predicted electricity bills (Fig. 7.2) derived from the relationship between average monthly remembrance with average monthly electricity bills (Fig. 7.1). Therefore, it was expected that energy consumption data by electricity energy source obtained were more reliable.

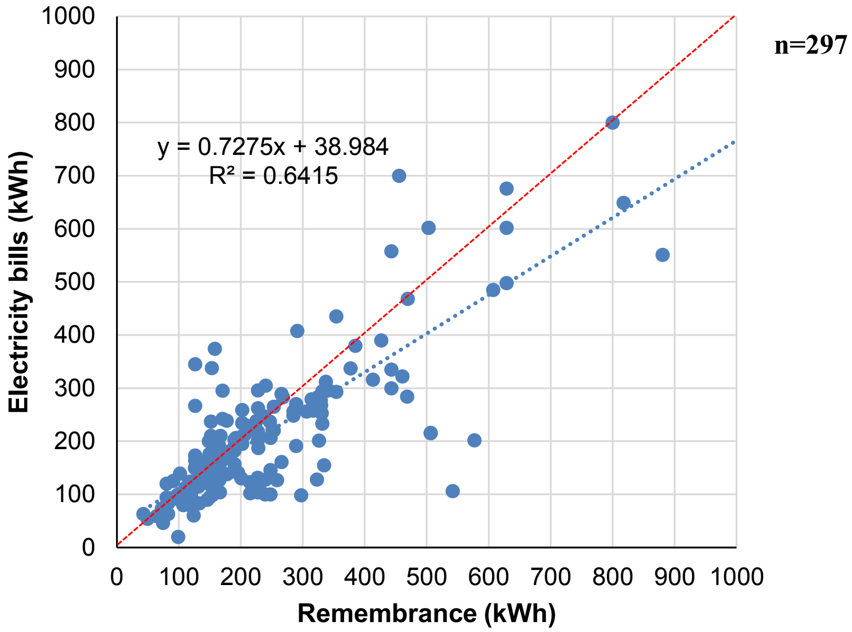


Fig. 7.1 *Relationship between average monthly remembrances with average predicted monthly electricity bill (Jakarta).*

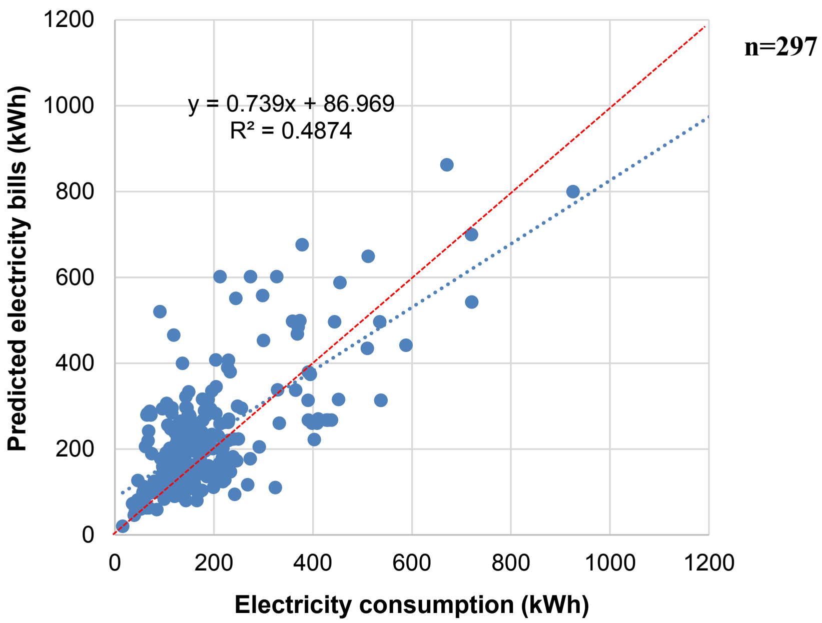


Fig. 7.2 *Relationship between average monthly measured electricity consumption with average predicted monthly electricity bill (Jakarta)*

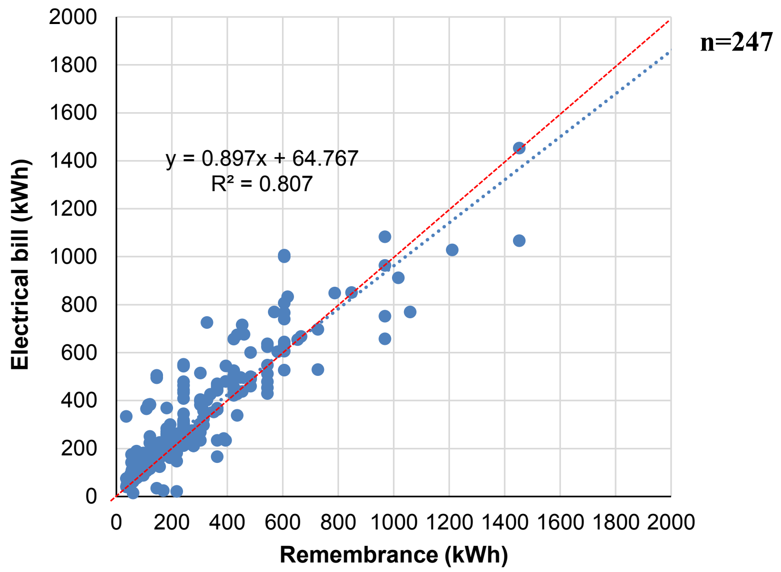


Fig. 7.3 *Relationship between average monthly remembrances with average predicted monthly electricity bill (Bandung)*

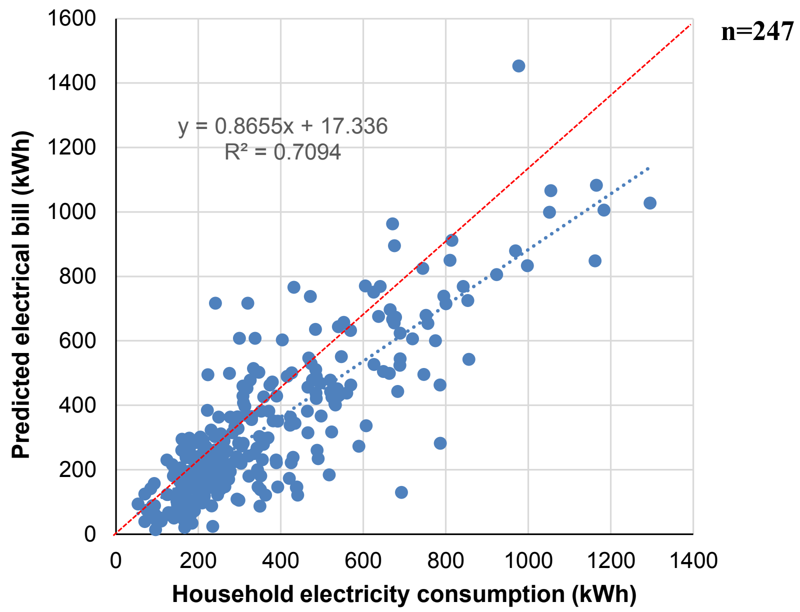


Fig. 7.4 *Relationship between average monthly measured electricity consumption with average predicted monthly electricity bill (Bandung)*

7.2 Ownership levels of household energy consumption

Fig. 7.5 present the ownership levels of major household appliances in respective case studies. As shown, lighting bulb (100%), television (96-100%) and refrigerator (72-100%) recorded high ownership levels similarly in the two cities among three house categories. In the case of Jakarta (Figure 7.5a), the stand fan also recorded high ownership levels of 75-83% reflecting its severe hot climatic conditions. In general, the ownership levels of other appliances increase from simple houses to luxurious houses respectively, except for some appliances such as water pump in Bandung. The ownership levels of air-conditioners significantly differs between the two cities: it is 6-89% in Jakarta and 0-29% in Bandung (Figure 7.5b). The similar patterns of ownership level of appliances by household cluster are shown in Appendix 7. However, the differences of ownership levels are not large between Cluster 1 and 2 in both cities. This is because the wealth levels (i.e. Factor 1) are almost the same between the two clusters as described before.

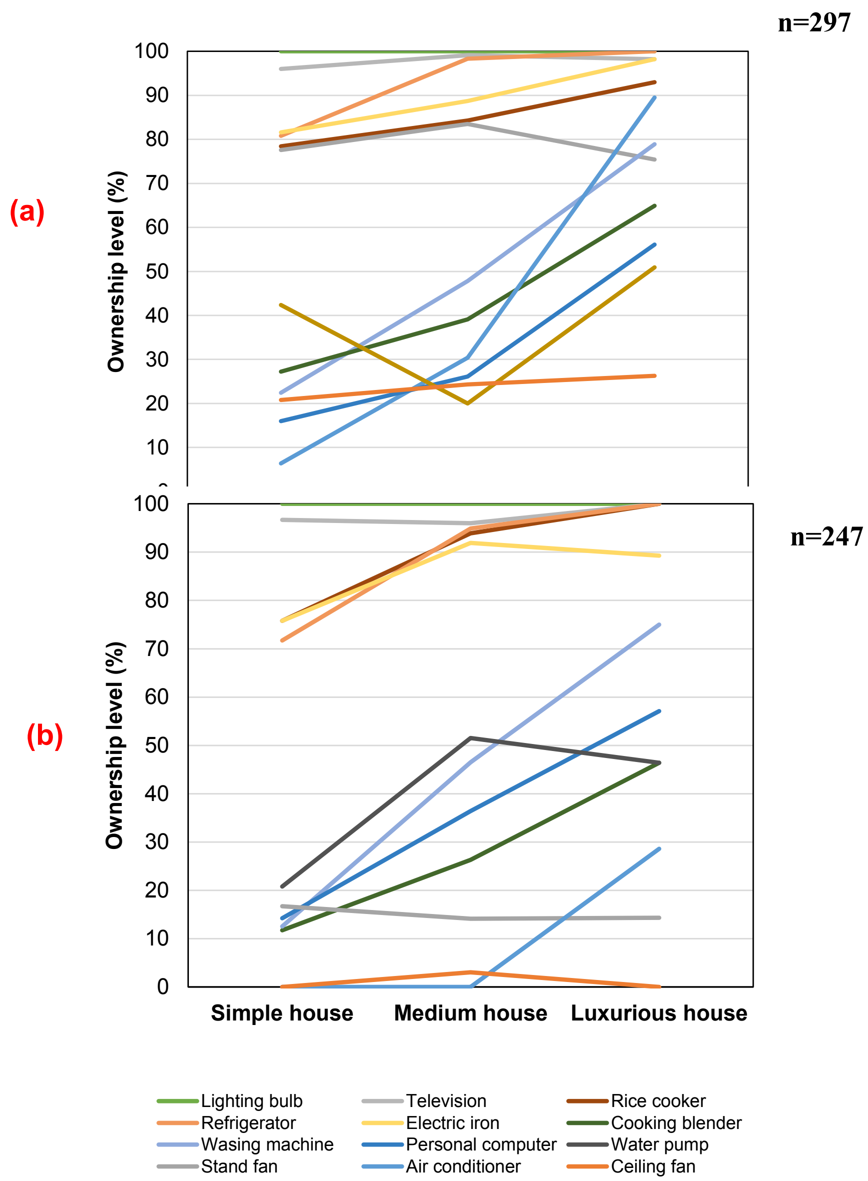


Figure 7.5 *Ownership levels of major household appliances by house category. (a) Jakarta; (b) Bandung*

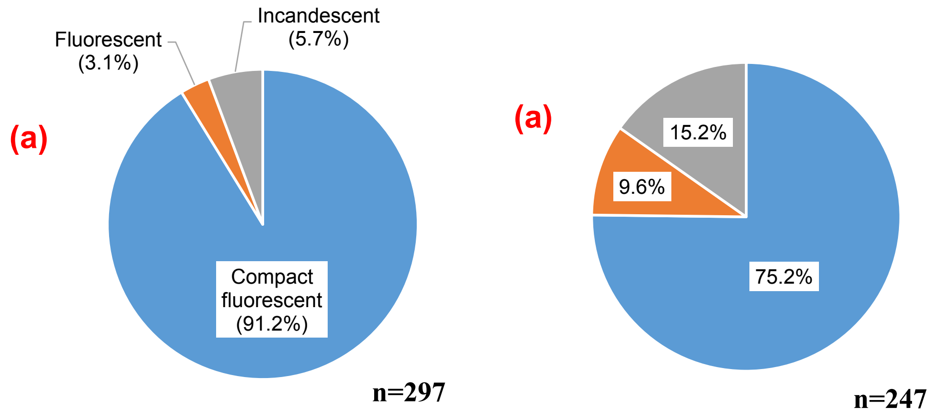


Figure 7.6 *Percentage of lighting bulbs used in their houses. (a) Jakarta; (b) Bandung.*

In both cities, compact fluorescent lamps are well penetrated among households regardless of the categories/clusters (Figure 7.6). It has been reported that the Indonesian government highly promoted fluorescent lamps for replacing incandescent lamps from 2007 (BUMN, 2007). The national power company (i.e. Perusahaan Listrik Negara) exchanged one incandescent bulb by three compact fluorescent bulbs for free for their customers all over Indonesia with the aim of reducing the nationwide electricity consumption and the government's subsidies for electricity tariffs.

7.3 Household energy consumption and CO_2 emissions

Figure 7.7 shows the annual household energy consumption averaged in respective house categories. Fig. 7.7a indicates the energy consumption by different energy sources and Fig. 7.7b shows those by different end-use categories. Overall, the average annual energy consumption of all samples in Jakarta is approximately 44.2 GJ, which is 14.9 GJ larger than that of Bandung. The difference is mainly attributed to the use of air-conditioning between the two cities.

As shown, the energy consumption for cooling accounts for 27.8% in Jakarta on average (Figure 7.71a)), whereas the corresponding percentage is only 1.8% in Bandung (Figure 7.7(1b)). Hence, in the case of Jakarta, basically, the average household energy consumption of house categories increases with the increase in ownership and use of air-conditioning (Figure 7.5 and 7.7(1b). In the case of Bandung, the energy consumption for cooking, lighting and entertainment largely influence the increase in the overall energy consumption (Figure 7.7(2b). Since the average household size di not vary largely among the three house categories, the above difference of ownership and usage levels of cooling appliances in Jakarta, especially air-conditioner, and those of cooking and lighting in Bandung is directly reflected in the large difference of annual energy consumption among three house categories in both cities. In both of the cities, primary energy consumption caused by electricity use is much larger than those by LPG: 82-88% in Jakarta (Figure 7.7a) and 67-79% in Bandung (Figure 7.7b). The value of η^2 for household cluster slightly lower effect (0.35) than that for house category (0.37) on household energy consumption.

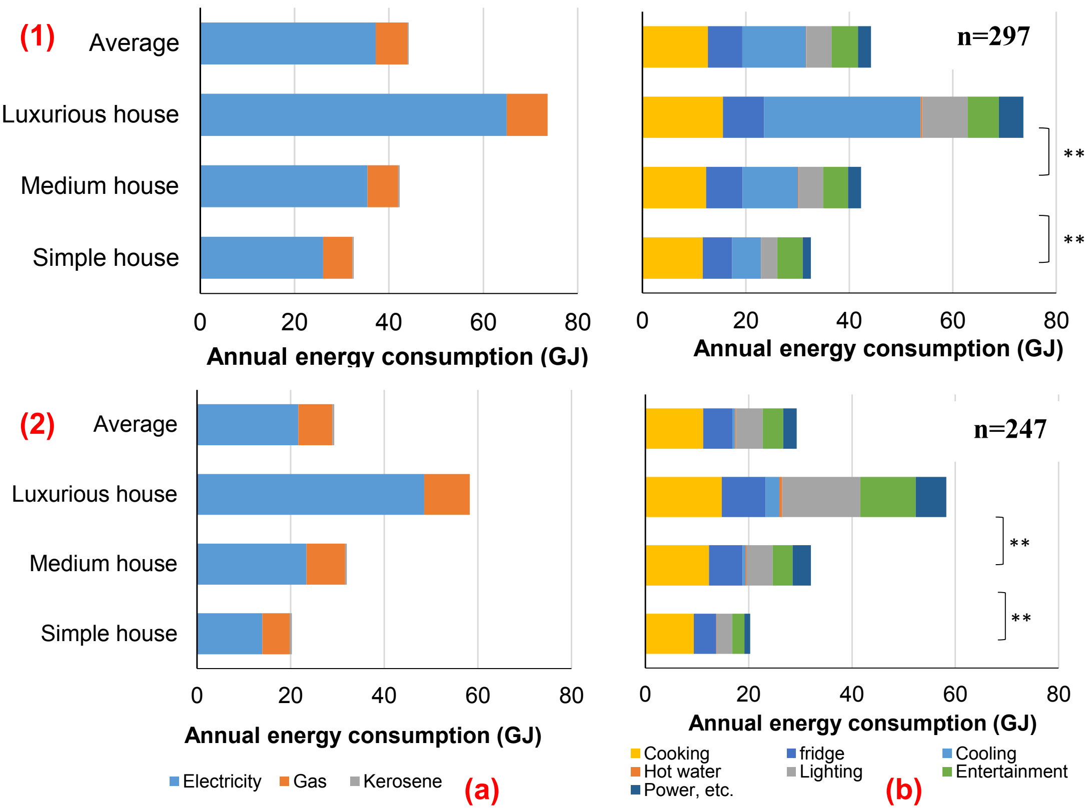


Figure 7.7 *Annual household energy consumption by house category (Primary energy) in (1) Jakarta; (2) Bandung. (a) by energy source; (b) by end-use.*

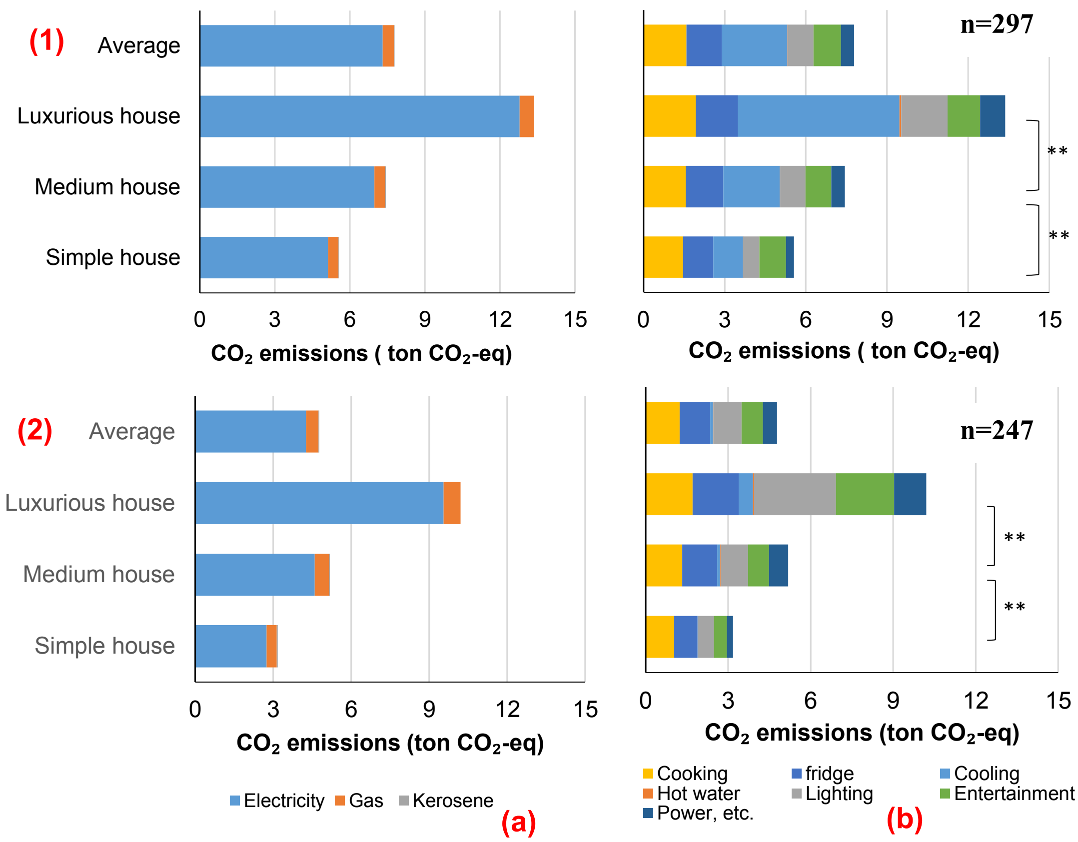


Figure 7.8 *Annual household CO_2 emissions by house category in (1) Jakarta; (2) Bandung. (a) by energy source; (b) by end-use.*

The annual household CO_2 emissions were estimated through multiplying the energy consumption for each fuel type by its corresponding CO_2 emission factor (Nansai et al., 2002). As shown in Fig. 7.8, the average annual CO_2 emission in Jakarta is estimated at 7.8 ton CO_2-equivalent, while that of Bandung is 4.8 ton CO_2-equivalent. The annual household CO_2 emissions were estimated through multiplying the energy consumption for each fuel type by its corresponding CO_2 emission factor (Nansai et al., 2002). As shown in Fig. 7.9, the average annual CO_2 emission in Jakarta is estimated at 7.8 contributors in Jakarta are cooling (2.4 ton (31%)), cooking (1.6 ton (20%)) and refrigerator (1.3 ton (17%)), while those in Bandung are cooking (1.2 ton (26%)), refrigerator (1.1 ton (23%)), lighting (1.0 ton (21%)). If the amount of CO_2 emissions caused by cooling are excluded, then the difference of total CO_2 emissions between the two cities would be insignificant (5.4 ton in Jakarta and 4.7 ton in Bandung). This clearly indicates that the increase in use of air-conditioning in the future would dramatically increase the household energy consumption and therefore their CO_2 emissions. The similar patterns of household energy consumption and CO_2 emissions are shown by those of ones by household clusters (see Appendices 8-9).

7.4 Causal structures on household energy consumption: Multiple regression analyses

Multiple regression analyses were carried out to further analyze the causal structure on household energy consumption in the two cities (Table 7.1). Since electricity and LPG were found to account for almost all the primary energy consumption in the two cities (see Figure 7.7a), firstly, we examined the major factors explaining consumption of these two energy sources (Table 7.1ab). In this analysis, the new variables (electricity consumption caused by respective appliances) were created for each of the household electric appliances by multiplying its electric capacity by the number of the appliance and its usage time. Secondly, further determinants for respective electric appliances were analyzed in the two cities respectively (Table 7.1c).

As shown in Table 7.1a, the major appliances contributing the electricity consumption largely differ between the two cities. In the case of Jakarta, air-conditioner (β=0.71) is found to be the major determinant for the electricity consumption in this model, followed by television (0.21), stand fan (0.20), ceiling fan (0.16), and refrigerator (0.14), etc. As seen in Figure 7.7b and 7.8b, this result confirms that energy consumption for cooling appliances, in particular air-conditioners, is significant and large in the case of hot-humid climate of Jakarta. In contrast, in the case of Bandung, water pump (β=0.35) is found to be the most influential contributor for the electricity consumption in this model, followed by television (0.29), lighting bulb (0.26), and refrigerator (0.24), etc. Both of the regression models obtain high R^2-values of 0.93 and 0.87, respectively. The determinants for LPG consumption are similar in the two models for respective cities, although both of the R^2-values record low values of 0.08 and 0.13 respectively (Table 7.1b). In the two cities, both household size and building size may be able to explain weakly the LPG consumption.

Table 7.1 Results of multiple regression analyses, depicting causal structure on household energy consumption. (a) Monthly electricity consumption; (b) Monthly gas (LPG) consumption; (c) Household appliances. (=5% significance; **=1% significance)*

(a) Jakarta

Variable	β		r	
Air-conditioner	0.71	**	0.84	**
Television	0.21	**	0.37	**
Stand fan	0.20	**	0.21	**
Ceiling fan	0.16	**	0.09	
Refrigerator	0.14	**	0.34	**
Lighting bulb	0.12	**	0.69	**
Rice cooker	0.11	**	0.13	*
Washing machine	0.11	**	0.34	**
Water pump	0.10	**	0.22	**
R^2	0.93	**		
n	297			

Bandung

Variable	β		r	
Water pump	0.35	**	0.53	**
Television	0.29	**	0.62	**
Lighting bulb	0.26	**	0.66	**
Refrigerator	0.24	**	0.53	**
Personal computer	0.17	**	0.39	**
Washing machine	0.14	**	0.50	**
Stand fan	0.12	**	0.32	**
Electric iron	0.11	**	0.30	**
R^2	0.87	**		
n	247			

(b) Jakarta

Variable	β		r	
Household size	0.23	**	0.25	**
Lot area	0.14	*	0.17	**
R^2	0.08	**		
n	297			

Bandung

Variable	β		r	
Household size	0.32	**	0.33	**
Lot area	0.14	*	0.15	**
R^2	0.13	**		
n	247			

(c) Jakarta

Air-conditioner

Variable	β		r	
Total floor area	0.52	**	0.62	**
Household income	0.31	**	0.49	**
Age of husband	-0.09	*	0.03	
R^2	0.47	**		
n	297			

Television

Variable	β		r
Total floor area	0.16	**	-
R^2	0.02	**	
n	297		

Stand fan

Variable	β		r
No. of children	0.13	*	-
R^2	0.02	*	
n	297		

Bandung

Water pump

Variable	β		r
Household income	0.43	**	-
R^2	0.18	**	
n	247		

Television

Variable	β		r	
Lot area	0.36	**	0.56	**
Household income	0.34	**	0.55	
R^2	0.39	**		
n	247			

Lighting bulb

Variable	β		r
Total floor area	0.70	**	-
R^2	0.49	**	
n	247		

As shown in Table 7.1c, in Jakarta, the energy consumption caused by air-conditioning, which is the main contributor to the electricity consumption, can be explained by the total floor area, the household income and the age of husband with a coefficient of determinant of 0.47. Other major appliances (i.e. television and stand fan) are weakly explained by the total floor area and the number of children, respectively. On the other hand, in Bandung, water pump is weakly explained by the household income. Other major appliances (i.e. television and lighting bulb) can be determined by the lot area and the household income, and total floor area, respectively.

It is seen that overall, the increase in household income and building size, such as total floor area and lot area, increase the electricity consumption caused by the major appliances. In both of the cities, it was found that the increase in household income increase their building size such as the total floor area (r = 0.38** in Jakarta and r = 0.72** in Bandung) and the lot area (r = 0.39** in Jakarta and r = 0.60** in Bandung). Hence, it is anticipated that the further increase in household income would increase the building size thus the energy consumption caused by major household appliances. As a consequence, the increase in household income would increase the total household energy consumption significantly in the near future in Indonesian cities. It has been reported that the household income in Indonesia is predicted to rise dramatically in the near future in line with the rise of middle class as described before (JETRO, 2011). The household energy consumption in major Indonesian cities is predicted to increase very sharply if proper energy-saving strategies are not implemented.

It is important to avoid the tendency that building size increases straightforwardly with the increase in household income. One of the possible solutions is to recommend more apartments rather than landed houses that generally increase total floor area. It should be noted that most of the incandescent bulbs were already replaced by compact fluorescent bulbs in Indonesian cities. This means that further energy-saving should be made for lighting by utilizing more natural lighting or using LED lamps. The increase in air-conditioning would be a major concern in terms of the energy-saving strategies in Indonesia (the relatively cool climate of Bandung is not typical of other major cities). Even in Jakarta, the ownership level of air-conditioner was only 32% on average at the moment in this survey. It is important to reduce the use of air-conditioning in the future despite the expected increase in household income. Passive cooling techniques should be adopted wherever possible.

On the other hand, the current energy efficiency in electricity generation in Indonesia is not as good as other developed nations. The total loss due to electric efficiency and transmission losses results in the increase in primary energy consumption by approximately 2.7 times than the end-use electricity consumption. This exceeds the scope of this paper but this should also be considered in the future energy-saving strategies in Indonesia.

Tables 7.2-7.4 summarized the value of household energy consumption/CO_2 emissions for Jakarta, Bandung and combination of Jakarta and Bandung.

Table 7.2 *Household energy consumption and CO_2 emissions for urban houses in Jakarta*

	Unit	House category			
		Simple house	Medium house	Luxurious house	Whole sample
Annual energy consumption	GJ/year	32.52	42.27	73.63	44.19
Unit annual energy per floor area	GJ/m^2 year	0.90	0.50	0.41	0.65
Unit annual energy per person	GJ/person year	8.17	10.49	15.12	10.40
Operational energy	GJ	650.44	1,479.47	3,681.71	1,553.20
Annual CO_2 emissions	ton CO_2-eq	5.56	7.44	13.37	7.79
Unit annual CO_2 emissions per floor area	ton CO_2-eq/m^2. year	0.15	0.09	0.07	0.11
Unit annual CO_2 emissions per person	ton CO_2-eq/person year	1.39	1.85	2.76	1.83
Operational CO_2 emissions	ton CO_2-eq	111.25	260.35	668.37	275.90

Table 7.3 *Household energy consumption and CO_2 emissions for urban houses in Bandung*

	Unit	House category			
		Simple house	Medium house	Luxurious house	Whole sample
Annual energy consumption	GJ/year	20.28	32.02	58.28	29.30
Unit annual energy per floor area	GJ/m^2 year	0.42	0.29	0.24	0.35
Unit annual energy per person	GJ/person year	4.99	7.86	11.91	6.92
Operational energy	GJ	405.65	1,120.80	2,914.09	976.64
Annual CO_2 emissions	ton CO_2-eq	3.29	5.19	10.86	4.91
Unit annual CO_2 emissions per floor area	ton CO_2-eq/m^2. year	0.07	0.05	0.04	0.06
Unit annual CO_2 emissions per person	ton CO_2-eq/person year	0.81	1.27	2.20	1.15
Operational CO_2 emissions	ton CO_2-eq	65.88	181.82	543.05	166.44

Table 7.4 *Household energy consumption and CO_2 emissions for urban houses in both cities*

	Unit	House category			
		Simple house	Medium house	Luxurious house	Whole sample
Annual energy consumption	GJ/year	26.52	37.53	68.57	37.42
Unit annual embodied energy per floor area	GJ/m^2 year	0.67	0.40	0.35	0.51
Unit annual embodied energy per person	GJ/person year	6.61	9.28	14.07	8.82
Operational energy	GJ	5,30.54	1,313.54	3,428.85	1,291.42
Annual CO_2 emissions	ton CO_2-eq	4.45	6.40	12.54	6.48
Unit annual CO_2 emissions per floor area	ton CO_2-eq/m^2. year	0.11	0.07	0.06	0.09
Unit annual CO_2 emissions per person	ton CO_2-eq/person year	1.11	1.58	2.58	1.53
Operational CO_2 emissions	ton CO_2-eq	89.03	224.02	627.09	226.20

7.5 Summary

The detailed household energy consumption patterns in Jakarta and Bandung were analyzed by household clusters based on the similarities of socio-economic and demographic characteristics of samples and by house category.

- In Jakarta, Cooling appliances in average recorded high ownership levels of 78-86% for stand fan and 30% for air conditioner and it is reflecting its severe hot climatic conditions. In general, the ownership levels of other appliances increase from simple to luxurious houses, respectively. The ownership levels of air-conditioners significantly differs between the two cities: it is 6-81% in Jakarta and 0-25% in Bandung. In both cities, compact fluorescent lamps are well penetrated among households regardless of the clusters. The similar patterns of ownership level were shown by house category.
- Overall, the average annual energy consumption of all samples in Jakarta is approximately 44.2 GJ, which is 14.9 GJ larger than that of Bandung. The difference is mainly attributed to the use of air-conditioning between the two cities. Hence, in the case of Jakarta, basically, the average household energy consumption of clusters increases with the increase in ownership and use of air-conditioning In the case of Bandung, the energy consumption for cooking, lighting and entertainment largely influence the increase in the overall energy consumption
- The average annual CO_2 emission in Jakarta is estimated at 7.8 ton CO_2-equivalent, while that of Bandung is 4.8 ton CO_2-equivalent. The major contributors in Jakarta are cooling (2.4 ton (31%)), cooking (1.6 ton (20%)) and refrigerator (1.3 ton (17%)), while those in Bandung are cooking (1.2 ton (26%)), refrigerator (1.1 ton (23%)), lighting (1.0 ton (21%)).

- If the amount of CO_2 emissions caused by cooling are excluded, then the difference of total CO_2 emissions between the two cities would be insignificant (5.4 ton in Jakarta and 4.7 ton in Bandung). This clearly indicates that the increase in use of air-conditioning in the future would dramatically increase the household energy consumption and therefore their CO_2 emissions
- The above results clearly indicates that the increase in household income, which has a strong relationship with house category, increases not only building size but also household size, thus increases the total household energy consumption in both of the cities. This implies that the increase in household income straightforwardly increases total household energy consumption in Indonesian cities
- It was anticipated that the further increase in household income would increase the building size thus the energy consumption caused by major household appliances. As a consequence, the increase in household income would increase the total household energy consumption significantly in line with the rise of middle class in the near future in Indonesian cities if proper energy-saving strategies are not implemented.
- It is important to avoid the tendency that building size increases straightforwardly with the increase in household income. We recommended the following potential energy-saving strategies for urban houses in Indonesia: (a) provision of more apartments rather than landed houses, (b) natural lighting and use of LED lamps, and (c) passive cooling techniques wherever possible.

8

Assessment of Life Cycle Energy and CO_2 emissions for Residential Buildings in Jakarta and Bandung

In the previous chapters, we investigated building material inventory, embodied energy and household energy consumption in two case studies, in consideration of climate and income differences, describing not only energy but also CO_2 emissions profiles in two main cities in Indonesia, Bandung and Jakarta, by using methods obtained from a pilot survey and main surveys in both cities (see Chapter 4). The profiles of sample houses were described in Chapter 5. Building material inventory and its future demolition waste as well as embodied energy and CO_2 emissions were analyzed in Chapter 6. Meanwhile, household energy consumption and CO_2 emissions profiles were investigated in Chapter 7. Further analyses to assess life cycle energy and CO_2 emissions throughout their buildings' life-spans will be explained in this chapter (Chapter 8). The objectives of further analyses are explained in Section 8.1. Section 8.2 describes the results of life cycle energy and CO_2 emissions of residential buildings in both case studies. Section 8.3 recommends potential energy-saving strategies based on the previous analyses. Section 8.4 summarizes this Chapter

8.1 Introduction

An important goal for the building sector is to produce buildings with minimum environmental impact. Energy used is a central issue as energy is generally one of the most important resources used in buildings over their lifetime. The aim of this chapter is to analyze life cycle energy and CO_2 emissions for residential buildings in Jakarta and Bandung throughout their buildings' life-spans.

8.2 Life cycle energy

Assessment of life cycle energy and CO_2 emissions was conducted based on existing data by house category in Jakarta and Bandung. This is because of the following reasons;

(1) house category can explain life cycle energy more than household cluster and (2) residential buildings in other cities are generally classified by house category. Therefore, the results of this study can be useful for other cities in making planning and evaluating with respect to life cycle energy and CO_2 emissions of residential buildings.

The life cycle energy was obtained by combining embodied energy and operational energy for respective house category in Jakarta and Bandung as shown in Figs. 8.1-8.2, respectively. As shown, in Fig. 8.1 (a), the operational energy accounted for much larger portions of about 87-91% than embodied energy for respected houses in Jakarta. The total life cycle energy was measured at 712.0, 1687.3 and 4251.7 GJ for simple, medium and luxurious houses, respectively. Meanwhile, in the case of Bandung (Fig. 8.1 (b)), the proportion of operational energy took about 78-86% of total life cycle energy, which was measured at 472.8, 1360.9 and 3731.2 GJ for simple, medium and luxurious houses, respectively.

The large differences among three house categories are due to the following three reasons. Firstly, as before, the embodied energy increased with house category from simple to luxurious houses along with the increase in total floor area. Secondly, the per-person annual energy consumption increased with house category mainly due to the increase in energy consumption for cooling in case of Jakarta and for lighting in case of Bandung. Thirdly, the lifespan increased with house category as described before.

Fig. 8.2 indicates the annual life cycle energy consumption per total floor area and per person in Jakarta and Bandung. As shown in Fig. 8.2 (1c), the life cycle energy consumption per person increases with house category from simple to luxurious houses sharply with significant differences in their mean values ($F(4, 295)=20.32$, $p<0.01$). This is mainly due to the difference of ownership and usage levels of cooling appliances, especially air-conditioners (in Jakarta) in operational energy, as described before. Since the average household sizes did not vary largely among the three house categories, the above difference is directly reflected in the large difference of life cycle energy consumption among three house categories. In contrast, the number of occupants per floor area is largely different among three house categories: the above number increases from luxurious to simple houses.

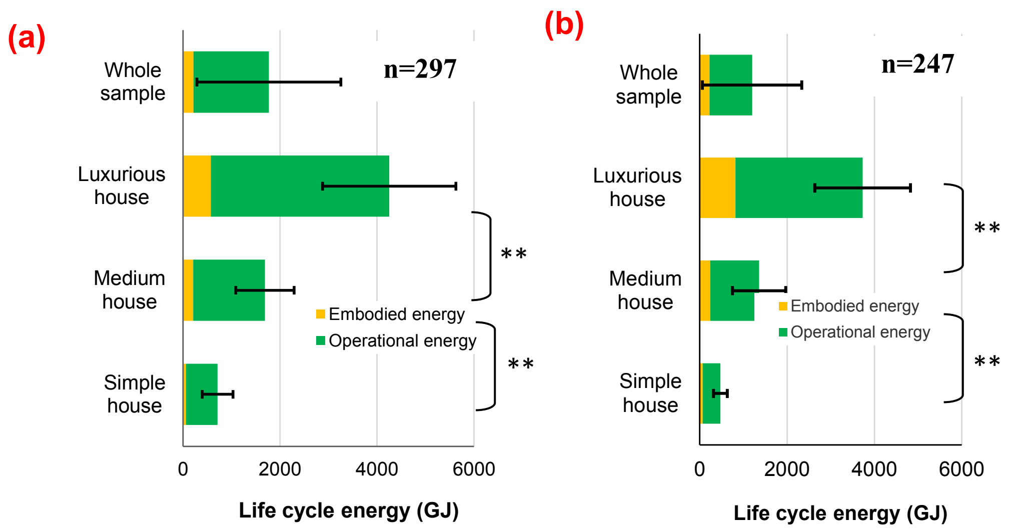


Fig. 8.1 *Average life cycle energy for respective house categories in (a) Jakarta and (b) Bandung. Note: The error bars indicate the mean values ± standard deviation.*

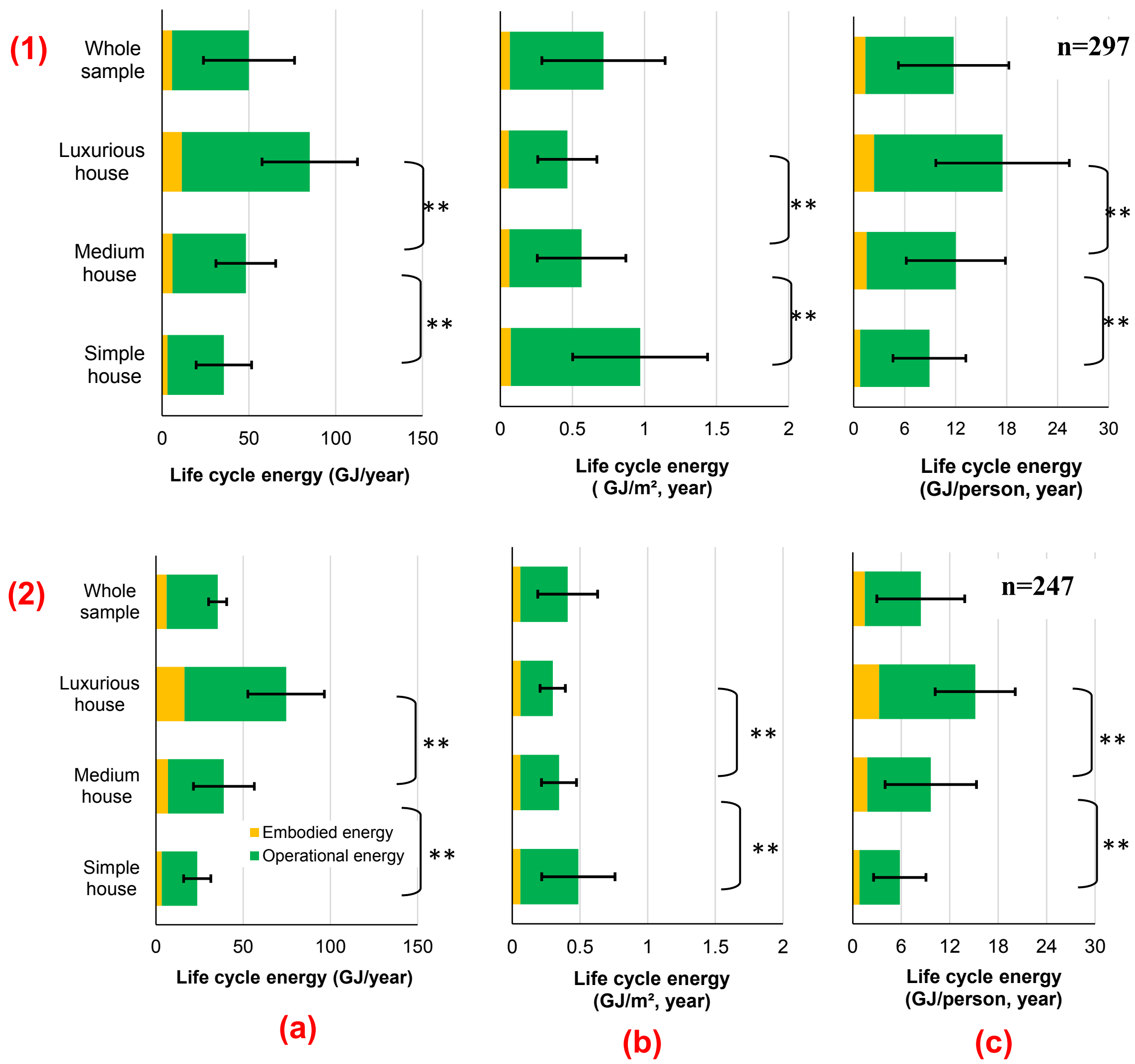


Fig. 8.2 *Average annual life cycle energy for respective house categories in (1) Jakarta and (2) Bandung. (a) Annual life cycle energy; (b) Unit annual life cycle energy (per total floor area); (c) Unit annual life cycle energy (per person).*
Note: The error bars indicate the mean values ± standard deviation.

Therefore, when the life cycle energy consumption is assessed in terms of per-floor area as indicated in Fig. 8.2 (1b), the unit energy consumption decreases with house category from simple to luxurious houses with significant differences in their mean values ($F(4, 295)=27.25$, $p<0.01$). The pattern of the annual average energy consumption per total floor area and person in Bandung (Fig. 8.2 (2a-c)) showed the similar patterns with Jakarta. In case of Bandung, the difference of life cycle energy is directly reflected in the large difference of cooking and lighting energy consumption due to the large difference of total floor area among three house categories.

The building's lifespan has big effect to the increasing of life cycle energy particularly to the operational energy. Figs. 8.3 shows life cycle energy by lifespan of residential buildings in 200 years for three house categories in Jakarta. As shown, the embodied energy keeps increasing due to the increasing of materials used for maintenance and reconstruction of the buildings. Meanwhile, the operational energy also keep increasing due to energy used in operational phase. On the other hand, if the buildings can be prolonged double for their lifespans than the previous values, the embodied energy will decrease significantly as shown in Fig. 8.4. In contrast, without any treatment to decrease operational energy, this longer lifespan for buildings or their materials cannot decrease life cycle energy significantly. The similar pattern occurs in the case of life cycle energy of residential buildings in Bandung (Figs. 8.5-8.6).

Therefore, in the frame of energy and CO_2 emissions study, it is to affirm that the use (operation) stage is the most influential stage in terms of energy consumption during the building life-cycle. The total operational energy is much larger than the embodied energy for respective house categories. In the same line of thoughts, the operational energy consumption is the major source of impacts in the two case studies, especially due to air conditioning and cooking consumption in Jakarta and lighting and cooking consumption in Bandung.

Fig. 8.7 shows the contribution ratios in life cycle energy by respective end-uses in three house categories in Jakarta. As shown, the proportion of embodied energy gradually increases with house category from simple to luxurious houses. In the simple houses, cooking was the largest contributor to the energy consumption (33% out of the whole life cycle), followed by the refrigerator (16%) and cooling (16%), etc. Meanwhile, the percentage of energy consumption caused by cooling increased with house category largely and became the largest contributors in the medium (27%) and luxurious houses (36%). Overall, energy consumption for cooling contributed the largest proportion (27%) followed by cooking (24%), refrigerator (13%), lighting (10%), etc.

Fig. 8.8 shows the contribution ratios in life cycle CO_2 emissions by respective end-uses in three house categories in Bandung. As shown, the proportion of embodied energy gradually increases with house category from simple to luxurious houses. In the simple houses, cooking was the largest contributor to the CO_2 emissions (40% out of the whole life cycle), followed by the refrigerator (18%), lighting (13%), etc. Meanwhile, the percentage of energy consumption caused by lighting increased with house category largely and became the largest contributors in the luxurious houses (21%). Overall, energy consumption for cooking contributed the largest proportion (30%) followed by lighting (16%), refrigerator (15.5%), entertainment (12%), etc.

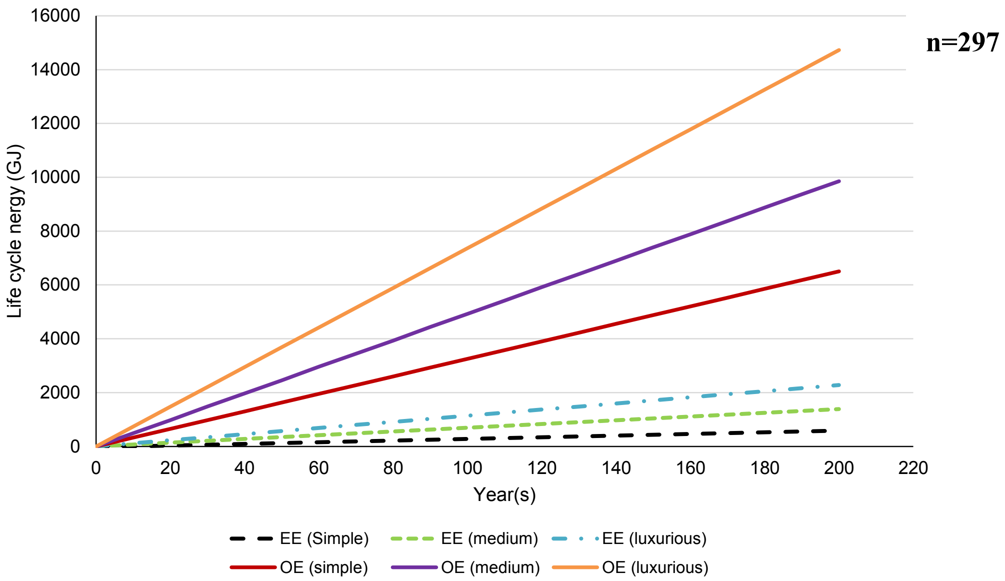


Fig. 8.3 *Life cycle energy of residential buildings by time period in Jakarta (existing building's lifespans)*

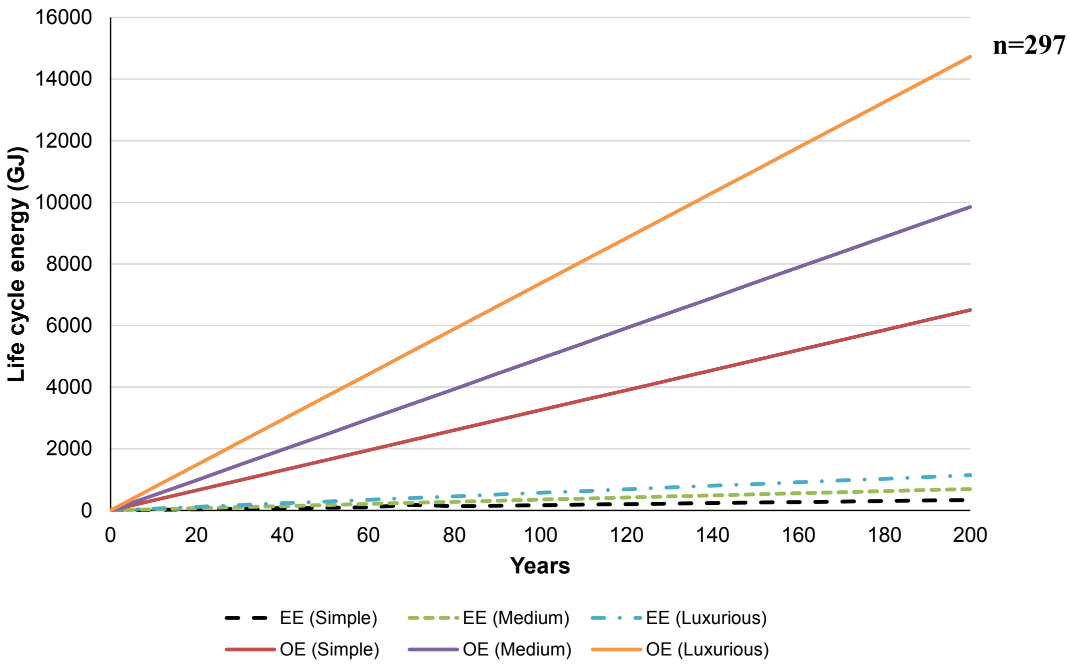


Fig. 8.4 *Life cycle energy of resident buildings by time period in Jakarta (double building's lifespans)*

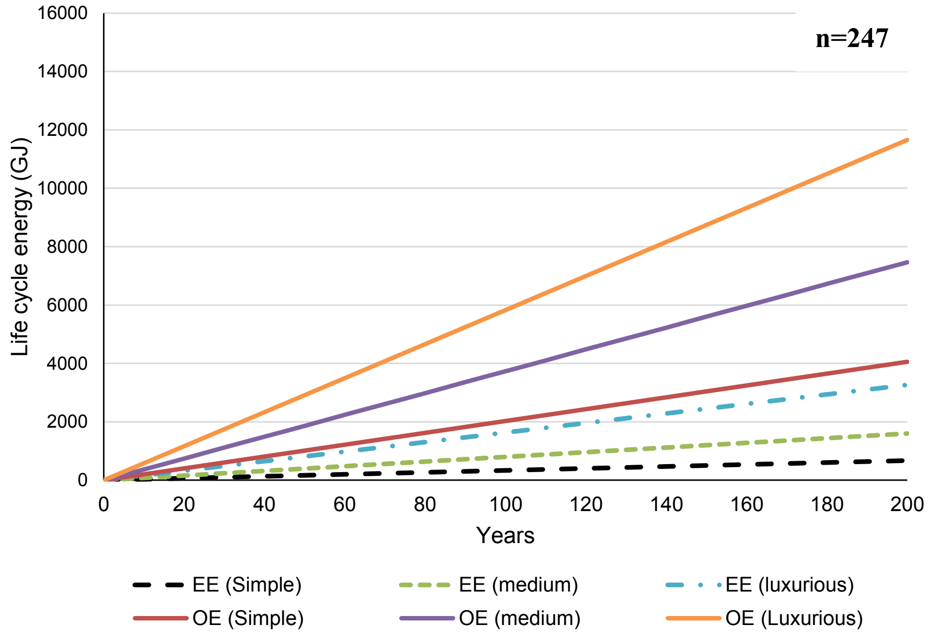


Fig. 8.5 *Life cycle energy of residential buildings by time period in Bandung (existing building's lifespans)*

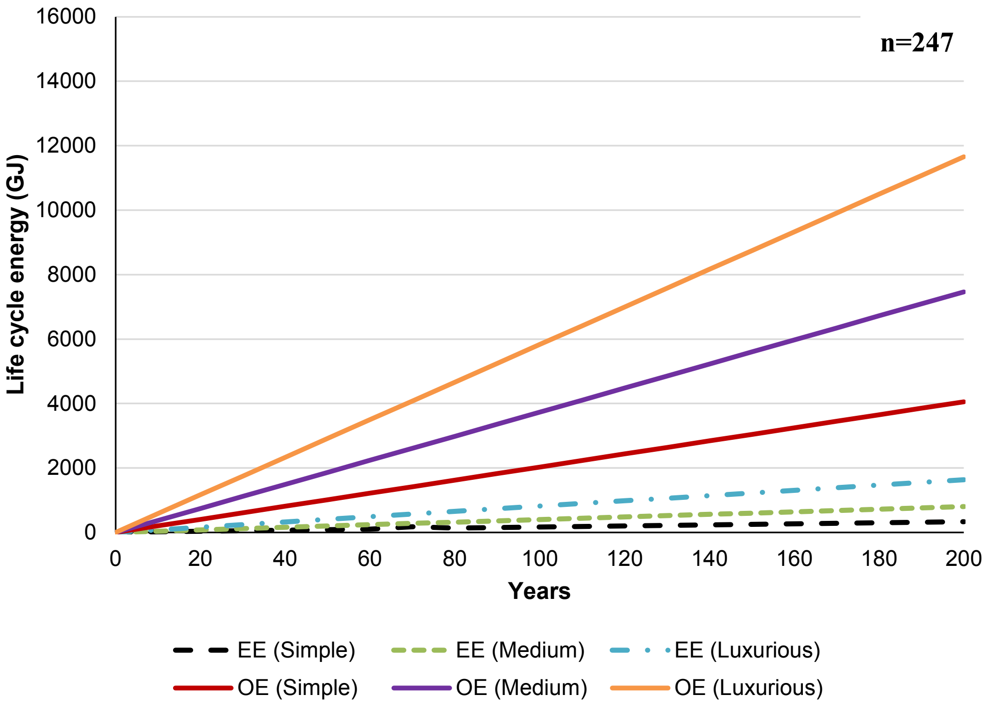


Fig. 8.6 *Life cycle energy of residential buildings by time period in Bandung (double building's lifespans)*

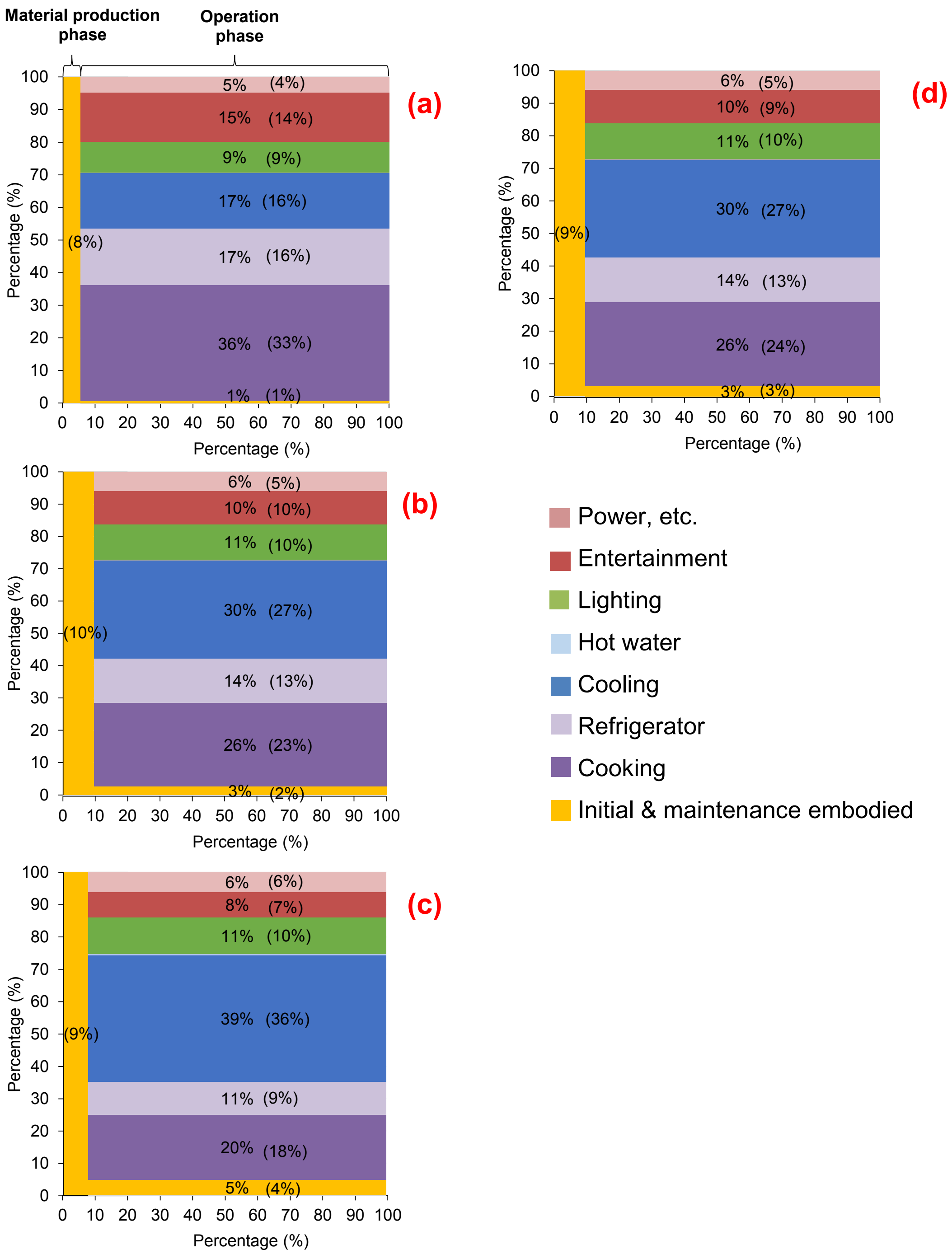


Fig. 8.7 *Contribution to energy consumption by end-use in the whole building's lifespan for respective house categories in Jakarta. (a) Simple house; (b) Medium house; (c) Luxurious house; (d) Whole sample*
Note: The percentages in the parentheses show the contribution to energy consumption by end-use in the whole building's lifespan.

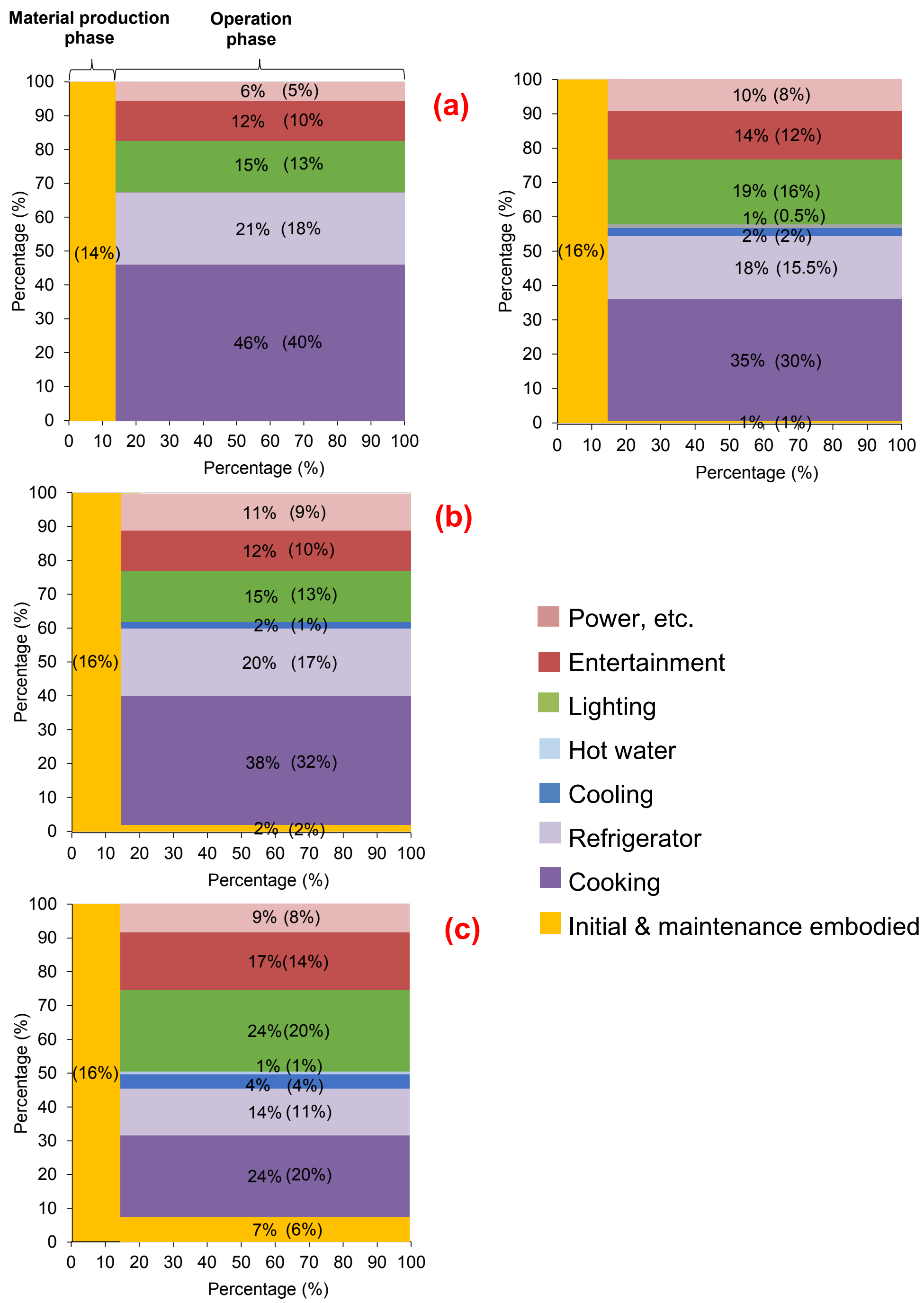


Fig. 8.8 *Contribution to energy consumption by end-use in the whole building's lifespan for respective house categories in Bandung. (a) Simple house; (b) Medium house; (c) Luxurious house; (d) Whole sample*
Note: The percentages in the parentheses show the contribution to energy consumption by end-use in the whole building's lifespan.

8.3 Life cycle CO_2 emissions

The embodied CO_2 emissions were calculated through multiplying the energy consumption for each fuel type by its corresponding CO_2 emission factor as shown in Fig. 8.9. Similarly, the CO_2 emissions during the operation phase were computed as shown in the same figure. As shown in Fig. 8.9a, the CO_2 emissions during operation phase were larger than the embodied CO_2 emissions by 12 to 18 times in three house categories in Jakarta. The estimated total life cycle CO_2 emissions were 117.3, 280.9 and 723.6 tons CO_2-eq for simple, medium, and luxurious houses, respectively. The profiles of average life cycle CO_2 emission were similar with those of the average life cycle energy for house category in Jakarta, respectively.

Fig. 8.9b shows life cycle CO_2 emissions by house category in Bandung. The total operational CO_2 emissions were larger by 7 to 10 times than embodied CO_2 emissions in three house categories. Fig. 8.10 shows the annual life cycle CO_2 emission for residential buildings in Jakarta and Bandung. As shown, the profiles of average total and annual life cycle CO_2 emission (Figs. 8.9-8.10) were similar with those of the average total and annual life cycle energy for house category in Bandung, respectively.

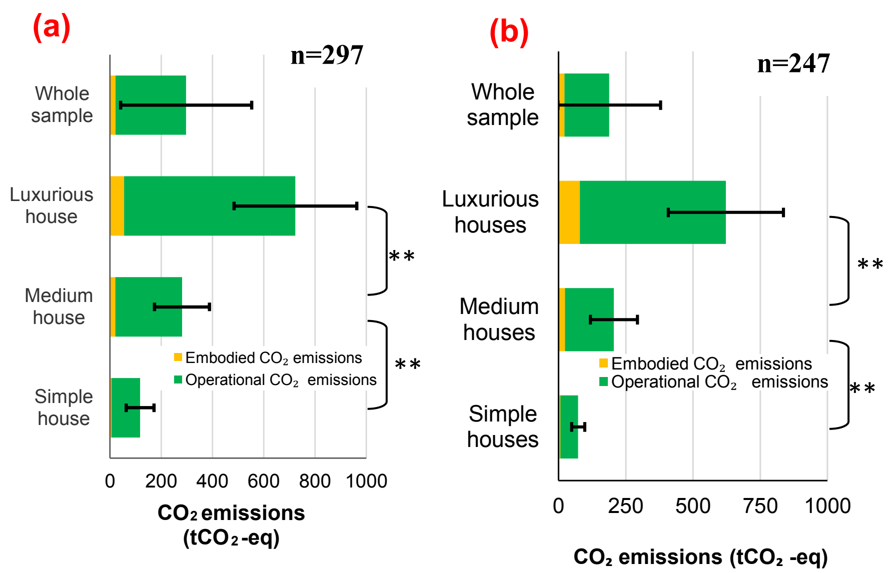


Fig. 8.9. *Average life cycle CO_2 emissions for respective house categories in (a) Jakarta and (b) Bandung.*
Note: The error bars indicate the mean values ± standard deviation.

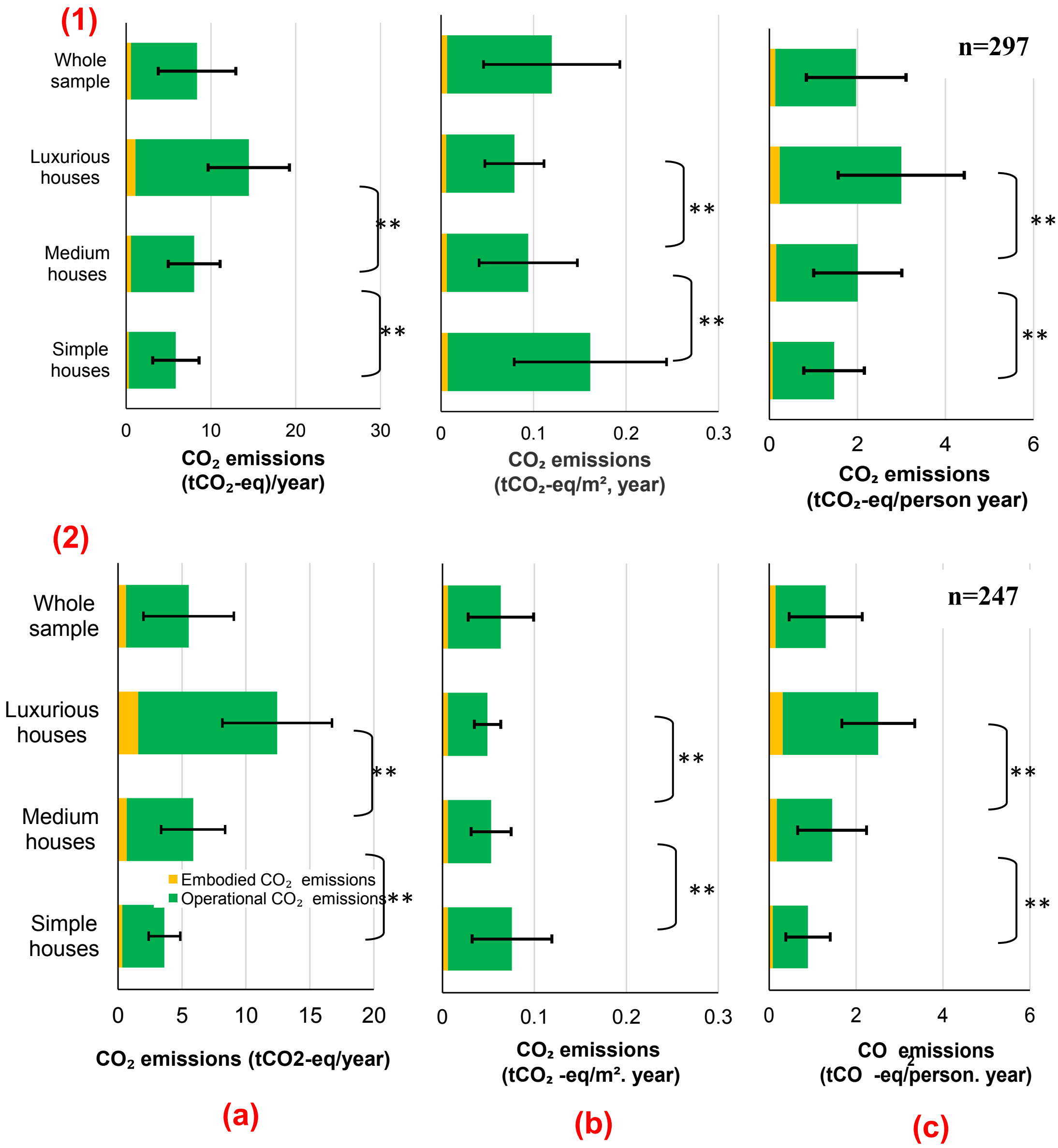


Fig. 8.10 *Average life cycle CO_2 emissions for respective house categories in (1) Jakarta and (2) Bandung. (a) Annual life cycle CO_2 emissions; (b) Unit annual life cycle CO_2 emissions (per total floor area); (c) Unit annual life cycle CO_2 emissions (per person).*
Note: The error bars indicate the mean values ± standard deviation.

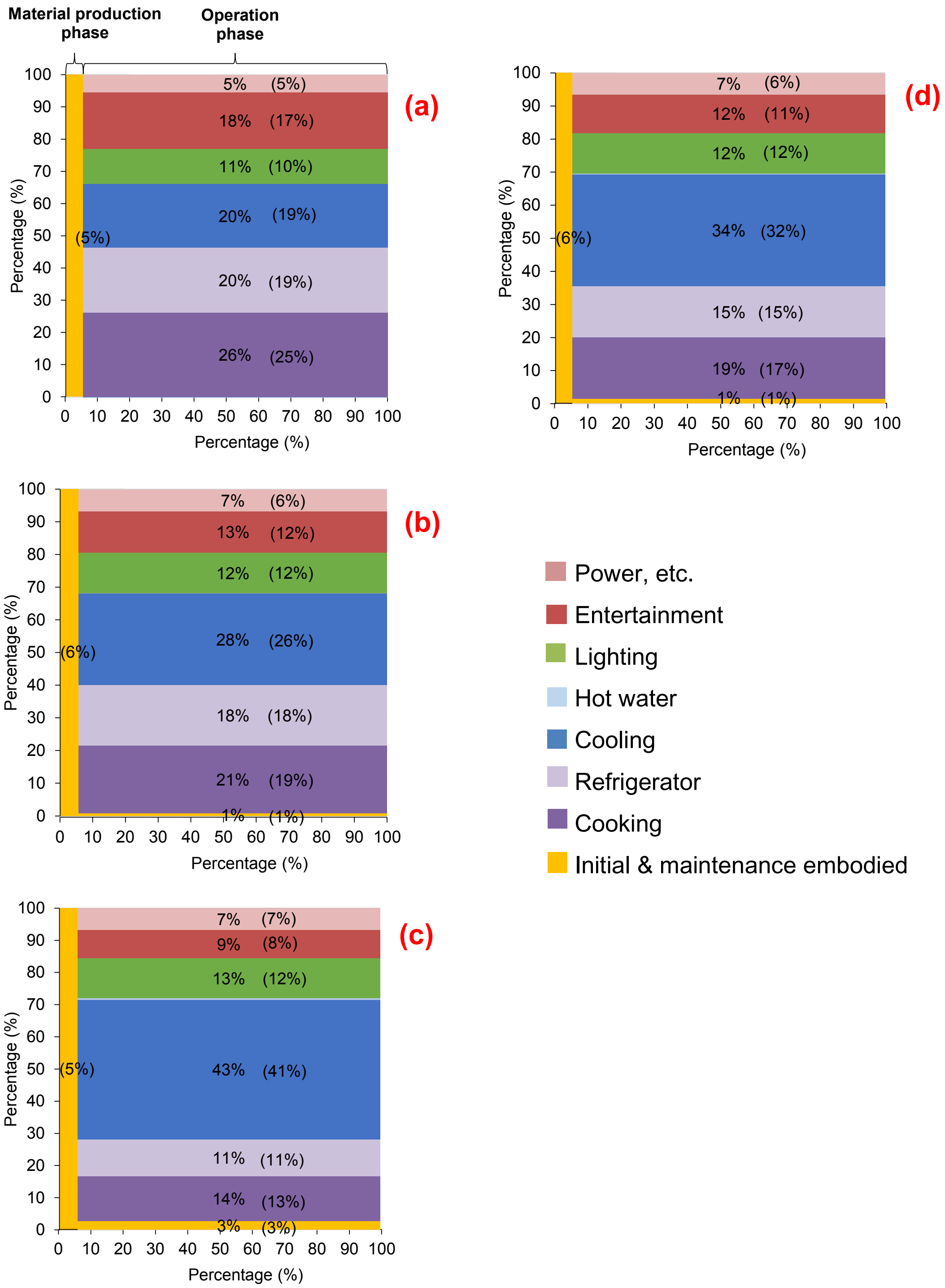


Fig. 8.11 *Contribution to CO_2 emissions by end-use in the whole building's lifespan for respective house categories in Jakarta. (a) Simple house; (b) Medium house; (c) Luxurious house; (d) Whole sample*
Note: The percentages in the parentheses show the contribution to CO_2 emissions by end-use in the whole building's lifespan.

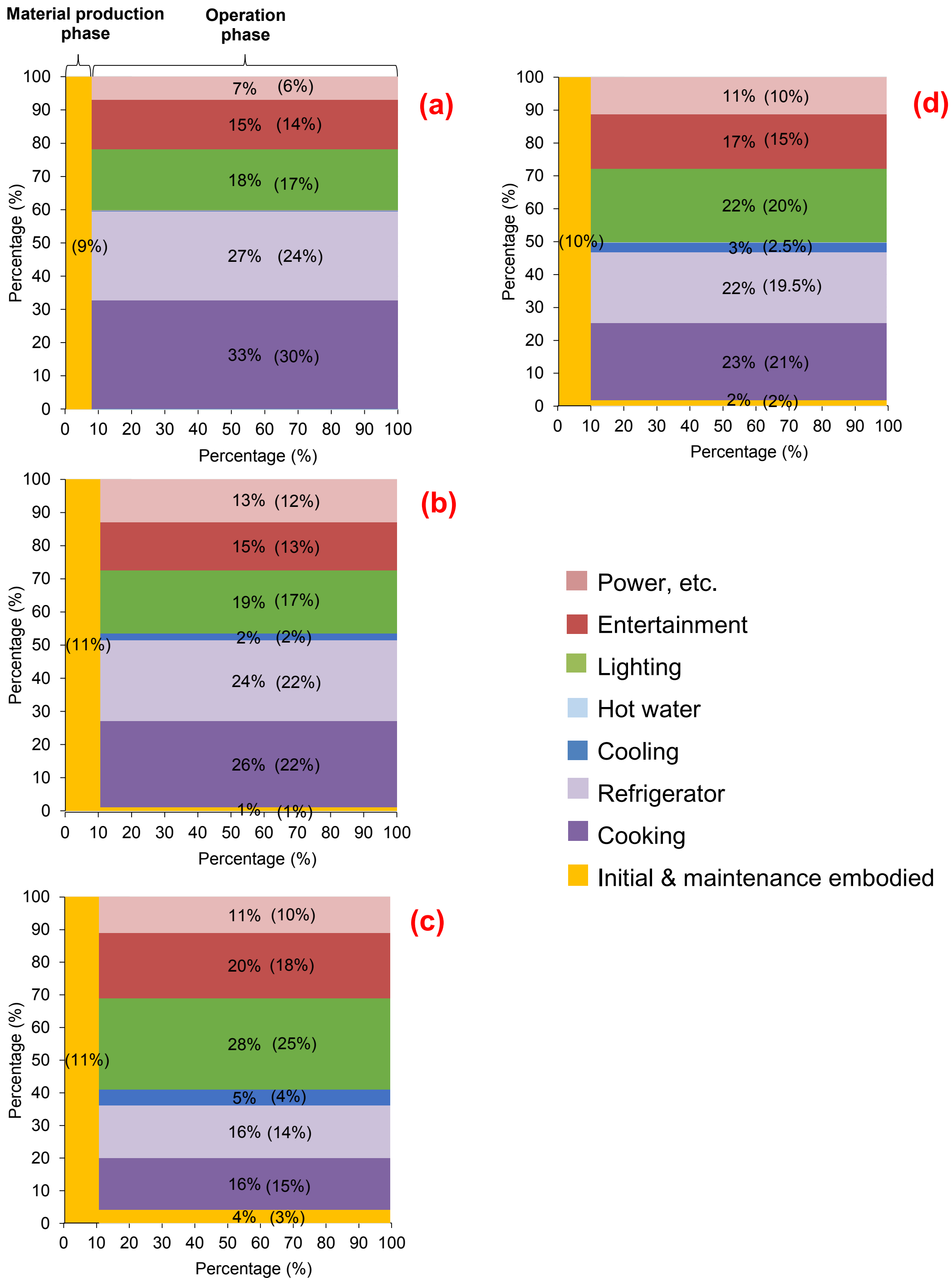


Fig. 8.12 *Contribution to CO_2 emissions by end-use in the whole building's lifespan for respective house categories in Bandung. (a) Simple house; (b) Medium house; (c) Luxurious house; (d) Whole sample*
Note: The percentages in the parentheses show the contribution to CO_2 emissions by end-use in the whole building's lifespan.

Figs. 8.11-12 show the contribution ratios in life cycle CO_2 emissions by respective end-uses in three house categories in Jakarta and Bandung. As shown, the proportion of embodied CO_2 emissions gradually increases with house category from simple to luxurious houses in both cities. In the simple houses of Jakarta, cooking was the largest contributor to the CO_2 emissions (25% out of the whole life cycle), followed by the refrigerator (19%) and cooling (19%), etc. Meanwhile, the percentage of CO_2 emissions caused by cooling increased with house category largely and became the largest contributors in the medium (26%) and luxurious houses (41%). Overall, cooling contributed the largest CO_2 emissions (32%), followed by cooking (17%), refrigerator (15%), etc.

Meanwhile, as shown in Fig. 8.12, in the simple houses of Bandung, cooking was the largest contributor to the CO_2 emissions (30% out of the whole life cycle), followed by the refrigerator (24%) and lighting (17%), etc. Meanwhile, the percentage of energy consumption caused by lighting increased with house category largely and became the largest contributors in the luxurious houses (25%). Overall, energy consumption for cooking contributed the largest proportion (21%), followed by lighting (20%), refrigerator (19.5%), entertainment (15%), etc.

8.4 Discussion and recommendations

Previous analyses anticipated that the further increase in household income would increase the building sizes and thus the energy consumption caused by major household appliances. As a consequence, the increase in household income would increase the total household energy consumption significantly in the near future in Indonesian cities. It has been reported that the household income in Indonesia is predicted to rise dramatically in the near future in line with the rise of middle class, as described before (JETRO, 2011). The household energy consumption in major Indonesian cities is predicted to increase very sharply unless proper energy-saving strategies are implemented.

Several technical and behavioral energy saving strategies can be used to reduce household energy consumption, based on the above analyses (Poortinga et al., 2003). Technical means are generally seen as the expensive way to reduce energy use because they often require an initial investment. But, in the long term, technical means may be cost saving. On the other hand, behavioral energy-savings are often associated with additional effort or decreased comfort.

The results of the foregoing scenario analysis of a building's lifespan proved that embodied energy/CO_2 emissions can be reduced not only by using reused/recycled materials but also by extending building's lifespan or building materials through increasing quality of materials used. The use of reusable/recyclable materials also decreases material waste and provides more material resource.

It is important to avoid the tendency that building size increases straightforwardly with the increase in household income. One of the possible solutions is to recommend more apartments rather than landed houses that generally increase total floor area.

Energy consumption for cooking was the largest contributor to energy usage and CO_2 emissions in simple houses in Jakarta, and simple and medium houses in Bandung. Therefore, it should be of concern. Improving energy efficiency for cooking appliances would reduce energy consumption/CO_2 emission caused by cooking (Schipper and Meyers, 1991)

The increase in air-conditioning would be a major concern in terms of the energy-saving strategies in Indonesia (the relatively cool climate of Bandung is not typical of other major cities). The energy and CO_2 emissions caused by air-conditioner increased with house category and peaked in medium and luxurious houses in Jakarta. Therefore, it is important to reduce the use of air-conditioning in the future despite the expected increase in household income. Passive cooling techniques should be adopted wherever possible and improving energy efficiency for air-conditioner such as using better insulation, setting point temperature of air-conditioner, etc. would reduce energy consumption/CO_2 emissions caused by air conditioner (Cahyono et al., 1997).

Meanwhile, energy consumed and CO_2 emissions caused by lighting also increased with house category and became the largest contributor in luxurious houses in Bandung. Most of the incandescent lamps were already replaced by compact fluorescent lamps (CFLs) and therefore, further energy saving should be made for lighting by utilizing more natural lighting. Shifting existing lamps (compact fluorescent and incandescent) to light emitting diode (LED) would make sufficient capacity of lamps around 47% (Sun et al., 2011). Control the usage of lighting can also be a technique to reduce its energy consumption (Cahyono et al., 1997). A number of energy saving lighting controls are now on the market, including multilevel switches, timers, photocell control, occupancy sensors and daylight-dimming systems.

Summary of potential energy-saving strategies for urban houses in major cities of Indonesia

Household income in Indonesia is predicted to rise dramatically in the future in line with the rise of emerging middle class. Thus, the household energy consumption in major cities is predicted to increase very sharply if we do not anticipate it. Therefore, the following energy-saving strategies are recommended for implementation:

Reduction in embodied energy

- Maximizing the use of reusable/recyclable materials.
- Extending the lifespan of buildings and building materials by increasing the quality of the materials.

Reduction in operational energy

- Improvement of energy-efficiency for cooking appliances.
- Reduction in the energy consumption for cooling
  - Adoption of passive cooling techniques.
  - Improvement of energy efficiency for air-conditioners.
- Reduction in the energy consumption for lighting
  - Most incandescent lamps have already been replaced by compact fluorescent lamps, however further energy saving should be made for lighting by incorporating more natural lighting or by using LED lamps.
  - Control the usage of lighting (multilevel switches, timers, daytime-dimming systems, etc.)
- Providing more apartments than landed houses. This is to avoid the tendency to that building size increases straightforwardly with the increase in the household income.

8.5 Summary

Two case studies, which investigated embodied energy and household energy consumption profiles, in Bandung and Jakarta, were analyzed in order to identify the profile of life cycle primary energy and CO_2 emissions in major cities of Indonesia for respective phases of the building life cycle; i.e. production and operation phases.

- The operational energy of house categories in Jakarta and Bandung accounted for 80 to 90 % and 78 to 86% of total life cycle energy, respectively.
- The pattern of life cycle CO_2 emissions shows the similar pattern with that of life cycle energy of residential buildings in Jakarta and Bandung.
- The operational energy consumption is the major source of impacts in the two case studies, especially due to air conditioning and cooking consumption in Jakarta and lighting and cooking consumption in Bandung.
- The contribution to energy and CO_2 emissions by end-use during each phase for respective house categories shows that in the simple houses of Jakarta, cooking was the largest contributor to the energy and CO_2 emissions (33% and 25%), while the energy and emissions caused by cooling increased with house category largely and became the largest contributors in the medium (27% and 26%) and luxurious houses (36% and 41%). Meanwhile, in the simple houses of Bandung, cooking was the largest contributor to the energy and CO_2 emissions (40% and 30%), while the energy and emissions caused by lighting increased with house category largely and became the largest contributors in the luxurious houses (20% and 25%).
- Embodied energy can be decreased by utilizing reused/recycled materials as much as possible and by extending lifespan of materials and buildings
- Energy consumption for cooking could be diminished by shifting from energy source of kerosene to that of gas for cooking, although energy source of kerosene showed small amount, and utilizing more energy efficiency of appliances for cooking.
- The other option besides adopting passive cooling technique, using more environmental air-conditioner and conducting efficiency improvement of air-conditioner usage such as using better insulation, setting point temperature of air-conditioner, etc. would reduce energy consumption/CO_2 emissions caused by air conditioner.
- Utilizing more natural lighting, shifting existing lamps (compact fluorescent and incandescent) to light emitting diode (LED) and using number of energy saving lighting controls would reduce energy consumed by lightings.

9

Conclusions

This doctoral thesis provides detailed profiles of life cycle energy and CO_2 emissions for residential buildings in major cities of Indonesia. Two main surveys were conducted in two major cities of Indonesia, Bandung and Jakarta, in order to obtain building material inventory and household energy consumption data. Building material inventory data were necessary to evaluate current building material stock and future demolition waste, and analyze their embodied energy and CO_2 emissions. Meanwhile, household energy consumption data were used to investigate household energy consumption profiles and the causal structures of household energy consumption were clarified. Then, the combination embodied and operational energy were analyzed to clarify the life cycle energy and CO_2 emissions throughout building's lifespan.

This chapter concludes all findings of this study. Section 9.1 summarizes the key findings. Further studies that will continue this study and beyond are recommended in Section 9.2.

9.1 Summary of key Findings

Database for life cycle assessment

Life cycle assessment (LCA) of energy and CO_2 emissions in buildings were conducted commonly in developed countries. Meanwhile, LCA studies in developing countries remain limited, including in Indonesia. This is mainly because the necessary raw data for LCA in buildings is hard to be accessed in developing countries unlike in developed countries. In particular, in the case of Indonesia, there is a serious lack of data on building material inventory and household energy consumption for unplanned urban houses.

A comprehensive database on material inventory and household energy consumption necessary for conducting LCA study for whole process construction in urban residential buildings of Indonesia has been constructed based on the two case studies in Jakarta and Bandung.

Embodied energy and CO_2 emissions of building materials for residential buildings in Jakarta and Bandung

The key findings of the study on evaluation of current building material stock and future demolition waste as well as their embodied energy/CO_2 emissions in Jakarta and Bandung are as follows:

- Overall, the averaged material quantity per m^2 used for the houses in Jakarta was higher (2.14 ton/m^2) than that in Bandung (2.06 ton/m^2). The current total material stock of urban houses in Jakarta was measured to be 232.0 million ton, while that of urban houses in Bandung was measured to be 77.2 million ton.
- If both reuse and recycling rates are assumed to be zero, then the total demolition waste of unplanned simple houses in Jakarta was determined to be 41.5 million ton until 2020, the corresponding amount of waste in Bandung is predicted to be lower (12.6 million ton) due to the smaller number of simple houses in Bandung. This scenario will cause a severe situation in which the amount of waste sent to landfills would be very large, thus overloading of landfills.
- Future expansion of unplanned simple houses due to demolition of unplanned simple houses by 2020 was 20.0 km^2 in Jakarta and 5.7 km^2 in Bandung. This expansion would force the cities to extend their boundaries further to the surrounding suburbs and accelerate urban sprawl.
- A relatively simplified LCA method based on I-O analysis under poor data availability environment (i.e. major cities of Indonesia) was developed to analyze embodied energy and CO_2 emissions.
- In Jakarta, embodied energy was estimated at 67.1, 240.1 and 817.1 GJ for simple, medium and luxurious houses, respectively.
- Maximizing reuse and recycling rates would decrease dramatically not only the average amount of material waste (37% to 41%) but also their embodied energy/CO_2 emissions by 27% to 28%. The promotion of reuse/recycling was demonstrated to effectively reduce the embodied energy/CO_2 emissions of building materials.
- Extension of building lifespan by double would reduce embodied energy by 50%.

Household energy consumption and CO_2 emissions for residential buildings in Jakarta and Bandung

The study on LCA were continued to investigate household energy consumption and CO_2 emission profiles for residential buildings in Jakarta and Bandung. The main findings were summarized are as follows:

- Overall, the average annual energy consumption of whole sample in Jakarta is approximately 44.2 GJ, which is 14.9 GJ larger than that of Bandung. The difference is mainly attributed to the use of air-conditioning between the two cities. Hence, in the case of Jakarta, basically, the average household energy consumption increases with the increase in ownership and use of air-conditioning. Meanwhile, in the case of Bandung, the energy consumption for cooking, lighting and entertainment largely influence the increase in the overall energy consumption.
- The average annual CO_2 emission in Jakarta was estimated at 7.8 ton CO_2-equivalent, while that of Bandung is 4.8 ton CO_2-equivalent. The major contributors in Jakarta are cooling (2.4 ton (31%)), cooking (1.6 ton (20%)) and refrigerator (1.3 ton (17%)), while those in Bandung are cooking (1.2 ton (26%)), refrigerator (1.1 ton (23%)), lighting (1.0 ton (21%)).

- The results of multiple regression analyses indicates that overall, the increase in household income and building size such as total floor area and lot area, increases the electricity consumption caused by the mentioned major appliances. As consequence, the increase in household income would increase the total household energy consumption significantly in line with the rise of middle class in the near future in Indonesia cities if proper energy-saving strategies are not implemented. Therefore, it is important to avoid the tendency that building size increases straightforwardly with the increase in household income.

Assessment on life cycle energy and CO_2 emissions for residential buildings in Jakarta and Bandung

Combination of embodied energy and operational energy were analyzed to identify the profile of life cycle energy and CO_2 emission for urban houses in the whole building's life-span. The key findings are as follows.

- The operational stage is the most influential stage in terms of energy consumption during the building's life cycle. Its energy for respective house categories in Jakarta and Bandung accounted for 80 to 90 % and 78 to 86% of total life cycle energy, respectively.
- The CO_2 emissions during operation phase were larger than the embodied CO_2 emissions by 12 to 18 times in three house categories in Jakarta and 7 to 10 times in Bandung.
- The contribution to energy and CO_2 emissions by end-use in the whole building's life-span for respective house categories shows that cooking was the largest contributor to the energy consumption and CO_2 emissions (33% and 25%) in the simple houses of Jakarta, while the energy and emissions caused by cooling increased with house category largely and became the largest contributors in the medium (27% and 26%) and luxurious houses (36% and 41%).
- Meanwhile, in the case of Bandung, cooking was the largest contributor to the energy and CO_2 emissions in all house categories, while the energy and emissions caused by lighting increased with house category largely and became the largest contributors in the luxurious houses (20% and 25%).

Recommendations

Several potential energy-saving strategies were recommended;

- Reduce, reuse and recycling (3Rs) for building materials and extension of building lifespan
- Improvement of energy-efficiency for cooking appliances
- Passive cooling techniques
- Natural lighting and energy-saving lighting such as LED lamps
- Provision of more apartments than landed houses

9.2 Future prospects

This thesis is mainly focused on analyzing life cycle energy and CO_2 emissions profiles for residential buildings, and projection of their primary energy consumption in two major cities of Indonesia, Bandung and Jakarta, in order provide its future visions. Thus, this thesis did not cover other aspects such as social, economic and behavior caused by reduction of energy consumption for respective residential types/ categories. These other aspects are important to be considered because reduction on primary energy consumption may affect household's quality of life, especially for simple and medium houses. Reduction on household's quality of life following reduction of energy consumption is significantly needed to be anticipated.

There are several key studies that need to be developed following this thesis: quality of life itself, economic factor in terms of cost and benefit assessment, and living preference of Indonesian people.

- Study on diminishing of operational energy in developing countries especially tropical countries is needed. Passive cooling may be one of the means to reduce air conditioning usage.
- Quality of life should not be determined only by income factors, but also plausible factors such as happiness and satisfaction. The reduction of primary household energy consumption should not been followed by diminishing their quality of life. There may be some other factors affecting their quality of life to balance with energy consumption reduction.
- Cost and benefit studies are needed to understand the balance of investment (initial cost to build a house) as well as revenue (energy consumption reduction in scale of time). The result will show the effectiveness of proposed project by life cycle cost analysis. Through this means, people will clearly understand the cost and benefit and may attract more people in shifting to low energy buildings.
- Preference of living is highly related to current trends of housing in Indonesia. Even though a lot of apartments has being erected, most of Indonesian people still prefer to live in landed houses. Shifting this trends in the sake of energy consumption reduction has to go through living behavior studies to nicely shift people preference on landed houses to vertical houses. By appropriate adaptation, promoting apartment can be successfully obtain a good response and eventually reduce total life cycle energy in residential buildings.

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Appendix 1

QUESTIONNAIRE FOR HOUSEHOLD ENERGY CONSUMPTION AND OBSERVATION FORM FOR BUILDING MATERIAL INVENTORY FOR UNPLANNED RESIDENTIAL BUILDINGS IN MAJOR CITIES OF INDONESIA

Usep Surahman
ID Number : D101894

Main Supervisor : Dr. Tetsu Kubota

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2012-2013

QUESTIONNAIRE FOR HOUSEHOLD ENERGY CONSUMPTION
FOR UNPLANNED RESIDENTIAL BUILDINGS IN MAJOR CITIES OF INDONESIA

A. IDENTIFICATION OF INTERVIEWER

Name	
Survey Date	
Started Time	
Ended Time	

B. IDENTIFICATION OF HOUSEHOLD

I. Household Address

Household Code	(Area number)	(Survey group number)	(Household number)
Address			
Sub-district/Village			

II. Demography and Livelihood

Fill up the following required information about the household according to the answer of the respondent and refer to the codes below

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
No	**Gender**	**Age**	**Relationship to the household head**	**Ethnic group**	**Civil status**	**Occupation**	**Highest educational attainment**	**Monthly income**	**Average daily staying time in the house**	
									Weekdays	**Weekends**
1										
2										
3										
4										
5										
6										
7										
8										
9										
								Total:		

Codes:

(1) Number of Family members

(2) M: male
F: female

(3) Write the age given

(4) 1. Head 5. Grand Child
2. Spouse 6. Parent
3. Child 7. House maid
4. in Law 8. Others, specify…

(5) 1. Sudanese
2. Javanese
3. Others, specify……..

(6) 1. Single
2. Married
3. Married but separated
4. Widow/widower

(7) 1. Government Permanent Employee
2. Government Temporary Employee
3. Private Permanent Employee
4. Private temporary Employee
5. Student
6. Others, specify…

(8) 1. Pre-elementary
2. Elementary
3. Junior High school
4. Senior High school
5. Vocational Course
6. Graduate
7. Post graduate
8. Others, specify…….

(9) 1. < Rp. 500000
2. Rp. 500000 - Rp.1000000
3. Rp. 1000001-Rp. 2000000
4. Rp. 2000001-Rp.3000000
5 Rp. 3000001-Rp. 4000000
6. Rp. 4000001-Rp. 5000000
7. Rp. 5000001-Rp. 10000000
8. > Rp. 10000000

(10) Write the time given in hours and minutes

C. HOUSING CONDITION

I. Kind of House ☐ Horizontal ☐ Vertical ☐ Mixed

II. Type of House ☐ Unplanned ☐ Planned

III. Housing category ☐ Simple house ☐ Medium house ☐ Luxurious house

IV. Storey of house ☐ Single storey ☐ Double storey ☐ Multy- storey

V. Location ☐ Corner ☐ Middle

VI. Established year [Years] [Months]

VII. Living duration [Years] [Months]

VIII. Area

	Area (m^2)
Lot	
Building	

D. ENERGY CONSUMPTION

I. Micro Climatic Condition at The Time of Survey

Location	**Floor**		**Window**		**AC**		**Temperature**	**Humidity**	**Time**
	Ground	First	Opened	Closed	On	Off			
Indoor (where AC is installed)									
Indoor (where refrigerator is put)									
Outdoor (front/backyard)									

II. Monthly Electric, Water bill and Frequency of refilling gas for cooking and water heater

a. Electric bills

2012

Month	January	February	March	April	May	June
Use (kWh)						
Month	July	August	September	October	November	December
Use (kWh)						

2011

Month	January	February	March	April	May	June
Use (kWh)						
Month	July	August	September	October	November	December
Use (kWh)						

How much does your household spend on electricity monthly?

The highest	Rp. Per month	In the month of
Average	Rp. Per month	In the month of
The lowest	Rp. Per month	In the month of

b. Water bills

What is the source of your fresh water?

☐ Well ☐ Governmental water enterprise ☐ Private water enterprise

If you mark (v) Governmental water enterprise, please fill the question below

2012

Month	January	February	March	April	May	June
Vol (m^3)/Cost (Rp)						
Month	July	August	September	October	November	December
Vol (m^3)/Cost (Rp)						

2011

Month	January	February	March	April	May	June
Vol (m^3)/Cost (Rp)						
Month	July	August	September	October	November	December
Vol (m^3)/Cost (Rp)						

How much does your household spend on water monthly?

The highest	Rp. Per month	In the month of
Average	Rp. Per month	In the month of
The lowest	Rp. Per month	In the month of

c. Refilling water gallon for drinking

If you mark (v) Private water enterprise, please fill the question below

2012

Month	January	February	March	April	May	June
Use (gallon)						
Month	July	August	September	October	November	December
Use (gallon)						

2011

Month	January	February	March	April	May	June
Use (gallon)						
Month	July	August	September	October	November	December
Use (gallon)						

1 water gallon (Indonesia) : 19 liter

How much does your household refill drinking water monthly

The highest	gallon	In the month of
Average	gallon	In the month of
The lowest	gallon	In the month of

d. What do you use for cooking?

☐ Electric ☐ Gas ☐ Kerosene ☐ Others,…………

If you mark (v) Gas, please fill the question below

Refilling Gas for Cooking

2012

Month	January	February	March	April	May	June
Use (kg)						
Month	July	August	September	October	November	December
Use (kg)						

2011

Month	January	February	March	April	May	June
Use (kg)						
Month	July	August	September	October	November	December
Use (kg)						

How often does your household refill the gas cylinder?

The longest	days	In the month of
Average	days	In the month of
The shortest	days	In the month of

If you mark (v) Kerosene, please fill the question below

e. Refilling Kerosene for Cooking

2012

Month	January	February	March	April	May	June
Use (liter)						
Month	July	August	September	October	November	December
Use (liter)						

2011

Month	January	February	March	April	May	June
Use (liter)						
Month	July	August	September	October	November	December
Use (liter)						

How much does your household refill kerosene monthly

The highest	liter	In the month of
Average	liter	In the month of
The lowest	liter	In the month of

f. What do you use for water heater?

☐ Electric ☐ Gas ☐ Solar

If you mark (v) Gas, please fill the question below

Refilling Gas for Water Heater

2012

Month	January	February	March	April	May	June
Use (kg)						
Month	July	August	September	October	November	December
Use (kg)						

2011

Month	January	February	March	April	May	June
Use (kg)						
Month	July	August	September	October	November	December
Use (kg)						

How often does your household refill the gas cylinder?

The highest	days	In the month of
Average	days	In the month of
The lowest	days	In the month of

E. LIGHTING AND ELECTRICAL APPLIANCES

1. LIGHTING

Location		Type	Brand Name	Year	Number of Units	Capacity (watt)	Using time per day			
						Panel	Weekdays		Weekends	
Room	Storey						Hours	Min	Hours	Min
Terrace										
Guest room										
Living room										
Dining room										
Master bedroom 1										
Bed room 2										
Bedroom 3										
Bedroom 4										
Bedroom 5										
Bath room 1										
Bath room 2										
Bath room 3										
Dry Kitchen										
Wet Kitchen										
Stairs										
Upstairs family space										
Store										
Carport										
Garage										
Gate fence										
Backyard										

CFL

A

Incandescent Lamp

B

Fluorescent Lamp 1

C

Fluorescent Lamp 2

D

Min : Minutes

2. COOLING

Cooling	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekend	
	Room	Storey								Hours	Min	Hours	Min
AC 1						HP	°C						
AC 2						HP	°C						
AC 3						HP	°C						
AC 4						HP	°C						
Ceiling fan 1							L/M/H						
Ceiling fan 2							L/M/H						
Ceiling fan 3							L/M/H						
Ceiling fan 4							L/M/H						
Stand fan 1							L/M/H						
Stand fan 2							L/M/H						
Stand fan 3							L/M/H						

Min : Minutes
Capacity of AC must be calculated and measured

2a. When do you ordinarily operate the air conditioners when you stay in the room?

a. Weekdays

Hour																							
am							pm												am				
6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

b. Weekends

Hour																							
am							pm												am				
6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

c. holidays

Hour																							
am							pm												am				
6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

Example

Hour																							
am							pm												am				
6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

3. COOKING

Cooking	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Blender													
Electric stove													
RC (cook)													
RC (warm)													
Toaster													
Mixer													
Electric kettle													
Micro wave													
Dispenser													
Others…..													
Refrigerator							°C						
	Frequency of opening refrigerator's door				…….Times/day (weekdays)			………Times/day (weekends)					
	Load of refrigerator				☐ Light (<10kg) ☐ Medium (10-20kg) ☐ Heavy (>20kg)								

Min : Minutes
RC : Rice cooker
Capacity of blender and refrigerator must be measured and calculated.

4. BATHING, WASHING AND CLEANING

Washing and Cleaning	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Electric iron													
Washing Machine													
Vacuum cleaner													
Water heater							°C						
Water pump													
Others……													

Min : Minutes
Capacity of electric iron must be measured.

5. **ENTERTAINMENT AND COMMUNICATION**

Entertainment and Communication	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Notebook													
Television													
Stereo compont.													
Computer (PC)													
CPU													
Monitor													
Video game													
HP charging													
VCD/DVD player													
Aquarium pump													
Others……													

Min : Minutes
Capacity of notebook must be calculated and measured

6. **OTHER PERSONAL GADGETS**

Other Personal Gadgets	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Hair blower													
Hair iron													
Others…..													

Min : Minutes

7. **LIVELIHOOD EQUIPMENTS**

Livelihood Equipments	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Sewing machine													
Welding machine													
Compressor													
Others……													

Min : Minutes

THANK YOU FOR YOUR COOPERATION

(All information derived from this interview will remain strictly confidential and will be used exclusively for this research purpose)

OBSERVATION FORM FOR BUILDING MATERIAL INVENTORY
FOR UNPLANNED RESIDENTIAL BUILDINGS IN MAJOR CITIES OF INDONESIA

A. IDENTIFICATION OF HOUSEHOLD

III. Household Address

Household Code	(Area number)	(Survey group number)	(Household number)
Address			
Sub-district/Village			

B. INVENTORY OF RESIDENTIAL BUILDING ELEMENTS AND MATERIALS

Mark (v) the materials used at the house surveyed

No	Building Elements	Sub-building Material	New Material			Recycled Material			Used Material		
			Yes	No	%	Yes	No	%	Yes	No	%
1	Foundation										
2	Column										
3	Wall										
4	1st Floor										
	2nd Floor										
5	Door	Door									
		Frame									
6	Window	Window									
		Frame									
7	Ceiling	Ceiling									
		Frame									
8	Roof	Roof									
		Frame									

C. HOUSING DESIGN

a. Was your house designed by an architecture consultant?

☐ Yes ☐ No

1. If your answer Yes, what is its name and where is it?

2. If your answer No, who designed and built your house?

b. Do you have the design drawing of your house?

☐ Yes ☐ No

1. If your answer Yes, may I have its copy?
2. If your answer No, please sketch the house plan surveyed and put its dimensions !

D. HOUSE'S PLANS

Ground plan

First Floor Plan

Second Floor Plan

Roof plan

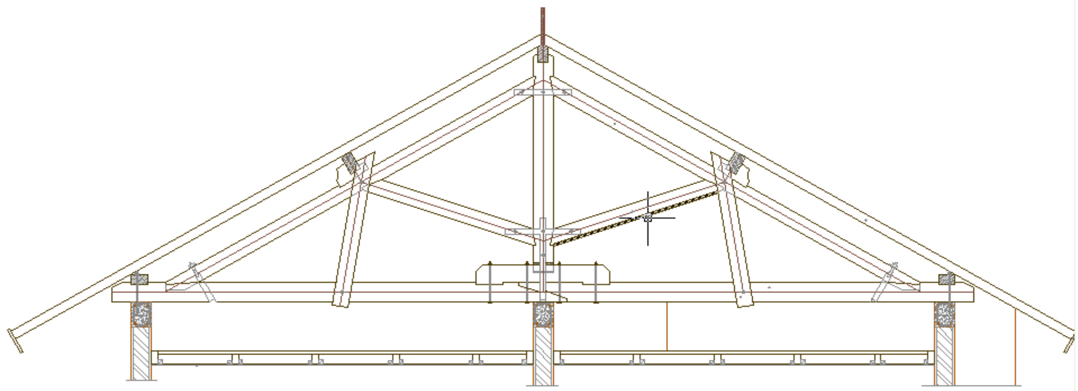
Front Elevation

Section 1-1

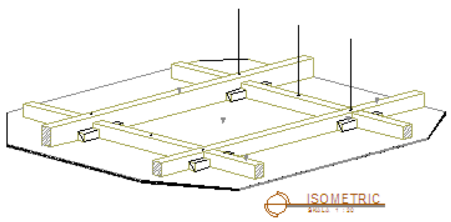
E. DETAILS

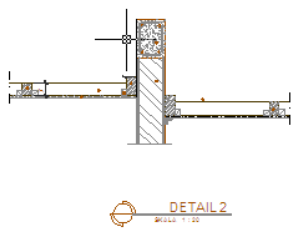
Put the dimensions on the drawing details below and change the drawing details if they are different with those of the house surveyed

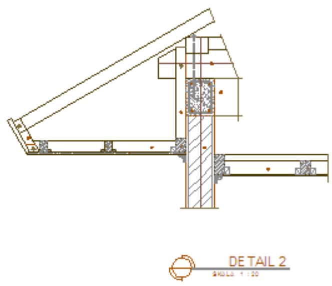
Roof's Detail



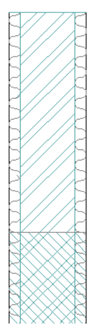
Ceiling's Detail



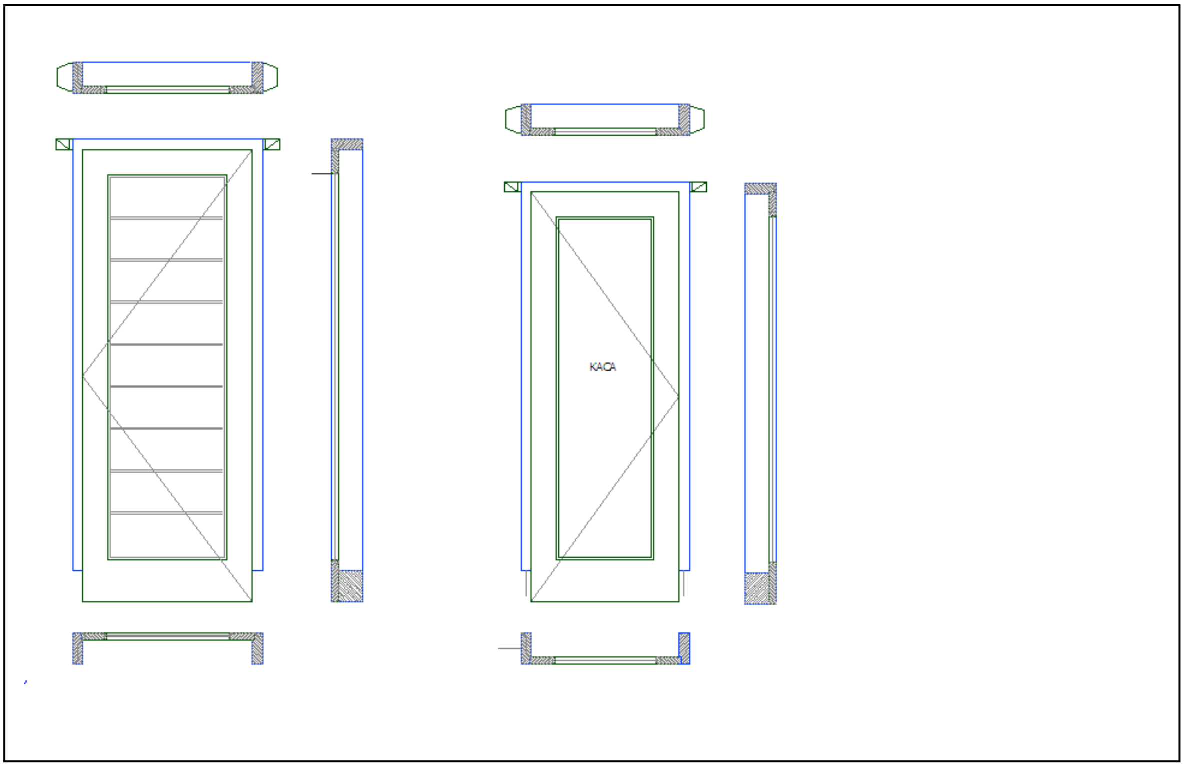




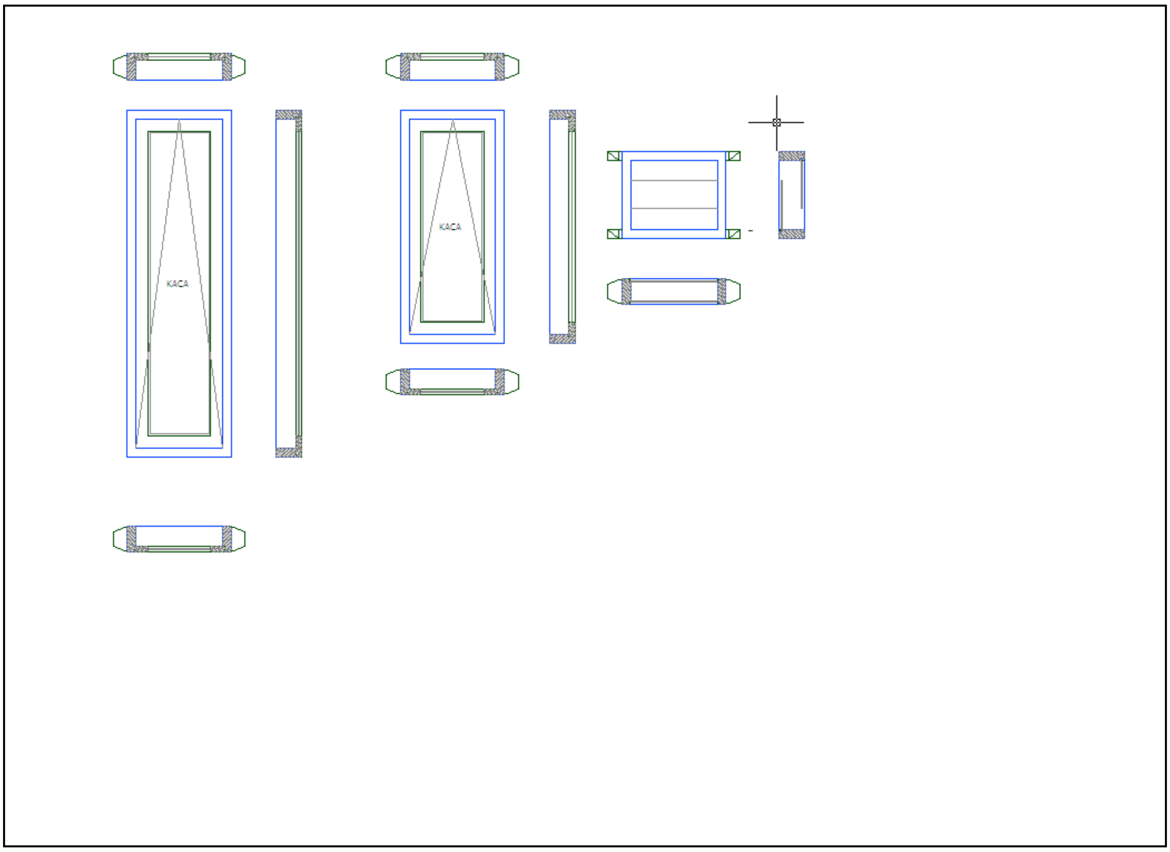
Wall's Detail



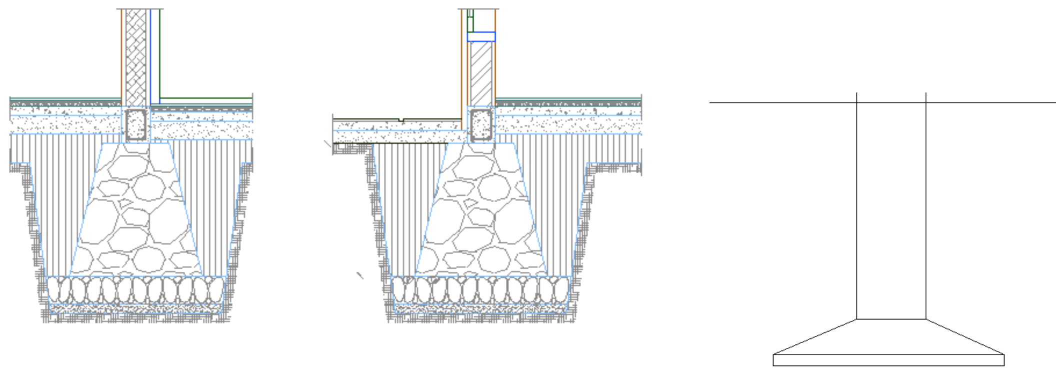
Door's Detail



Window`s detail



Foundation's Detail



F. MODIFICATIONS

Did you make any modification or extension work to your house when you move in to this house?

☐ Yes ☐ No

If you answer Yes in question above, where did you modify and how much does it cost?

Modified part	Year	Cost (IDR)

G. RECONSTRUCTION (Lifespan of building)

Have you ever reconstructed your house?

☐ Yes ☐ No

If you answer Yes in question above, please fill the table below.

Which part of your house did you reconstruct and how much did you spend on it?

No	Building Elements	Year	Cost (IDR)
1	Foundation		
2	Column		
3	Wall		

H. MAINTENANCE (Lifespan of building materials)

Have you ever done maintenance for your house?

☐ Yes ☐ No

If you answer Yes in question above, please fill the table below.

Which part of your house did you do maintenance and how much did you spend on it?

No	Building Elements	Sub-building Material	Year	Cost (Rupiahs)
1	Floor (1^{st})			
	Floor (2^{nd})			
2	Door	Door		
		Frame		
3	Window	Window		
		Frame		
4	Ceiling	Ceiling		
		Frame		
5	Roof	Roof		
		Frame		

THANK YOU FOR YOUR COOPERATION

(All information derived from this interview will remain strictly confidential and will be used exclusively for this research purpose)

Appendix 2

QUESTIONNAIRE FOR HOUSEHOLD ENERGY CONSUMPTION AND OBSERVATION FORM FOR BUILDING MATERIAL INVENTORY FOR PLANNED RESIDENTIAL BUILDINGS IN MAJOR CITIES OF INDONESIA

Usep Surahman
ID Number : D101894

Main Supervisor : Dr. Tetsu Kubota

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2012-2013

QUESTIONNAIRE FOR HOUSEHOLD ENERGY CONSUMPTION FOR PLANNED RESIDENTIAL BUILDINGS IN MAJOR CITIES OF INDONESIA

A. IDENTIFICATION OF INTERVIEWER

Name	
Survey Date	
Started Time	
Ended Time	

B. IDENTIFICATION OF HOUSEHOLD

I. Household Address

Household Code	(Area number)	(Survey group number)	(Household number)
Address			
Sub-district/Village			

II. Demography and Livelihood

Fill up the following required information about the household according to the answer of the respondent and refer to the codes below

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
No	**Gender**	**Age**	**Relationship to the household head**	**Ethnic group**	**Civil status**	**Occupation**	**Highest educational attainment**	**Monthly income**	**Average daily staying time in the house**	
									Weekdays	**Weekends**
1										
2										
3										
4										
5										
6										
7										
8										
9										
								Total:		

Codes:

(1) Number of Family members

(2) M: male
F: female

(3) Write the age given

(4) 1. Head 5. Grand Child
2. Spouse 6. Parent
3. Child 7. House maid
4. in Law 8. Others, specify…

(5) 1. Sudanese
2. Javanese
3. Others, specify……..

(6) 1. Single
2. Married
3. Married but separated
4. Widow/widower

(7) 1. Government Permanent Employee
2. Government Temporary Employee
3. Private Permanent Employee
4. Private temporary Employee
5. Student
6. Others, specify…

(8) 1. Pre-elementary
2. Elementary
3. Junior High school
4. Senior High school
5. Vocational Course
6. Graduate
7. Post graduate
8. Others, specify…….

(9) 1. < Rp. 500000
2. Rp. 500000 - Rp.1000000
3. Rp. 1000001-Rp. 2000000
4. Rp. 2000001-Rp.3000000
5 Rp. 3000001-Rp. 4000000
6. Rp. 4000001-Rp. 5000000
7. Rp. 5000001-Rp. 10000000
8. > Rp. 10000000

(10) Write the time given in hours and minutes

C. HOUSING CONDITION

I. Kind of House ☐ Horizontal ☐ Vertical ☐ Mixed

II. Type of House ☐ Unplanned ☐ Planned

III. Housing category ☐ Simple house ☐ Medium house ☐ Luxurious house

IV. Storey of house ☐ Single storey ☐ Double storey ☐ Multy- storey

V. Location ☐ Corner ☐ Middle

VI. Established year [Years] [Months]

VII. Living duration [Years] [Months]

VIII. Area

	Area (m^2)
Lot	
Building	

D. ENERGY CONSUMPTION

I. Micro Climatic Condition at The Time of Survey

Location	Floor		Window		AC		Temperature	Humidity	Time
	Ground	First	Opened	Closed	On	Off			
Indoor (where AC is installed)									
Indoor (where refrigerator is put)									
Outdoor (front/backyard)									

II. Monthly Electric, Water bill and Frequency of refilling gas for cooking and water heater

a. Electric bills

2012

Month	January	February	March	April	May	June
Use (kWh)						
Month	July	August	September	October	November	December
Use (kWh)						

2011

Month	January	February	March	April	May	June
Use (kWh)						
Month	July	August	September	October	November	December
Use (kWh)						

How much does your household spend on electricity monthly?

The highest	Rp.	Per month	In the month of
Average	Rp.	Per month	In the month of
The lowest	Rp.	Per month	In the month of

b. Water bills

What is the source of your fresh water?

☐ Well ☐ Governmental water enterprise ☐ Private water enterprise

If you mark (v) Governmental water enterprise, please fill the question below

2012

Month	January	February	March	April	May	June
Vol (m^3)/Cost (Rp)						
Month	July	August	September	October	November	December
Vol (m^3)/Cost (Rp)						

2011

Month	January	February	March	April	May	June
Vol (m^3)/Cost (Rp)						
Month	July	August	September	October	November	December
Vol (m^3)/Cost (Rp)						

How much does your household spend on water monthly?

The highest	Rp.	Per month	In the month of
Average	Rp.	Per month	In the month of
The lowest	Rp.	Per month	In the month of

c. Refilling water gallon for drinking

If you mark (v) Private water enterprise, please fill the question below

2012

Month	January	February	March	April	May	June
Use (gallon)						
Month	July	August	September	October	November	December
Use (gallon)						

2011

Month	January	February	March	April	May	June
Use (gallon)						
Month	July	August	September	October	November	December
Use (gallon)						

1 water gallon (Indonesia) : 19 liter

How much does your household refill drinking water monthly

The highest	gallon	In the month of
Average	gallon	In the month of
The lowest	gallon	In the month of

d. What do you use for cooking?

☐ Electric ☐ Gas ☐ Kerosene ☐ Others,…………

If you mark (v) Gas, please fill the question below

Refilling Gas for Cooking

2012

Month	January	February	March	April	May	June
Use (kg)						
Month	July	August	September	October	November	December
Use (kg)						

2011

Month	January	February	March	April	May	June
Use (kg)						
Month	July	August	September	October	November	December
Use (kg)						

How often does your household refill the gas cylinder?

The longest	days	In the month of
Average	days	In the month of
The shortest	days	In the month of

If you mark (v) Kerosene, please fill the question below

e. Refilling Kerosene for Cooking

2012

Month	January	February	March	April	May	June
Use (liter)						
Month	July	August	September	October	November	December
Use (liter)						

2011

Month	January	February	March	April	May	June
Use (liter)						
Month	July	August	September	October	November	December
Use (liter)						

How much does your household refill kerosene monthly

The highest	liter	In the month of
Average	liter	In the month of
The lowest	liter	In the month of

f. What do you use for water heater?

☐ Electric ☐ Gas ☐ Solar

If you mark (v) Gas, please fill the question below

Refilling Gas for Water Heater

2012

Month	January	February	March	April	May	June
Use (kg)						
Month	July	August	September	October	November	December
Use (kg)						

2011

Month	January	February	March	April	May	June
Use (kg)						
Month	July	August	September	October	November	December
Use (kg)						

How often does your household refill the gas cylinder?

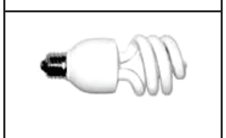
The highest	days	In the month of
Average	days	In the month of
The lowest	days	In the month of

E. LIGHTING AND ELECTRICAL APPLIANCES

1. LIGHTING

Location		Type	Brand Name	Year	Number of Units	Capacity (watt)	Using time per day			
						Panel	Weekdays		Weekends	
Room	Storey						Hours	Min	Hours	Min
Terrace										
Guest room										
Living room										
Dining room										
Master bedroom 1										
Bed room 2										
Bedroom 3										
Bedroom 4										
Bedroom 5										
Bath room 1										
Bath room 2										
Bath room 3										
Dry Kitchen										
Wet Kitchen										
Stairs										
Upstairs family space										
Store										
Carport										
Garage										
Gate fence										
Backyard										

CFL



A

Incandescent Lamp

B

Fluorescent Lamp 1

C

Fluorescent Lamp 2

D

Min : Minutes

2. COOLING

Cooling	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekend	
	Room	Storey								Hours	Min	Hours	Min
AC 1						HP	°C						
AC 2						HP	°C						
AC 3						HP	°C						
AC 4						HP	°C						
Ceiling fan 1							L/M/H						
Ceiling fan 2							L/M/H						
Ceiling fan 3							L/M/H						
Ceiling fan 4							L/M/H						
Stand fan 1							L/M/H						
Stand fan 2							L/M/H						
Stand fan 3							L/M/H						

Min : Minutes
Capacity of AC must be calculated and measured

2a. When do you ordinarily operate the air conditioners when you stay in the room?

a. Weekdays

Hour																							
am							pm												am				
6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

b. Weekends

Hour																							
am							pm												am				
6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

c. holidays

Hour																							
am							pm												am				
6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

Example

Hour																							
am							pm												am				
6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5

3. COOKING

Cooking	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Blender													
Electric stove													
RC (cook)													
RC (warm)													
Toaster													
Mixer													
Electric kettle													
Micro wave													
Dispenser													
Others…..													
Refrigerator							°C						

	Frequency of opening refrigerator's door	…….Times/day (weekdays)	………Times/day (weekends)
	Load of refrigerator	☐ Light (<10kg) ☐ Medium (10-20kg) ☐ Heavy (>20kg)	

Min : Minutes
RC : Rice cooker
Capacity of blender and refrigerator must be measured and calculated.

4. BATHING, WASHING AND CLEANING

Washing and Cleaning	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Electric iron													
Washing Machine													
Vacuum cleaner													
Water heater							°C						
Water pump													
Others……													

Min : Minutes
Capacity of electric iron must be measured.

5. ENTERTAINMENT AND COMMUNICATION

Entertainment and Communication	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Notebook													
Television													
Stereo compont.													
Computer (PC)													
CPU													
Monitor													
Video game													
HP charging													
VCD/DVD player													
Aquarium pump													
Others……													

Min : Minutes
Capacity of notebook must be measured.

6. OTHER PERSONAL GADGETS

Other Personal Gadgets	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Hair blower													
Hair iron													
Others…..													

Min : Minutes

7. LIVELIHOOD EQUIPMENTS

Livelihood Equipments	Location		Brand Name	Model	Year	Size and Ability	Setting point	Capacity (watt)		Using time per day			
								Panel	Measured	Weekdays		Weekends	
	Room	Storey								Hours	Min	Hours	Min
Sewing machine													
Welding machine													
Compressor													
Others……													

Min : Minutes

THANK YOU FOR YOUR COOPERATION

(All information derived from this interview will remain strictly confidential and will be used exclusively for this research purpose)

OBSERVATION FORM FOR BUILDING MATERIAL INVENTORY FOR PLANNED RESIDENTIAL BUILDINGS IN MAJOR CITIES OF INDONESIA

A. IDENTIFICATION OF HOUSEHOLD

III. Household Address

Household Code	(Area number)	(Survey group number)	(Household number)
Address			
Sub-district/Village			

B. INVENTORY OF RESIDENTIAL BUILDING ELEMENTS AND MATERIALS

Mark (v) the materials used at the house surveyed

No	Building Elements	Sub-building Material	New Material			Recycled Material			Used Material		
			Yes	No	%	Yes	No	%	Yes	No	%
1	Foundation										
2	Column										
3	Wall										
4	1st Floor										
	2nd Floor										
5	Door	Door									
		Frame									
6	Window	Window									
		Frame									
7	Ceiling	Ceiling									
		Frame									
8	Roof	Roof									
		Frame									

C. HOUSING DESIGN

Was your house designed by an architecture consultant?

☐ Yes ☐ No

1. If your answer Yes, what is its name and where is it?

2. If your answer No, who designed and built your house?

D. MODIFICATIONS

Did you make any modification or extension work to your house when you move in to this house?

☐ Yes ☐ No

If you answer Yes in question above, where did you modify and how much does it cost?

Modified part	Year	Cost (IDR)

E. RECONSTRUCTION (Lifespan of building)

Have you ever reconstructed your house?

☐ Yes ☐ No

If you answer Yes in question above, please fill the table below.

Which part of your house did you reconstruct and how much did you spend on it?

No	Building Elements	Year	Cost (IDR)
1	Foundation		
2	Column		
3	Wall		

F. MAINTENANCE (Lifespan of building materials)

Have you ever done maintenance for your house?

☐ Yes ☐ No

If you answer Yes in question above, please fill the table below.

Which part of your house did you do maintenance and how much did you spend on it?

No	Building Elements	Sub-building Material	Year	Cost (Rupiahs)
1	Floor (1st)			
	Floor (2nd)			
2	Door	Door		
		Frame		
3	Window	Window		
		Frame		
4	Ceiling	Ceiling		
		Frame		
5	Roof	Roof		
		Frame		

THANK YOU FOR YOUR COOPERATION

(All information derived from this interview will remain strictly confidential and will be used exclusively for this research purpose)

Appendix 3

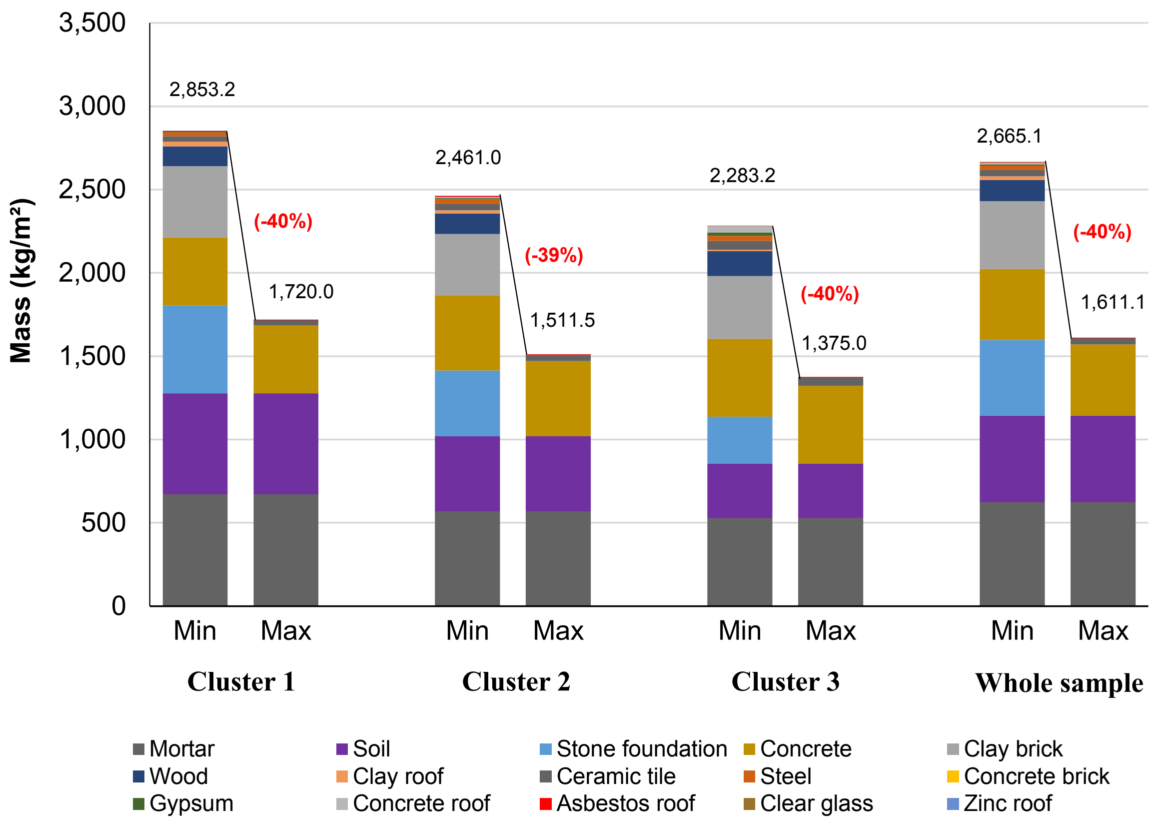
Current building material inventory by household cluster

(unit: kg/m^2)

Materials	Density (kg/m^3) *	Cluster 1		Cluster 2		Cluster 3		Whole sample	
		Jakarta	Bandung	Jakarta	Bandung	Jakarta	Bandung	Jakarta	Bandung
1. Stone	1450	742.9	671.4	632.5	605.5	528.1	569.7	678.4	644.7
2. Sand	1400	697.7	623.1	614.7	588.9	564.7	664.1	655.3	626.8
3. Clay brick	950	429.2	400.0	367.2	363.1	376.4	410.8	407.4	397.7
4. Cement	1506	160.9	150.1	160.1	146.9	176.9	192.4	164.1	157.6
5. Wood	705	118.0	150.8	123.6	167.9	149.0	77.4	125.6	139.2
6. Ceramic tile	2500	32.1	22.9	36.7	27.0	53.7	58.6	37.5	30.0
7. Steel	7750	25.5	26.5	28.8	27.0	30.1	31.0	27.0	27.4
8. Clay roof	2300	28.4	23.9	19.5	28.9	9.1	11.6	22.8	22.2
9. Concrete roof	2500	0.0	0.5	8.0	0.0	38.7	22.0	9.6	4.4
10. Gypsum	1100	2.8	1.1	6.7	0.7	19.9	14.0	7.1	3.4
11. Paint	700	3.5	2.9	4.9	3.0	8.8	8.8	4.9	4.0
12. Asbestos roof	2200	4.1	0.4	3.7	0.8	0.4	0.2	3.2	0.4
13. Concrete brick	2300	0.0	2.8	0.0	14.23	0.0	0.0	0.0	3.6
14. Clear glass	2579	0.8	1.2	0.7	1.3	1.2	4.1	0.9	1.8
15. Zinc roof	3330	0.8	0.5	0.2	0.4	0.0	0.0	0.5	0.4
Total		2,246.7	2,078.1	2,007.3	1,975.6	1,957.0	2,064.7	2,144.3	2,063.6

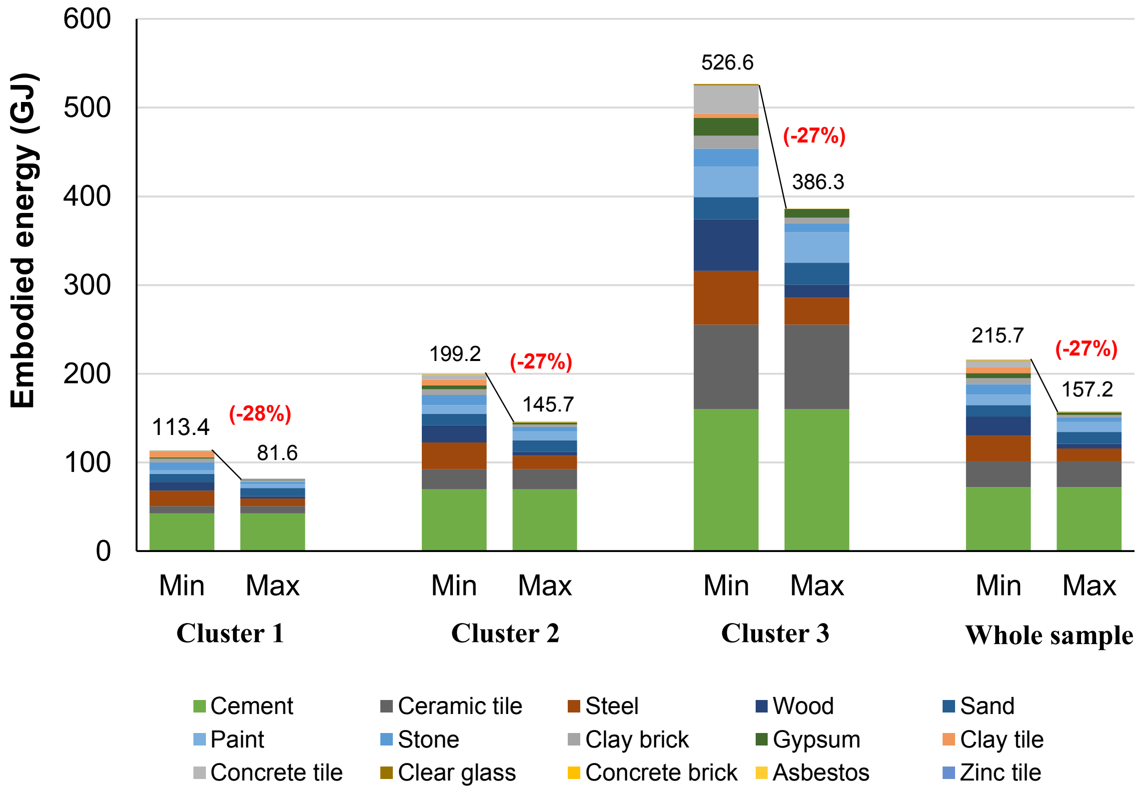
* SNI, 1989

Appendix 4



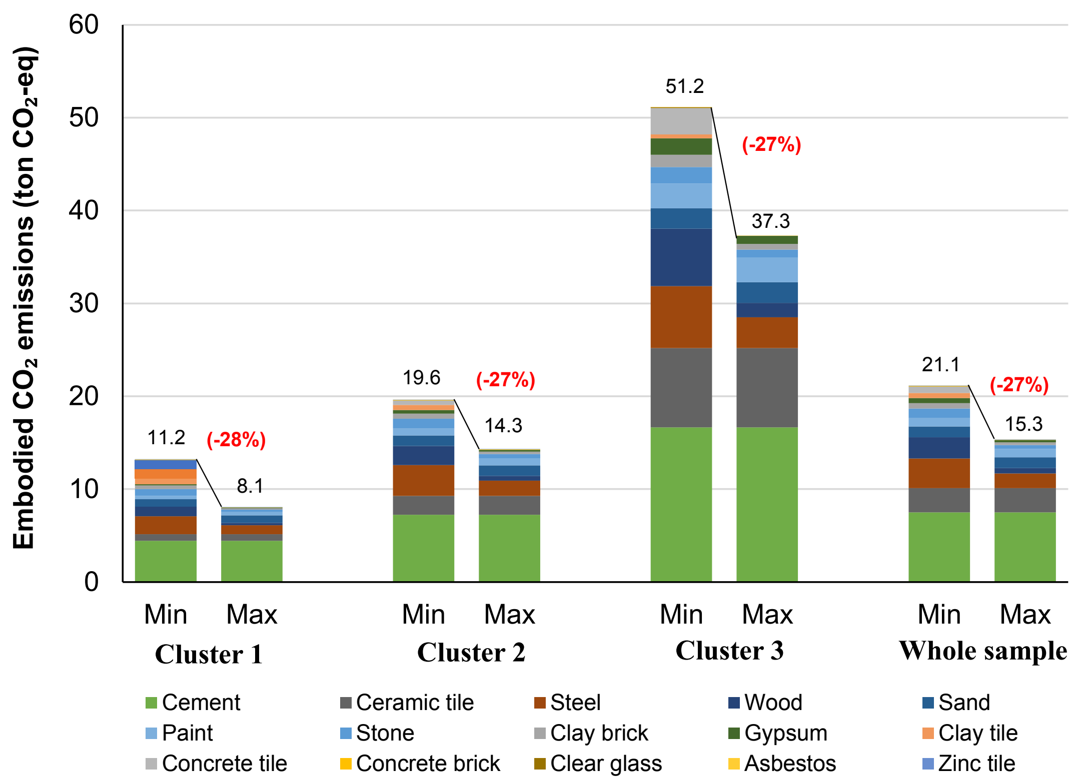
The average material waste for respective household clusters in both scenarios in Jakarta

Appendix 5



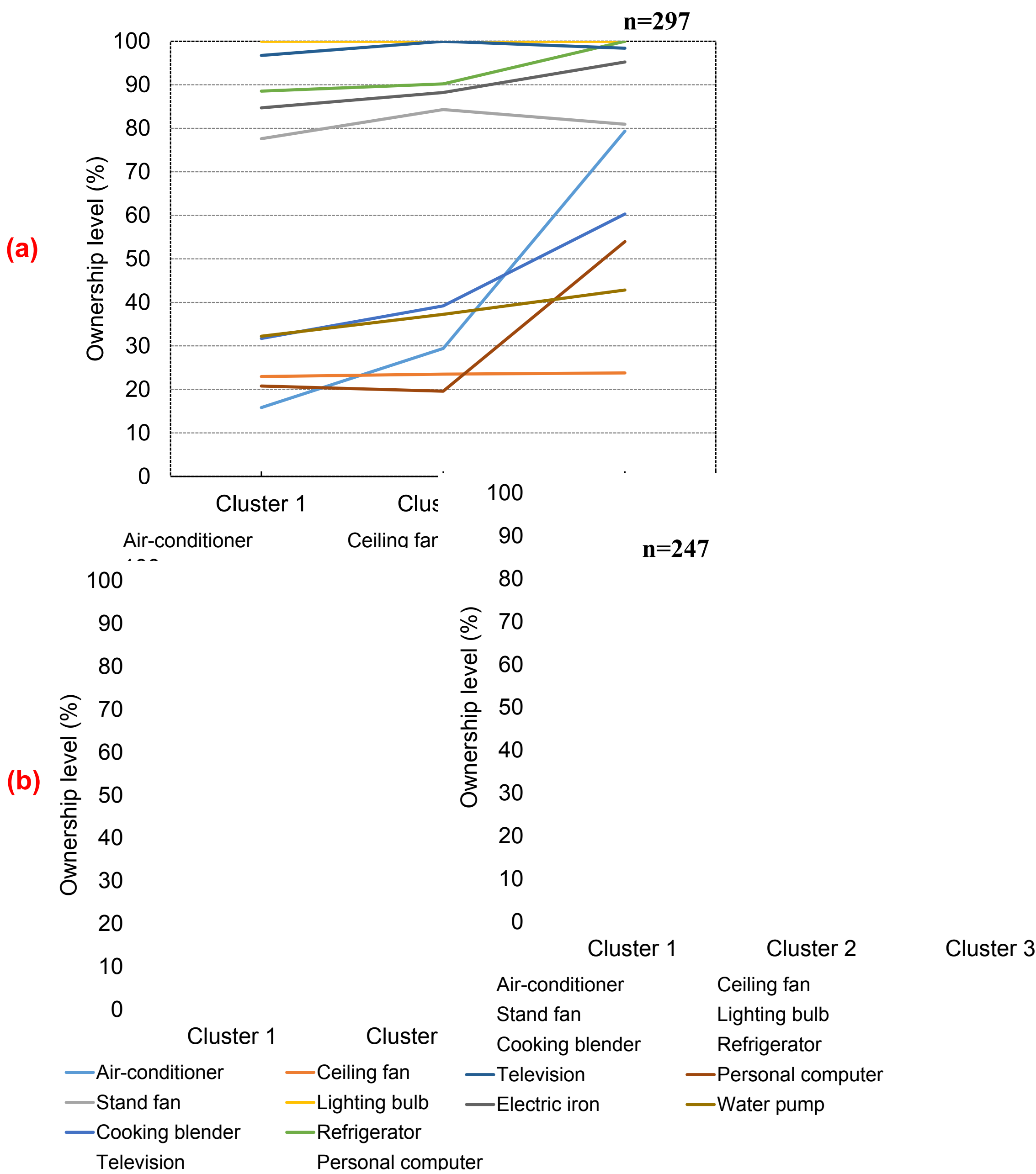
Embodied energy for respective household clusters in both scenarios in Jakarta.

Appendix 6



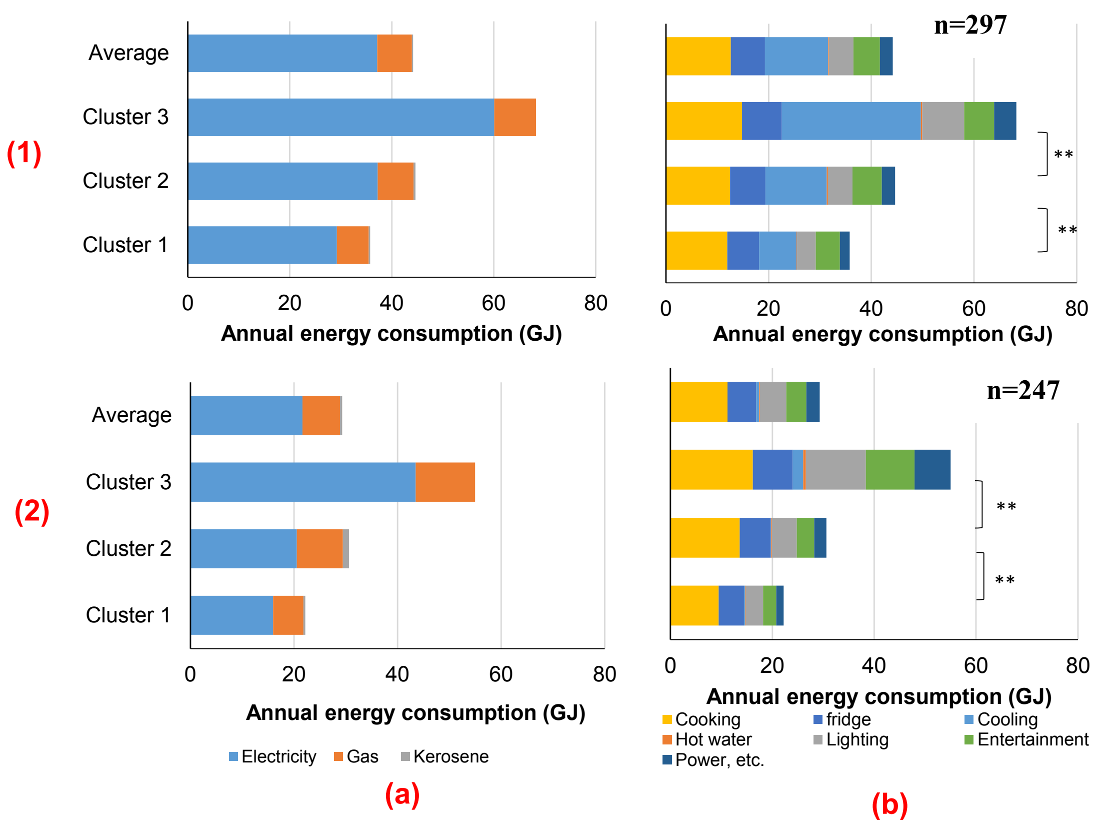
CO_2 emissions for respective household clusters in both scenarios in Jakarta

Appendix 7



Ownership levels of major household appliances by household cluster. (a) Jakarta; (b) Bandung

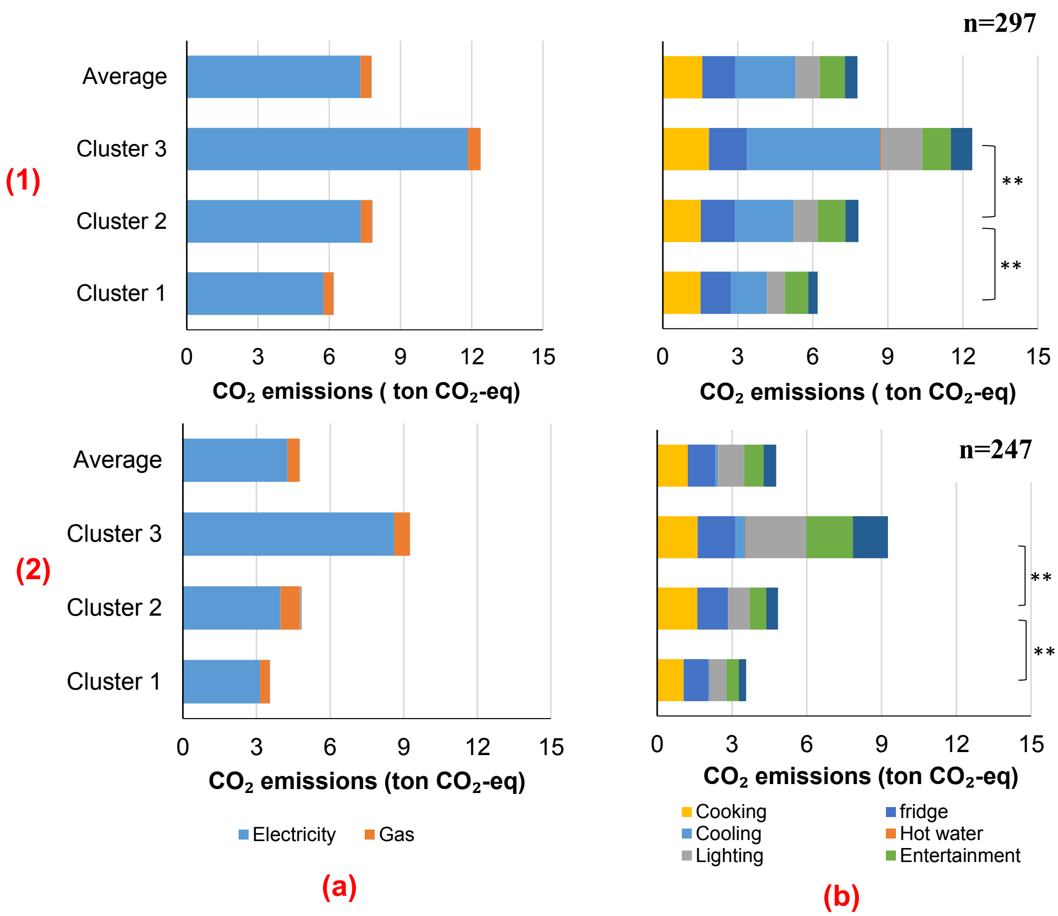
Appendix 8



Annual household energy consumption by clusters (Primary energy) in (1) Jakarta; (2) Bandung. (a) by energy source; (b) by end-use.

Note: *=5% significance; **=1% significance; - = insignificant.

Appendix 9



Annual household CO_2 emissions by clusters in (1) Jakarta; (2) Bandung. (a) by energy source; (b) by end-use.

Note: *=5% significance; **=1% significance; - = insignificant.