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THE ANALYSIS OF HOUSEHOLD ENERGY CONSUMPTION OF PUBLIC APARTMENTS IN INDONESIA: A CASE STUDY OF RUSUNAWA BUILDINGS IN BANDUNG CITY

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Abstract

This paper discussed what profiles of household energy consumption in the public apartments (namely Rusunawa) in Bandung, Indonesia. Data of household energy consumption were obtained through a survey conducted within the city in 2016. The energy consumption profiles of households and the household appliances were obtained through face-to-face interviews and measurements of appliances' capacity using watt checker. Then, a calculation of the annual energy consumption, including gas and electricity, was conducted. The experimental results replied that the annual average operational energy for public apartments is 9.80 GJ/year, and the largest energy for the annual average energy is found for cooking (4.70 GJ/year) of operational energy followed by refrigerator (2.6 GJ/year), lighting (1.0 GJ/year), entertainment (0.9 GJ/year), cooling (0.3 GJ/year), power (0.2 GJ/year) and hot water (0.1 GJ/year). Most of the energy source of cooking came from LPG. Further, the operational energy usage patterns varied among households. The factor significantly contributing to the increase of the Rusunawa operational energy is the energy consumption for cooking and fridge. The profiles of CO_2 emissions are identical to those of energy. Then, the potential energy-saving strategies for public apartments in Indonesia are proposed. The results of this analysis would be useful for further insights for policy making in Indonesia, specifically for the energy policy for achieving low-energy as well as low-carbon societies.

Keywords: Apartment, Energy saving, Household energy consumption, Operational energy, Rusunawa Indonesia

1. Introduction

This study aims to suggest low energy and low carbon apartment buildings in Indonesian major cities. In the past decades, the economy of Indonesia has grown along with the rapid growth of population and urbanization. In 2014, the percentage of individuals living in urban areas reached the value of 53% [1]. The Indonesian population has also increased significantly, from 97.1 million in 1970 to 237.6 million in 2010 [2]. As a result, the demands for living areas increase significantly, resulting in the development of residential buildings, including apartments, in big cities such as Bandung and Jakarta. The increases in urbanization in the major cities result in the increase of energy consumption. The current Indonesian energy consumption is 14 times than that of 1970s. This results in energy scarcity in big cities and contributes to global warming.

In 2005, the Indonesian energy sector accounted for 18.5% of the total CO_2 emissions. Meanwhile, the CO_2 emission in the building sector was 36% of the total energy emissions [3]. In the period of 2000 to 2013, the Indonesian household sector contributed 33.2% to the nation energy consumption [4]. As the number of the middle class in urban areas increases dramatically, the household energy consumption is predicted to increase significantly [5]. As reported by Asian Development Bank [6], the number of the Indonesian middle class has increased from 38% in 2003 to 57% in 2010. Subsequently, the demands of housing increase significantly. Asian Development Bank [6] reported that the percentage of the Indonesian middle class has increased from 38 (in 2003) to 57% (in 2010). Therefore, it can be predicted that the housing demand will increase in the future. Since major cities have been fully crowded, the cities are extending vertically. The governments of the major cities have been promoting the development of vertical housing to meet the demand of housing and address the issue of limited land and green space. For example, in the last five years, the number of apartments in Bandung has doubled. To make the city more sustainable, energy-saving strategies should be introduced.

Some studies on energy consumption have been done in Indonesia, such as Surahman and Kubota [7-9] who examined the energy consumption of landed houses in Jakarta and Bandung. Other researchers such as Utama and Ghewala [10, 11] investigated the life cycle energy of private apartment in Jakarta and single landed houses with different wall materials in Semarang. Such studies provide useful insights into the energy consumption of residential and apartment buildings in Indonesia. However, the studies only focus on mass/planned houses and private apartments. In Indonesia, public apartments will be a typical type of apartments in major cities rather than the said apartments in the near future as discussed in this paper.

This study focused on public apartments in major cities of Indonesia. Specifically, this study aims to assess the household energy consumption and CO_2 emissions of urban and public apartment buildings. To obtain the profiles of household energy consumption as well as CO_2 emissions from these buildings, surveys were conducted in Bandung (n=100 apartment units) on March 2016. Factors affecting the increases in operational energy are discussed. The results of this analysis hopefullt can provide useful further insights for policy making in Indonesia, specifically for energy policy in achieving low-energy and low-carbon societies.

2. Methods

2.1. Case study city and apartments

Bandung was selected as the case study city, which represents rapidly developing cities. Bandung, the capital of West Java Province, is located in Java region. The population of the city in 2014 was 2.45 million [12]. The city has a cool and humid tropical climate. From November to March, the climate is dominated by the north monsoon while from May to September, it is dominated by the south monsoon. The average rainfall intensity throughout the year ranges from 117.2-388.8 mm per month with the daily average outdoor relative humidity of 70-81%. The monthly average city temperature is 23.5–24.2 °C throughout the year with the average minimum and maximum temperature are 18.3-20.7 ºC and 27.0-30.9 ºC, respectively. This is due to the high altitude of the city and the small temperature daily variation. Bandung is situated 700–800 m above the sea level [12].

The rapid urbanization and significant growth of housing in Bandung can represent the housing stock of Indonesian major cities. Bandung build land is estimated to be 85% in 2015 with 54% for housing [13]. Thus, the government has been encouraging the development of apartments to avoid the decrease of green spaces. The number of apartments keeps growing.

According to Act No. 20/2011 regarding apartments, based on the ownership and management, there are three categories of apartments in Indonesia, i.e. private, public, and special apartments. Private apartments are built, constructed, and owned by private companies, whereas the rest types of apartments are owned and managed by the government. The special apartments are constructed for special purposes. This type of apartment is limited in the construction and used for specific purposes, such as apartments for employees of national institutions. Recently, private and public apartments are highly demanded, specifically by the emerging low-to-middle class market.

In the near future, public apartments, which are commonly called "Rumah Susun Sewa (Rusunawa), will account for one of the largest proportion of apartment stocks. This apartment is allocated for low-income people. As presented in Fig. 1, The Government of Bandung will develop 100 public apartments in the next three years to meet the city housing demand [14].

It is assumed that the population living in the apartment units was homogeneous. Thus, the research employs stratified sampling. The sample size does not represent the whole population (1098 units for Rusunawa in Bandung). Statistically, in most cases, a sample size of less than about 30 respondents will provide too little certainty. Generally, the number of samples regarded as a minimum size by experienced researchers is 100 respondents [15]. Thus, we selected two typical apartments from two areas. Then, 100 units in the selected neighborhoods were selected randomly by considering two aspects: the distance from the center of the city and the year of establishment (see Table 1).

As shown in Table 1, the apartments are for 2-3 persons with a small variation. A multiple-choice question was used to identify the monthly average household income. The average incomes vary, as expected, and so does the total gross floor area. The largest percentage was around 67% for apartment units or 18-24 m^2.

Fig. 1. Public apartments.

Table 1. Socio-economic profile of respondents.

Profiles	**Public apartments**
Sample size (1 person/1 unit apartment)	100 persons
Male	51%
Female	49%
Age	
< 40 years old	55.60 %
40-49 years old	35.30 %
50-59 years old	8.10 %
60-64 years old	1.00 %
> 65 years old	0.00 %
Household size	
1 person	44.00 %
2 Persons	28.00 %
3 persons	12.00 %
4 persons	12.00 %
> 4 persons	4.00 %
Household size average	2 persons
Monthly household income	
< 153 US$	10.50 %
153-307 US$	64.00 %
308- 615 US$	25.50 %
> 615 US$	0.00 %
Total floor area	
< 18 m^2	0.00 %
18-24 m^2	67.00 %
25-36 m^2	32.00 %
> 36 m^2	1.00 %

2.2. Operational energy and CO_2 emissions

The analysis of operational energy requires detailed data of energy consumption. The data were obtained using interviews (household profile, number of appliances and usage time) and the measurement of appliance capacity by using watt checkers (MWC01, OSAKI) (see Fig. 2). The energy consumption of the household appliances was estimated by multiplying the number of appliances by their usage time and electric capacity. In Indonesia, the primary energy sources consist of 42% of coal, 17% of oil, 28% of natural gas, 10% of hydro and 3% of geothermal as [16, 17]. The consumption of electricity was converted into primary energy by considering the energy mix, transmission losses, and electric efficiencies. The annual average energy consumption was obtained by combining the consumption of all appliances. The unit of gas (LPG) is also converted into energy unit (47.3 MJ/kg) [17]. As previously mentioned, the variation of seasons in Bandung is relatively low. Thus, it is assumed that the usage time of appliances is constant throughout the year. Yet, the changes of air temperature and humidity were taken into account in the calculation of the energy consumption of refrigerators and air-conditioners even though the identified resultant changes were negligible.

Fig. 2. Household energy consumption survey.

Meanwhile, the CO_2 emissions were calculated by multiplying the energy consumption of each type of fuel with the related CO_2 emission factor obtained from references [18, 19], as presented in Table 2. It is assumed that the CO_2 removed from the atmosphere during the growth of new biomass balances the CO_2 emissions released during the biomass combustion [20]. The calculation of the total CO_2 emissions of houses was done by adding the emissions for the energy of end-uses.

Table 2. Emission factors of energy sources for Indonesia.

Energy sources	Emission factor (kg/GJ)
Electricity	196.9 [18]
Coal	94.6 [19]
Oil	73.3 [19]
Natural gas	56.1 [19]
Kerosene	71.9 [19]
LPG	63.1 [19]

As the type of fuel is important for CO_2 emissions, the choice of energy resource is also crucial. It suggests that decreasing the purchased or secondary energy does not necessarily decrease the CO_2 emissions of a building or the use of natural resources. Therefore, measured energy should be in the form of primary energy, particularly for the assessment of CO_2 emissions [20]. Due to such a reason, operational energy was measured in the form of primary energy in this paper.

3. Results and Discussion

3.1. Operational energy

As previously described, the usage of time and level of ownership of the appliances were examined. The consumption of kerosene and gas (LPG) was also surveyed. Figure 3 indicates that such appliances as light bulbs, televisions, rice cookers, water dispensers, desktop PCs, electric irons and refrigerators/fridge record high ownership levels. For lighting appliances, the Compact Fluorescent Lamp (CFL) is commonly used in households; its ownership level reaches 90%. Similarly, the ownership level of such major appliances as rice cookers, water dispensers, refrigerators, televisions, desktop portable computers (PC) and electric irons reach 80-100%. On the other hand, some appliances have different levels of ownership, such as blender, air-conditioner, laptop PC, and hair blower. Cooling (standing fan) has an ownership level of 0-30%. This is due to the cool climate of Bandung.

The annual average energy consumption related to electricity, gas and kerosene was then calculated in primary energy terms. Figure 4 presents the annual household energy consumption averaged by different end-use categories. Overall, the average annual energy consumption of all samples in Bandung is approximately 9.80 GJ. As shown in Fig. 4, the cooking takes account for the largest percentage (48%), in which this is followed by fridge (27%), lighting (10%), etc. The energy consumption for cooling gives values for 3.5% on average. Hence, basically, the average household energy consumption of house units increases with the increase in ownership and use of cooking end-use, lighting and the entertainment. In total, energy consumption caused by electricity is larger than by LPG (90%) for apartments in Bandung.

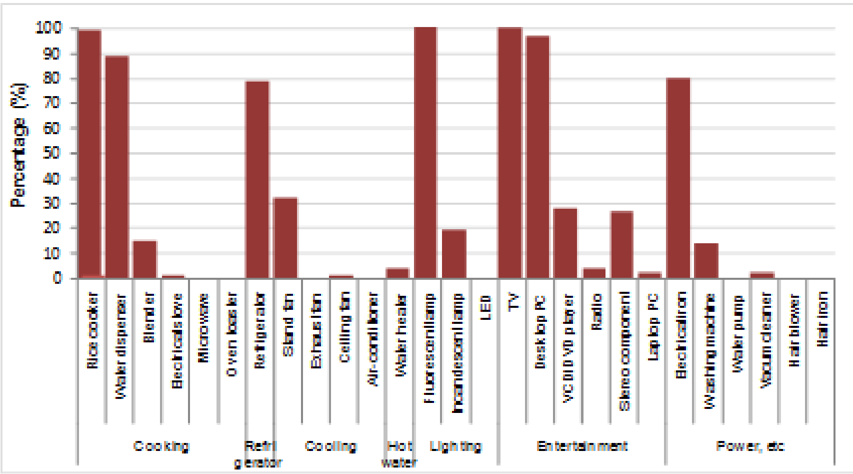

Fig. 3. Type of appliances available per household.

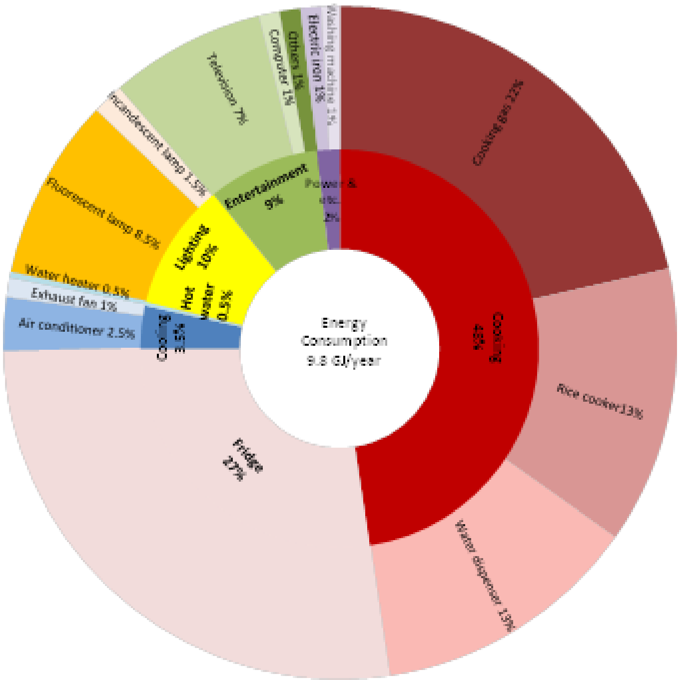

Fig. 4. Annual household energy consumption (GJ/year).

The results were compared with previous studies. Annual household energy consumption was calculated and normalized in terms of per-floor area (0.4 GJ/m^2.year) and per-person (6.1 GJ/person.year) to neutralize the differences in building and household parameters. These values accounted slightly higher than those of individual simple houses in Bandung (0.4 GJ/m^2.year and 5.0 GJ/person.year) [8]. However, it was lower than that of individual simple houses in Jakarta (0.9 GJ/m^2.year and 8.2 GJ/person.year) [8] due to different climate. In general, per capita electricity power consumption in Indonesia accounted lower (2.9 GJ/person.year) [4]. This indicates that household energy consumption is still high and therefore, energy saving strategies are still necessary to make more sustainable building of Rusunawa.

3.2. Operational CO_2 emissions

The estimation of the annual household CO_2 emissions was done by multiplying the energy consumption of each type of fuel with the corresponding CO_2 emission factor. The profiles of CO_2 emissions are similar to those of energy (see Fig. 5). The average annual CO_2 emission is predicted at 1.70 ton CO_2 per year for apartments. The major contributors are cooking (40%), fridge (31%), and lighting (12%). Cooling gave only 0.10 ton CO_2/year (4%), in which this is due to the cool condition and humid climate in Bandung.

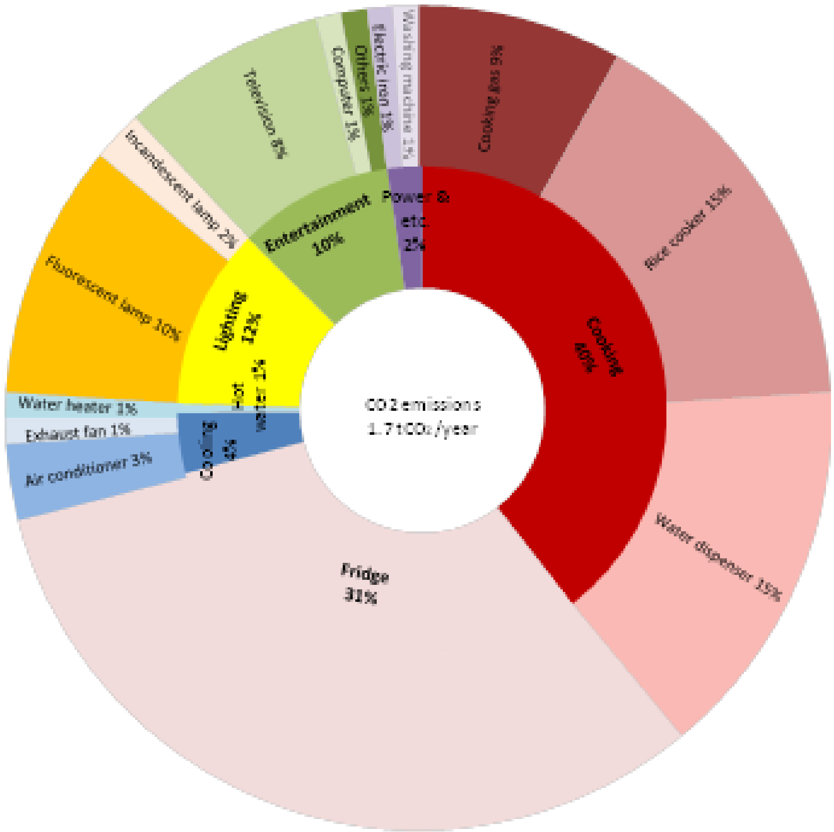

Fig. 5. Annual CO_2 emissions (tCO_2 /year).

3.3. Causal structures on household energy consumption: Multiple regression analyses

To examine the determinants of the annual average energy consumption, a correlation analysis was conducted. Some variables such as household size, household head's age, total monthly income, electricity consumption, gas consumption (LPG) and electricity consumption of respective appliances were examined. Then, several variables having relatively high *R*-values were obtained. Multiple regression analyses were done to further analyze the causal structure on household energy consumption (Table 3). Since electricity and gas consumption were found to account for almost all the energy consumption, firstly, we examined the major factors explaining consumption of these two energy sources, Tables 3(a) and 3(b). 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 appliances and usage time, Table 3(c). As indicated in Table 3a, the standardized coefficient is the highest in 'fridge', followed by 'rice cooker', 'water dispenser', 'lighting of CFL', etc.

In the regression equations of annual electricity consumption, the coefficient of determination (R^2) is 0.95, which indicates that 95% of the spatial variation of annual electricity consumption can be explained by the above variables. As shown in Fig. 4, this result confirms that energy consumption for fridge is significant and large in the case of Bandung. It confirms also for operational CO_2 emission as shown in Fig. 5. Table 3(b) shows that the determinants for gas consumption may be able to be explained by both 'household size' and 'total monthly income' although the R^2-values record low values of 0.44. As shown in Table 4(c), the energy consumption caused by fridge, which is the main contributor to the electricity consumption, can be explained weakly by the 'household size' and 'household head's age' with a coefficient of determinant of 0.23. Other major appliances, i.e., 'rice cooker' and 'lighting', can be determined by the 'household size' and 'total monthly income' as well as 'unit area' respectively. Therefore, this indicates that it is possible to explain the annual average energy consumption and its appliances by those variables. It is seen that overall, the increase in household size and income increases the electricity and gas consumption caused by the major appliances

Energy consumption for cooking was the largest contributor to energy usage and CO_2 emissions followed by fridge, lighting, etc. in public apartment (Rusunawa). Therefore, it should be of concern. Improving energy efficiency for cooking appliances and fridge would reduce energy consumption/CO_2 emissions caused by cooking and fridge [21]. Meanwhile, energy consumption for lighting should be noticed as well. 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%. Control the usage of lighting can also be a technique to reduce its energy consumption [22]. A number of energy saving lighting controls are now on the market, including multilevel switches, timers, photocell control, occupancy sensors and daylight-dimming systems.

One major step to reduce building environmental impacts is improving the performance of the energy system, such as energy generation technologies. The shift from power generation technologies using fossil fuel to technologies, which use more efficient resources (gas, hydrogen, and fuel cells), or renewable power sources can reduce the environmental impacts.

Although renewable power systems are still cost prohibitive, the energy ratio of wind, photovoltaic and biomass electricity generation systems are better than the current power systems [23-25]. Due to the advancement of technology, the cost of renewable energy is decreasing and the market share is increasing. Renewable energies could be implemented to reduce the operational burden of buildings.

The environmental impacts and energy consumption of buildings are concentrated on their operational phase. The operation of buildings accounted for more than 80% of the environmental burden. The design of buildings should focus on optimizing the operational phase performance until a significant shift of the distribution of burdens is achieved.

Table 3. Results of multiple regression analyses. (a) Annual electricity consumption; (b) Gas consumption (LPG); (c) Electricity consumption of appliances. (* = significant at 5% level; ** = significant at 1% level).

(a) Annual electricity consumption ***n*=100**

No	Variables	Non-standard Coefficient	Standard Coefficient	Sig.	*R*-value	Sig.
1	Fridge	121.43	0.57	**	0.59	**
2	Rice cooker	1.12	0.48	**	0.50	**
3	Water dispenser	0.87	0.45	**	0.25	*
4	Lighting (CFL)	1.12	0.23	**	0.24	**
5	TV	1.18	0.20	**	0.12	*
6	Electric iron	0.56	0.09	**	0.11	
	Constant	332.54				
	R^2	0.91				

(b) Gas consumption

No	Variables	Non-standard Coefficient	Standard Coefficient	Sig.	*R* - value	Sig.
1	Household size	654.8	0.34	**	0.45	**
2	Monthly income	59.8	0.28	**	0.40	**
	Constant	944.0				
	R^2	0.44				

(c) Fridge electricity consumption

No	Variables	Non-standard Coefficient	Standard Coefficient	Sig.	*R* - value	Sig.
1	Household size	129.1	0.09		0.10	
2	Head’s age	4.3	0.03		0.05	
	Constant	-1074.1				
	R^2	0.23				

(d) Rice cooker electricity consumption

No	Variables	Non-standard Coefficient	Standard Coefficient	Sig.	*R* - value	Sig.
1	Household size	67.6	0.07	*	0.05	*
2	Monthly income	59.7	0.11		0.11	
	Constant	173.3				
	R^2	0.02				

(e) **Lighting electricity consumption**

No	Variables	Non-standard Coefficient	Standard Coefficient	Sig.	*R* - value	Sig.
1	Unit area	21.6	0.23	*	0.2	*
2	Household size	-0.82	-0.18		-0.10	
	Constant	880.8				
	R^2	0.06				

4. Conclusion

We investigated household energy consumption profiles in Bandung in order to identify the profiles of household energy consumption and CO_2 emissions in major cities of Indonesia. The following conclusions can be drawn:

- The samples' average annual energy consumption was approximately 9.8 GJ.
- The energy used for cooking, fridge, lighting and entertainment contributes significantly to the increase of the overall energy consumption. Accordingly, the average annual CO_2 emission in Bandung was 1.7 ton CO_2/year for public apartments. The results generated by the statistical analyses suggest that 'fridge' and 'gas consumption (LPG)' predominantly determine the operational energy, supported by some explanatory variables such as 'rice cooker', 'lighting (CFL)', and etc. This clearly shows that the dependent variable in Indonesian public apartments can be predicted by the above variables.
- It was anticipated that the further increase in household size and income would increase the energy consumption caused by major household appliances. As a consequence, the increase in household size and 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.
- In conclusion, it is important to reduce the energy consumption/CO_2 emissions caused by cooking, fridge and lighting as one of the potential energy-saving strategies for public apartment (Rusunawa) in Indonesia. Therefore, it should be of concern to improve energy efficiency for cooking appliances and fridge. 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 be one possibility besides using energy saving lighting controls (timers, photocell control, daylight-dimming systems, etc.).

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