Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Investigation on household energy consumption of urban residential buildings in major cities of Indonesia during COVID-19 pandemic

Usep Surahmana a,⇑, Djoni Hartono b, Erni Setyowati c, Aldissain Jurizata a

a Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi No. 207, Bandung 40154, Indonesia
b Universitas Indonesia, Jl. Margonda Raya, Pondok Cina, Kota Depok 16424, Indonesia
c Universitas Diponegoro, Jl. Prof. Soedarto, SH., Tembalang, Semarang 50275, Indonesia

A R T I C L E  I N F O

Article history:
Received 28 November 2021
Revised 1 February 2022
Accepted 14 February 2022
Available online 16 February 2022

Keywords:
Household energy consumption
CO2 emissions
COVID-19 pandemic
Statistical analysis
Indonesia

A B S T R A C T

The implementation of the movement control order (MCO) to curb the spread of the 2019 novel corona virus disease (COVID-19) have influenced household energy consumption patterns around the world. This study aims to investigate household energy consumption of urban residential buildings in major cities of Indonesia during COVID-19 pandemic. Three representative major cities of Indonesia were selected to investigate detailed information about household appliances and gas consumption through face-to-face interviews in 2021 (n = 311). The factors affecting household energy consumption were investigated by multiple regression analysis. The results showed that, overall, the average annual energy consumption of all samples during pandemic was approximately 23.5 GJ, 3.0 GJ larger than before pandemic. The difference was primarily attributed to the use of air conditioning and cooking. The statistical analysis clearly indicated that the increase in household income (low-to high-cost houses), which would increase household size and number of appliances including air conditioning, thus increased total household energy consumption. We recommended the following potential energy-saving strategies for urban houses in Indonesia: (a) control the number of family members, (b) use more energy efficiency standards for electrical appliances and (c) encourage energy-saving lifestyles, particularly to younger adults by adopting passive cooling techniques (window opening) whereever possible.

© 2022 Elsevier B.V. All rights reserved.

1. Introduction

The 2019 novel corona virus disease (COVID-19) pandemic triggered at the beginning of 2020 have witnessed a significant change in human activities around the world. Beyond the global health crisis, COVID-19 pandemic has caused economic and social disruptions. To mitigate the spread of the disease, many countries have undertaken various measures such as movement control order (MCO) which involved travel ban, city lockdown and work from home policy. The downturn and change in the economy inevitably impact the energy system. As people were restricted for travel and to stay at home, residential sector starts to take a greater share and the transition in working and living style resulted in a significant change in the use of electrical appliances which affects the household energy consumption patterns.

Forecasting residential energy consumption during the pandemic has become difficult as there is a lack of literature on the impact of an outbreak on household energy consumption. The energy profiles are shifting as the patterns of lives shift in response to the MCO. Several studies and reports have proven that energy demand in the residential sector across the globe has increased significantly during the lockdown [1–3].

Carbon dioxide (CO2) emissions are currently largest in industrialized countries, although estimates suggest that developing countries will increasingly contribute to global warming in the coming decades [4]. In the United States, CO2 emissions per capita is 20.1 ton, almost twice than those in China and Brazil, 16 times than that in India, and 50 times than those in Nigeria and Sudan [5]. If highly-populated developing countries follow the same unsustainable production and consumption paths as developed countries, the consequence for the global environment will be significant. The challenge is to determine how industrialized countries can manage their environmental impacts while developing countries achieve economic growth in sustainable ways.

The building sector contributes up to 30% of annual global greenhouse gas (GHG) emissions and consumes up to 40% of all energy [5]. For example, the Japanese building industry is responsible for almost 30% of the nationwide CO2 emissions [6]. The British construction industry accounts for about half the UK domestic
energy consumption [7]. It is predicted that if nothing is done, globally, GHG emissions from buildings will be more than double in the next 20 years [8]. Therefore, if targets for GHG emission reduction are to be met, it is clear that mitigation is necessary in the building sector.

Over the last few decades, the Southeast Asian countries have been experiencing rapid economic growth coinciding with rapid urbanization and population growth. Total population increased from 114.8 million in 1970 to 241.8 million in 2010 in Indonesia [9]. The percentage of people living in urban areas reached approximately 49.8% in Indonesia as of 2010 [9]. As a consequence, the need for living spaces increased rapidly, and an enormous number of residential buildings have been developed, particularly in major cities such as Jakarta, Bandung, Semarang and so forth. At present, in the case of Indonesia, 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 proper basic urban infrastructure and services. Cities with this kind of urbanization see large increases in urban energy consumption.

In Indonesia, the household sector was responsible for approximately 14.8% of the nationwide energy consumption in 2018, 3.4% larger than that in 2012 [10]. Furthermore, household energy consumption was expected to increase dramatically with the middle class in urban areas for years to come [11]. Therefore, energy-saving strategies will be essential to making the cities more sustainable. This study aims to investigate the detailed patterns of household energy consumption and CO2 emissions for major urban residential buildings (landed houses) in Indonesia during COVID-19 pandemic in contrast with those before pandemic. A total of 311 households were investigated in Jakarta, Bandung and Semarang, Indonesia. The detailed information about household electrical appliances and gas consumption were investigated through face-to-face interviews with highly health protocol. In addition, causes of household energy consumption were determined. Further, potential energy-saving strategies for urban houses are discussed.

This paper has five main sections. Section 2 gives a brief introduction to the existing literature. Section 3 briefly covers the data and methodologies used. Section 4 presents results and discusses household energy consumption and its drivers. The potential strategies to reduce household energy consumption are proposed. The last section summarizes and discusses conclusions.

2. Literature review

In-home energy consumption has been found to constitute the largest or at least one of the largest sources of energy demand and GHG emissions of a residential sector [12–16]. Increasing the energy efficiency of housing is currently one of the key climate change mitigation strategies used throughout the world [17] because housing inevitably have a significant impact on operational energy requirements before and during pandemic.

In response to this finding, there has been considerable interest in the developed world in recent years in the production of sustainable buildings to promote protection of the environment. Before pandemic, research has been widely conducted in developed countries to investigate household energy consumption patterns [18–20]. Genjo et al. [19] investigated the relationship between owning home appliances and electricity consumption in Japanese households and found that the use of residential electricity consumption was related to the number of home appliances owned. Sanquist et al. [21] conducted a lifestyle analysis of residential electricity consumption in United States with respect to social and behavioral patterns associated with income, local electricity price, access to natural gas, air conditioning, laundry usage, personal computer usage, climate zone, and television use, but failed to link cultural differences to electricity consumption [22]. A study conducted on Dutch households by Biesiot and Noorman [23] demonstrated that the main determinants of differences in household energy demand were income and household size. Weber and Perrels [24] investigated socio-economic and household characteristics by developing a model of lifestyle effects on energy demand. Wilhite et al. [25] investigated energy studies related to culture by comparing household electricity consumption in two countries, Japan and Norway, with similar levels and patterns of material culture and economic development. The results showed certain significant differences in end-use patterns for space heating, lighting, and hot water use that were linked to differences in the countries’ cultures.

The COVID-19 pandemic has impacted the energy sector by affecting energy supply and demand, while the majority of citizens have stayed in passive or active house quarantine. The majority of studies indicate that household energy consumption increased, which contrasts with a decline in commercial energy consumption. For example, in the United States, household electricity consumption escalated by 30% during pandemic lockdowns [26]. In comparison, Wang et al. [27] compared China’s overall energy usage (residential, commercial, etc.) to a hypothetical COVID-19-free situation and found that actual energy consumption would be decreased by an average of 28% as a result of pandemics. COVID-19 related improvements raised the heating energy consumption of residential buildings by 182 percent in Barcelona, Spain [28]. According to a study of Canadian social housing, electricity and hot water consumption increased slightly during the first two months of the lockdown. Consumption was distributed throughout the day, rather than peaking in the evening as it had been before the pandemic [29]. In South Korea, energy consumption has declined for the majority of facilities, while consumption by residential buildings has increased, highlighting the need for innovative energy system management [30]. Social distancing, self-quarantine, and home transformation were the most important factors influencing energy consumption [31]. Furthermore, optimal population distribution can reduce energy consumption by 32%, owing to less use of HVAC systems [32], which are said to significantly increase energy consumption [33]. The governments were proposed to consider domestic energy consumption as an emergency sector and healthcare due to increased consumption and importance during the COVID-19 pandemic [34]. Domestic electricity consumption of residents in urban and rural areas in China increased by 5.3 percent in the first quarter of 2020 as a result of the stay-at-home policy. Similarly, electricity consumption in the agricultural sector has increased by 4%. In contrast, it has fallen by 3.1 percent and 19.8 percent, respectively, in the manufacturing and service industries [27,35].

As seen in other developed countries, the use of household energy in developing Asian countries gradually rose in the last decade, together with rising per capita income, living standards, and lifestyles. Before pandemic, as mentioned by Nakagami et al. [36], Asian countries will see future large increases in household energy consumption as unavoidable, especially in tropical regions (e.g., Indonesia) where potential demand for cooling is extremely large. The existing research on household energy consumption in developing Asian countries shows that in the past 15 years, the diffusion of various home appliances in households has largely contributed to the increased consumption of energies such as electricity and gasoline [19,37–39].

This consumption has led to serious environmental problems such as increasing energy demand, global warming, and air pollution. As a consequence, it is important to analyze household energy consumption behavior to formulate policies for promotion of sustainable energy consumption [40]. In developing countries, the
number of new buildings is growing rapidly and energy prices as well as markets often do not encourage the use of efficient technologies [41]. However, the study in the context of Asian developing countries is very limited, and one of the main reasons is scarcity of data. To provide detailed information on energy consumption, household-level surveys are normally conducted by the National Bureau of Statistics of each country. They can be divided into two types: consumer expenditure surveys (in countries such as USA, the Netherlands, Sweden, Japan, and UK) and household energy consumption surveys (in countries such as Canada and Japan).

Household-level surveys are widespread in developed countries, but in developing countries they are limited. Because of the important role of Asia in the increase of global energy consumption, it is necessary to carry out these kinds of household energy consumption surveys in developing Asian countries such as in Indonesia to derive more accurate information for energy research and relevant policy decisions.

A few studies attempted to reveal household energy consumption patterns in Southeast Asia. Schipper et al. [42] found that appliances sold in Indonesia at the time were much less efficient than models typically sold in Organization for Economic Co-operation and Development (OECD) countries. The authors recommended adopting higher-efficiency appliances such as those available in the OECD. However, these sorts of recommendations may no longer be relevant because most manufacturers have adopted global standards. Permata et al. [43] conducted a comparative study analyzing and comparing the quantities of energy consumed in transport, non-cooking, and cooking purposes in urban areas. The results indicated that the unplanned areas consumed more energy per unit of income than planned and control areas. A study on household energy consumption-related air conditioner use and building material selection in planned houses and apartments has recently drawn attentions [44,45]. Indonesia already converted its primary cooking fuel from kerosene to LPG in 50 million households through a massive energy program in 2007 [46]. This megaproject, which was to be completed in late 2011, provided an improved household cooking fuel and associated benefits in user costs, cleanliness, convenience, and environmental friendliness, as well as reducing the government’s huge subsidy for petroleum fuels.

One socio-economic energy study was conducted in Indonesia by Wijaya et al. [47]. It compared household electricity consumption characteristics between Yogyakarta and Bandung to understand how drivers were related to cultural backgrounds that play important roles in designing proper regulations related to household energy-savings. It revealed that in Bandung, family size, time spent at home, education level, home appliances, and lighting had significant positive effects on the monthly electric bill. However, in Yogyakarta, education level and time spent at home had negative impacts. An energy conservation policy may not be generalizable, but will have to be specified based on local characteristics to ensure that the policy is broadly adopted by society.

During the pandemic, there was relatively little research on home energy consumption in developing countries. For example, Mustapa et al. [48] investigated the impact of a COVID-19 pandemic movement control order (MCO) on Household Electrical Appliance Consumption Levels (HEACL) across Malaysia before, during, and after the MCO, as well as the likelihood of the pandemic hastening household behavior toward use of energy-saving appliances based on a self-reported household survey. Furthermore, the energy consumption pattern in Malaysia during the COVID-19 pandemic revealed that the electricity consumption of various industries and commercial sectors decreased in the second quarter of 2020, which was offset by higher residential consumption due to the city lockdown [48]. Raman et al. [49] revealed how daily behaviors of Singapore residents changed during the COVID-19 pandemic.

Nevertheless, there is no comprehensive study related to energy residential consumption in Indonesia during the COVID-19 pandemic which considers the importance of socio-economic driving factors and building profile when designing energy conservation policy in the framework of different cultural backgrounds and building profiles. One study reported how COVID-19 and its stimulus policy affected the macroeconomic indicator, energy consumption and emission at the national and regional levels [50].

To improve our understanding on its patterns and drivers, this study provides the detailed patterns and information of household energy consumption during COVID-19 pandemic in Southeast Asian countries focusing on major cities of Indonesia. Further, the socio-economic and building factors affecting household energy consumption are analyzed and potential energy-saving strategies are proposed based on the above analysis.

3. Methodology

3.1. Case study houses

Jakarta, Bandung and Semarang, the major cities of Indonesia, were selected as case study cities. The cities saw rapid population growth over the last few decades. For example, the population of Jakarta and Semarang increased from 4.6 and 1.6 million in 1970 to 10.2 and 2.6 million in 2021, respectively [51,52]. The population of Bandung also increased from 644 thousand in 1850 to 2.5 million in 2021 [53]. The three cities experience uniform hot-humid climates throughout the year which is dominated by the north monsoon (November to March) and the south monsoon (May to September). However, the average temperature in Bandung is not as high as other cities because of its relatively high altitude (700–800 m above the sea level). Therefore, it is considered to have a relatively moderate (but humid) climate. Fig. 1 shows climate of three cities including temperature, relative humidity and rainfall. The average rainfall intensity of all major cities are 22.1–78.4 mm per month with the daily average outdoor relative humidity of 70–81%. As a coastal city, the daily variation of temperature in Jakarta and Semarang is relatively small. The monthly average temperature varies at 27.7–30.5 °C throughout the year [54,55]. In contrast, the monthly average temperature ranges from 25.2 to 26.9 °C in the highland city, Bandung [56].

In Indonesia, landed houses (individual houses) 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 [57]. These unplanned houses are scattered across the city as pockets of low income settlements and accounted for about 74% in Jakarta [51] and 89% of the total housing stocks in Bandung as of 2010 [53], respectively. In contrast, planned houses are defined as houses constructed in a proper modern urban planning. This accounted for another 26% in Jakarta [51] and 11% in Bandung [53], respectively. Moreover, these planned and unplanned houses can be further classified into three house categories based on its household income, namely low cost, medium cost, and high cost houses for low (<200 USD), medium (201–485 USD) and high (>486 USD) income, respectively (Fig. 2). These houses have an approximate lifespan of 20, 35, and 50 years on average, respectively [58]. Although the quality and size of houses differ among these three house categories, they are similarly constructed of brick-walled structure. Moreover, most
of the building materials used and the construction methods of these houses are similar regardless of the house category [45,59].

A total of 311 residential buildings were selected in the survey. These samples were selected by considering the above-mentioned existing ratio of unplanned and planned houses in Jakarta (n = 100), Bandung (n = 111) and Semarang (n = 100). The Ministry for Housing and Settlement of Indonesia recently set the target of proportion for balanced residential patterns for the national housing sectors [60]. They proposed the composition of low, medium and high cost houses to be 3:2:1. However, the data for existing proportions of these house categories 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.

3.2. Household energy consumption and CO₂ emissions

The detailed information about household appliances and gas consumption were obtained by means of face-to-face interviews using a paper-based questionnaire form conducted by Macromills Ltd. During May to July 2021. 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 annual average household electricity consumption (kWh) for respective appliances was estimated through multiplying the number of appliances (unit) by usage time (hour(s)/year), and measured electric capacity (kW), which were acquired through the said interviews and measurements. The monthly gas (LPG) was estimated simply based on the data from their bills.

Due to the permission problem for measurement, the electric capacities of some appliances were obtained from their nameplates which usually represent the maximum power draw of an appliance. Therefore, the appliance-specific assessments were conducted to define Unit Energy Consumption (UEC) to estimate energy consumption derived by CLASP and Ipsos [61]. Wattage-based calculation method utilizes wattage, use frequency, and
additional appliances-specific survey variables to estimate UEC values for appliances, including air conditioning, except for rice cooker, refrigerator, and water pump. Additional factors were included in the calculation to reflect actual use and operating principle, namely *Hour Fraction Factor* and *UEC Adjustment Factor*. The Hour Fraction Factor is an assumption adjusting the usage of some appliances that are typically used for less than one hour, while UEC Adjustment Factor is an assumption adjusting the wattage of products that are power cycled or operate at partial load. The formula for wattage-based calculation is shown in Eq. (1), as follows:

\[ UEC = \text{Wattage} \times \text{Use Frequency} \times \text{Hour Fraction Factor} \times \text{UEC Adjustment Factor} \]  

where UEC is the annual energy consumption per appliance unit in kWh/year, Wattage is the reported power rating in Watt, *Use Frequency* is the total hours in-use per year, and *Hour Fraction Factor* and *UEC Adjustment Factor* are dimensionless factors, which are CLASP assumptions designed to reflect actual in-use duration and power draw. A full list of assigned *Hour Fraction Factor* and *UEC Adjustment factor* is provided in CLASP and Ipsos [61].

A regression analysis was performed to generate a mathematical model that utilize the survey’s individual household responses for rice cooker, refrigerator and waterpump.

### 3.2.1. Rice cooker UEC regression model

These variables include UEC rice cooker (the annual rice cooker unit energy consumption in kWh/year), *Container Volume* (the estimated container capacity of the rice cooker in the unit of Liter), *Cooking Power* (the adjusted cooking wattage that includes average national average of cooking event in the unit of Watt) and *Warming Energy Use* (the adjusted warming energy use that includes average warming power and duration). All of these variables were incorporated into Eq. (2) and were used in calculating UEC values of the rice cooker unit.

\[ UEC = 60.3737 + (72.9733 \times \text{Container Volume}) + (0.11734 \times \text{Cooking Power}) + (0.09914 \times \text{Warming Energy Use}) \]  

### 3.2.2. Refrigerator UEC regression model

A regression analysis was performed to generate a mathematical model that utilize the survey’s individual household responses for refrigerator as shown in Eq. (3) and was used in calculating UEC values of the refrigerator unit.

\[ UEC = 255.595 + (\text{-}0.53303 \times P) + (0.686 \times \text{Adjusted Volume}) \]  

where UEC is the annual refrigerator unit energy consumption in kWh/year, *P* is the nameplate refrigerator power rating in Watt, and *Adjusted Volume* is the estimated adjusted volume according to temperature targets and compartment volumes in Liter.

### 3.2.3. Water pump UEC regression model

Eq. (4) below was used in calculating UEC values of the water pump unit, as follows:

\[ UEC = \left( P \times \text{Daily Operating Time} \times \text{Monthly Operating Frequency} \times 12 \text{months} \right)/1000 \]  

Where UEC is the annual energy consumption of the water pump unit(s) in kWh/year, *P* is the nameplate water pump power rating in Watt, and *Daily Operating Time* is the estimated running time of the water pump unit(s) in the unit of hour, *Monthly Operating Frequency* is the reported frequency of use in days per month.

The annual average household energy consumption was calculated by combining electricity consumption for all the household appliances as well as gas and kerosene consumption.

To analyze the factors affecting household energy consumption, the multiple regression analysis—Statistical Package for the Social Sciences (SPSS) software is applied in this study by including interaction effect of two variables and considering multicollinearity to carry out our statistical analysis. Thirteen independent variables were obtained from the survey such as “No. of AC” (number of air conditioning), “No. of fans” (number of fans), “No. of other appliances” (number of appliances), “Building size”, “Daily usage of AC”, “Daily usage of fan”, “Household size”, “Education”, “Age”, “Staying people at home”, “No. of children” (number of children), “Occupation” and “Gender”.

Interaction terms (representing interaction of the model variables) are commonplace when it comes to multiple regression [62]. Interactions provide researchers with the ability to enrich our understanding of economic and social relationships by establishing the conditions under which such relationships apply, or are stronger or weaker. The regression model used for multiple regression analysis including interaction term as shown in Eq. (5)

\[ Y = \beta_1 p_1 + \beta_2 p_2 + \beta_3 p_1 p_2 + \epsilon \]  

where *Y* is dependent variable, *p*1 and *p*2 are independent variables along with *p*1*p*2 as cross product interaction term.

Multicollinearity involves the situation when the cross product term *p*1*p*2, representing interaction, is highly correlated with the term *p*1 and *p*2. As a result, it gets difficult to distinguish the separate effects of *p*1*p*2 and *p*1 (and/or *p*2). To avoid multicollinearity, several researchers including Aiken and West [63] recommended mean-centering the variables *p*1 and *p*2 for creating interaction term.

### 4. Results and discussion

#### 4.1. Profile of respondents

Table 1 shows the socio-economic profiles of the respondents. As shown, Jakarta sample comprised approximately 39%, 49%, and 12% low, medium and high cost houses, respectively, whereas Semarang sample comprised 27%, 49%, and 24%, respectively for landed houses. Bandung sample comprised for low cost (36%), medium cost (22%) and high cost (42%) houses. The average household size was about 3.5–5.0 persons with little variations between the three categories in all cities. High cost houses tended to have slightly larger households of about 4.2–5.0 persons. The head's highest education attainment increases with the house category. Monthly average household income was converted in USD. Proportions of household income strata were almost the same between the three cities, although the average income in Bandung was slightly greater. In general, household income increased with house category from low to high, as did total floor area. The largest floor area was 99 m² (33.3% to 44.9%) for medium cost houses, and 100 to 300 m² (8.3% to 66.7%) for high cost houses. Several houses have total floor area>300 m² (4.3%–16.7%).

#### 4.2. Ownership levels of household appliances

Fig. 3 presents the ownership levels of major household appliances. As shown, light bulbs, televisions, refrigerators, rice cooker and washing machine were highly owned in all cities among all house categories. The stand fan (78–91%) was also found in most homes, reflecting the severe hot climatic conditions. In general, ownership levels of other appliances increased with house type,
except for cooking blender and DVD player. The ownership level of air conditioners (14–69%) and ceiling fan (8–17%) increased with house category from low to high cost houses. Majority of high cost houses were equipped by cooling appliances (air conditioner) despite the climate.

In all cities, Low Emission Diode (LED) and compact fluorescent lamps (CFL) were well penetrated among households regardless of the house categories (Fig. 4). It has been reported that the Indonesian government highly promoted LED and fluorescent lamps for replacing incandescent lamps starting in 2007[64]. The national power company (i.e., Perusahaan Listrik Negara) exchanged one incandescent bulb for three compact fluorescent bulbs free to their customers in Indonesia with the aim of reducing nationwide electricity consumption and the government’s subsidies for electricity tariffs.

### 4.3. Household energy consumption and CO2 emissions

Annual household energy consumption was estimated by multiplying energy consumption for each fuel type by its corresponding energy conversion rates[65,66], as shown in Table 2.

#### Table 1

|             | Jakarta | Semarang | Bandung | Total |
|-------------|---------|----------|---------|-------|
|             | L       | M        | H       | A     |
| Sample size (households) | 39 | 49 | 12 | 100 |
| Gender (%) |         |          |         |       |
| Female     | 47.4    | 50.6     | 52.9    | 49.7  |
| Male       | 52.6    | 49.4     | 50.3    | 47.1  |
| Age (%)    |         |          |         |       |
| <40 years  | 70.0    | 68.1     | 62.8    | 66.9  |
| 40–49      | 13.9    | 25.1     | 25.5    | 21.5  |
| >60        | 2.2     | 3.4      | 3.9     | 3.2   |
| Household size (persons) | 3.5 | 3.6 | 4.2 | 3.6 |
| Head’s highest education (%) |         |          |         |       |
| Elementary | –       | 2.1      | 0.7     | 7.4   |
| Junior high school | 7.6    | 2.0      | 3.2     | 11.1  |
| Senior high school | 82.1   | 55.1     | 75.0    | 70.7  |
| Vocational course | –      | 20.4     | 8.3     | 9.6   |
| Graduate | 10.3    | 20.4     | 16.7    | 15.8  |
| Post graduate | –      | –        | –       | –     |
| Others     | –       | –        | –       | –     |
| Household income (USD) |         |          |         |       |
| < 200      | 100     | –        | –       | 39    |
| 201–485    | –       | 100      | –       | 49    |
| 486–694    | –       | –        | 58.3    | 7     |
| >695       | –       | –        | 41.7    | 5     |
| Total floor area (%) |         |          |         |       |
| <50 (m²)  | 30.8    | 42.9     | 8.3     | 34    |
| 50 – 99    | 41      | 44.9     | 66.7    | 46    |
| 100 – 300  | 28.2    | 12.2     | 8.3     | 18    |
| > 300      | –       | 16.7     | 2       | –     |

L = low-cost houses; M = medium-cost houses; H = high-cost houses; A = all samples; 1USD = 14,413 IDR.

---

**Fig. 3.** Ownership levels of major household appliances by house category.
shows the average annual household energy consumption by house category. Fig. 5a indicates energy consumption from various energy sources and Fig. 5b shows it by end-use categories. Overall, the average annual energy consumption of all sampled houses during pandemic was approximately 23.5 GJ, which is 3.0 GJ more than before pandemic. The difference is mainly attributed to the use of cooling and cooking among the three different house categories of the cities.

As shown, average energy consumption for cooling and cooking accounted for 7.2 GJ (30%) and 8.1 GJ (34%) respectively of total energy consumption during pandemic, whereas they were higher 2.0 GJ and 0.8 GJ than before pandemic (Fig. 5b). Hence, in all cities, average household energy consumption increased with increasing ownership and the use of air conditioning (Figs. 3 and 5). Because average household size did not vary largely among the three house categories, the above difference in ownership and usage of cooling appliances, especially for air conditioners, and those of cooking was directly reflected in the large difference in annual energy consumption among all house categories in all cities. In all cities, secondary energy consumption for house with high and medium cost is more significant compared to the house with lowest cost. This is due to the larger electricity consumption of both household category where most of the activities for highest household income required electricity. The consumption through electricity is much greater than by LPG use: 2.85 GJ to 20.70 GJ during pandemic and 2.85 GJ to 17.68 GJ before pandemic (Fig. 5). As been reported above on program of kerosene conversion to LPG, the usage of kerosene is very small in Indonesia and therefore, it is negligible.

Fig. 6 indicates annual average energy consumption per floor area and per person. As shown in Fig. 6b, the annual energy consumption per person increased sharply with house category. Because average household size did not vary largely among the house categories, this difference was directly reflected in the large difference in annual energy consumption among the categories. This indicates that there is a disparity in consuming electricity between house with larger cost and house with lower cost in addition, the number of occupants per floor area increased with category (see Table 1). Therefore, when annual energy consumption was assessed in terms of per-floor area, it also increased with category by significant differences in their means (Fig. 6a).

Annual household CO2 emissions were estimated by multiplying energy consumption for each fuel type by its corresponding CO2 emission factor [65,66]. The CO2 emission factors by energy source of Indonesia are shown in Table 3. Fig. 7 shows annual household CO2 emission of residential buildings of Indonesia. As shown, average annual CO2 emissions during pandemic were estimated at 4.2 ton CO2-equivalent, while those were 3.6 ton CO2-equivalent before pandemic. The major contributors during pandemic were cooling (1.4 ton (33%), cooking (1.2 ton (28%)), and refrigeration (0.7 ton (18%)), while those before pandemic were cooking (1.0 ton (28%)), cooling (1.0 ton (28%)), and refrigeration (0.7 ton (20%)). If the amount of CO2 emissions caused by cooling are excluded, then the difference of total CO2 emissions between the two climate groups is insignificant (2.8 ton during pandemic and 2.6 ton before pandemic). This clearly indicates that an increase in air conditioning use in the future would dramatically increase household energy consumption and therefore, CO2 emissions. Similar patterns in unit CO2 emissions per floor area and per person are shown in Fig. 8. The annual households CO2 emissions per person in every type of house also vary where house with the highest cost consume cooling around four times compared to the house with lowest cost, especially during the pandemic. The more activity for wealthier household in the house, the more significant they consume energy during pandemic.

4.4. Factors affecting household energy consumption

This study reveals household energy consumption patterns as well as their drivers. For this purpose, a multiple regression analysis was built to quantitatively examine the factors affecting household energy consumption during pandemic as shown in Tables 4 and 5, respectively. Thirteen independent variables were obtained from the survey as explained in Methodology and were selected to explain household energy consumption during and before pandemic in the major cities of Indonesia (insignificant variables were excluded).

The correlation analysis was conducted to explain the household energy consumption during pandemic by including interactive effect of two variables and considering multicolinearity as shown in Table 4. Several variables recorded high r-values. Multiple regression analyses were carried out by using the above selected variables in three house categories. Table 5 indicates the coefficient of all variables included in the regression equations in respective houses.

In the regression equations, the coefficient of determination (R²) is 0.24 for low-cost houses, 0.64 for medium-cost houses, and 0.56 for high-cost houses, respectively. As indicated in Table 5, the standardized coefficient is the highest in interactive variables “Daily usage of AC, No. of fans” at 1% significant level for low-cost house, “No. of AC, No. of fans” for medium-cost house and “Household size, No. of AC” for high-cost house, followed by “No. of other appliances” and “Daily usage of fans, No. of fans” for low-cost house, while “No. of other appliances”, “No. of other appliances, No.of fans” and “Household size, Age of respondents” for medium-cost house. This indicates that the above single and interactive variables are considered to be good predictors to the annual household energy consumption during pandemic, except for low-cost house (low R²).

As before, the correlation analysis was attempted to examine the determinants of the above annual household energy consumption before pandemic in respective houses as shown in Table 6. Several variables also recorded high r-values. Multiple regression

### Table 2
Energy conversion rates by energy source (Indonesia).

| Energy source | Energy conversion rates | Year | References |
|---------------|-------------------------|------|------------|
| Electricity   | 3.6 (MJ/kWh)            | 2012 | IEA [65]   |
| LPG           | 48 (MJ/kg)              | 2014 | GHG Protocol [66] |
analyses were carried out by using the above selected variables in three house categories. Table 7 indicates the coefficient of all variables included in the regression equations in respective houses. As shown, the both results (during and before pandemic) showed similar factors affecting household energy consumption in the first one or two main factors, except for medium cost houses that has other affecting interactive variables (“No. of other appliances_ Daily usage of fans” and “Household size_Gender”).

The results obtained point to the fact that household energy consumption (in high cost house) is affected by household size and number of AC, especially in high-cost house. The effect of household size on household energy consumption is dependent on number of AC and the effect of number of AC on household energy consumption is dependent on household size. Similarly, the number of family members has positive correlation with household energy consumption, suggesting that as the household size increases, more household energy consumption is consumed [23,67,68]. In addition, number of other appliances and joint effect of number of AC and number of fans influenced household energy consumption for medium and low-cost houses, respectively. The results is inline with investigation of Genjo et al. [19], Wijaya et al. [47] and Surahman et al. [59] which showed the use of residential electricity consumption was related to the number of home appliances owned, especially number of AC and fans and their usage.

Hence, it is anticipated again that further increases in household income (represented by house category) would increase household size and number of appliances including number of AC and fans and thus, energy consumption. As a consequence, the increase in household income will soon increase total household energy consumption significantly in Southeast Asian cities.
It can be concluded that household energy consumption in major cities of Southeast Asia is projected to increase sharply if proper energy-saving strategies are not implemented. First, it is important to avoid the tendency to increase household size and number of appliances especially number of AC and fans directly with the increase in household income. One possible solution is to control number of family members. Indonesia’s Family Planning Program can be one solution to prevent pregnancy [69,70]. Second, but the most importantly, the increase in cooling, especially AC would be a major concern in terms of energy-saving strategies in the hot-humid cities, which is typical of Southeast Asia. Even in the hot-humid cities, the ownership of AC was still averaged at 39.9% according to the present survey, through it is rapidly rising. It is important to reduce the use of AC in the future despite the expected increase in household income. In addition, the usage of more energy efficiency standards for appliances is also necessary. As been seen in Fig. 9, the households headed by the younger adults (<40 years old) consumed more cooling energy (1.9 GJ and 0.8 GJ in average during and before pandemic, respectively) than those headed by the adults (>40 years old) in low-cost house and in high-cost houses. Therefore, it is important to encourage the occupants to modify their current lifestyle changes, particularly to the younger adults in low and high-cost houses and promote environmental education. For example, to reduce the electricity consumption by ACs in residential buildings would be preferable for people to open window rather than running an AC in each room of house.

**Table 3**: CO₂ emission factors by energy source (Indonesia).

| Energy source | CO₂ emission factors (g CO₂-eq/MJ) | Year | References |
|---------------|-----------------------------------|------|------------|
| Electricity   | 196.94                            | 2012 | IEA [65]   |
| LPG           | 56.10                             | 2014 | GHG Protocol [66] |

It can be concluded that household energy consumption in major cities of Southeast Asia is projected to increase sharply if proper energy-saving strategies are not implemented. First, it is important to avoid the tendency to increase household size and number of appliances especially number of AC and fans directly with the increase in household income. One possible solution is to control number of family members. Indonesia’s Family Planning Program can be one solution to prevent pregnancy [69,70]. Second, but the most importantly, the increase in cooling, especially AC would be a major concern in terms of energy-saving strategies in the hot-humid cities, which is typical of Southeast Asia. Even in the hot-humid cities, the ownership of AC was still averaged at 39.9% according to the present survey, through it is rapidly rising. It is important to reduce the use of AC in the future despite the expected increase in household income. In addition, the usage of more energy efficiency standards for appliances is also necessary. As been seen in Fig. 9, the households headed by the younger adults (<40 years old) consumed more cooling energy (1.9 GJ and 0.8 GJ in average during and before pandemic, respectively) than those headed by the adults (>40 years old) in low-cost house and in high-cost houses. Therefore, it is important to encourage the occupants to modify their current lifestyle changes, particularly to the younger adults in low and high-cost houses and promote environmental education. For example, to reduce the electricity consumption by ACs in residential buildings would be preferable for people to open window rather than running an AC in each room of house.

**Fig. 6**: Unit annual average secondary household energy consumption. (a) Per floor area; (b) per person."** = 1% significant level; * = 5% significant level.
Fig. 7. Annual average household CO₂ emissions. (a) By energy source; (b) by end-use. ** = 1% significant level; * = 5% significant level.
Fig. 8. Unit annual average household CO₂ emissions. (a) Per floor area; (b) per person. ** = 1% significant level; * = 5% significant level.
### Table 4
Correlation coefficient between selected variables and annual household energy consumption of each house (during pandemic).

| Variables                                      | r-value | Sig. | Variables                                      | r-value | Sig. | Variables                                      | r-value | Sig. |
|------------------------------------------------|---------|------|------------------------------------------------|---------|------|------------------------------------------------|---------|------|
| 1 Daily usage of AC, No. of fans               | 0.32    | **   | No. of AC, No. of fans                           | 0.62    | **   | Household size, No. of AC                      | 0.75    | **   |
| 2 No. of other appliances                      | 0.29    | **   | No. of other appliances                          | 0.57    | **   | Household size, Daily usage of AC              | 0.45    | **   |
| 3 No. of other appliances, No. of fans         | 0.27    | **   | No. of other appliances                          | 0.50    | **   | Household size, Education                      | 0.24    |    * |
| 4 Daily usage of fans, No. of fans             | 0.21    | *    | No. of other appliances, Daily usage of fans     | 0.37    | **   | Staying people at home, Education              | 0.21    |    * |
| 5 No. of other appliances, Gender              | 0.21    | **   | Building size, Staying people at home            | 0.28    | **   | Staying people at home, Age of respondents     | 0.21    |    * |
| 6 Age of respondents, Occupation               | −0.21   |    * | Staying people at home, Education                | 0.26    | **   | Household size, Gender                         | 0.21    |    * |
| 7 −                                            | −−      |      | No. of AC, No. of children                       | 0.24    | **   | Staying people at home, Gender                 | 0.19    |    * |
| 8 −                                            | −−      |      | No. of other appliances, Occupation              | 0.22    | **   | No. of other appliances, Occupation            | 0.20    |    * |
| 9 −                                            | −−      |      | Staying people at home, Age of respondents       | 0.19    | **   | −−                                              |    −    |    − |
| 10 −                                           | −−      |      | No. of other appliances, No. of children         | 0.16    | *    | −−                                              |    −    |    − |
| 11 −                                           | −−      |      | Education                                        | 0.16    | *    | −−                                              |    −    |    − |

Sig.: significant level.

* = Significant at 5% level; ** = significant at 1% level.

### Table 5
Coefficient of variables included in regression equation for annual household energy consumption of each house (during pandemic).

| Variables                                      | Low-cost houses | Medium-cost houses | High-cost houses |
|------------------------------------------------|-----------------|--------------------|------------------|
|                                               | Unstandardized  | Standardized      | Sig.             | Unstandardized  | Standardized      | Sig.             | Unstandardized  | Standardized      | Sig.             |
| Constant                                      | −1.74           | 11.74              | 20.35            |                |                  |                  |                |                  |                  |

Sig.: significant level.

* = significant at 5% level; ** = significant at 1% level.

### Table 6
Correlation coefficient between selected variables and annual household energy consumption of each house (before pandemic).

| Variables                                      | r-value | Sig. | Variables                                      | r-value | Sig. | Variables                                      | r-value | Sig. |
|------------------------------------------------|---------|------|------------------------------------------------|---------|------|------------------------------------------------|---------|------|
| 1 Daily usage of AC, No. of fans               | 0.32    | **   | No. of AC, No. of fans                           | 0.54    | **   | Household size, No. of AC                      | 0.77    | **   |
| 2 No. of other appliances                      | 0.29    | **   | No. of other appliances                          | 0.52    | **   | Daily usage of fans, No. of AC                 | 0.52    | **   |
| 3 No. of other appliances, No. of fans         | 0.22    | *    | No. of other appliances, No. of fans             | 0.51    | **   | Household size, Staying people at home         | 0.32    | **   |
| 4 No. of other appliances, Gender              | 0.21    | *    | No. of other appliances, No. of AC               | 0.46    | **   | Household size, Education                      | 0.26    | **   |
| 5 Occupation, Education                        | −0.21   | *    | No. of other appliances, Daily usage of fans     | 0.40    | **   | Household size, Gender                         | 0.23    | *    |
| 6 No. of other appliances, Daily usage of fans | 0.18    | *    | No. of other appliances, Occupation              | 0.30    | **   | Staying people at home, Gender                 | 0.21    | *    |
| 7 −                                            | −−      |      | No. of other appliances, No. of children         | 0.25    | **   | Staying people at home, Age of respondents     | 0.21    |    * |
| 8 −                                            | −−      |      | No. of AC, No. of children                       | 0.25    | **   | −−                                              |    −    |    − |
| 9 −                                            | −−      |      | Building size, Education                         | 0.21    | **   | −−                                              |    −    |    − |
| 10 −                                           | −−      |      | Building size, Staying people at home            | 0.21    | **   | −−                                              |    −    |    − |
| 11 −                                           | −−      |      | No. of fans, No. of children                     | 0.21    | **   | −−                                              |    −    |    − |
| 12 −                                           | −−      |      | Staying people at home, Education                | 0.20    | *    | −−                                              |    −    |    − |

Sig.: significant level.

* = Significant at 5% level; ** = Significant at 1% level.
5. Conclusions

The detailed household energy consumption patterns in major developing cities of Indonesia were analyzed by house category during and before pandemic.

- Cooling appliances in average recorded high ownership levels of 78–91% for stand fan and 14–69% for air conditioner and it is reflecting its severe hot climatic conditions. In general, the ownership levels of other appliances increase from low to high cost houses, respectively. In all categories, LED and compact fluorescent lamps are well penetrated among households regardless of the house category. The similar patterns of ownership level were shown by household category.

- Overall, the average annual energy consumption of all samples during pandemic is approximately 23.5 GJ, which is 3.0 GJ larger than before pandemic. The difference is mainly attributed to the use of air-conditioning and cooking between the two situations. Hence, in all cities, basically, the average household energy consumption of house categories increases with the increase in ownership and use of air-conditioning.

- The average annual CO₂ emissions during pandemic are estimated at 4.2 ton CO₂-equivalent, while those are 3.6 ton CO₂-equivalent before pandemic. The major contributors during pandemic were cooling (1.4 ton (33%)), cooking (1.2 ton (28%)), and refrigeration (0.7 ton (18%)), while those before pandemic were cooking (1.0 ton (28%)), cooling (1.0 ton (28%)), and refrigeration (0.7 ton (20%)).

- The results of multiple regression analysis clearly indicate that the effect of household size on household energy consumption is dependent on number of AC and vice versa. The increase in household income (low to high-cost houses) would increase household size and number of appliances especially the increase of number of air conditioner, thus total household energy consumption in both situation.

- It is important to avoid the tendency that household size and number of appliances (including number of AC and fans) increases straightforwardly with the increase in household income. We recommended the following potential energy-saving strategies for urban houses in Indonesia: (a) control number of family members by preventing pregnancy, (b) use more energy efficiency standards for appliances and (c) encour-

---

### Table 7

Coefficient of variables included in regression equation for annual household energy consumption of each house (before pandemic).

| Variables                      | Low-cost houses | Medium-cost houses | High-cost houses |
|-------------------------------|-----------------|--------------------|------------------|
|                               | Unstandardized  | Standardized       | Sig.             | Unstandardized  | Standardized       | Sig.             | Unstandardized  | Standardized       | Sig.             |
| 1 Household size_No. of AC    | -               | -                  | -                | -               | 2.20              | 0.77 **            |                  |                  |
| 2 No. of AC, No. of fans      | -               | -                  | 2.30             | 0.43 **         | -                 | -                |                  |                  |
| 3 Daily usage of AC, No. of fans | 0.59           | 0.31               | 0.50             | 0.44 **         | -                 | -                |                  |                  |
| 4 No. of other appliances     | 0.72            | 0.29               | -                | -               | 0.02              | 0.27 **           | -                 | -                |
| 5 No. of other appliances, Daily usage of fans | -              | -                  | -0.78            | -0.14 *         | -                 | -                |                  |                  |
| 6 Household size_Gender      | -               | -                  | -                | -               | -                 | -                |                  |                  |
| Constant                      | 2.08            | 6.55               | 15.67            |                  |                  |                  |                  |                  |

Sig.: significant level.

* = Significant at 5% level; ** = Significant at 1% level.

---

**Fig. 9.** Annual average secondary household cooling energy consumption based on household’s age. Younger adults (≤40 years); adults (>40 years) [71] ** = 1% significant level; * = 5% significant level.
age energy-saving lifestyles, particularly to younger adults and promote environmental education by adopting passive cooling techniques (window opening) wherever possible.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We acknowledge a collaborative PPKI program from the Indonesian World Class University Research Scheme (No. 165/UN40.D/PT.01.03/2021; NKB-458/UN2.RST/HKP.05.00/2021; 117-15/UN7.6.1/PP/2021) and would like to thank students of UI and Macromills who kindly supported our surveys.

Author contributions

U. Surahman: Conceptualization, Original draft, Review and editing. Djoni Hartono: Methodology, Validation. Erni Setyowati: Formal analysis, Investigation. Aldissain Jurizat: Visualization, Project administration.

References

[1] H. Farrow, Commercial Down vs Residential Up: COVID-19’s Electricity Impact, Energy Network Australia, 2020, pp. 1–23.
[2] S. Hinson, COVID-19 is changing residential electricity demand - Renewable Energy World. Renewable, Energy World (2020) 1–15.
[3] S. Yoshi How coronavirus measures have changed electricity demand RTE Brainstorm 2020 January 2021 https://www.terebrainstorm/2020/02/327/ 112678/irlelectricity-coronavirns/
[4] OECD, 2020. OECD Economic Outlook. Volume 2020 Issue 1, No. 107, OECD Publishing, Paris.
[5] UNEP, Buildings and Climate Change. Summary for Decision-Makers, UNEP Sustainable Consumption and Production, Milan, United Nations Environment Programme, Paris, 2009.
[6] T. Ikaga, S. Murakami, S. Kato, Y. Shiraishi, Estimation of CO 2 emissions associated with building construction and operation until 2050 in Japan, study on social lifecycle assessment of building and cities, J. Archit. Plan. Environ. Eng. (Transactions of AJJ), 535 (2000) 53-58.
[7] N. Howard, Sustainable Construction – the Data, BRE, UK, Watford, 2000.
[8] Levine, M., D. Urge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. Mongameli Mehlwana, S. Miragfidi, A. Novikova, R. Qiu, J. Rilling, and H. Yoshino, 2007. Residential and commercial buildings. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the UNEP. 2007. Buildings and Climate Change. Status, Challenges and Opportunities. United Nations Environment Programme, Paris.
[9] Indonesia, Population Census of Indonesia, Statistical Centre of Indonesia, Jakarta, 2010.
[10] Indonesia, Handbook of Energy and Economic Statistics of Indonesia, Ministry of Energy and Mineral Resources of Indonesia, Jakarta, 2018.
[11] JETRO, Market investment attraction-Indonesia (in Japanese), Japanese External Trade Organization, Japan, 2011.
[12] J. Heinonen, The Impacts of Urban Structure and the Related Consumption Patterns on the Carbon Emissions of an Average Consumer, Aalto University, 2009.
[13] E.C. Hertwich, G.P. Peters, Carbon footprint of nations: a global, trade-linked analysis, Environ. Sci. Technol. 43 (16) (2009) 6414–6420.
[14] A. Kerkhof, S. Nonhebel, H.C. Moll, Relating the environmental impact of household energy use to lifestyle indicators, Energy Policy. 28 (2000) S46-S56.
[15] H. Wilhite, H. Nakagami, T. Masuda, Y. Yamaga, H. Haneda, A cross-cultural analysis of household energy use behavior in Japan and Norway, Energy Policy 24 (9) (1996) 795–803.
[16] M. Krarti, M. Aldubyan, Review analysis of COVID-19 impact on electricity demand for residential buildings, Renew. Sustain. Energy Rev. 143 (2021) 110888, https://doi.org/10.1016/j.ress.2021.110888.
[17] Q. Wang, S. Li, F. Jiang, Uncovering the impact of the COVID-19 pandemic on energy consumption: New insight from difference between pandemic-free scenario and actual electricity consumption in China, J. Clean. Prod. 313 (2021) 127897, https://doi.org/10.1016/j.jclepro.2021.127897.
[18] M. Monzön-Chavarrías, S. Guáil-Lambea, S. García-Pérez, A.L. Montealegre-González, J. Sierra-Pérez, Heating energy consumption and environmental implications due to the change in daily habits in residential buildings derived from COVID-19 crisis: the case of Barcelona, Spain, Sustainability 13 (2) (2021) 918, https://doi.org/10.3390/su13020918.
[19] J. Rouda, L. Gosselin, Impacts of the COVID-19 lockdown on energy consumption in a Canadian social housing building, Appl. Energy 287 (2021) 116565, https://doi.org/10.1016/j.apenergy.2021.116565.
[20] H. Kang, J. An, H. Kim, C. Ji, T. Hong, S. Lee, Changes in energy consumption according to building use type during COVID-19 pandemic in South Korea, Renew. Sustain. Energy Rev. 148 (2021) 112194, https://doi.org/10.1016/j.ress.2021.112194.
[21] Qarnain, S.S., Sathanarayan, R., Ali, S.M., 2020. Analyzing energy consumption factors during coronavirus (COVID-19) pandemic outbreak: A case study of residential society. Energy Sources, Part A Recover. Util. Environ. Eff., 1–20.
[22] I. Hazrati, M.H. Javadi, The effect of occupant distribution on energy consumption and COVID-19 infection in buildings: A case study of university building, Build. 190 (2021) 107561, https://doi.org/10.1016/j.buildenv.2020.107561.
[23] W. Zheng, J. Hu, Z. Wang, J. Li, Z. Fu, H. Li, J. Yan, COVID-19 impact on operation and energy consumption of heating, ventilation and air-conditioning (HVAC) systems, Adv. Appl. Energy 3 (2021) 100040, https://doi.org/10.1016/j.apenergy.2021.100040.
[24] S. Qarnain, S. Muthuravel, S. Bathini, Review on government action plans to reduce energy consumption in buildings amid COVID-19 pandemic outbreak, Mater. Today Proc. 45 (2021) 1264–1268.
[25] I. Huang, Q. Liao, R. Qiu, Y. Liang, Y. Long, Prediction-based analysis on power consumption gap under long-term lockdown policy of China under COVID19, Appl. Energy. 283 (2021) 116339, https://doi.org/10.1016/j.apenergy.2021.116339.
[26] H. Nakagami International comparison of residential energy consumption ACSEE Summer Study on Energy Efficiency in Buildings. 2006 Available from: http://www.acsee.org/ files/proceedings/2008/data/papers/8_24.pdf. Accessed on August 2, 2020.
[27] A. Musata, Y. Kondou, M.U. Hainlin, Z. Weisheng, Electricity demand in the Chinese urban household-sector. Appl. Energy 85 (12) (2008) 1113–1125.
[28] R. Saidur, H.H. Masjuki, M.Y. Jamaluddin, S. Ahmed, Energy and associated greenhouse gas emissions from household appliances in Malaysia, Energy Policy 35 (3) (2007) 1648–1657.
[29] S.B. Tyler, Household energy use in Asian cities: responding to development success, Atmos. Environ. 30 (5) (1996) 809–816.
[30] ESCAP, 2009. Economic and Social Commission for Asia and the Pacific Annual Report 2009, Available from: http://www.unescap.org/EDC/English/AnnualReports/2009/65/ pdf. Accessed on August 5, 2020.
[31] Hui, S.C.M., 2000. Building energy efficiency standards in Hong Kong and mainland China. In: Proceedings of the 2000 ACSEE Summer Study on Energy Efficiency in Buildings, 20–25 August 2000, Pacific Grove, California.
[32] L. Schaper, S. Meyers, Improving appliance efficiency in Indonesia, Energy Policy 19 (6) (1991) 578–588.
[33] A.S. Permana, R. Pereira, S. Kumar, Understanding energy consumption pattern of households in different urban development forms: a comparative study in Bandung city, Indonesia, Energy Policy 36 (11) (2008) 4287–4297.
[34] A. Utama, S.H. Gheewala, Influence of material selection on energy demand in residential houses, Mater. Des. 30 (6) (2009) 2173–2180.
[35] A. Utama, S.H. Gheewala, Life cycle energy of single landed houses in Indonesia, Energy Build. 40 (10) (2008) 1911–1916.
[36] H. Budya, M. Yasir Arafat, Providing cleaner energy access in Indonesia through the megaproject of kerosene conversion to LPG, Energy Policy 39 (12) (2011) 7575–7586.
M.E. Wijaya, T. Tezuka, A comparative study of households’ electricity consumption characteristics in Indonesia: a techno-socioeconomic analysis, Energy Sustain. Devel. 17 (6) (2013) 596–604.

S.I. Mustapa, R. Rasiah, A.H. Jaafar, A.B. Bakar, Z.K. Kaman, Implications of COVID-19 pandemic for energy-use and energy saving household electrical appliances consumption behaviour in Malaysia, Energy Strategy Rev. 38 (2021) 1–16.

Raman, G., Peng, J.C.H., 2021. Electricity consumption of Singaporean households reveals proactive community response to COVID-19 progression. Proceedings of the National Academy of Sciences of the United States of America (PNAS). 118 (34).

D. Hartono, A.A. Yusuf, S.H. Hastuti, N.K. Saputri, N. Syaifudin, Effect of COVID-19 on energy consumption and carbon dioxide emissions in Indonesia, Sustain. Product. Consumpt. 28 (2021) 391–404.

JAKARTA, Jakarta in Figures, Statistical Centre of Jakarta, Jakarta, 2021.

Semarang, 2021a. Surabaya in Figures. Agency for the Centre of Statistic of Mid Java.

Bandung, 2021a. Bandung in Figures. Agency for the Centre of Statistic of West Java.

Jakarta, Climatology Data in Jakarta from 2010–2020, Climatology and Meteorology Station of Kemayoran, Jakarta, 2021.

SEMARANG, Climatology Data in Surabaya from 2010–2020, Climatology and Meteorology Station of Surabaya, 2021.

BANDUNG, Climatology Data in Bandung from 2010–2020, Climatology and Meteorology Station of Bandung, 2021.

World Bank, 1995, Indonesia Impact Evaluation Report, Enhancing the Quality of Life in Urban Indonesia: The Legacy of Kampung Improvement Program. Report No. 14747-IND, Operation Evaluation Department, the World Bank, Washington, D.C., United States of America.

Indonesia, 2007: Planning Procedures for Developing Earthquake Resistant on Buildings, The Ministerial Decree of Public Work no. 45. Department of Public Work (PU), Indonesia.

U. Surahman, T. Kubota, Life cycle energy and CO2 emissions of residential buildings in Bandung, Indonesia, Adv. Mater. Res. 689 (2013) 54–59.