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A study of appliance ownership and electricity consumption determinants in urban Ghanaian households

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ABSTRACT

The residential sector in Ghana accounts for about 40% of aggregate electricity consumption out of which urban centers contribute 70%. The high weighted share of residential electricity use is attributed to high appliance ownership and use, and other household/building factors. The ability to determine how changes in the pattern of these factors influence electricity demand is critical if efforts to reduce consumption are to be effective. This study combines a residential electricity consumption survey (RECS) with electricity end-use monitoring of 60 households in Tema city Ghana, to yield the first ever comprehensive investigation of city-scale electricity consumption in urban Ghanaian homes. A multiple linear regression analysis is used to identify the most statistically significant indicators of appliance ownership and household electricity consumption. Results indicate that ownership of air conditioner, freezer, fan, refrigerator and television; and changes in socio-economic and building factors such as energy efficiency awareness and practice; income; household size and floor space show high statistical significance, and collectively explain 57% variance in households' total electricity consumption. The presence of dependent children increases ownership of television, iron, washing machine and small kitchen appliances. This work provides a solid foundation for developing more tailored energy-saving policy interventions targeted at households.

1. Introduction

The demand for electrical energy in developing economies of the sub-Saharan African region is expected to increase rapidly in line with global trends (2013, ICLEI, UN-Habitat, & UNEP, 2009; International Energy Agency, 2017; OECD/IEA, 2009). Electricity consumption of residential buildings already represents approximately 40% of total electricity use in Ghana (Gyamfi, Diawuo, Nyarko Kumi, Sika, & Modjinou, 2018). The maximum peak load of aggregate sectors occurs between 19:00 and 21:00-hours which suggests the residential sector as a high contributor to peak demand (Gyamfi et al., 2018). The residential sector has historically been the fastest growing electricity consuming sector with an average annual growth of 6.3% over the last decade (Gyamfi et al., 2018).The high growth rate is attributed to rising appliance ownership and their electricity use (Gyamfi, Modjinou, & Djordjevic, 2015). These developments are linked to the rise in wider national development indicators such as high rates of economic growth, urbanization and industrialization (Bawakyillenuo & Agbelie, 2015; Kwakwa, 2014; Mensah, Marbuah, & Amoah, 2016). Appliance ownership in Ghana is concentrated in urban communities. Cities accommodate about 55% of the population but consume 70% of total residential electricity supply (Gyamfi et al., 2015; World Bank, 2017). The expansion in electricity consumption by household appliances is therefore expected to continue.

Aggregate sectorial electricity demand in Ghana over the last decade grew at an average annual rate of about 10% while the country's generation capacity grew by an average of only 7% annually within that same period (Gyamfi et al., 2018). The resulting imbalance between

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demand and supply of electricity is such that the smallest disturbance in generation often leads to frequent interruptions in electricity supply and total blackout in some cases (Diawuo & Kaminski, 2017; Sakah, Diawuo, Katzenbach, & Gyamfi, 2017). The generation hiccups have been reported as mainly due to fuel supply constraints for thermal plants and/or reduced inflow into hydroelectric power plants due to non-perennial rivers together with inadequate and unreliable rainfall patterns (Gyamfi et al., 2015; Sakah et al., 2017). The traditional solution mostly applied in Ghana to address this imbalance is to increase the generation capacity of thermal power plants to provide flexibility that can safeguard system stability and cover increased peak demand (Energy Commission, 2017). This approach is unsustainable in terms of capital expenditure, fossil fuel availability and environmental conservation (Haider, See, & Elmenreich, 2016), especially when Ghana depends largely on foreign sources for its refined crude oil and natural gas supply used in thermal power generation (Sakah et al., 2017). Global interest in flexibility of electricity use on the demand-side has grown significantly over the past decade (Dupont, Dietrich, Jonghe, De Ramos, & Belmans, 2014) owing to the possibility to reduce electricity consumption via demand side management (DSM) programs (Feuerriegel & Neumann, 2016; Sepehr, Eghtedaei, Toolabimoghadam, Noorollahi, & Mohammadi, 2018). DSM has been defined as the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e., changes in the time pattern and magnitude of a utility's load (de Almeida, Moura, Gellings, & Parmenter, 2007). Improving the energy efficiency of home appliances as a DSM strategy could play an important role for mitigating electricity demand and supply deficit at lower costs (Alasseri, Tripathi, Rao, & Sreekanth, 2017), particularly in Ghana where financial investment in power utilities is highly constrained (Kumi, 2017).

Ghana's energy commission is committed to implementing energy efficiency standards for household appliances as a cost-effective way of using available energy resources to improve electrical energy security (Ahenkorah, n.d.). Appliance energy efficiency regulations were passed for air conditioners and compact fluorescent lights in 2005 and for refrigerators and freezers in 2010 (Agyarko, 2015). Although these standards have produced significant peak load reduction particularly from lighting (Ahenkorah, 2014), the overall electricity consumption in Ghanaian households increased by 7% per year between 2006 and 2014 (Agency, 2014). Policy makers now face the challenge of implementing measures that can address the ever-increasing electricity end-use intensity in Ghanaian homes. Although both appliance ownership and usage patterns determine residential electricity consumption, it is less known how households actually use their appliances (Matsumoto, 2016). There is therefore great interest amongst the country's government, grid operators and utilities and energy research community in understanding the details of electrical energy end-uses in addition to the factors that influence the dynamics of the magnitude of electricity consumption in households.

This study combines a residential electricity consumption survey (RECS) with electricity end-use monitoring of 60 households in Tema city Ghana, to yield a comprehensive investigation of city-scale electricity consumption in urban Ghanaian homes. The survey was designed such that the coverage area and collected data permit meaningful analysis based on the set objectives as follows:

- Provide in-depth understanding of the electricity consumption of typical appliances in urban homes including their hourly variation and contribution to peak load.
- Explore the influences of socio-economic and building factors (i.e. income grade, employment status, household size, household composition, age of household head, building type and energy efficiency awareness) on ownership of household appliances.
- Investigate the influence of socio-economic and building factors (i.e. income grade, household size, age of household head, building type, energy efficiency awareness) as well as appliance ownership on household electricity consumption.

While isolated surveys have been conducted to collect data, no energy use monitoring study is reported for Ghana (Gyamfi et al., 2018). Few studies have been conducted on electricity end-uses in households and these have varying primary foci. Kankam and Boon (2009) explored the linkages between government energy policies and energy use for rural development and found that electricity use contributes to improving conditions for education due to lighting services at the household and community levels. In exploring possible modifications to the usual energy efficiency labelling and standards paradigm for effective refrigerator market transformation in Ghana, Van Buskirk, Ben Hagan, Ofosu Ahenkorah, and McNeil, (2007) estimated an average energy savings potential of 550 kW h/refrigerator/year was feasible. Diawuo, Pina, Baptista, and Silva, (2018) modelled the electricity consumption of refrigerator, freezer, air conditioner, washing machine and lighting with dynamic characteristics of data such as appliance ownership, population and GDP and found that the electricity consumption of these end-uses could be reduced by 24–51% in 2050 via energy efficient technologies. In a review of the status of energy efficiency regulation on household refrigerators, air conditioners and lighting systems in Ghana, Gyamfi et al. (2018) report that energy efficiency measures that were carried out especially for lighting systems made significant savings that offset the national electricity peak demand by 200–240 MW.

Still to date, there is no study in literature on urban residential electricity end-uses in Ghana. This study fills that knowledge gap in an approach based on a combination of survey information and measurement data of hourly load variations for a broader range of residential appliances. For the first time, such data is made available to the scientific community. Authors additionally identify easily accessible parameters that explain the underlying determinants of the level and variance of electricity consumption in Ghanaian households. These are the original contributions of the current work. Results of this study significantly improve the ability to effectively predict how changes in ownership and usage pattern for different types of household appliances could affect electricity consumption. The findings should therefore be of interest to energy policy makers and electricity service providers because it identifies those appliances that should be priority targets for energy efficiency regulation or electricity end-use campaigns to produce desired changes in the demand profile. The results also serve as an important reference for grid operators and utilities in determining their own energy supply strategic plans for the residential sector. Since Ghana is amongst countries in the Economic Community of West African States (ECOWAS) that are advanced in promulgating energy efficiency regulation for household appliances in Africa, results of this study also provide a learning curve for other ECOWAS member states who are at the early stages of residential energy efficiency policy formulation.

The rest of the paper is organized as follows. Section 2 discusses previous works, highlighting approaches used and findings. Section 3 explains the methods used in the survey design, data collection and data processing. Section 4 presents the results of appliance ownership, frequency of appliance use at peak times, reactions to existing energy efficiency regulation and behavioral campaigns, hourly variation of appliance electricity consumption, socio-economic influences on residential electricity use and its analysis. Section 5 summarizes findings and recommendations of the study and concludes the paper with limitations and future works.

2. Review of modelling approaches

Several authors around the world have investigated the determinants of residential electricity consumption with focus on appliance ownership and use patterns, socio-economic factors and other household characteristics. Bottom-up or top-down modelling approaches have been used in these studies based on the nature of available data (Hakimi, 2016). The most common techniques are statistical/regression, engineering and neural network as discussed in Mcloughlin, Duffy, and Conlon, (2012).

Baker and Rylatt (2008) used simple and multiple regression analysis to examine how changes in energy usage patterns of different dwelling types affect electricity consumption in UK households based on data from survey questionnaire and electricity meter. It was found that the number of bed rooms and regular home working had a significant relationship with electricity consumption. Kavousian, Rajagopal, and Fischer, (2013) developed a weighted regression model to examine structural and behavioral determinants of domestic electricity consumption using data set from 1628 households. Results indicate that floor area, weather and location are very important determinants of domestic electricity consumption. In addition, the stock of refrigerators and entertainment devices (e.g. VCRs) contributed significantly to daily minimum consumption while other determinants such as number of occupants and high-consuming appliances (e.g. electric heaters) were significant to daily maximum consumption. Mcloughlin et al. (2012) applied a multiple linear regression model using data from 4200 Irish households to examine the influence of dwelling and occupant characteristics on electricity consumption pattern. It was found that household composition, appliance ownership, cooking and water heating significantly influence maximum electricity demand. Bedir, Hasselaar, and Itard, (2013) used 3 regression models to investigate the influence of lighting, appliance use and other indirect determinants (presence, dwelling-household-economic-system (DHES) characteristics) on electricity consumption using data gathered from a survey questionnaire in 323 Dutch households. The results of the first model indicated that appliance use duration contributed 37%, presence in rooms 14%, and combined model 37% to the explanation in the variations in the electricity consumption. The second model showed that the number of appliances explained 21% while its combination with dwelling/household characteristics was 42%. In the third model, appliance use duration and dwelling/household characteristics explained 58% of variance in electricity consumption.

A multiple regression analysis was done by Kim (2018) to identify the characteristics and determinants of electricity consumption in which households were categorized into five groups (quintile) using 2015 survey data acquired from the Energy Economics Institute in Korea. A comparison of two groups (first and fifth quintiles) indicates that the first quintile has a low ratio of middle-aged, high education, self-employed, high income and house area compared to the fifth quintile. Household size was more statistically significant for power consumption in the first quintile while housing area was more significant in the fifth quintile. Appliance ownership was significant in both groups. Esmaeilimoakher, Urmee, Pryor, and Baverstock, (2016) performed a questionnaire-based survey which was crafted as a combination of structured, semi-structured and open-ended questions to investigate the determinants of electricity use within the Perth social housing in Western Australia. Survey results were analyzed both qualitatively and quantitatively to identify the most significant building and occupant-related factors. Summary of the results indicate that floor area, household size, disposable household income and head of household gender are statistically significant to variations in electricity use. It was also observed that window opening behavior of building occupants and presence of children in the house on the other hand is insignificant to the variations in electricity consumption. Authors in (Hasanov & Mikayilov, 2017) used the Autoregressive Distributed Lags Bounds Testing approach to examine the influence of population age groups of 0–14, 15–64 and 65-above on household electricity use in Azerbaijan. The study established that the age group15–64 which captures the working population has the highest significant impact on electricity consumption.

Chévez, Barbero, Martini, and Discoli, (2017) applied the k-means clustering method to detect the geographical residential areas with homogeneous electricity consumption in the region of Great La Plata, Buenos Aires, Argentina. The study identified socio-demographic indicators that impact electricity demand with a bimonthly data obtained from the electric distribution company. The results show that electricity demand increases rapidly with growing average household size. Places with high number of flats demanded relatively less electricity while areas with poor quality of building construction consumed higher electricity. A multinomial logit model and an ordered probit model was used by Rahut, Behera, Ali, and Marenya, (2017) to examine household factors that influence adoption of electricity for lighting only and for lighting and cooking in four African countries (Ethiopia, Malawi, Tanzania and Uganda). Results indicate that education, wealth, access to infrastructure and location explain the variation of electricity use for lighting only or lighting and cooking.

Aydinalp-Koksal and Ugursal (2008) modelled residential electricity consumption in Canada based on household characteristics to compare modelling techniques: neural network, engineering and conditional demand analysis (CDA). The neural network model showed that income, appliance ownership and usage, dwelling type and household composition influence electricity consumption. Matsumoto (Matsumoto, 2016) used CDA model to examine how socioeconomic characteristics impact appliance use considering 12 categories of household appliances based on micro-level dataset secured from the Nation Survey of Family and Expenditure in Japan. The findings indicate that family structure and income level affect appliance usage and households tend to use more electricity for newly purchased personal computers than older ones.

Jones and Lomas (Jones & Lomas, 2016) collected a large-scale, city-wide survey data and applied the odds ratio (OR) statistical method to analyze the impact of appliance ownership and use factors on electrical energy demand in UK households. The findings suggest that households owning more than 30 appliances have increased probability of contributing to high residential electricity demand. Sanquist et al. (Sanquist, Orr, Shui, & Bittner, 2012) applied multivariate statistical approach to analyze lifestyle factors in residential electricity consumption based on the 2001 US residential energy consumption survey (RECS) data. Findings of the study show that lifestyle factors account for about 40% of variance in electricity consumption. Zhou and Teng (Zhou & Teng, 2013) applied an econometric model to urban-scale survey data collected from Sichuan Province in China to estimate income and price elasticities of domestic electricity demand, along with the influence of lifestyle related variables. The results show that domestic electricity demand is price and income inelastic while lifestyle-related variables such as appliance ownership, dwelling size and demographic variables are significant determinants of electricity demand. Wiesmann, Azevedo, Ferrao, and Fernandez, (2011) used an econometric model to assess the influence of household characteristics on residential electricity consumption in Portugal using 2 distinct scales of data set (bottom-up and top-down). Analyses results at both scales were consistent in showing that household characteristics have significant impact on residential electricity use. The direct effect of income on electricity consumption was low. Socio-economic factors and changes in housing stock were projected as drivers of future electricity demand.

Ozawa, Kudoh, and Yoshida, (2018) developed an energy use model based on survey of household appliances and hot water use to evaluate the effect of energy conservation measures. The findings of the study show that greenhouse gas emissions can be cut down by purchasing new refrigerator and using LED lamps in living/dining room. Shimoda, Fujii, Morikawa, and Mizuno, (2004) modelled hourly electricity consumption based on variations in household and dwelling characteristics for Osaka city, Japan. The results indicate that electricity consumption is significantly influenced by the dwelling's thermal characteristics, external temperature, occupant's time-of-use and appliance efficiencies. Other related studies that examine the influence of household characteristics on electricity consumption and/or reduction strategies

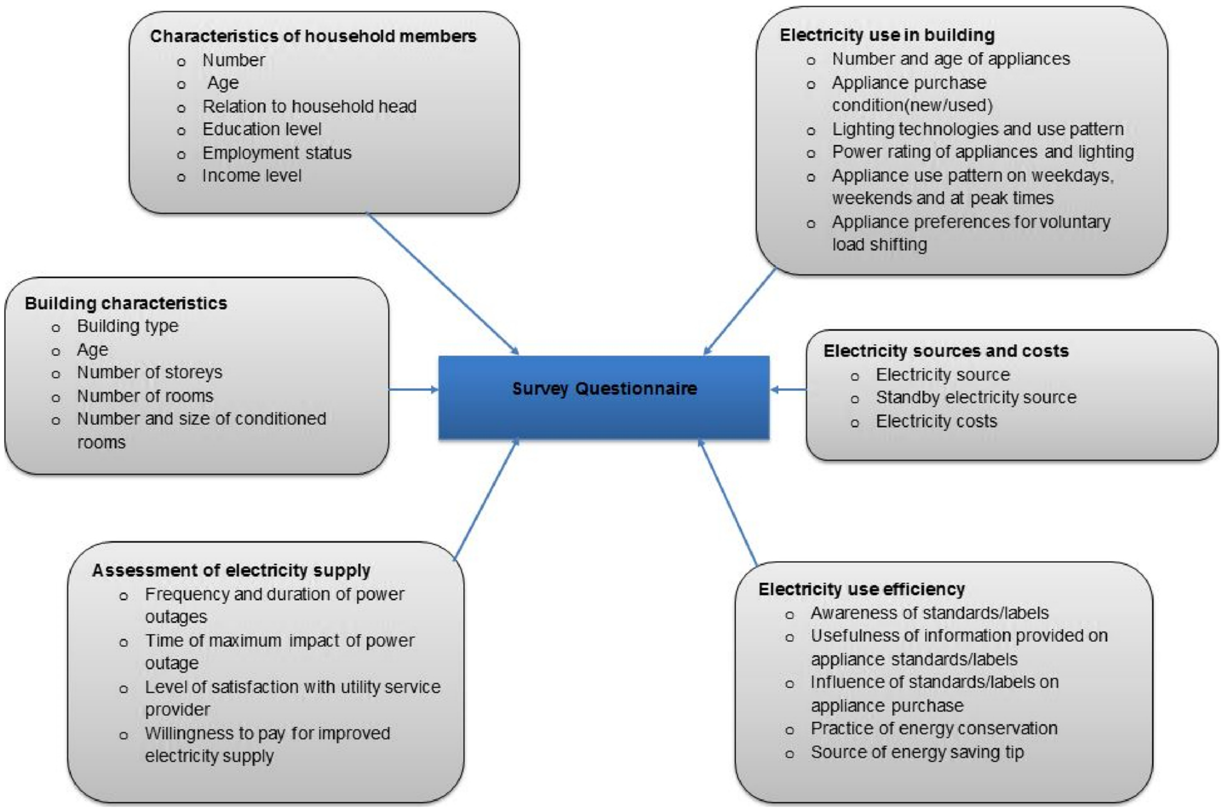

Fig. 1. Framework of residential electricity consumption survey (RECS).

(energy efficiency and conservation) are discussed in (Cialani & Mortazavi, 2018; Coleman, Brown, Wright, & Firth, 2012; De Almeida, Fonseca, Schlomann, & Feilberg, 2011; Fan, MacGill, & Sproul, 2017; Hu, Yoshino, & Jiang, 2013; Iwafune & Yagita, 2016; Leahy & Lyons Sean, 2010; Louw, Conradie, Howells, & Dekenah, 2008; Nakano et al., 2018; Sheng, Loi, & Ng, 2018; Suástegui Macías et al., 2018).

Based on the reviewed methodological approaches, data type and ensuing results, there is a congruent of thought which suggests that the statistical/regression approach is usually preferred when dealing with sizeable datasets and can deliver in-depth understanding of the variations in the dependent variable (e.g. electricity consumption, appliance ownership, etc.). The major drawback is their high possible cost of implementation and possible issues of multi-collinearity between variables (Mcloughlin et al., 2012). The engineering approach can use data related to the power ratings of an appliance to estimate electricity consumption pattern. The advantage of this approach is that it does not necessarily require any historical data to model electricity consumption (Mcloughlin et al., 2012). The challenge is that its implementation can be complex and requires validation. The neural network can simulate electricity consumption of a building using mathematical model of biological networks. This approach can use input data from a complex number of independent variable(s) and provides reliable and accurate results. The drawback is problems related to multi-collinearity of the input variables (Mcloughlin et al., 2012).

Authors in this study use measured electricity consumptions as dependent variables and survey results of socio-economic and building characteristics as independent variables in a multiple linear regression analysis to identify the underlying determinants of variations in appliance ownership and household electricity consumption in Ghana. The study makes this information available to the scientific community as foundation for further research.

3. Methodology

Many previous studies have been undertaken worldwide on electricity consumption of households to support policy design (Jones & Lomas, 2015) and electricity supply infrastructure planning (Willis, 2002). Data gathering in these studies is usually conducted either through household energy end-use surveys or end-use monitoring/logging (HEEPS, 2010). This study combines both approaches, supplementing measured appliance electricity use and household meter readings with the results of a residential electricity end-use (REC) survey to enhance data accuracy and enable a more meaningful analysis of the results. Meter readings provide data on total electricity consumption which is used to obtain shares of the investigated appliances whereas survey results provide data for assessing the sensitivity of electricity use to selected socio-economic and building factors. The residential electricity end-use survey was designed by authors in close collaboration with the International Energy Studies group of Lawrence Berkeley National Laboratory and executed by research partners on the ground at the Regional Maritime University in Ghana. While isolated surveys have been conducted to collect data, to the authors' knowledge this is the first study on residential electricity use and appliance ownership in Ghana that combines both survey results and end-use monitoring to yield a comprehensive analysis of city-scale electricity end-uses.

3.1. Study area

Tema city is located on latitude 5.67 °N and longitude 0.00 °E, in the coastal savannah zone (Tema Metropolitan Assembly, 2014). The city is on the Bight of Benin and Atlantic coast of Ghana. It is located 25 km east of the capital city; Accra, in the region of Greater Accra, and is the capital of the Tema Metropolitan District (Tema Metropolitan Assembly, 2014). The city has a very hot and humid climate. Annual high temperature averages above 30 °C and humidity levels reach 80%

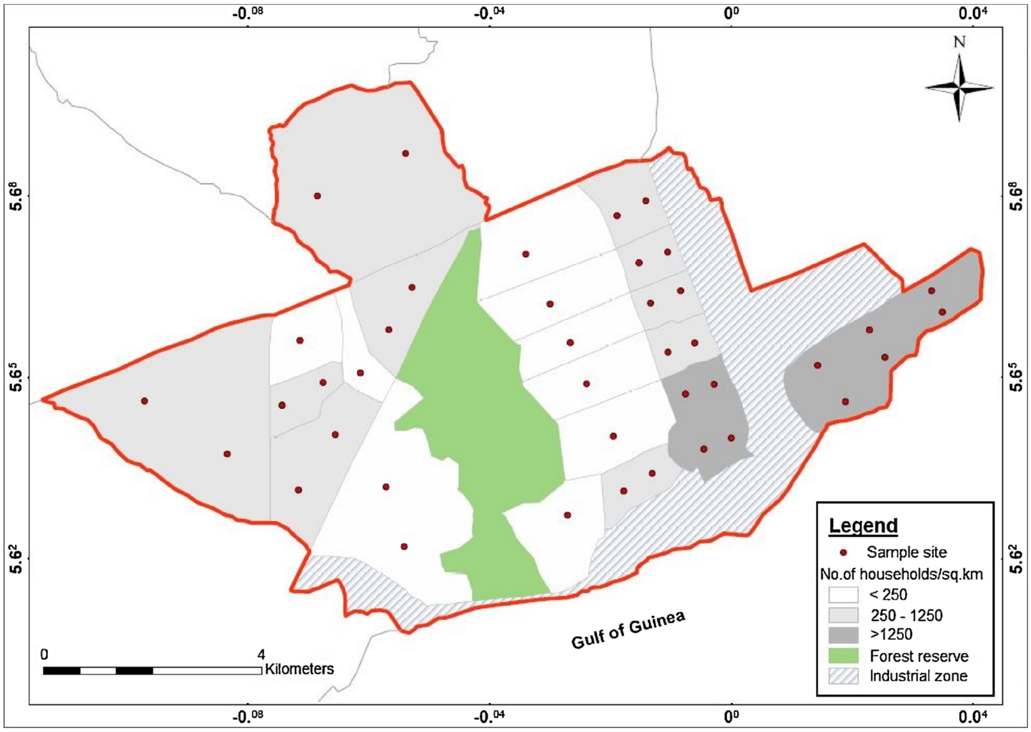

Fig. 2. Tema metropolitan map showing distribution of sampled household locations and household densities.

June through September (Agency, 2007; Meteoblue, 2018; Nyarko, 2014) Tema is the 11th most populous settlement in Ghana with a population of appropriately 292,773 and is home to 70,797 households (Nyarko, 2014).

3.2. Data collection

3.2.1. Survey design

An overview of the survey content and coverage area are as shown in Figs. 1 and 2 respectively. The survey approach included the use of questionnaires and interviews with key informants (e.g. household heads). In households where illiteracy was encountered, a guided oral interview approach was adopted. The survey content was anchored on 6 thematic areas consisting of characteristics of household members, electricity usage in buildings, electricity sources and costs, assessment of electricity supply, building characteristics and electricity use efficiency. Eq. (1) was used to determine a sample size of 440 households at a confidence interval of 95% in accordance with the United Nations guidelines for households survey design in developing and transition economies (UN-Department of Economic & Social Affairs Statistics Division, 2005).

$$Sample\ size = \frac{Z^2 \times r(1-r) \times f \times k}{p \times n \times e^2} \tag{1}$$

Where z is the z-score, which is 1.96 at a 95% confidence level; r is an estimate of a key indicator to be measured by the survey; f is the sample design effect, assumed to be 2.0; k is a multiplier to account for the anticipated rate of non-response (value of 1.1); p is the proportion of the total population accounted for by the target population and upon which the parameter, r, is based; n is the average household size; e is the margin of error (10% of r; thus $e = 0.10r$).

Initially, 440 households were approached out of which 126 participated in the survey which was conducted between June and August 2017. The reduced sample size is due to unwillingness of some households to participate for reasons pertaining mostly to data privacy and security. Individual households were selected randomly (Ahemen, Amah, & Agada, 2016) following geographic stratification of household densities (ratio of number of households to land size/area). The communities were classified into three household densities: high density (more than 1250 households per square kilometer), medium density (between 250 and 1250 households per square kilometer) and low density (less than 250 households per square kilometer). The resulting sample size distribution was 23% for low density communities, 67% for medium density communities and 10% for high density communities. Household income/social class in Tema city is a function of household density. For instance low density areas correspond to high income households and high density areas correspond to low income households (Tema Metropolitan Assembly, 2014). The survey results are therefore a good stratified representation of the city in terms of geographic distribution and household income which is directly related to appliance ownership and hence electricity consumption (Daioglou, van Ruijven, & van Vuuren, 2012; Gyamfi et al., 2018; Mensah et al., 2016).

The survey outcome provided data about appliance ownership and use pattern, household demographics, building characteristics and energy use, electricity sources and costs, appliances preferences for voluntary demand shifting, energy use efficiency and quality of power supply as shown in Fig. 1. It should be noted that some of the information gathered in the survey were based on self-reported data. This could lead to inaccuracy in the results obtained due to recollection bias where participants are unable to accurately report data and/or social desirability bias where participants intentionally report incorrect information in order to conform to social norms or to please the interviewer (Jones & Lomas, 2016).

3.2.2. End-use monitoring

In a second step, an energy audit was conducted in the selected households to supplement the survey information. Respondents were asked during the survey whether they would participate in follow-up activities which included regular electricity meter readings and appliance electricity use monitoring. A total of 80 households agreed to take part in the energy audit which was done between June and September 2017. This period is a conservative representation of the year with reference to climate-dependent electrical energy end-uses. The local climate does not vary much over the year (Nyarko, 2014).

The 11 most common electrical appliances and lighting in urban households were selected based on three key criteria: appliances with existing minimum energy performance standards (MEPS) for assessing effects of the legislation (Agyarko, 2015), appliance contribution to load curve (i.e. high-power ratings and long duration of use) and appliance viability for potential demand side management systems. The investigated appliances include; air conditioner, fan, refrigerator and freezer, television, satellite receiver, computer, washing machine, electric pressing iron, microwave oven, electric kettle, rice cooker, and electric water heaters.

For each household, the electricity consumption of the selected appliances were monitored with data logging power analyzers having a time resolution of 30 min over a 24-hour period for a typical weekday, Saturday and Sunday. Average hourly readings were recorded for all monitored appliances and used to obtain daily load profiles for a typical weekday, Saturday and Sunday. The hourly meter readings in the participating households were also monitored to enable accounting for non-investigated loads. The measurement of appliance electricity use counteracts social and reporting biases to which the survey results are subjected. For example, indicated duration of air conditioner use in some households would have resulted in an estimation that is 400% above the measured value if reported results were based on reported use patterns only. Household electrical energy consumption presented throughout this study is therefore limited to appliances owned and used as measured. Furthermore, to understand the reasons for variations in appliance usage patterns over the monitored period, household activity patterns such as room occupancy and schedules for cooking, eating, showering, washing, etc. were observed. Owing to incomplete responses by households to both components of the study, the overall sample size reduced as only 60 households produced a complete dataset for detailed analysis in line with the objectives of the study.

3.3. Data processing

Collected data from the survey and the energy audit were processed and analyzed with standard statistical methods as described below.

3.3.1. Data analysis

The multiple linear regression (MLR) method was used to analyze the data obtained. Regression is used to estimate the unknown effect of changing one variable over another. The MLR function shows the linear relationship between dependent variable (Y) and several independent variables or functions of independent variables (X). Technically, the linear regression estimates how much Y changes when X changes by one unit. The MLR function is presented by Eq. (2):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + ... + \beta_n x_n + \varepsilon \quad (2)$$

Where y is the dependent variable, β_0 is the intercept (the value of y when all the variables are 0), $\beta_{1...n}$ are the regression coefficients, $x_{1...n}$ represent the independent variables, and ε is the random error component which measures how far above or below the True Regression Line (i.e. the line of means) the actual observation of y lies. The mean of ε is zero. We used ordinary least squares (OLS) to estimate all the model regression coefficients. The coefficient of determination (R^2) measures the proportion of variance in the dependent variable that is predictable from the independent variables. It shows how well the values fit the data and is used as a guideline to measure the accuracy of the model (Kwame, Agbejule, & Yao, 2016). In this study, the dependent variables used are appliance ownership and electricity consumption based on the context of analysis. The independent variables included socioeconomic and building characteristic factors. The parametric data of the variables used were based on the survey work which is discussed in detail in the subsequent sections. Correlation between independent variables were initially examined to check possible multi-collinearity. The highest correlation coefficients between the independent variables were 0.402 (income and age of household head) and 0.357 (income and floor area). Consequently, there is no difficulty using the selected independent variables in the multiple regression analysis.

3.3.2. Estimation of annual electricity consumption

As the meter readings and appliance electricity use monitoring for each household were taken on different dates, the recorded daily electricity uses were normalized to annual consumption for the year 2017 using Eq. (3) as adapted from Paatero and Lund (2006):

$$UEC_i = 52\ [5^*EC_{wk} + EC_{sat} + EC_{sun}] - [14^*EC_{wk}] + [14^*EC_{sat}] \quad (3)$$

where UEC_i is the unit electricity consumption of appliance i (kWh/yr), EC_{wk} is the electricity consumption measured on a typical weekday (kWh/day), EC_{sat} is the electricity consumption measured on a typical Saturday (kWh/day), EC_{sun} is the electricity consumption measured on a typical Sunday (kWh/day) and the number *14,* is the number of public holidays, which were treated as Saturdays because energy use activity patterns of four holidays monitored within the study period were similar to that of Saturdays.

Measured average daily electricity meter readings when normalized to monthly for the purpose of validating robustness of the estimates, produced an error margin of less than 5% in comparison with average monthly electricity use recorded on bills/prepaid receipts of the participating households for the investigated months. Results of Eq. (3) for investigated appliances during the energy audit provided the data on electricity consumption of appliances used for further analysis in this study.

3.3.3. Data description

3.3.3.1. Socio-economic and building characteristics of the sample population. Relationship of household electricity consumption to socioeconomic and building factors defined in Table 1 such as income grade, number of occupants (household size) and age of household head was investigated with regression analysis. These factors were selected

Table 1
Definitions and numerical values assigned to socio-economic and building factors.

Dependent variable	Average value
Socio-economic factors	
Income Grade	
A	2300 USD/month*
B	1300 USD/month*
C	850 USD/month*
D	400 USD/month*
E	140 USD/month*
Age of household head	
19-34	26.5 years
35-44	39.5 years
45-54	49.5 years
55-64	59.5 years
65-74	69.5 years
75+	79.5 years
Building factors	
Building type	Floor area
Single family detached (SFD)	198 m^2
Apartment block (AB)	106 m^2
Single family semi-detached (SFSD)	78 m^2
Improvised homes (IM)	51 m^2
Multi-family house (MFH)	18 m^2
Household size (number of occupants)	
1	1 occupant
2	2 occupants
3	3 occupants
4	4 occupants
5	5 occupants
6+	6 occupants

Note 1: Income based on 1USD to GHC 4.3959 conversion ratio.

Table 2
Descriptive statistics for independent and dependent-socio-economic and building factors variables.

Variable	No. of records	Unit	Mean	Std. dev	Min.	Max	Mode
Dependent							
Electricity consumption	60	kWh/yr	3234	2653	364	12,578	
Independent							
Income	60	USD/month	906	584	114	2844	569
Building type (floor area)	60	sq. meters	132	93	28	388	96
Household size	60	persons	4.2	1.4	1.0	8.0	4.0
Age of household head	60	years	48	14	20	78	56

based on widely reported statistical significance to residential electricity use as reviewed by Jones, Fuertes, and Lomas, (2015). To gain a better understanding of the data, descriptive statistics are shown in Table 2. Mean values were determined for each group of socioeconomic and building factors as independent variables from the survey information. Floor area was used as proxy for building type in the regression analysis. The average electricity use per household is 3234 kWh/year, income is US$ 906/month, floor area is 132 m^2, household size is 4.2 and age of household head is 48 years. Fig. 3 shows the histogram of the individual household characteristics and electricity consumption and is briefly discussed below.

3.3.3.1.1. Income. About 88% of the participants earn a monthly income ranging from US$ 500–1500 (see Fig. 3 (a)). Close to 37% of households fall within the working-class group (D), 29% in lower middle class (C), 20% in upper middle class (B), 10% in high income class (A) and 4% in low class (E).

3.3.3.1.2. Household size. Majority of the survey participants (92%) have a family size ranging between 2–6 persons (see Fig. 3(b)). Within the different classes of household composition, a family consisting of a couple and dependent children is dominant with a share of 37%, followed by family with dependent children, 32%, family with non-dependent children, 13%, couple with non-dependent children, 12% while couple only and single person accounted for 3% each.

3.3.3.1.3. Floor area. The survey outcome shows that about 78% of participants live in buildings with floor area ranging between 50-200 m^2 (see Fig. 3(c)). The building type that participants reside in vary; 45% live in SFD, 28% in AB, 13% in SFSD, 10% in IM while 3% live in MFH.

3.3.3.1.4. Age of household head. Sizeable number of participants (76%) indicated that the age of the household head ranges from 40 to 60 years (see Fig. 3(d)). Ages between 45–54 accounts for 28% of household heads, 27% for ages between 55–64, 18% for 19–34, 15% for 35–44, 8% for 65–74 and 3% for 75 years and above.

3.3.3.1.5. Electricity consumption. Different households own varying number of appliances based on the income level and lifestyle of the particular household. Majority of the participants (73%) consume electricity ranging from 1000 to 4000 kWh/year (see Fig. 3(e)).

3.3.3.2. Appliance ownership characteristics of the sample population. Fig. 4 indicates that 82% of participants have between 2–10 appliances while 84% have 3–21 number of lighting fixtures (both indoor and outdoor) in their homes. Collectively, every household owns an average of 8 appliances. Indoor and outdoor lighting have the highest saturation of 11.00 and 3.14 respectively followed by fans (1.76), T.V (1.43), refrigerators (1.02) while the lowest was electric water heater (boiler) with 0.04 as shown in Fig. 5(a). Ownership of indoor and outdoor lighting and television reached or almost reached 100% whereas fans, electric iron and refrigerators reached between 80–84% (see Fig. 5(b)). The rest of the appliances have ownership rates of less than 50% with the electric boiler lowest at 4%.

3.3.4. Analysis of the effects and reactions to MEPS and energy conservation campaigns

The REC survey provided data on energy efficiency awareness and practice from three categories of survey responses: (1) Building occupants' awareness of appliance MEPS, (2) Influence of MEPS labels on decision to purchase appliances and (3) Energy-conservative practices in the home. The responses on these 3 indicators were converted into a single factor by applying a weighting factor of 0.33 to each response. Occupants of houses that had checks for all three factors were classified as having “high” energy efficiency awareness and practice while occupants of houses that had zero checks were classified as having “lack” of energy efficiency awareness and practice as shown in Table 3.

4. Results and discussion

4.1. Profile of measured residential electricity consumption

The magnitude of a household’s electricity demand is dependent on the number of appliances owned (Jones & Lomas, 2016) and the duration of use which was found as explanation for 37% of the variance in residential electricity consumption (Bedir et al., 2013). Results of the measured residential electricity consumption are presented and discussed below.

4.1.1. Variation of load curve per day of the week

Electricity demand profiles of the monitored households on a typical weekday, Saturday and Sunday are shown in Fig. 6. There are two clear peaks on weekdays; morning peak which occurs between 05:00 and 08:00 h, and evening peak which occurs between 18:00 and 22:00 h. The morning peak generally occurs when people have breakfast and prepare for work and/or school. On Saturday and Sunday where there is no preparation for school or work in majority of homes, the morning peak reduces by about 50% while the evening peak stays almost the same. High occupancy on weekends results in higher loads in the late morning and afternoon except for Sunday when electricity demand reduces significantly between 09:00 and 12:00 h as Christians who constitute 90% of the population (Nyarko, 2014) leave home for church service. The evening peak therefore represents the peak load of the residential sector. The average load factor on Weekday, Saturday and Sunday ranged between 36% and 39% over the 24 h period indicating potential and opportunity for demand side management strategies.

4.1.2. Hourly variation of appliance use and contribution to daily residential peak

Lighting is clearly used in the late afternoon and evening when it is dark and throughout the night for outdoor lighting with peaks at 05:00 and 20:00 h as illustrated in Fig. 6. Lighting contributes on average little over 25% of morning peak on weekends (Saturday and Sunday) and 16% on weekdays. The share of lighting in evening peak is about 26% for weekdays and weekends. Technological improvement in lighting fixtures will therefore yield maximum reduction in peak load. For example, a 50% improvement in energy efficiency of lighting technologies on average could translate to 13% reduction in overall daily peak load.

Air conditioners are mainly used in the late afternoons and evenings with evening peaks at 20:00 h for all days. Afternoon peaks are at 14:00 h for weekdays and Sundays when children return from school

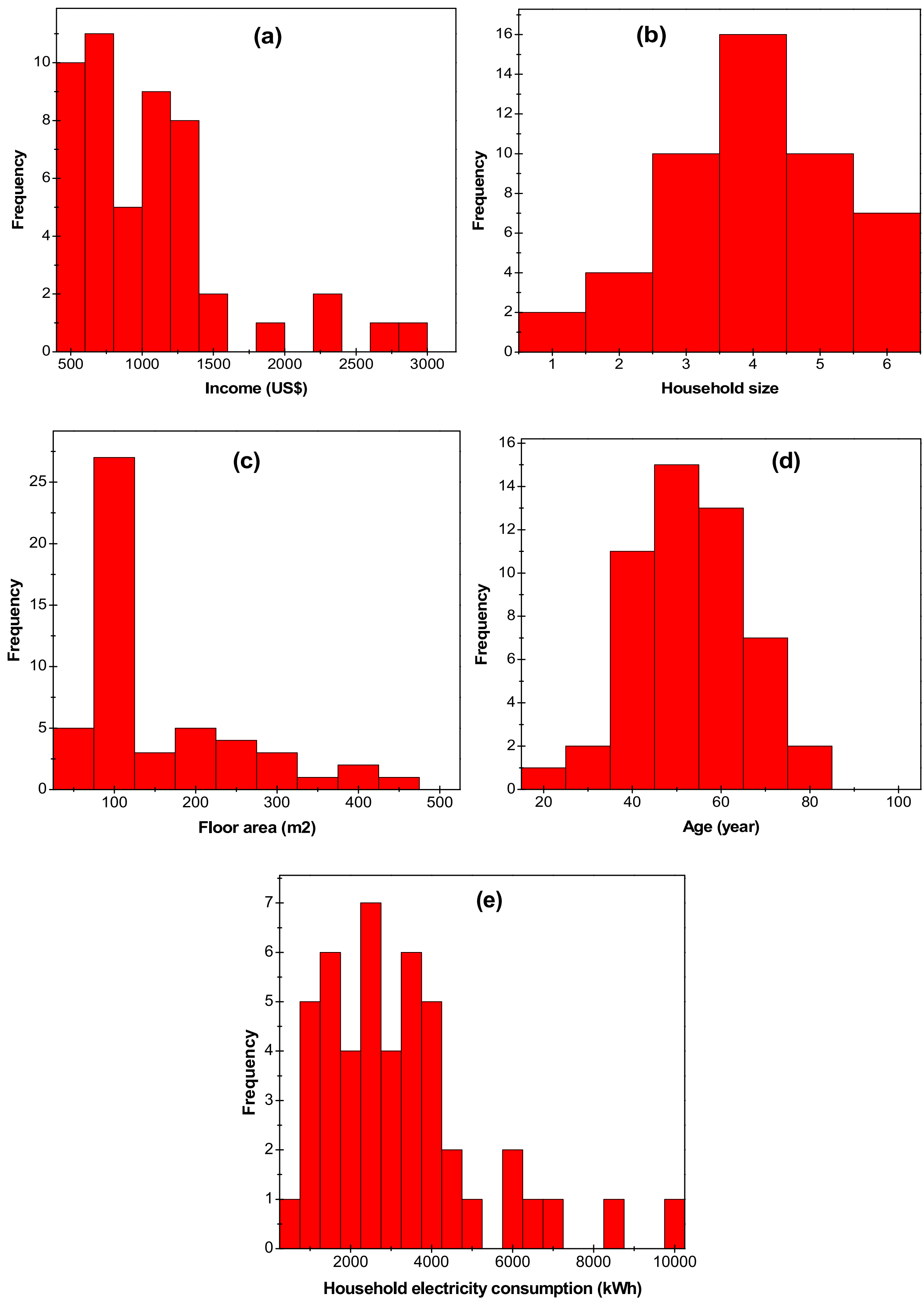

Fig. 3. Distribution of household (a) income, (b) household size, (c) floor area, (d) age of household head and (e) electricity consumption (n = 60).

and the family returns from church respectively, and at 12:00 h on Saturdays when children and/adults are at home. Night time consumption is low. Air conditioners account for 25% of residential peak load which makes it the second priority target for peak reduction.

Refrigeration is used throughout the 24-hour period with noticeable spikes at 20:00 and 14:00 h due to increased frequency of use around

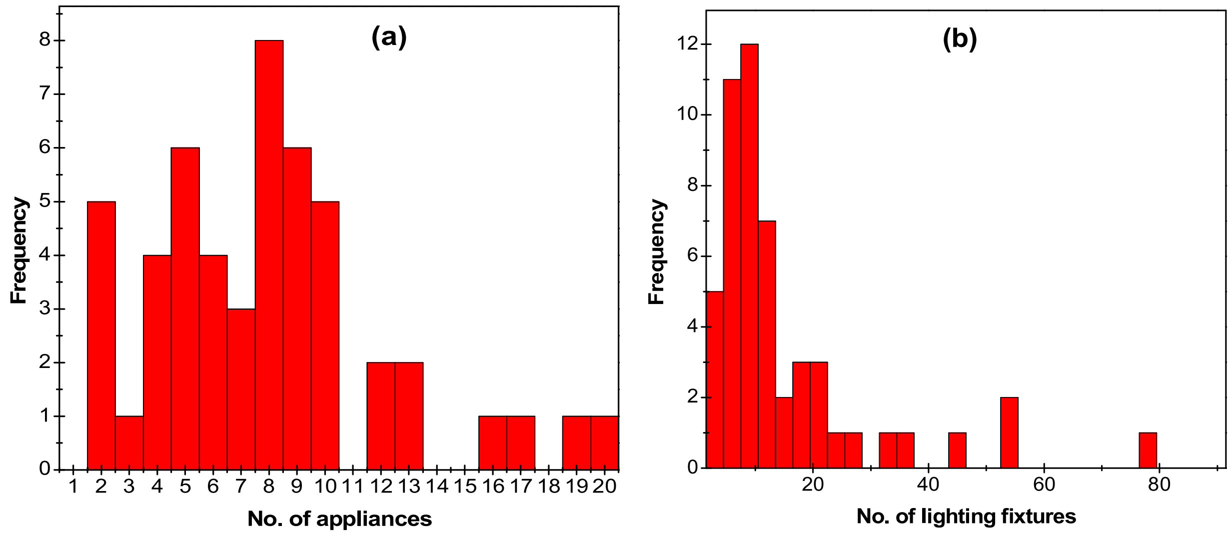

Fig. 4. Distribution of household (a) number of appliances and (b) number of lighting fixtures (n = 60).

dinner time and lunch time when children return from school. Refrigeration contributes 15% of peak load which makes it the third priority target for reducing peak electricity consumption.

Television is mostly used in the late afternoons and evenings with peak between 18:00 and 22:00 h when people are home. Morning consumption is highest on Saturdays when children are home and lowest on Sundays when the families attend church service. There is little “on” or “standby” electricity use at night. Television has 13% share of residential peak load making it the fourth priority target for peak reduction. Satellite receivers are used jointly with television and contribute only 0.5% of peak load.

Fans are used throughout the 24-hour period at a relatively flat consumption rate. Morning use is significantly lower between 05:00 and 11:00 h as some people prepare to leave home. Fan contributes 7% of peak load making it the fifth priority target for demand reduction.

Ironing of clothes is mostly done in the mornings with peaks at 06:00 h on weekdays and 08:00 h on weekends in preparation for work, school, church service or stepping out in general. Ironing has notable 20% and 36% share of morning peaks on weekdays and Sundays respectively. There is virtually no ironing in the evenings of these days which could be due to lifestyle activities and behavioral pattern of occupants. Electricity consumption of ironing on Saturdays on the other hand is relatively flat through the morning and evening as people dress up in the morning and straighten clothes for Sunday’s church service in

Table 3
Weighting factors for energy efficiency awareness and practice levels of households.

Classification	Awareness of MEPS (0.33)	Influence of MEPS on purchase (0.33)	Energy conservation practice (0.33)	Numerical value (sum)
High	√	√	√	0.99
Fair	Any two			0.66
Low	Any one			0.33
Lack	None			0
Did not answer				0

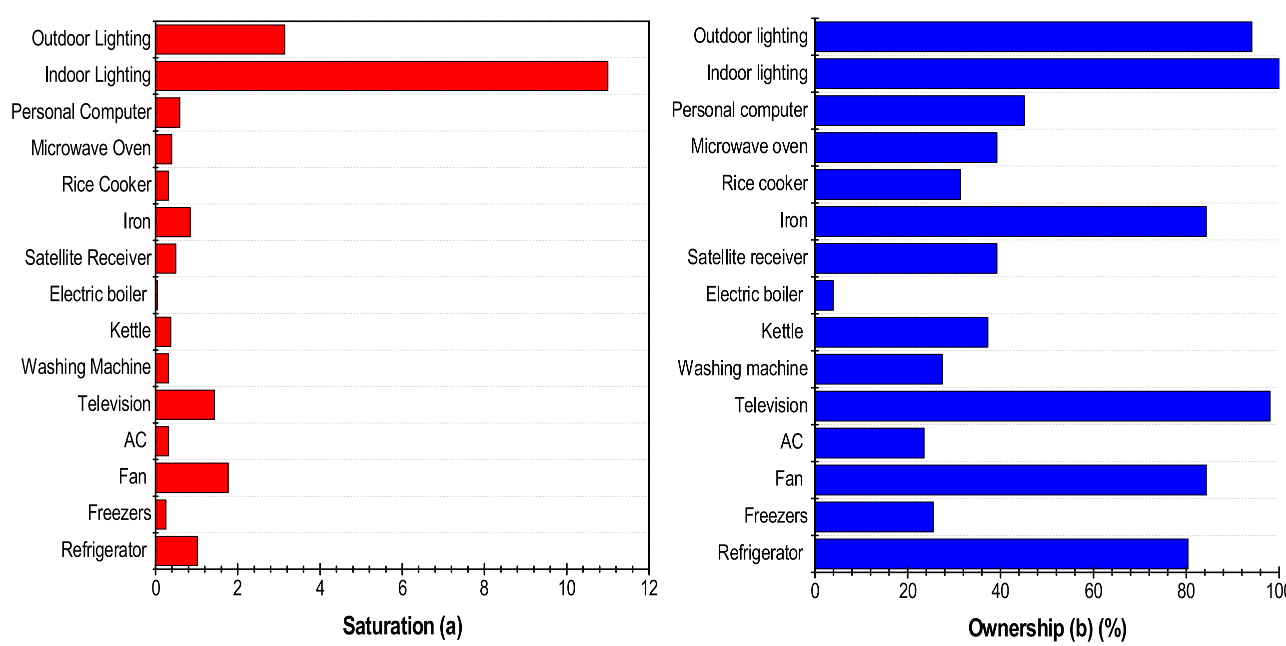

Fig. 5. Household appliance (a) saturation and (b) ownership (n = 60).

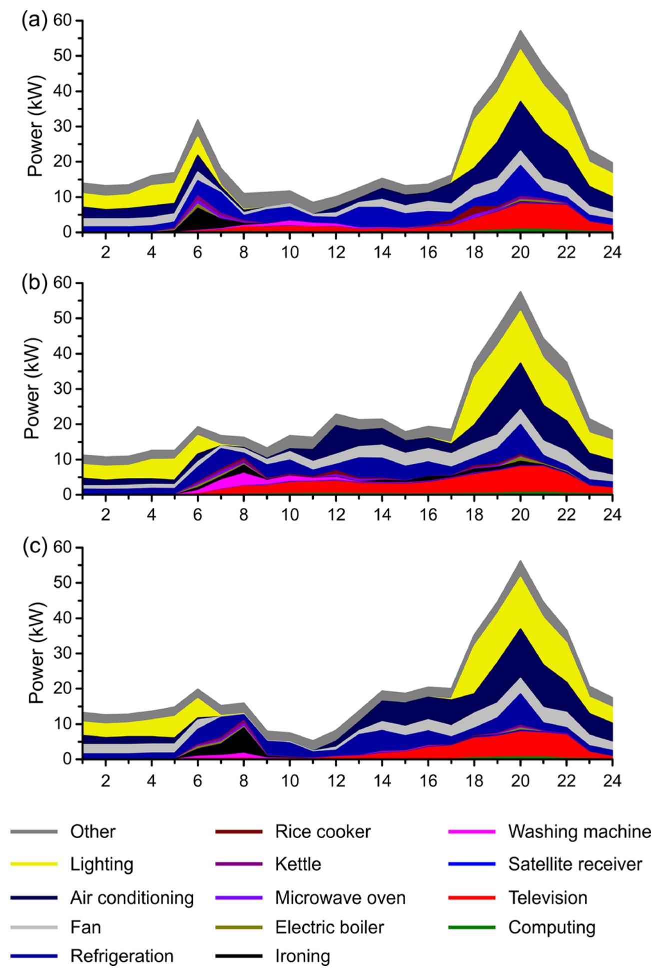

Fig. 6. Hourly variation of appliance electricity consumption in 60 monitored households of Tema city for a typical a) weekday, b) Saturday and c) Sunday.

the evening. The electricity use profile of pressing iron indicates lack of bulk ironing culture amongst residents. While ironing is a very significant contributor to morning peaks, its share of evening peak is only 0.3% on weekdays and Sundays, and 2% on Saturdays.

Computers are mostly used throughout the day and in the evenings with peak between 18:00 and 22:00 h when children/students do their assignments and adults work at home. Others who use computers for entertainment do not turn the equipment off but leave it in standby mode which consumes electricity at night. The contribution of computers to peak load is 2% on weekdays and 1% on weekends.

Washing machines are often used in the mornings with peak between 07:00 and 10:00 h. Evening consumption is very low and there is no night time consumption. Majority of washing is done on Saturday mornings for accumulated laundry during the weekdays. Washing machines contribute 0% of residential peak load.

Electric boiler and kettle are used in the morning between 05:00 and 09:00 h and in the evening between 18:00 and 22:00 h to heat water for bathing in the case of the boiler, and for bathing and food preparation in the case of the kettle. The contribution of electric boiler to peak load is 1% on weekdays and Sundays, and 2% on Saturdays due to increased frequency of warm showers at peak hour. The impact of kettle use on peak load on the other hand is 1% on weekdays and Sundays, and 0.2% on Saturdays due to reduced use in food preparation at peak hour.

Microwave oven and rice cooker are mostly used around breakfast, lunch and dinner times. Rice cooker has noticeable higher consumption on weekdays between 16:00 and 19:00 h due to increased use in "packaged food" preparation for school children. Rice cooker has only 0.15% share of peak load on weekdays and Sundays, and 1% share on Saturdays due to its use in dinner preparation. Microwave oven contributes on average about 0.5% of peak load on all days.

Other than refrigerators that have a steady use, the operating schedules of other appliances are dependent on the activities of occupants.

4.1.3. Distribution of average annual electricity consumption per end-use

The lowest household in terms of electricity use intensity consumed 384 kWh/yr and the highest household consumed 12,578 kWh/yr while the average household consumed 3234 kWh/yr as shown in Table 2. The distribution of annual electricity consumption in the participating households by end-use is as shown in Fig. 7. Lighting, i.e. indoor and outdoor lighting, is shown to be the largest end-use application of electricity and account for 23% of the total electricity consumption. Air conditioner ranks second, accounting for 21% of annual electricity consumption followed by refrigeration (16%), fan (12%) and television (11%). While lighting, air conditioning and refrigeration maintain their ranks for peak load contribution in share of annual electricity use, fan displaces television for the fourth rank due to higher electricity use of fan at off-peak hours as illustrated in Fig. 6.

4.1.4. Flexibility of appliance use at peak load

There is flexibility in the use of priority appliances (i.e. major peak contributors) during peak hours as shown in Fig. 8. Lighting was not

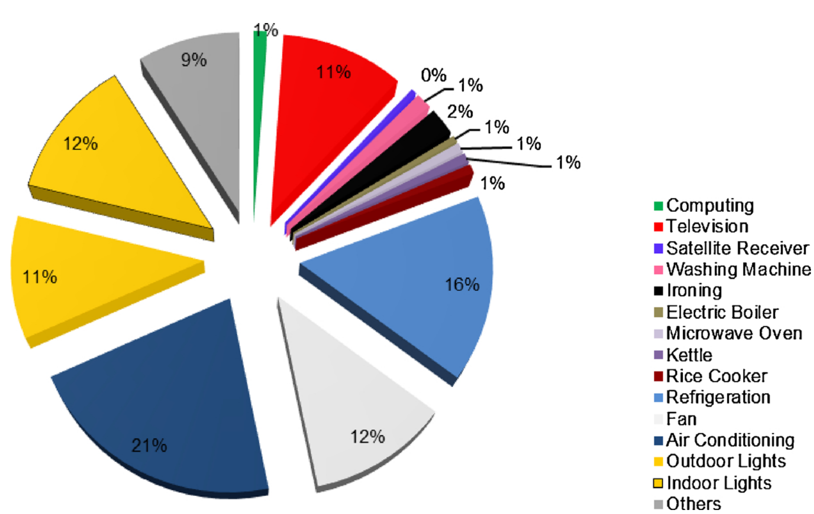

Fig. 7. Annual electricity consumption breakdown in the participating households.

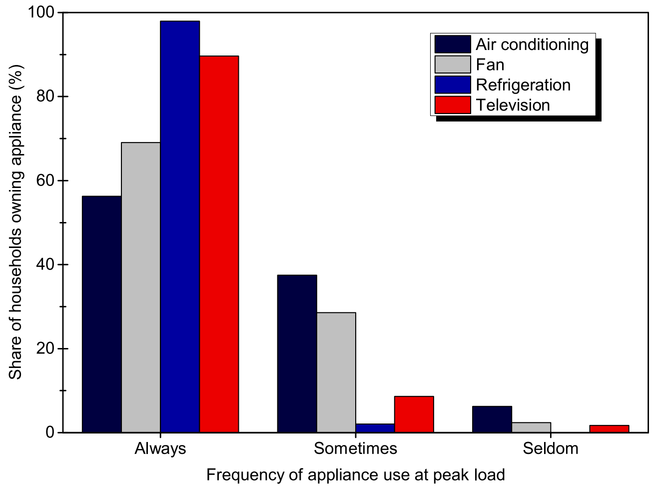

Fig. 8. Flexibility of priority appliance use at peak load.

considered due to its necessity for vision. Electricity demands of appliances that are not in use "always" are considered flexible.

Appliances for space cooling i.e. air conditioner and fan have the highest flexibility of use during peak hours with 44% and 31% of households indicating that these appliances are not always on. Television is the third most flexible peak load at 10% and refrigeration is the least flexible peak load as expected at 2%. These results suggest space cooling as the most significant electricity end-use that residents can comfortably do without during peak hours. Air conditioning alone could reduce residential peak load by 11% (via combination of 44% flexibility and 25% share of peak load).

4.1.5. Appliance preferences for DSM initiatives

In order to prevent temporary curtailing of power supply at critical load of the utility service provider, consumers were asked to indicate which appliances they would voluntarily turn off or change their time of use. Fig. 9. shows that more than 40% of owners of air conditioner, refrigerator and television prefer turning off their appliance or shifting the time of use to temporarily losing their power supply. Management of the use of these appliances could collectively reduce residential peak demand by 28% or yield desired changes in the load profile of power suppliers.

Two pathways exist for demand reduction. Firstly, energy conservation measures with increased energy efficiency (EE) via minimum energy performance standards (MEPS) could reduce both baseline and peak electricity demand. Although MEPS already exist for some

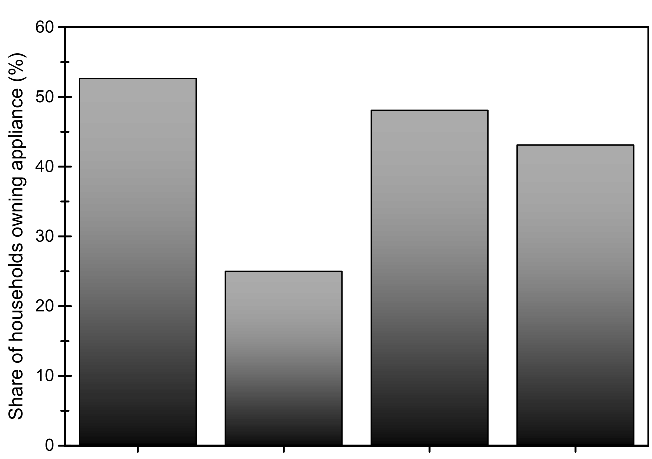

Fig. 9. Appliance preferences for voluntary demand response management.

appliances (i.e. refrigerator, air conditioner, lighting) (Gyamfi et al., 2018), a number of identified high electricity consuming appliances and major contributors to residential peak load (i.e. television, fan, iron) are currently not included in this policy. The range of appliances for which MEPS are required could be extended in addition to continuous revision of existing MEPS requirements in consistency with technological advancement. Secondly, economic means of induced use behavior via increased electricity tariffs or time-based pricing could reduce residential electricity consumption. In December 2015 for example, residents responded to a 59% rise in electricity tariffs with changes in electrical energy consumption patterns, resulting in significant reduction in power demand (GRIDCo, 2017). This report is in line with many studies (Bartusch, Wallin, Odlare, Vassileva, & Wester, 2011; Bradley, Coke, & Leach, 2016; Cosmo & O'Hora, 2017; Thakur & Chakraborty, 2016) that found demand response management has potential to be used as standby power resource and is feasible for application in several parts of the world.

4.2. Appliance ownership

4.2.1. Characteristics of appliance ownership

The survey results on appliance ownership are presented in groups of socio-economic and building factors as illustrated in Table A1 (Appendix A). Electric boiler was excluded from this section of results analysis because only two households owned the appliance. Refrigerators and freezers were combined in this section to represent refrigeration end-use mainly because there were few freezers and their owners were also owners of refrigerators. In this study, appliance ownership refers to the share of households owning one or more type of appliance while saturation refers to the quantity of a given appliance per household (McNeil & Letschert, 2010; Rosas-Flores, Rosas-Flores, & Gálvez, 2011). Often, the total number of households across socio-economic and building factors is 60. Though 126 households provided responses to appliance ownership, electricity uses of the owned appliances were monitored in 60 homes due to high costs and unwillingness of some household participants. Observations from the analysis are presented below.

The share of lamp technologies used for indoor lighting are 62%, 35%, 3% and 0% for compact fluorescent lamps (CFL), light emitting diodes (LED), ballast fluorescent tubes (FL) and incandescent bulbs (INC) respectively while that for outdoor lighting are 62%, 17%, 20% and 1% for CFL, LED, FL and INC respectively. Single family detached (SFD) houses have the highest saturation of lamps at 22 while multi-family houses and improvised homes have the lowest at 3. SFD houses have larger floor area which demands higher lighting needs. The average household uses 11 lamps for indoor lighting and 3 lamps for outdoor lighting.

Over 80% of ownership of air conditioners is amongst household heads aged between 19 and 54 years and in full-time paid employment. Households with dependent children account for 75% of air conditioner ownership. This result is consistent with that of Matsumoto (2016) who finds that younger people use air conditioners more intensely because they prefer cooler temperatures at home although electricity use per capita was higher for household heads above 65 years.

Refrigeration is owned in every category for all socioeconomic and building factors showing that refrigeration is widely owned and a major driver of growth in residential electricity demand.

Ownership of television is highest amongst households with dependent children at 67% and in line with previous study Matsumoto (2016), which found that the presence of teenagers increases use of television. Satellite receivers were used jointly with televisions in monitored households. Similar to television, its ownership is mostly by homes with dependent children.

Ownership of fans is highest in homes comprising of a couple and non-dependent children. The average of such household owns 4.14 fans.

Households whose heads are in full time employment dominate ownership of pressing iron as expected at 76% because it is often used in straightening clothes for work as discussed in section 4.1.2. Computer ownership in homes is about 81% for full-time employed household heads and about 70% for household heads aged between 19 and 54 years, suggesting a "home-working" culture amongst employed residents.

Homes with dependent children dominate ownership of washing machine at 78% due to increased workload that is associated with looking after children who generally use more clothes than adults.

Households with dependent children top ownership of electric kettle at 59% because children are more inclined to have warm shower which is made possible with kettle in most homes. About 53% of ownership of rice cookers is amongst households with dependent children probably because children generally prefer rice as a packaged lunch for school. Similarly, about 67% of ownership of microwave oven is amongst households with dependent children.

4.2.2. Determinants of appliance ownership

A regression model was developed by looking at the effect of socioeconomic and building characteristics on each independent appliance separately. The results of the regression analysis are presented in terms of the regression coefficients which reflect the magnitude and direction of change in the number of a given appliance in a household when the degree of a given socioeconomic or building factor increases by one while holding all other variables constant. Negative coefficient indicates reduction in number of appliances while positive coefficient indicates increase in the number of appliances. The results are presented in Table 4.

A unit rise in household size reduces the number of satellite receivers in a home by 0.123 because household members tend to share the appliance in a common living room. Household size positively influences the number of washing machines at 10% significance level and is supported by higher tendency to generate more dirty laundry as reported in Jones and Lomas (2015).

Age of household head has a negative influence on the saturation of air conditioner, iron and washing machine such that the number of these appliances in a home reduces by 0.013 on average when the age of the household head increases by one. This finding is supported by concentration of ownership of these appliances within 19–64 year groups of household heads in Table A1 (Appendix A). Previous studies in other parts of the world have had similar findings. Leahy and Lyons Sean (2010) found that in Ireland, household heads above 75 years and retired are less likely to have a washing machine. Jones and Lomas (2015) report that in the United Kingdom, homes with household heads older than 65 years likely have fewer occupants who generally own less appliances. A lower number of air conditioners in homes headed by over 65 year-olds in Ghana may be because such households have less income and cannot afford the electricity costs associated with the energy intensive appliance. Compared to working families, retired residents change clothes less often and thus need less use of iron and washing machine.

Floor area positively influences the number of lighting fixtures, air conditioners, refrigerators, televisions, computers, washing machines and rice cookers. A 10 m^2 rise is floor area would increase the number of lamps by 0.9. These findings are supported by (Bedir et al., 2013; Jones & Lomas, 2015) who find that larger floor areas mean additional rooms which demand additional cooling and lighting. Bigger houses in Ghana are mostly owned by the wealthy who can afford domestic workers such as cooks, gardeners, drivers, gate keepers, baby sitters etc., whose presence increases the need for additional appliances.

Income had the expected effect on all appliances. When income increases by US$100, each appliance increases by an average of 0.04 and lighting by 0.8. This result is in line with findings in (O'Doherty, Lyons, & Tol, 2008) that as income increases by £100 in Irish homes, the weighted number of appliances increased by 0.6%.

It can be inferred from the results that economic development in Ghana and associated rise in income levels will not only enable households purchase "new entrant appliances" but will also increase the saturation of existing appliances in homes. While Section 4.1 identifies the highest electricity consumers and major contributors to peak load, this section identifies the specific groups of households that own majority of these priority appliances and provides the basis for developing demand side management initiatives that would guide targeted households to reduce their electricity consumption over time.

4.3. Determinants of household electricity consumption

The electricity consumption of households were regressed against appliance ownership and socio-economic/building variables i.e. income, household size, age of household head, building type and energy efficiency awareness & practice. The derived regression coefficients of the variables are presented in Table 5.

4.3.1. Building type

The size of the floor area positively affects electricity consumption because the larger the house, the more the requirement for lighting and cooling needs to maintain visual and thermal comfort. Single family detached houses have larger floor areas and use an average of 80% more electricity than other building types because single family

Table 4
Regression results for determinants of appliance ownership.

	Household size		Energy efficiency awareness		Age of household head		Floor area		Income	
	Co-eff	Std.err.	Co-eff	Std.err.	Co-eff	Std.err.	Co-eff	Std.err.	Co-eff	Std.err.
Lighting	–	–	–	–	–	–	0.092***	0.017	0.0084***	0.0032
Air conditioner	–	–	0.309*	0.187	−0.016**	0.006	0.002***	0.001	0.0003*	0.0001
Refrigerator	–	–	0.426*	0.229	–	–	0.003***	0.001	0.0006***	0.0002
Television	–	–	–	–	–	–	0.004***	0.001	0.0005***	0.0002
Fan	–	–	–	–	–	–	–	–	0.0009**	0.0004
Computer	–	–	0.478*	0.253	–	–	0.003**	0.001	0.0004**	0.0002
Satellite receiver	−0.123**	0.066	–	–	–	–	0.002*	0.001	0.0006***	0.0002
Iron	–	–	–	–	−0.010**	0.004	–	–	0.0002**	0.0001
Washing machine	0.079*	0.044	–	–	−0.014***	0.005	0.002***	0.001	0.0002*	0.0001
Kettle	–	–	–	–	–	–	0.001*	0.001	0.0003**	0.0001
Microwave	–	–	–	–	–	–	–	–	0.0003**	0.0001
Rice cooker	–	–	–	–	–	–	0.001**	0.001	0.0003**	0.0001

-Not significant.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

Table 5
Statistic for the variables found to be best indicators of a household's electricity consumption.

Variable	Co-eff (standard error)
Socioeconomic and building characteristics	
Income	1.942 (0.912)**
Building type (floor area)	7.151 (5.924)**
Household size	580.433 (318.695)***
Age of household head	–
Energy efficiency awareness and practice	−1277.196 (1230.964)*
Appliance ownership	
Air conditioner	1990.497 (1189.932)**
Refrigerator	226.155 (685.451)*
Freezer	886.322 (1003.405)**
Television	126.715 (836.403)*
Fan	649.459 (307.903)***
Personal computer	–
Satellite receiver	–
Iron	–
Washing machine	–
Electric kettle	–
Electric boiler	–
Microwave	–
Rice cooker	–
Lighting	87.488 (47.488)***

$R^2 = 0.568$.
- Not significant.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

detached houses in the city are owned by high-income households who prefer larger homes to accommodate domestic workers.

Table 5 shows that a 1 m^2 rise in floor area increases a household's annual electricity use by 7 kWh. This result agrees with the findings of Zhou and Teng (2013) in China who found that 10 percentage point increase in the size of a building increases electricity consumption by 1 percentage point. Other studies (Carlson, Matthews, & Bergés, 2013; Jones & Lomas, 2015; Zhou & Teng, 2013) also found buildings with larger floor areas consumed more electricity and attributed the rise in electricity use to larger heating and cooling needs.

4.3.2. Income

Household income is statistically significant with positive coefficient and has varying effect in electricity consumption. A unit rise in the income of the household results in almost 2 kWh increase in electricity consumption. This means that electricity use in a home increases with rising income mainly because the number of appliances which offer opportunity for electricity use in a home, is proxy to wealth. The more households purchase appliances and use it frequently, the more the electricity consumption, ceteris paribus. This finding is consistent with previous studies (Carlson et al., 2013; Jones & Lomas, 2015; Louw et al., 2008; Wiesmann et al., 2011; Zhou & Teng, 2013). For instance, Louw et al. (2008) found that income had a positive relationship with electricity demand in all tested models and suggested that electricity use is a cost-based decision.

4.3.3. Household size and age of household head

Household size has a strong influence on the variance of electricity consumption. For every addition to the number of occupants in a home, the annual electricity consumption of the household increases by 580 kWh as shown in Table 5. The increased consumption is due to increased floor space, appliance ownership, appliance saturation and frequency of use to meet the needs and comfort of the many occupants. Typically, with relatively similar lifestyle, more household occupants result in increased consumption. For instance, single family households in detached houses with domestic workers such as drivers, cooks, and gardeners in this study had very high electricity consumption.

Other studies in different parts of the world have reported varying findings on the influence of household size in electricity consumption. A study conducted in Japan by Genjo, Tanabe, and Matsumoto, (2005) found that household size (Beta = 0.23, $p < 0.05$) in addition to income and appliance ownership has a significant influence on electricity consumption. Wiesmann et al. (2011) found that occupants of single family houses in Portugal consume more electricity than occupants of multifamily house depicting the concept of economies of scale. The model 4 developed by Louw et al. (2008) on another hand indicated that household size was insignificant (t-value = 0.57) and explained that household size does not affect electricity use since end-use demands of household occupants can be met simultaneously. The differences in the influence of household size on electricity use could be attributed to the different lifestyles and socio-cultural dynamics of the particular environment. Age of household head had no significant influence on electricity use which suggests occupant behavior as a more relevant energy-use driving factor than age.

4.3.4. Appliance ownership, lighting and EE awareness and practice

Lighting and some of the appliances are statistically significant in the variance of electricity use with positive coefficient while EE awareness and practice also show strong significance but with a negative coefficient. Air conditioner, refrigerator, freezer, television and fan were all significant at various levels (99%, 95% and 90%). Air conditioner shows the highest influence followed by freezer, fan, refrigerator and television. These impacts are linked to the high shares of end-uses such as cooling, refrigeration and entertainment which collectively account for about 48% of households' annual electricity consumption. Appliances such as personal computer, satellite receiver, iron, washing machine, electric kettle, electric boiler, microwave and rice cooker show no significance at all which can be explained by their negligible running power and/or relatively low frequency of use. The holding of appliance may reflect partially the effect of home appliances on electricity use but its power and rate of use is key. Lighting is very significant in the variance of electricity use because various homes have high number of lighting fixtures and long hours of use. Some few households leave lights on in unoccupied rooms.

Table 5 shows that a unit increase in the number of lighting fixtures increases household electricity consumption by 87 kWh annually. Lighting is a major factor and this is supported by Genjo et al. (2005) who found that lighting and household appliances contributed 3 MWh and 60% of the variance in the yearly electricity consumption of 505 Japanese households. The results for the EE practice and awareness is expected because as households purchase efficient appliance and use it cautiously, the energy required to meet the same specific end-use service is curtailed. This means households with large consumption who effectively partake in EE activities save and minimize waste in electricity use.

Collectively, these factors, i.e. income, household size, age of household head, building type and energy efficiency awareness & practice explain 57% of variance in residential electricity consumption. These results are particularly valuable to city planners and developers in designing local building and energy regulation towards energy-efficient communities. They also provide a key reference for grid operators and utilities to better predict future electricity demand growth, plan grid expansion in existing communities and design grid capacity for new developments.

5. Policy implications

5.1. Effects and reactions to energy efficiency initiatives

5.1.1. Minimum energy performance standards and labelling (MEPS)

Lighting fixtures, air conditioners and refrigerators in Ghana have energy efficiency labels. Fig. 10 shows that about 42% of the respondents claim they would pay attention to energy efficiency label when buying an appliance and 38% of the respondents claim they

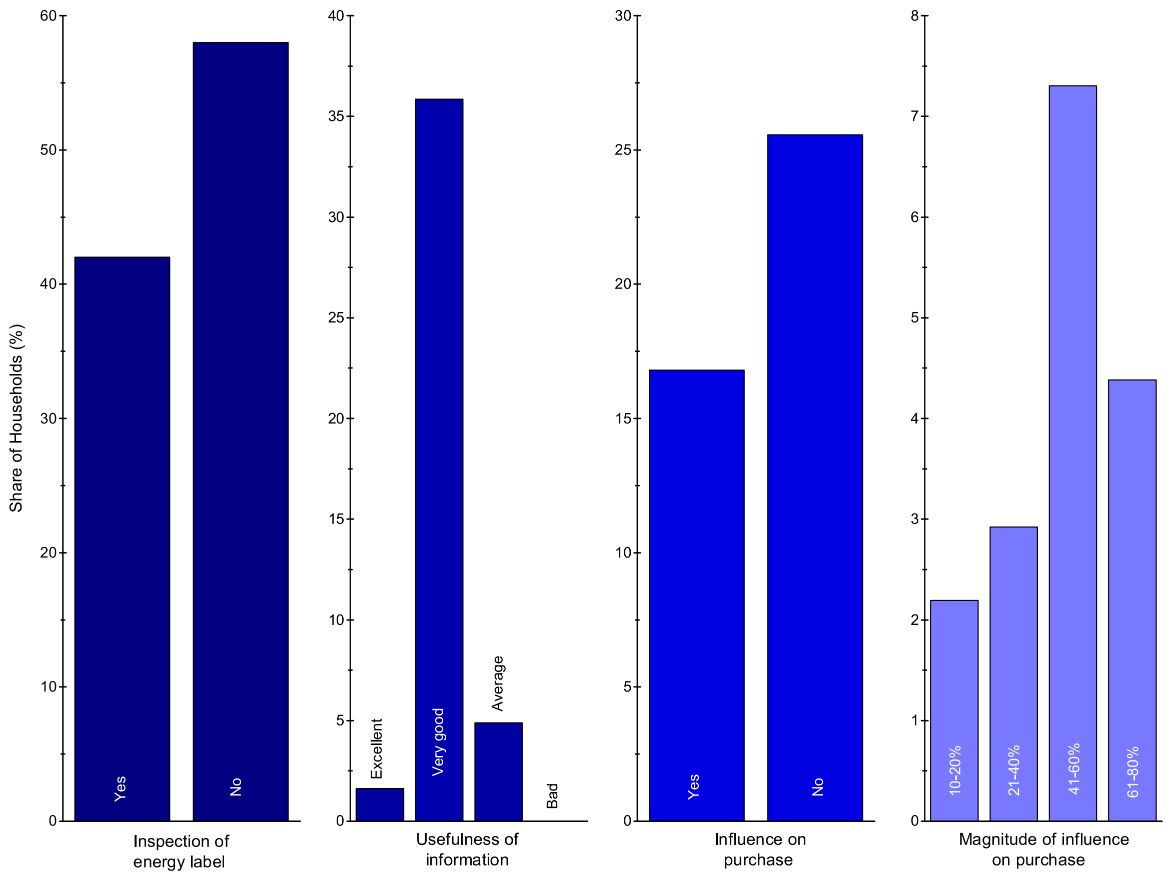

Fig. 10. Reaction to minimum energy efficiency standards (MEPS).

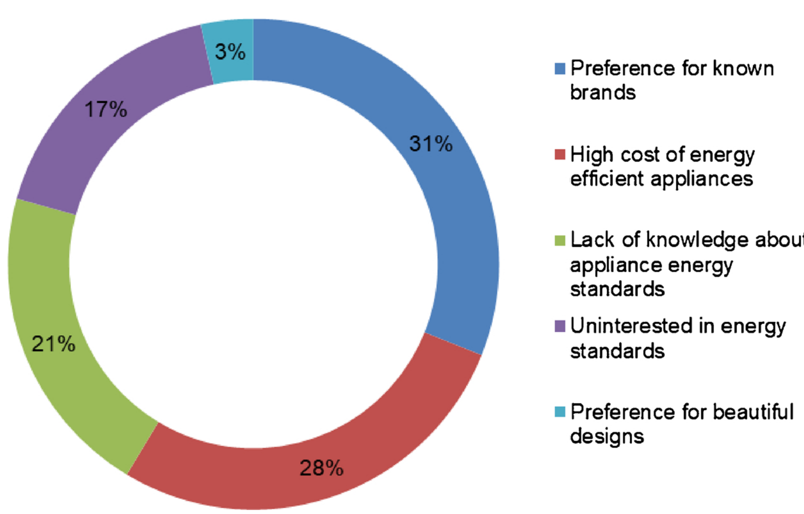

Fig. 11. Key barriers to purchasing energy efficient appliances.

found information on the label extremely useful, indicating that the promotion of Ghana's MEPS had positive impact. However, only 17% of the respondents claim their decision to purchase a particular appliance would be influenced by its energy label. Preference for trusted brands and high costs were identified as the key barriers to purchase of highly efficient appliances, with 31% and 28% of the respondents specifying these reasons for not buying an energy-efficient appliance respectively as shown in Fig. 11. Explanations for the remaining respondents were split mainly between ignorance and lack of interest, indicating that though some successes have been achieved in promoting Ghana's MEPS, there is still considerable room for improvement.

Ghana and China have similarities in the type and timing of government sponsored energy efficiency initiatives. China sought to rid its homes of incandescent bulbs through the Green Lighting Project in 2004 while Ghana did the same with legislation in 2005 and with the Efficient Lighting Project in 2007 (S. Hu, Yan, Guo, Cui, & Dong, 2017). Both countries invested in public education to promote awareness of the legislation and encourage efficient electricity use behavior (Gyamfi

Table 6
Label classification of the average electricity consumption for monitored appliances.

Appliances	A+++[*]	A++[*]	A+[*]	A[*]	B[*]	C[*]	D[*]	Outdated[*]
Air conditioner						√		
Refrigerator							√	
Freezer						√		
Television[a]								√
Washing machine[a]				√				

Note 2:
[*] appliance standards and label classification based on Ghana's MEPS and energy efficiency index (EEI) in (Diawuo et al., 2018).
[a] MEPS not in-force.

et al., 2018; Hu et al., 2017). After a decade of EE implementation, 44% of urban Chinese households claim they would pay attention to energy efficiency labels when buying an appliance (Hu et al., 2017) which is comparable to Ghana's 42%. High costs was identified as key barrier to the purchase of highly efficient appliances in China (Hu et al., 2017) as it was in Ghana. The share of incandescent bulbs in lighting was only 0.2% (2 out of 817), indicating a highly successful implementation of Ghana's Efficient Lighting Project. This result is in line with the findings of previous studies (Diawuo et al., 2018; Gyamfi et al., 2018). In comparison, (Hu et al., 2017) found incandescent bulbs represent 4% of lighting fixtures in urban Chinese homes.

Table 6 shows how the average electricity consumption of appliances measured in this study conform to Ghana's MEPS. The average electricity consumption of refrigerator and freezer were found to be 375 kWh/yr and 417 kWh/yr respectively, both of which meet their respective MEPS. This result could be explained by the use of the city as pilot for Ghana's Refrigerator Energy Efficiency project, and is consistent with (Gyamfi et al., 2018) who found that households who participated in the project had the electricity consumption of their refrigerators reduced to 385 kWh/yr. The average television in the city was found to consume 225 kWh/yr and outdated. Television is very widely owned, second to refrigeration (refer Table A1 in Appendix A) and as such, is a major driver for growth in residential electricity consumption. Similarly, the average air conditioner was found to consume 2221 kWh/yr and outdated though this consumption meets the MEPS. Air conditioner was found to contribute 25% of peak load (Section 4.1). These results show great potential for energy savings and emphasize the need for revision of existing MEPS as well as expansion of coverage of appliances for which MEPS are required. Regulatory policies should be supported by financing incentives to overcome the barriers to penetration of highly efficient appliances in Ghanaian homes.

5.1.2. Energy conservation awareness and practice

About 70% of the respondents claim awareness and practice of energy conservation at home, indicating that Ghana's energy-conservative behavioral campaigns have had some success as shown in Fig. 12. Switching off unused appliances and use of energy-efficient lighting were identified as the most known and accepted energy conservation measures, with 29% and 19% of the respondents specifying these as their energy-saving practice respectively. Another 12% of respondents claim they would switch off air conditioning to conserve energy, supporting the argument that this appliance could be a priority target for residential load management.

Television was identified as the most effective medium for launching energy-efficient behavioral campaigns, with 35% of respondents indicating it as their main source of information. Education on energy-use efficiency in schools and friends were the second most successful means with 10% of the respondents choosing each channel as their source of information. Broad energy conservation and energy efficiency advocacy on major television channels as well as intensified teaching of energy-saving behavior in schools should be given priority in educating the public on the efficient use of electricity at home.

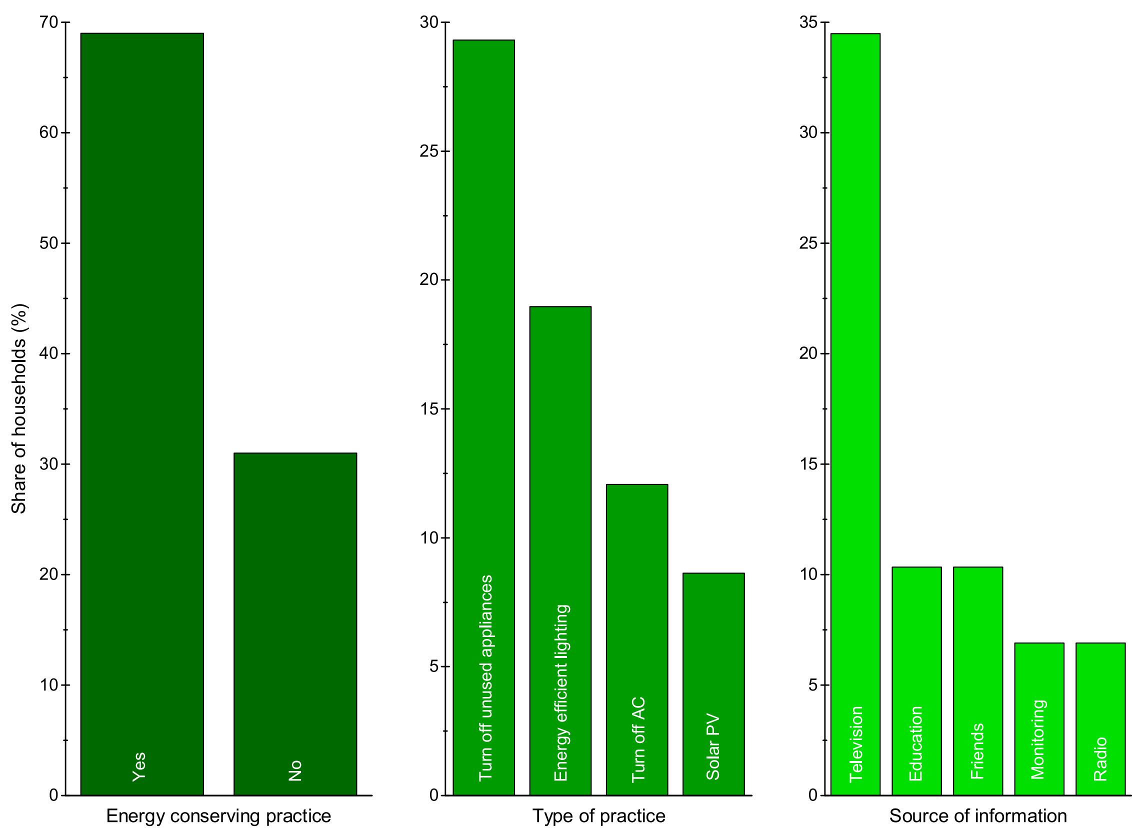

Fig. 12. Reaction to energy saving behavioral campaigns.

6. Limitations of the study

Though this study has provided considerable insight, the results obtained are limited by three main restrictions; the sample size available for analysis, time period for electricity end-use monitoring and proclivity of socio-economic and building factors to reporting biases. While a total of 440 households in a single Ghanaian city were targeted in the whole survey, the eventual sample size used in the analysis reduced to 60 households because many respondents did not provide a complete set of data, and high cost of end-use monitoring limited coverage to a smaller fraction of households. This resulted in small group sizes for some socioeconomic and building factors. The distribution nonetheless, was able to capture all groups under consideration. Further research is required to ensure better level of representation with regards to the wider population of Ghanaian homes to validate generalization of the findings.

Electricity end-use monitoring was conducted for selected households over a 24-hour period of time on a weekday as well as Saturday and Sunday. The weekday measurements were assumed to be representative of all other weekdays during the year, as were the Saturdays and Sundays. A year-long end-use monitoring study would be beneficial to accurately capture seasonal variations in household electricity consumption and the usage patterns of the various appliances but would also entail significant cost implications.

Aside floor area/building type which could be verified, information on other socio-economic and building factors used in this study were derived from self-reported data and are subjected to reporting biases of the respondents.

Future study on the functions of appliances and the activity patterns of household occupants could further provide substantial insight into electricity consumption in residential buildings. A follow-up study on assessing the potential of balancing and trimming the peak of the load curve through voluntary demand response strategies could be interesting.

7. Conclusion

This study combines a residential electricity consumption survey (RECS) with electricity end-use monitoring of 60 households conducted between June and September 2017 in Tema Ghana, to yield a comprehensive investigation of city-scale electricity consumption in Ghanaian homes. To the authors' knowledge, this is the first electricity end-use monitoring study carried out in Ghana. Meter readings provide data on total household electricity consumption which is used to obtain shares of measured appliances' electricity consumption whereas survey results provide data for assessing the sensitivity of electricity uses to selected socioeconomic and building factors.

Lighting, air conditioning, refrigeration, television and fan are found to collectively contribute 85% of residential peak load. The results suggest space cooling i.e. air conditioning and fan, as the most significant end-use with flexibility in operating schedule during peak period. Management of the use of air conditioning alone could reduce residential peak load by 11%.

This study identifies the vast majority of ownership and electricity use of air conditioners is amongst household heads aged between 19 and 54 years and in full-time paid employment. Refrigeration is widely owned and high-income earners own twice as many refrigerators as low-income earners. Ownership of fans increases with increasing levels of income and highest in homes with non-dependent children. The presence of dependent children in a home is found to increase ownership of television, iron, washing machine and small kitchen appliances. The presence of retirees as household heads on the other hand, is found to decrease ownership of air conditioners, washing machines and irons in a home.

The results show that income, household size, floor area and ownership of some appliances such as air conditioner, freezer, fan, refrigerator and television are significant determinants of household electricity demand. This study reveals the importance of socioeconomic and household factors with regards to electricity consumption in Ghanaian homes and enables development of policies that go beyond the usual consideration of income to reducing the impact of such social and building characteristic influences on residential load growth. Residential building energy standards that require optimization of lighting and cooling energy intensity could be implemented for instance, to curb load growth due to increasing building floor area and air conditioning.

Although Ghana's minimum energy performance standards (MEPS) have had successful promotion, this study finds that the energy label influences only 17% of residents' decision to purchase an appliance due to high cost of efficient ones and preference for trusted brands. Switching off unused appliances and use of energy-efficient lighting are identified as the most known and accepted energy conservation measures and television as the most effective medium for launching energy-efficient behavioral campaigns. The range of appliances for which MEPS are required should be extended in addition to continuous revision of existing MEPS requirements in consistency with technological advancement, to counteract electricity demand of appliances from "trusted brands" that may otherwise be energy-inefficient. Introduction of fiscal incentives, subsidies, soft loans and other credit facilities could be effective in eliminating the high cost barrier to purchase of highly efficient appliances. As price sensitivity exists for appliance ownership amongst income groups, effective discrimination of these incentives is necessary to avoid excessive appliance ownership and saturation which can thwart the purpose of such schemes.

Overall, the results of this study increase understanding of the patterns of appliance ownership and residential electricity consumption associated with social and economic variation in Ghana's urban homes and provide a foundation for developing more tailored energy-saving policy interventions. They also provide a key reference for grid operators and utilities to better predict future electricity demand growth, plan grid expansion in existing communities and design grid capacity for new developments.

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Appendix A

Table A1
Characteristics of appliance ownership.

	Number of households owning 1 or more & percentage	Average number of appliances per household	Number of households owning 1 or more & percentage	Average number of appliances per household
Factors	**Lighting**		**Air Conditioner**	
Income grade				
A	13 (10%)	22	4 (33%)	1.50
B	25 (20%)	25	4 (33%)	1.50
C	36 (29%)	14	2 (17%)	1.50
D	47 (37%)	8	2 (17%)	1.00
E	5 (4%)	2	0	
Employment status				
Self employed	18 (14%)	4	0	
Full-time paid work	83 (66%)	16	11 (92%)	1.36
Retired	15 (12%)	10	1 (8%)	1.00
Unemployed	5 (4%)	9	0	
Full-time higher education	5 (4%)	6	0	
Household size				
1	5 (4%)	12	0	
2	18 (14%)	33	2 (17%)	1.00
3	25 (20%)	10	1 (8%)	1.00
4	37 (29%)	11	2 (17%)	1.50
5	20 (16%)	8	2 (17%)	1.50
6+	21 (17%)	25	5 (41%)	1.40
Household composition				
Single person	5 (4%)	12	0	
Couple only	5 (4%)	36	2 (17%)	1.00
Couple with dependent children	52 (41%)	17	6 (50%)	1.33
Couple with non-dependent children	15 (12%)	13	1 (8%)	2.00
Family with dependent children	34 (27%)	9	3 (25%)	1.33
Family with non-dependent children	15 (12%)	15	0	
Age of household head				
19-34	21 (17%)	7	2 (17%)	1.50
35-44	20 (16%)	18	3 (25%)	1.67
45-54	35 (28%)	14	5 (41%)	1.20
55-64	35 (28%)	12	0	
65-74	11 (9%)	16	2 (17%)	1.00
75+	4 (3%)	17	0	
Building type				
SFD	64 (51%)	22	10 (84%)	1.40
SFSD	18 (14%)	8	1 (8%)	1.00
AB	34 (27%)	7	1 (8%)	1.00
MFH	5 (4%)	3	0	
IM	5 (4%)	3	0	
Energy efficiency awareness and practice				
High	39 (31%)	16	7 (58%)	1.29
Fair	9 (7%)	18	1 (8%)	2.00
Low	45 (36%)	14	3 (25%)	1.33
Lack	30 (24%)	11	1 (8%)	1.00
Did not answer	3 (2%)	12	0	
Factors	**Refrigeration**		**Television**	
Income grade				
A	5 (10%)	2.20	5 (10%)	2.40
B	10 (20%)	1.50	10 (20%)	1.70
C	15 (29%)	1.45	15 (29%)	1.40
D	19 (37%)	1.27	19 (37%)	1.17
E	2 (4%)	1.00	2 (4%)	1.00

(*continued on next page*)

Table A1 (*continued*)

	Number of households owning 1 or more & percentage	Average number of appliances per household	Number of households owning 1 or more & percentage	Average number of appliances per household
Employment status				
Self employed	7 (14%)	1.14	9 (16%)	1.11
Full-time paid work	34 (66%)	1.39	42 (72%)	1.50
Retired	6 (12%)	1.17	6 (10%)	1.50
Unemployed	2 (4%)	1.00	1 (2%)	1.00
Full-time higher education	2 (4%)	1.00	0	
Household size				
1	2 (4%)	1.00	2 (3%)	1.00
2	7 (14%)	1.43	6 (10%)	1.33
3	10 (20%)	1.20	12 (21%)	1.25
4	15 (29%)	1.47	17 (29%)	1.35
5	8 (16%)	1.5	12 (21%)	1.17
6+	9 (17%)	1.89	9 (16%)	2.33
Household composition				
Single person	2 (4%)	1	2 (3%)	1.00
Couple only	2 (4%)	2.5	2 (3%)	2.00
Couple with dependent children	21 (41%)	1.43	21 (36%)	1.57
Couple with non-dependent children	6 (12%)	1.83	7 (12%)	1.71
Family with dependent children	14 (27%)	1.36	18 (31%)	1.22
Family with non-dependent children	6 (12%)	1.33	8 (14%)	1.25
Age of household head				
19-34	11 (22%)	1.27	10 (17%)	1.30
35-44	7 (14%)	1.57	9 (16%)	1.56
45-54	13 (25%)	1.69	16 (28%)	1.50
55-64	13 (25%)	1.23	16 (28%)	1.06
65-74	5 (10%)	1.6	5 (9%)	2.00
75+	2 (4%)	2.00	2 (3%)	2.50
Building type				
SFD	26 (51%)	1.65	27 (47%)	1.74
SFSD	7 (14%)	1.43	7 (12%)	1.43
AB	14 (27%)	1.07	16 (28%)	1.13
MFH	2 (4%)	1.00	2 (3%)	1.00
IM	2 (4%)	1.00	6 (10%)	1.00
Energy efficiency awareness and practice				
High	16 (31%)	1.47	18 (31%)	1.61
Fair	3 (6%)	1.00	4 (7%)	1.50
Low	18 (35%)	1.00	21 (36%)	1.29
Lack	13 (26%)	1.15	14 (24%)	1.36
Did not answer	1 (2%)	2.00	1 (2%)	2.00
Factors	**Fan**		**Computer**	
Income grade				
A	5 (10%)	4.40	5 (19%)	2.33
B	10 (20%)	3.30	9 (33%)	1.67
C	15 (29%)	3.15	8 (30%)	1.33
D	19 (37%)	2.67	7 (26%)	1.00
E	2 (4%)	2.00	0	
Employment status				
Self employed	6 (11%)	2.33	0	
Full-time paid work	39 (74%)	3.13	22 (81%)	1.36
Retired	6 (11%)	3.33	3 (11%)	1.67
Unemployed	1 (2%)	1.00	0	
Full-time higher education	1 (2%)	2.00	2 (7%)	1.00
Household size				
1	2 (4%)	2.00	1 (4%)	1.00
2	7 (13%)	3.29	5 (19%)	1.00
3	10 (19%)	3.40	3 (11%)	1.00
4	16 (30%)	2.56	7 (26%)	1.14
5	10 (19%)	2.90	5 (19%)	1.20
6+	9 (17%)	3.11	6 (22%)	2.33

(*continued on next page*)

Table A1 (*continued*)

	Number of households owning 1 or more & percentage	Average number of appliances per household	Number of households owning 1 or more & percentage	Average number of appliances per household
Household composition				
Single person	2 (4%)	2.00	1 (4%)	1.00
Couple only	2 (4%)	4.00	1 (4%)	1.00
Couple with dependent children	16 (30%)	3.40	8 (30%)	1.88
Couple with non-dependent children	17 (32%)	4.14	5 (19%)	1.67
Family with dependent children	14 (26%)	3.14	9 (33%)	1.00
Family with non-dependent children	7 (13%)	3.29	3 (11%)	1.33
Age of household head				
19-34	10 (19%)	2.20	3 (11%)	1.33
35-44	8 (15%)	3.50	7 (26%)	1.60
45-54	14 (26%)	3.07	9 (33%)	1.33
55-64	13 (25%)	3.31	6 (22%)	1.00
65-74	5 (9%)	2.80	2 (7%)	3.00
75+	3 (6%)	4.50	0	
Building type				
SFD	24 (45%)	3.42	18 (67%)	1.50
SFSD	6 (11%)	2.50	2 (7%)	1.00
AB	17 (32%)	3.12	7 (26%)	1.14
MFH	2 (4%)	1.50	0	
IM	4 (8%)	2.00	0	
Energy efficiency awareness and practice				
High	18 (34%)	2.72	9 (33%)	1.44
Fair	4 (8%)	4.50	5 (19%)	1.67
Low	18 (34%)	2.83	11 (41%)	1.36
Lack	13 (25%)	3.69	2 (7%)	1.00
Did not answer	1 (2%)	2.00	0	
Factors	**Satellite receiver**		**Iron**	
Income grade				
A	4 (15%)	2.00	5 (10%)	1.00
B	9 (35%)	1.33	10 (20%)	1.00
C	9 (35%)	1.11	15 (29%)	1.00
D	4 (15%)	1.00	19 (37%)	1.00
E	0		2 (4%)	1.00
Employment status				
Self employed	1 (4%)	1.00	6 (12%)	1.00
Full-time paid work	24 (92%)	1.21	39 (76%)	1.00
Retired	0		4 (8%)	1.00
Unemployed	1 (4%)	1.00	1 (2%)	1.00
Full-time higher education	0		1 (2%)	1.00
Household size				
1	0		2 (4%)	1.00
2	5 (19%)	1.40	7 (14%)	1.00
3	7 (27%)	1.00	10 (20%)	1.00
4	6 (23%)	1.17	16 (31%)	1.00
5	3 (12%)	1.00	8 (16%)	1.00
6+	5 (19%)	1.40	8 (16%)	1.00
Household composition				
Single person	0		2 (4%)	1.00
Couple only	2 (8%)	2.00	2 (4%)	1.00
Couple with dependent children	13 (50%)	1.08	20 (39%)	1.00
Couple with non-dependent children	1 (4%)	2.00	5 (10%)	1.00
Family with dependent children	6 (23%)	1.00	16 (31%)	1.00

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Table A1 (*continued*)

	Number of households owning 1 or more & percentage	Average number of appliances per household	Number of households owning 1 or more & percentage	Average number of appliances per household
Family with non-dependent children	4 (15%)	1.00	6 (12%)	1.00
Age of household head				
19-34	5 (19%)	1.20	10 (20%)	1.00
35-44	5 (19%)	1.00	8 (16%)	1.00
45-54	10 (38%)	1.30	15 (29%)	1.00
55-64	4 (15%)	1.00	12 (24%)	1.00
65-74	2 (8%)	2.00	4 (8%)	1.00
75+	0		2 (4%)	1.00
Building type				
SFD	14 (54%)	1.36	26 (51%)	1.00
SFSD	3 (12%)	1.00	6 (12%)	1.00
AB	8 (31%)	1.00	14 (27%)	1.00
MFH	1 (4%)	1.00	2 (4%)	1.00
IM	0		3 (6%)	1.00
Energy efficiency awareness and practice				
High	8 (31%)	1.13	18 (35%)	1.00
Fair	2 (8%)	1.50	4 (8%)	1.00
Low	10 (38%)	1.10	16 (31%)	1.00
Lack	4 (15%)	1.25	12 (24%)	1.00
Did not answer	2 (8%)	1.00	1 (2%)	1.00
Factors	**Washing machine**		**Kettle**	
Income grade				
A	4 (21%)	1.00	4 (18%)	1.00
B	5 (37%)	1.00	7 (32%)	1.00
C	6 (32%)	1.00	6 (27%)	1.00
D	2 (11%)	1.00	5 (23%)	1.00
E	0		0	
Employment status				
Self employed	0		0	
Full-time paid work	16 (84%)	1.00	18 (82%)	1.00
Retired	3 (16%)	1.00	3 (14%)	1.00
Unemployed	0		1 (5%)	1.00
Full-time higher education	0		0	
Household size				
1	0		1 (5%)	1.00
2	4 (21%)	1.00	3 (14%)	1.00
3	4 (21%)	1.00	6 (27%)	1.00
4	3 (16%)	1.00	3 (14%)	1.00
5	1 (5%)	1.00	2 (9%)	1.00
6+	7 (37%)	1.00	7 (32%)	1.00
Household composition				
Single person	0		1 (5%)	1.00
Couple only	2 (11%)	1.00	2 (9%)	1.00
Couple with dependent children	10 (53%)	1.00	8 (36%)	1.00
Couple with non-dependent children	3 (16%)	1.00	4 (18%)	1.00
Family with dependent children	3 (16%)	1.00	5 (23%)	1.00
Family with non-dependent children	1 (5%)	1.00	2 (9%)	1.00
Age of household head				
19-34	0		4 (18%)	1.00
35-44	2 (11%)	1.00	3 (14%)	1.00
45-54	8 (42%)	1.00	7 (32%)	1.00
55-64	5 (26%)	1.00	4 (18%)	1.00
65-74	3 (16%)	1.00	3 (14%)	1.00
75+	1 (5%)	1.00	1 (5%)	1.00
Building type				
SFD	12 (63%)	1.00	15 (68%)	1.00

(*continued on next page*)

Table A1 (*continued*)

	Number of households owning 1 or more & percentage	Average number of appliances per household	Number of households owning 1 or more & percentage	Average number of appliances per household
SFSD	3 (16%)	1.00	2 (9%)	1.00
AB	4 (21%)	1.00	3 (14%)	1.00
MFH	0		2 (9%)	1.00
IM	0		0	
Energy efficiency awareness and practice				
High	7 (37%)	1.00	7 (32%)	1.00
Fair	2 (11%)	1.00	5 (23%)	1.00
Low	4 (21%)	1.00	6 (27%)	1.00
Lack	5 (26%)	1.00	6 (27%)	1.00
Did not answer	0		0	
Factors	**Microwave oven**		**Rice cooker**	
Income grade				
A	3 (13%)	1.00	4 (21%)	1.00
B	9 (38%)	1.00	5 (37%)	1.00
C	7 (29%)	1.00	6 (32%)	1.00
D	5 (21%)	1.00	2 (11%)	1.00
E	0		0	
Employment status				
Self employed	1 (4%)	1.00	0	
Full-time paid work	21 (88%)	1.00	16 (84%)	1.00
Retired	2 (8%)	1.00	3 (16%)	1.00
Unemployed	0		0	
Full-time higher education	0		0	
Household size				
1	1 (4%)	1.00	0	
2	6 (25%)	1.00	4 (21%)	1.00
3	3 (13%)	1.00	4 (21%)	1.00
4	2 (8%)	1.00	3 (16%)	1.00
5	5 (21%)	1.00	1 (5%)	1.00
6+	7 (29%)	1.00	7 (37%)	1.00
Household composition				
Single person	1 (4%)	1.00	0	
Couple only	2 (8%)	1.00	2 (11%)	1.00
Couple with dependent children	10 (42%)	1.00	10 (53%)	1.00
Couple with non-dependent children	2 (8%)	1.00	3 (16%)	1.00
Family with dependent children	6 (25%)	1.00	3 (16%)	1.00
Family with non-dependent children	3 (13%)	1.00	1 (5%)	1.00
Age of household head				
19-34	3 (13%)	1.00	0	
35-44	5 (21%)	1.00	2 (11%)	1.00
45-54	8 (33%)	1.00	8 (42%)	1.00
55-64	4 (17%9	1.00	5 (26%)	1.00
65-74	2 (8%)	1.00	3 (16%)	1.00
75+	2 (8%)	1.00	1 (5%)	1.00
Building type				
SFD	17 (71%)	1.00	12 (63%)	1.00
SFSD	3 (13%)	1.00	3 (16%)	1.00
AB	4 (17%)	1.00	4 (21%)	1.00
MFH	0		0	
IM	0		0	
Energy efficiency awareness and practice				
High	8 (33%)	1.00	7 (37%)	1.00
Fair	2 (8%)	1.00	2 (11%)	1.00
Low	9 (38%)	1.00	4 (21%)	1.00
Lack	4 (17%)	1.00	5 (26%)	1.00
Did not answer	1 (4%)	1.00	0	

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