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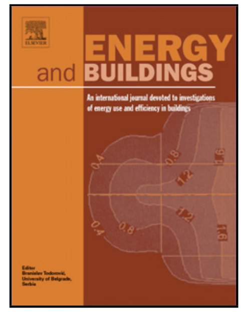

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Identifying the Determinants of Residential Electricity Consumption for Social Housing in Perth, Western Australia

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Highlights

- The residential sector contributes significantly to the overall energy consumption in Australia.
- The indoor thermal discomfort experienced by the households during cold winter days was relatively higher than that experienced in summer.
- The factors including floor area, household size, disposable household income and HoH gender are significant in explaining the variation of electricity consumption in Social Housing in Australia.

Abstract

The residential sector contributes significantly to the overall energy consumption in Australia. A survey was undertaken to provide an indication of the determinants of electricity consumption in Perth Social Housing in Western Australia. The household survey provided a range of information about a number of building and occupant-related factors, including floor area, household size, disposable household income, occupancy hours, Head of Household (HoH) gender, presence of children in the households and occupants' window opening behaviour that may influence the consumption in the dwellings. Outcomes of the research revealed that the floor area, household size, disposable household income and HoH gender are significant in explaining the variation in electricity consumption of the sample households. Other factors such as the presence of children in the household and window opening behaviour of the building users, however, did not precisely explain the changes in the households' electricity usage. It is concluded that further studies into the determinants discussed in this paper are required to support the findings and gain a better understanding of the impact of these factors on electricity consumption in Western Australia (WA).

Keywords

Residential energy consumption, Building physical characteristics, Household socio-economic characteristics, Disposable Household Income (DHI), Social Housing

1. Introduction

Today, a substantial amount of energy is being used by the building sector. This sector accounted for more than one-fifth of total worldwide consumption of delivered energy in 2010 [1]. Accounting for approximately 40% of the primary energy use and one-third of the global Greenhouse Gas (GHG) emissions [2], buildings also highly contribute to climate change [3], [4]. Due to increased demand and improved lifestyle, energy use in the building sector is growing sharply, placing additional pressure on the energy system [1].

In Australia, the residential sector contributes significantly to the overall energy consumption. According to a report published by the Department of Industry and Science (2015), 11% of the total final energy consumption in 2013-2014 was used by this sector (See Figure 1) [6].

Data from "Household Energy Use and Costs" by Australian Bureau of Statistics (ABS) in 2012 revealed that between 2000-01 and 2010-11, energy consumption in the Australian residential sector (excluding fuel used for transport) grew by 14% from 398 PJ to 452 PJ [7]. Annual per capita energy consumption in this sector is also anticipated to increase by 20% from 17 GJ in 1990 to 20 GJ in 2020[8]. Population growth, an increase in the number of dwellings combined with improving lifestyle in households is driving an increase in total residential energy demand. Therefore, a lot of effort has been undertaken to reduce the energy used in this sector. Developing awareness among the homeowners about excess energy use, the introduction of regulatory instruments, energy conservation policies and regulations for governing the energy performance in buildings, House Energy Rating Schemes (HERS) [9], etc. are some examples of initiatives that have been undertaken, aiming at decreasing energy consumption in residential buildings.

Households use energy for a variety of purposes including heating and cooling, cooking, hot water, lighting and home appliances. According to the Australian Bureau of Statistics (2014), most Australian households used mains electricity as a source of energy, while 50% used mains gas, 20% used solar energy or LPG/bottled gas and 14% used some other source of energy [10]. For hot water, however, electricity, mains gas, and solar water heating were found to be used by 56%, 38% and 10% of Australian households respectively [10].

Figure 2 shows the breakdown of the final electricity consumption by various industries in Australia in 2012 (Source: IEA 2014). As shown in Figure 2, the residential sector is the second biggest electricity consumer in Australia after industry. Growth in population, increasing comfort requirements and global warming are also predicted to significantly increase the energy consumption in this sector. Therefore, this sector has considerable potential for energy savings at the national level (See Figure 2).

Social Housing in Australia

Over the past two decades, Australia has experienced a strong growth in residential property prices [11]. In order to mitigate the adverse social impacts of high housing prices for low-income households, all levels of government, the private sector, community organisations and individuals have been involved in assisting such people to access housing, which is appropriate, available and affordable. In Western Australia, the WA Government's Department of Housing provides affordable housing in partnership with community housing organisations (mostly non-profit organisations) and local government.

Community Housing (CH) is a very diverse sector in Australia and encompasses providers ranging from very small to very large organizations, with a multitude of organisational structures and funding models. This sector provides various rental options to low-to-moderate income tenants, ranging from short-term crisis accommodation to long-term housing [12]. In 2014, the total number of community housing dwellings in WA was reported as 6967 [13]. These houses that are either owned or under the legal control of community housing providers are designed and constructed similar to the privately owned dwellings. In fact, ownership is the primary factor that differentiates these houses from those privately owned dwellings.

Foundation Housing Limited (FHL) is WA's largest provider of community housing with more than 2,200 units of accommodation in its portfolio. In order to meet its targets, FHL works in collaboration with private and community organisations and local government. As owner, developer, and landlord asset manager, FHL holds a unique position involving the cradle-to-grave provision of affordable housing for low to middle-income households. Other than low levels of income, tenants in community housing may also have some special needs including suffering from mental illnesses, disability, substance abuse, or domestic violence [12]. Hence, such tenants are more likely to spend a longer time at home and as a result, have higher energy consumption than other households [12]. This makes them highly vulnerable to increasing energy prices.

Energy Consumption in the Residential Sector

The overall energy consumption in a building depends on the building itself and the users living in the building [14, 15]. In order to seek methods of reducing the total energy consumption in buildings, an in-depth knowledge of the factors affecting their consumption is essential. According to the literature, variation in domestic energy consumption can be attributed to four distinct factors:

- Weather and location;
- Building related attributes;
- Occupants related attributes and their energy use behaviour and;
- Appliances and electronic devices.

The influence of local climate has been reported by numerous authors as one of the key determinants of building energy consumption [15-20]. Although climate influences the extent to which, different factors may affect energy consumption in dwellings in different locations, this determinant is normally outside the scope of the influence of households [21]. Building physical characteristics (e.g. dwelling type, dwelling age, number of rooms, number of floors, total floor area, HVAC system including electric space heating, air-conditioning and mechanical ventilation, insulation, Hot-Water system, lighting) along with building users (e.g. number of occupants, family composition, Head of the Household's (HoH)[1] age, HoH's employment status, HoH's education level, disposable household income) and the appliances used in the dwelling (e.g. electrical appliances, IT equipment, entertainment systems, HVAC system, cooking appliances, laundry appliances, etc.) are also pointed as significant contributors to building energy performance in the literature [14, 15, 20-27]. Determining the combined effect of all these factors on building energy performance requires an in-depth knowledge of each determinant [21].

Although energy consumption in the residential sector is well-studied in numerous national and international studies, to the best of our knowledge, no previous study has investigated the energy consumption in the social dwellings in WA. In order to respond to the research question "What are the influential factors affecting residential energy consumption in community housing in the WA context?", this paper aims at exploring how a number of building and household related attributes affect electricity consumption – as the primary source of energy for most Australian households – in social dwellings in Perth, WA. It mainly focused on building and occupant related factors and excluded the impact of weather and location. Section 1 has presented brief background information on residential energy consumption on the national and international level. Literature review on the determinants of residential energy consumption is presented in Section 2. In Section 3, the methods used in this research are discussed. Results from the field survey are then, discussed in Section 4. Section 5 discusses the results and identifies the determinants of electricity consumption in the Perth social dwellings, followed by Section 6 that summarizes the paper. Finally, Section 7 concludes the paper.

2. Determinants of Residential Energy Consumption

Understanding the determinants of residential energy consumption is the key step towards the design and implementation of effective policies to reduce energy consumption in this sector. Wilson and Dowlatabadi [28] categorised the determinants of residential energy consumption into contextual and behavioural factors. In this study, the behavioural domain encompasses the socio-economic characteristics of the building users, their lifestyle and energy use behaviour. The contextual domain, on the other hand, comprises of local climate, building characteristics and the appliances used in dwellings [28]. Jones et al.[15] reviewed 43 international papers on the determinants of electricity consumption in domestic buildings and found that 62 factors potentially affect residential electricity consumption, out of which, thirteen are socio-economic factors, twelve are dwelling-related factors and thirty-seven are appliance-related factors.

With statistically significant variation among different housing types, free-standing dwellings have higher energy consumption than other dwellings [26, 27]. Ewing and Rong [29] compared detached with attached dwellings of the same size in the U.S. and found that the former require more energy for the same level of thermal comfort than the latter. This is mainly because single detached houses have more exposed surface area compared to other dwellings, resulting in more heat exchange with their

[1]Investopedia defined HoH as "A status held by the person in a household who is running the household and looking after a qualified dependent".

surroundings. Sardianou [30], however, found that dwelling type has no significant influence on the residential demand for space heating in Greece.

Larger dwellings have more space to be heated and cooled. Therefore, as homes become larger (measured by either floor area or the number of rooms), energy consumption in dwellings increases [16, 21, 29, 30]. Additionally, the number of home appliances in larger houses is expected to be more [15, 30], resulting in higher energy consumption. Ewing and Rong [29] compared energy consumption for space heating and cooling by the two households living in 1,000 and 2,000 square-foot buildings in the U.S. and found that more energy was required for cooling, heating and all other usages by the household living in the larger house. A significant positive relationship was also reported between the number of rooms and electricity consumption in Irish [31] and Dutch [32] dwellings. In another study, however, Brounen et al. [24] showed that by increasing the number of rooms in Dutch dwellings, electricity consumption decreases.

A small negative correlation was established between the dwellings' age and local heating required in the living area by Guerra Santin et al. [14] in the Netherlands. In New Zealand, newer houses were found to be warmer in winter than older houses (with no renovation) [17]. This is mainly because of the higher level of insulation, higher airtightness, and more efficient systems in newer dwellings [17]. Generally, as a building becomes older, as a result of unavoidable wear and tear, the functionality of building components may fall, unless regular maintenance or replacement is undertaken.

By using US Residential Energy Consumption Survey (RECS) data, Kaza [33] demonstrated that year of construction mainly affects the energy requirement for heating rather than cooling. McLoughlin et al. [20], however, disproved the direct impact of the dwelling age on its energy performance in Ireland as a result of the strong collinearity between the dwelling age and the HoH age. According to this study, younger HoHs mostly live in newer dwellings compared to the older HoHs.

A large percentage of variation in energy consumption in dwellings with similar characteristics can be justified through the building users and their behaviour [20]. Through analysing observations on 300,000 dwellings in the Netherlands, Brounen et al. [24] showed that variation in domestic electricity consumption is linked with households' characteristics, their composition and income [24]. As household age increases, the energy required for space heating also increases [26, 34]. Liao and Chang [35] showed that the elderly need more energy for space and water heating than younger people. The presence of children, particularly teenagers was also found to increase the electricity consumption in Dutch dwellings [24]. However, no correlation was reported by Guerra Santin and Itard [36] between the presence of children in the household and the use of heating systems.

An increase in the number of households at the national level increases the total energy consumption in the residential sector [33]. More energy is generally used by larger households with household size mainly affecting the energy required for space cooling and home appliances rather than space heating [26, 30, 37, 38]. A positive relationship was reported by a number of researchers between the household income and the energy used in dwellings [15, 26, 28, 39]. Yohanis et al. [38] showed that higher income households can pay for larger dwellings, which subsequently results in higher electricity usage. However, when annual electricity cost per person was considered, lower income people were found to pay nearly 67% more on electricity per person [25]. In order to identify the difference between thermal comfort for males and females, Karjalainen [40] conducted a quantitative interview survey on 3094 individuals. He found that females preferred a higher room temperature than their male counterparts [40]. This is also supported by Li et al. [41], who confirmed that with no difference in the neutral temperature, females prefer slightly warmer environment than males mainly because their skin temperature is constantly lower than males [41]. Brounen et al. [24], however, found no evidence on the influence of gender on temperature preferences of individuals.

Occupants react to both internal and external stimulus in order to either maintain or improve their thermal comfort. Energy consumption in buildings is also affected by window opening behaviour of the building users and their clothing habits at home [42]. Such actions result in changes in the indoor environment and subsequently, in the building energy consumption [42, 43].

From the above literature review, it was found that building energy consumption is affected by many different factors at the same time. These factors include dwelling size, dwelling type, year of construction, disposable household income, occupancy hours, HoH gender, HoH level of education, window opening behaviour and presence of children and elderly. Due to the limitation of our survey sample and from interviewing experts in the social housing fields, we limited the factors contributed in this study to these shown in Figure 3.

3. Methodology

Figure 4 presents the flowchart of the methodology used for this research.

The research was conducted in 5 main steps (See Figure 4). An extensive review of existing literature was conducted to identify the factors that directly and indirectly affect residential energy consumption. This was then used as the basis for drafting the survey questionnaire, which was designed as a combination of structured, semi-structured and open-ended questions.

Social housing was selected for conducting the survey as these houses are constructed similar to most privately owned dwellings and were easier to approach as a control group. Several social housing providers were invited to take part in the project, out of which, Foundation Housing agreed to participate. Upon receiving the formal consent from FHL, approval was obtained from the "Human Research Ethics Committee" at Murdoch University before commencing the field survey.

Participants were recruited through FHL from the dwellings managed by this organisation. The households were shortlisted by FHL based on construction type, year of construction and location of dwellings and were sent an expression of interest to participate in the survey. The interested households were asked to send their consent to the FHL office in Perth and later on, contacted by the research team. The process of the survey was explained to them and the date and time of interview were set with the potential participants.

Analysis Techniques

The results of the survey were analysed using qualitative and quantitative techniques to identify the determinants of residential electricity consumption. Due to the small sample size, analysis methods used in this study are limited to descriptive statistics, frequency analysis and cause and effect analysis.

4. Results and Discussion

In-person interviews were used to collect information on households' socio-economic characteristics, occupants' sensation of thermal comfort in summer and winter, their clothing habits, window opening behaviour and the use of electronic appliances including heating and cooling systems. The households' representatives (who in the majority of cases were the HoH) were asked to respond to a number of socio-demographic as well as thermal comfort-related questions. The survey was then followed by a walk-through energy audit and the installation of temperature loggers in some dwellings, the results of which are not within the scope of this paper.

Initially, one-third of the invited households (32%) agreed to participate in the survey. After giving a brief outline of the project and the possible risks involved, however, only 17 households (18%) decided to proceed with the further process of the survey. Figure 5 provides a snapshot of the suburbs where the surveyed dwellings are located with respect to the Perth Central Business District (CBD).

Completing the field survey took longer than anticipated, from October 2014 to March 2015. This was mainly because households joined at different points of time during the survey. Out of the total 17 households, which participated in the survey, 4 households did not provide their historical energy information. Four more households, on the other hand, used different sources of energy other than electricity and gas for heating and hot water system respectively (dwellings with electric heaters and gas hot water systems were assigned for electricity analysis). By removing these 8 households, the number of households for analysing electricity consumption in the dwellings stood at only 9 households. All of these households used electricity for heating and cooling and gas hot water system. Using information extracted from household's online electricity bills (collected upon obtaining HHs' consent at the time of interview), the average annual electricity consumption during 2013-2014 was then calculated in these dwellings.

4.1 Socio-Economic Characteristics

In order to create an insight into the socio-economic status of the survey sample, respondents were asked about the socio-economic information of their household. In this section, every individual in the households was taken into account, except for income for which, the total disposable household income ($/Fortnight) was considered. Along with the socio-economic information, historical energy use data (2013 -2014) were also collected from the participating households. Table 1 summarizes the findings.

Overall, 17 households participated in the interview and thermal comfort analysis (See Table 1), all but one of which, were living in single-detached brick dwellings. The total number of bedrooms in these dwellings varies between 2 to 5, with nearly half of the households living in 3 bedroom dwellings.

Household size in the survey sample varied between 1-8 persons with an average size of 4 persons per household. A small difference was established in the number of male and female occupants, with females slightly outnumbering males (51% versus 49%). In more than half of the surveyed households, HoHs were female (9 out of 17 households). Figure 6 shows the breakdown of the survey sample with respect to age of individuals in the survey sample.

As shown in figure 6, 43% of the survey sample comprised of children (below 12 years old), followed by adults (between 20-60 years old), teenagers (between 13-19 years old) and elderly (above 60 years old) that constituted 34%, 17% and 6% of the survey sample (70 people) respectively. In terms of education, most of the occupants have at least some level of education with the majority having completed primary school or secondary/high school, and a few (13 out of 70) having obtained a university degree. Seven out of the 70 occupants do not have any education, and there are either elderly or children below school age. It is worth noting that most of the HoHs are educated. They either completed secondary/high school or have a university degree.

The years of residency in the dwellings varied between 4 months to 6 years with an average of 2.9 years per household. It was found that 65% (11 out of 17) of the households have lived in their current house for 2-4 years, less than one-third (29%) lived for less than 2 years and only two households have lived in their current house for more than 4 years.

Disposable Households' Income was classified based on the guidelines obtained from the Australian Bureau of Statistics (ABS) [44]. According to ABS [44], households with weekly income below $581 were grouped as low-income, between $689 and $904 as middle-income and above $1,236 as high-income households. The weekly Equivalised Disposable Household Income (EDHI) values that have not fallen within the above clusters are categorised as low-to-middle income or middle-to-high income level [44]. Figure 7 presents the percentage of the surveyed households falling in each income category.

Living in social dwellings, the DHI of the surveyed households was expected to vary between low and low-middle levels. However, as shown in Figure 7, less than half of the households fell into the low-income category, followed by 12% in both the low-to-middle income and high-income households (See Figure 7).

4.2 Occupancy Patterns

From the survey data, it was found that occupancy hours in the dwellings ranged between 11-24 hours on a typical weekday and between 5-24 hours on a typical weekend. On weekends, the majority of the dwellings were either vacant or occupied by the entire occupants. Occupancy patterns for weekdays were reported to be more variable than weekends. On a typical weekday, more than half of the surveyed dwellings were fully occupied[2] in the morning (5:00 am-12:00 pm) and afternoon (12:00 pm-5:00 pm). These dwellings were mainly those with unemployed housewives and children below school age, followed by households with elderly occupants or members with a physical disability. Towards evening and night, the occupancy rate in almost all the dwellings increased to 100%.

4.3 Thermal Sensation in Winter

In this section, the respondents were asked to remember when they entered the house on a cold winter day when no heating system was on. They were then asked to describe their thermal sensation at that time on a scale from -3 to +3 (with -3 = cold, -2 = cool, -1 = slightly cold, 0 = naturally comfortable, +1 = slightly warm, +2 = warm and +3 = hot).

[2]In this study, a fully occupied dwelling during a period of time is the one where at least one person is present in the dwelling during the assigned period.

Unlike socio-economic information, for which every individual in the household was taken into account when a household's thermal comfort and energy use pattern were sought, the HoH was considered as the household's representative and his/her perception of thermal comfort was taken as that of the household.

As shown in Figure 8, the majority of the respondents reported an extreme level of thermal discomfort in both living areas as well as in bedrooms. One respondent described her indoor discomfort:

//... during winter, inside the house is even colder than outside! Not comfortable at all ...//

On a typical winter day, more than half of the households felt uncomfortably cold (-3) in the living area. The number increased at night (See Figure 8). This also applies for the bedrooms: most of the households felt extremely cold in bedrooms both during day and night if there is no heating system on. As shown in Figure 8, the living area was not reported comfortable by any of the respondents.

The respondents were then asked to rank a list of actions they might take when they feel cold in the house. During day-time, adjusting clothing level was the first action taken by more than half of the respondents (53%), followed by closing the windows (35%) and blinds (11.76%) (See Figure 9). Interestingly, switching on the heater was not reported as the first action by any of the respondents in cold winter days. Some households, however, mentioned about prioritizing their comfort and not adjusting their closing level:

//… I love my comfort! In winter, I prefer to heat up the house rather than wearing a heavy jumper...//

During night-time, a small percentage of the households (11.8%) turned on the heater immediately after feeling uncomfortably cold (Figure 9). A comparison between occupants' thermal sensation and the heated zones in the surveyed dwellings revealed that in winter, bedrooms were likely to be more comfortable than living areas. However, this might be simply because bedrooms are mostly used during sleep hours when blankets are used to keep the occupants warm. Half of the respondent only heated up the living area.

Three out of 17 households did not use any type of heating system. In the morning, when eight (out of 14 remaining households) heated up the living area, only 1 household heated the bedroom. In the afternoon, the number of households heating the living area fell to 5 (mainly those with children and elderly); with no household heating the bedroom. Towards evening, the number of households who turned on the heater raised to 13 (out of 14 households) in the living area and 2 in the bedroom. Although, the duration of using the heating system on a typical winter day was reported to be between 1-13 hours in the living area and 0.5-8 hours in the bedroom (with the majority of the households use heaters in the evening, followed by morning, night and afternoon), almost all the households reported that they turned off the heater soon after they felt thermally comfortable. During night-time (9:00 pm-5:00 am), 5 households used the heater in the living area and 3 households used it in the bedroom. Figure 10 shows different types of heating systems used in the surveyed dwellings. As shown in Figure 10, some households use more than one heating system (2 out of 14 households). Through direct observation, it was found that some households even turn on more than one heating system at the same time. For example, in one of the surveyed dwellings, 2 reverse cycle AC units were running simultaneously in the living area. According to the tenant:

//… the ACs are undersized to heat up the entire area. Sometimes, I need to turn on both the ACs at the same time...//

Among different heating options, electric heaters were ranked as the most popular heating systems used by two-fifth of the households, followed by reverse cycle AC (17%) and gas heaters (12%) (See Figure 10).

4.4 Thermal Sensation in Summer

In this section, the respondents were asked to remember when they entered the house on a hot summer day when no cooling system was on. They were then asked to describe their thermal sensation at that time on a scale from -3 to +3 (with -3 = cold, -2 = cool, -1 = slightly cold, 0 = naturally comfortable, +1 = slightly warm, +2 = warm and +3 = hot). Summary of the responses is presented in Figure 11.

Bedrooms were reported uncomfortably hot by most of the households (hotter than living areas) especially during daytimes (Figure 11). With no cooling system in use, 40% of the households felt extremely hot (+3) in the living area against the 60% in the bedroom. The natural comfort experienced in the living area was more than bedrooms (See Figure 11). As shown in Figure 11, one individual even mentioned that she felt slightly cold in the living area during summer nights.

The respondents were then asked to rank a list of actions they might take in summer when they feel uncomfortably hot. During day-time, adjusting the clothing level and closing the windows were reported as the two common actions by more than a third of the households, followed by 12%, who turn on the AC. During summer nights, however, closing windows was reported as the first action by slightly less than half of the households, followed by adjusting the clothing level (29%), closing the blinds (18%), switching on the fan (6%) and AC (6%) (See Figure 12).

Two out of the seventeen households did not have any type of cooling system. The survey revealed that the living /kitchen area was cooled in more than half of the surveyed dwellings; while nearly one-third of the households cooled both living area and bedroom. As shown in Figure 13, portable fans were the most common cooling system being used by more than one-third of the households, followed by reverse cycle AC (29%). Only twenty-five percent of the households used evaporative coolers (See Figure 13).

4.5 Window Opening Behaviour

In order to understand the relationship between window opening behaviour and electricity consumption in the dwellings, the respondents were asked to describe their window opening pattern on a typical summer and winter day separately. In winter, most of the households (82%) opened the windows in the living area for a few hours to get fresh air. Two out of seventeen households opened the windows only in the morning (about an hour) and closed it for the rest of the day. Eight households, however, opened the windows once again in the afternoon (12:00 pm-5:00 pm) and let the natural heat of the sun enter into the house. Towards evening, only five households opened the windows for 1-4 hours. Finally, all the respondents reported that they closed all the openings at night. When respondents were asked about their window opening behaviour in their bedrooms, it was found that 33% of the households kept a small portion of the window in their bedroom constantly open to allow fresh air ventilate the room. However, direct observation revealed that even this group of households shut the windows if the outside temperature was below their comfort range.

A significant difference was found between window opening behaviour in summer and winter. In summer, more than 75% of the households opened the window in the living area early in the morning and let the fresh and cool air enter into the room (on average for 2.4 hours). As air temperature rises in the afternoon, nearly 70% of the households closed the windows. Seventy-five percent of this group, however, opened the windows once again in the evening to cool down the house.

> //…in summer, when the front door and the back door are open at the same time, the breeze comes in and makes the house cold ...//

It is worth noting that in summer, less than a third of the households kept a small portion of windows in the living area constantly open.

Window opening behaviour in bedrooms was found to be similar to the living areas. Although for 65% of the households, security was the main reason for closing the windows at nights, 35% kept the windows open throughout summer nights and let the house cool down.

5. Influence of Building and Occupant-Related Factors on Domestic Electricity Consumption

In order to create an insight into how different factors affect electricity consumption in the sample dwellings, a number of factors including floor area, household size, disposable household income, HoH gender, occupancy patterns, presence of children and window opening behaviour are plotted against the Average Annual Electricity Consumption (AAEC) in the dwellings and presented in the following subsections. Consumption data was transformed into 3 different metrics including Average Annual Electricity Consumption per Person (AAEC/P), Average Annual Electricity Consumption per m^2 floor area (AAEC/m^2) and Average Annual Electricity Consumption per person per m^2 floor area (AAEC/P.m^2) in order to create a measure for comparing the electricity consumption in different dwellings. Out of the three measures, however, AAEC/P.m^2, which takes into account both the HH size and the floor area, is used as the common metric in this paper.

5.1 Household (HH) Size

Figures 14 presents the AAEC/P.m^2 against the number of people living in the surveyed households.

As shown in Figure 14, by increasing the number of occupants in the households, the AAEC/P.m^2 decreased ($R^2 = 0.667$ and 0.815 for 2013 and 2014 respectively). A similar graph plotting AAEC/P (kWh) versus the household size also revealed that on average, less per person electricity was used in the households with more occupants. However, there was no significant correlation between the average annual electricity consumption (MJ/year) and the HH size in the sample households ($R^2 = 0.09$ and 0.02 for 2013 and 2014 respectively).

5.2 Floor Area

The variation in the electricity consumption in the dwellings with respect to the dwelling size is presented in Figure 15.

From the survey result, it was found that less electricity per person per m^2 was used in the bigger dwellings (R^2= 0.22 and 0.39 for 2013 and 2014 respectively) (See Figure 15). For example, in 2013, the AAEC/P.m^2 in a 144.19 m^2 dwelling was much higher than that in a bigger dwelling with 198 m^2 floor area (24.84 kWh/P.m^2 and 10.97 kWh/P.m^2 respectively). Similarly, the graphs plotting the AAEC per person and per m^2 against the dwelling size revealed a downward trend, suggesting that households living in bigger dwellings spent less on electricity both per person and per unit area. However, the wide distribution of consumption data together with small R^2 values indicated the lack of a strong relationship.

5.3 Disposable Household Income ($/fortnight)

Disposable household income was used as a measure for evaluating the relationship between households' income and the average annual electricity consumption in the dwellings. Out of the total households that participated in the electricity analysis (9 households), two households treated income as strictly confidential information and did not share it. Therefore, they have been removed from further analysis in this section and the sample size reduced to 7 households. The summary of responses is presented in Figure 16.

From the survey result, it was found that the presence of the only one high-income household in the survey sample significantly affects the relationship between disposable household income and the electricity consumption in the households. By removing the only high-income household from the sample, however, it was found that the higher income households spent less on electricity per person per square meter than other households (See Figure 16). The small R^2 value (R^2 = 0.12 and 0.13 for 2013 and 2014 respectively) due to having a small sample, however, verifies the weakness of the relationship. Interestingly, there was a similar trend between the average annual electricity consumption in the households, both per person and per unit floor area, and the DHI.

5.4 Hours of Occupancy

Figure 17 presents the average electricity consumption in the surveyed dwellings against the number of hours the houses were occupied on a typical weekday.

Electricity consumption in the surveyed dwellings with different occupancy patterns ranged between 1.8 and 24.9 kWh/P.m^2 in 2013 and between 2.0 and 16.4 kWh/P.m^2 in 2014 respectively (See Figure 17). Surprisingly, the results of the survey revealed that as the weekday occupancy hours in the dwellings increased, less electricity per person per m^2 was used in the households (R^2 = 0.45 and 0.36 for 2013 and 2014 respectively). A similar trend in the electricity consumption, both per person and per unit of floor area (m^2), versus weekday occupancy hours was also observed. However, with small R^2 values, these relationships are not statistically significant.

5.5 Gender

In order to understand how electricity consumption in the dwellings is affected by the HoH gender, the average annual electricity consumption was calculated separately for the households with male and female HoHs. Table 2 presents the summary of findings.

The average annual electricity consumption with respect to all three measures, AAEC/P, AAEC/$m^{2,}$ and AAEC/P. $m^{2,}$ in the households with a female HoH was higher than those with a male HoH (See Table 2). In some cases, the households with a female HoH consumed up to 3.4 times more electricity than the households with a male HoH (e.g. See AAEC/P.m^2 in 2013).

5.6 Presence of Children/Elderly in the Households

With the elderly contributing to only 6% of the survey sample, their influence on electricity consumption in the households has been negated. At the time of the interview, seven out of the total nine households participating in the electricity analysis had children (occupants below 12 years old). A comparison between electricity consumption by the households with and without children revealed that on average, households with children consumed less electricity (per person per m2) than those without children. Less per person electricity consumption in the former group is, however, attributed to the higher number of occupants in these households compare to the other group. Moreover, when the average consumption is calculated, higher consumption by some households might be, to some extent, offset by the lower consumption in other households (in the same group). Therefore, the presence of children in the surveyed households is not significant in explaining the electricity consumption trends of the surveyed dwellings.

5.7 Number of Hours Windows Were Open in the Living Area

From the survey data, it was found that the majority of the surveyed households heated or cooled only the living area. Therefore, window-opening behaviour and the influence it might have on the electricity consumption in the dwellings were only investigated in the living area. The number of hours windows were reported to be open varied over a wide range, between 0-18 hours in summer and 0-16 hours in winter. Diverse trends were observed in the relationship between households' window opening behaviour and AAEC/P, AAEC/$m^{2,}$ and AAEC/P.m^2. By increasing the number of hours windows were open in the living area, the AAEC/P significantly decreased. AAEC/m^2, however, experienced an upward trend, with an almost steady value for AAEC/P.m^2. Therefore, occupants' window opening behaviour is not significant in explaining the electricity consumption trends in the surveyed dwellings.

6. Summary and Discussion

This paper scrutinized the links between electricity consumption in a sample of social housing dwellings in Perth, WA and a number of building, as well as occupant-related factors, obtained through a field survey. These factors include floor area, household size, disposable household income, occupancy hours, HoH gender, the presence of children in the households and occupants' window opening behaviour.

Section 5.2 showed that the floor area has a negative impact on the normalized electricity consumption in the surveyed dwellings. Although larger dwellings were expected to consume more electricity mainly due to having more lighting fixtures and electronic appliances, the majority of the surveyed households (who are from the low –to middle income level) did not have extensive electronic devices to impact their consumption. In India, Pachauri [46] demonstrated that larger areas require more electrical fittings and fixtures such as fans, lights, coolers, etc. [46]. Therefore, people living in larger dwellings would have higher total per capita energy requirements (MJ/capita/year) [46]. Similarly in the United State, Ewing and Rong [29] compared energy consumption by two households living in 1,000 and 2,000 - square - foot buildings and showed that more energy is required for cooling, heating and all other usages by the household in the larger house.

In our study, less electricity per person, per square meter and per person per square meter, was used in the larger households. However, the total annual electricity consumption in the larger dwellings was higher than in the smaller houses. A similar result was reported by Kavousian et al. [19] in the USA, Yohanis [38] in the UK, Bedir et al. [32] in the Netherlands and Wiesmann et al. [47] in Portugal.

By removing the only one high-income household from our analysis, increasing disposable household income was found to negatively affect the electricity consumption in the dwellings, suggesting that the higher income households in the survey sample spent less on electricity. This is also supported by a study conducted by Santamouris et al. in Greece [25]. In this study, Santamouris et al. [25] showed that the low - income households, that are more likely to be living in older dwellings with inefficient envelopes, pay more for both heating and electricity per person and per unit area. In the Netherlands, Guerra Santin et al. [14] found a small link between income and domestic energy consumption for space and water heating (MJ/year).

More electricity is expected to be used in the households with higher occupancy hours. Guerra Santin et al. [14] established that more energy (MJ/year) is used in the Dutch households that are always occupied compare to those in which, the users are never home or their presence is variable [14]. This is mostly because more appliances and lighting are used in the former dwellings compare to that in the latter houses. In our research, less electricity was used in the dwellings that were occupied for longer periods of time. The small sample size on one hand and inaccurate occupancy patterns (as one of the highly-biased independent variables) reported by the households' representatives at the time of the interview, on the other hand, are likely to be the two key reasons for such inconsistency.

Findings from the field survey revealed that the perception of thermal comfort significantly varies between individuals. This is also supported by Holopainen et al. [50], who showed that thermal comfort is strongly related to environmental and personal parameters [50]. It was also found that more electricity was used in the dwellings with a female HoH. With heating and cooling appliances being the two major electricity consumers in the surveyed households, this suggests that households with a female HoH use these appliances more often. Through using quantitative interviews and controlled experiments in Finland, Karjalainen [40] confirmed that females feel both uncomfortably cold and hot more often than males, less satisfied with the room temperature and prefer higher room temperatures than their male counterparts [40]. Li et al. [41] also suggested that females prefer a slightly warmer environment than males as their skin temperature is constantly lower than males [41]. Brounen et al. [24] , however, found no indication that gender affects temperature preferences of individuals.

Although the above factors were shown to affect the electricity consumption in the surveyed dwellings, other parameters such as the presence of children and window opening behaviour of the building users, which have been shown in other literature [14], [24] to affect domestic energy use, were not found to be significant in this study. Furthermore, when the average annual electricity consumption (MJ/year) in the households was plotted against the aforementioned factors i.e. HH size, floor area, disposable household income and hours of occupancy, the very small R^2 obtained in all cases indicated that unlike the literature [45], these factors are not significant in explaining the annual electricity consumption in the households. It would be worthwhile to do a larger study to explore these issues further.

7. Conclusion

Determinants of electricity consumption in social housing were investigated through a field survey in the dwellings managed by Foundation Housing in Perth, WA. Despite having a small sample size, the designated households represent a useful sample of the existing diversity in the Perth residential sector. Participants, who were from a wide variety of social classes with different socio-economic characteristics indeed, utilise similar heating, cooling and general appliances as the majority of Perth houses, and so the results could provide an indicator of trends in the wider Perth residential sector. It can also assist the managing organization (FHL) in particular, to enhance the energy efficiency of their dwellings by taking into account the occupants' energy use patterns alongside energy efficient building design.

Electricity was found to be the main source of heating and cooling with 76% of the households using different types of electric heaters in winter and 88% using electricity to cool the house in summer. The survey result further revealed that the indoor thermal discomfort experienced by the households during cold winter days was relatively higher than that experienced in summer. During hot summer days, bedrooms were reported to be hotter than living areas. East or west facing windows with no well-designed shading means that the bedrooms receive the direct radiation from the sun, making them uncomfortably hot for the occupants. Although adjusting the clothing level was reported as the first action taken by the occupants for improving their thermal comfort, direct observation revealed that insufficient clothing, especially during winter, is one of the foremost reasons for experiencing thermal discomfort. In some cases, no difference was observed between occupants' clothing level during summer and winter. In winter, none of the households turned on their heating systems immediately when they felt cold. In summer, however, a small percentage (11.8%) immediately turned on their cooling systems upon feeling uncomfortably hot.

The floor area, household size, disposable household income and occupancy hours are found to have a negative impact on electricity consumption per person per m^2 in the surveyed households. Nevertheless, a more detailed analysis should be undertaken to explore the reason for the unexpected negative impact of occupancy hours on the electricity consumption in the dwellings.

HoH gender was shown to be a significant factor in the variation of domestic electricity consumption. Surveyed households with a female HoH consumed a lot more electricity than those with a male HoH. Other variables such as the presence of children in the households and window opening behavour of the occupants, however, were found to be not significant in explaining the variation of electricity consumption in the sample dwellings.

In order to improve the overal energy efficiency of the social housing dwellings, this study highlights the necessity of educating such households towards more efficient energy use at the same level with improving building thermal performance. Further studies with bigger samples, however, may result in establishing the influential factors on social housing energy consumption in WA with more certainty.

Acknowledgments

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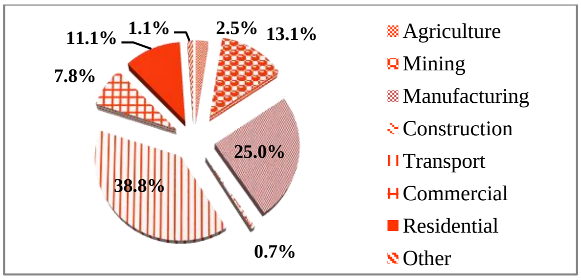

Figure 1: Australian total final energy consumption in 2013-2014, by industry, Source: "Australian Energy Update (2015)"

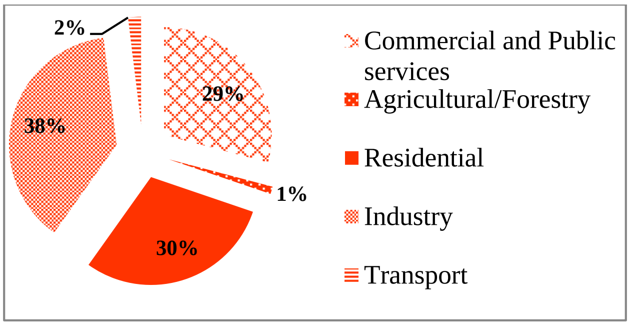

Figure 2: Final electricity consumption by different sectors in 2012 (Analysed by Author), Source: IEA (2014)

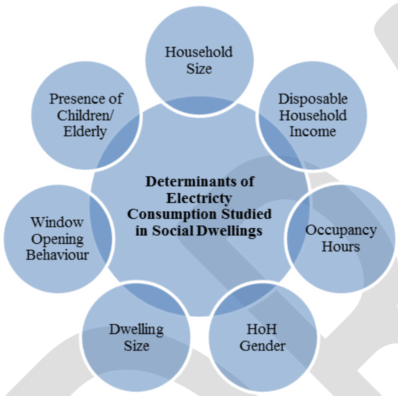

Figure 3: Determinants of Consumption in Perth Social Housing contributed in this study

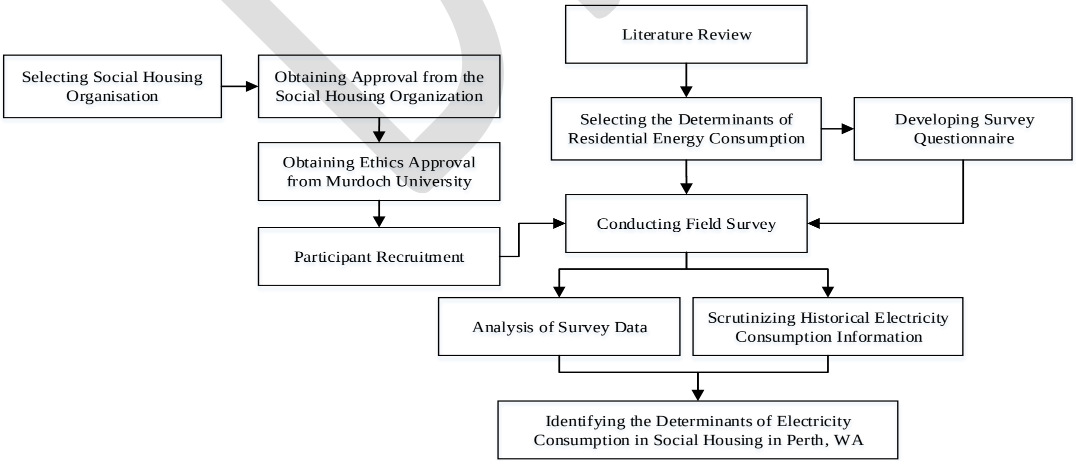

Figure 4: Methodology Flowchart

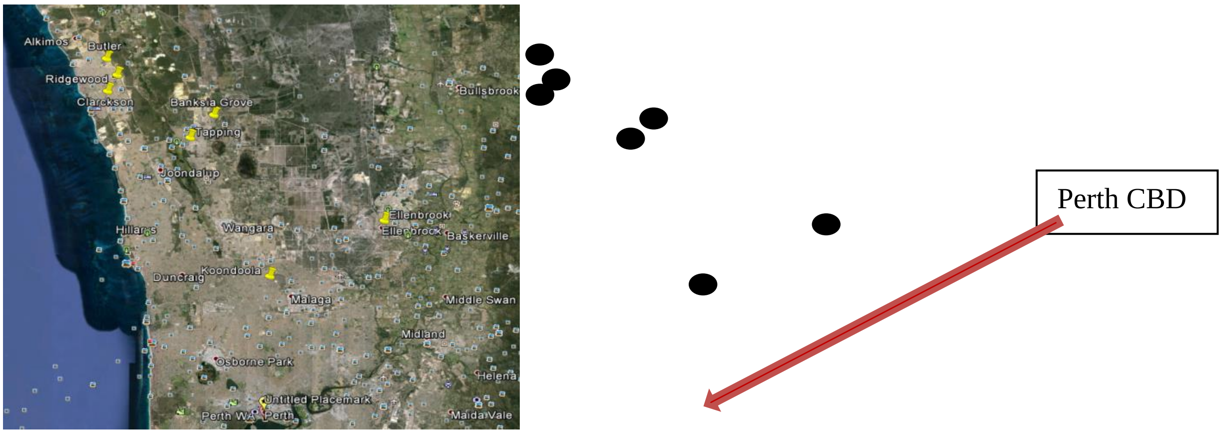

Figure 5: Scattering of the dwellings participated in the survey, by Google Earth

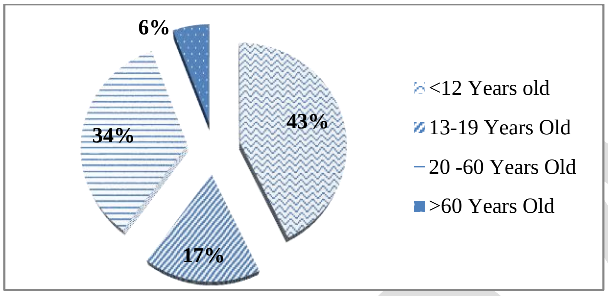

Figure 6: Breakdown of the survey sample with respect to the occupants' age

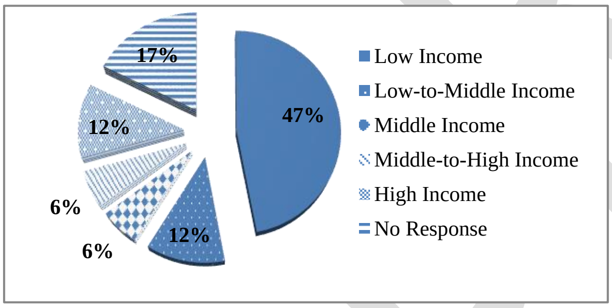

Figure 7: Breakdown of the survey sample with respect to Disposable Household Income

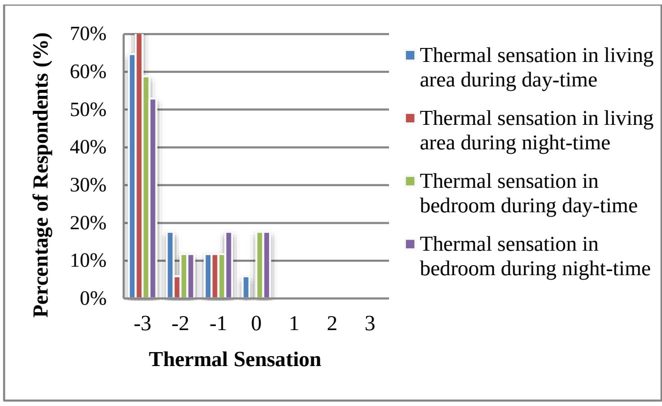

Figure 8: Thermal sensation in winter

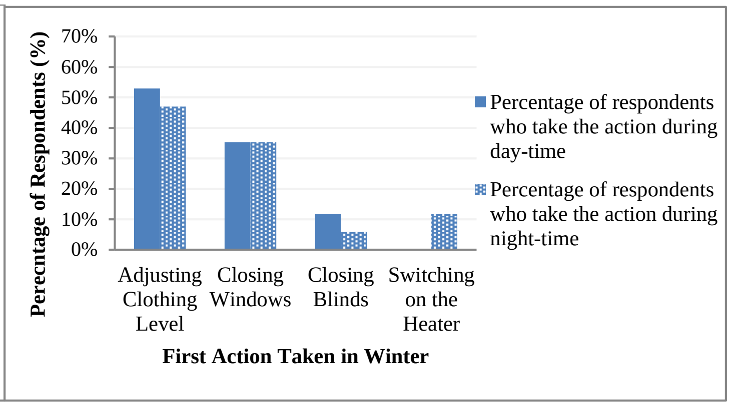

Figure 9: First action taken in winter to achieve thermal comfort

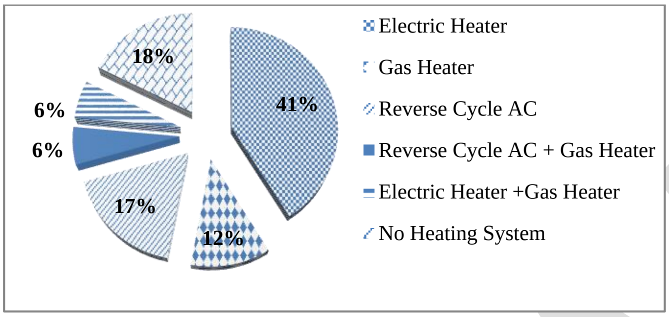

Figure 10: Different types of heating systems used by the surveyed households

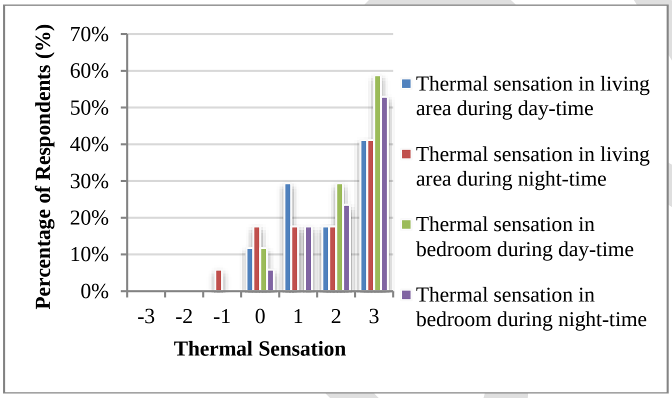

Figure 11: Thermal sensation in summer

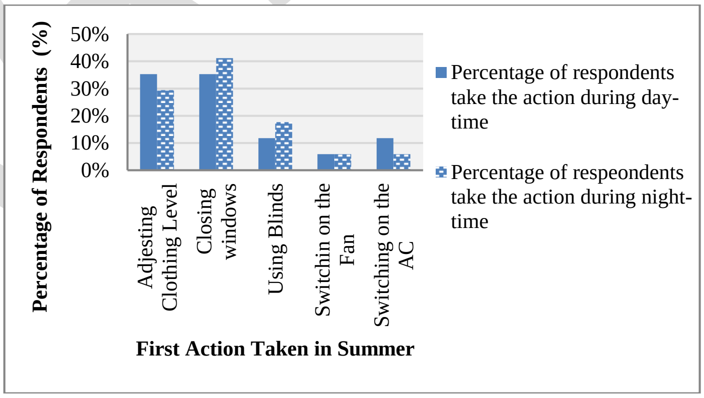

Figure 12: First action taken to achieve thermal comfort

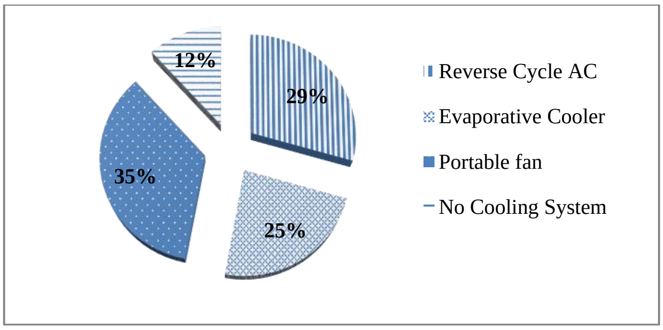

Figure 13: Types of cooling systems used by the surveyed households

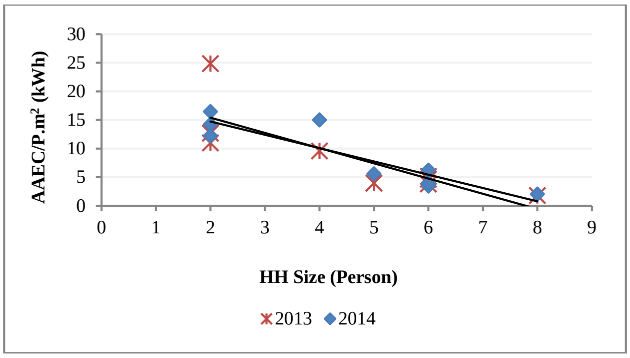

Figure 14: AAEC/P.m² (kWh) against HH size

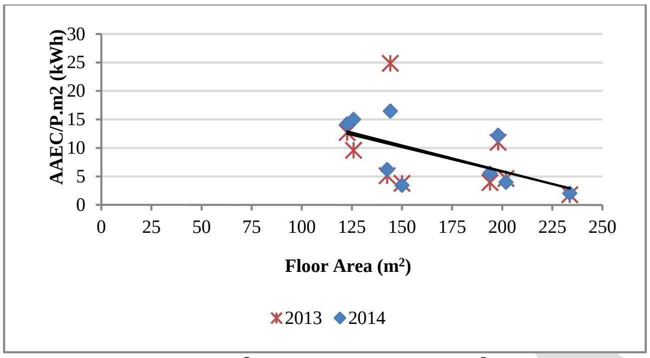

Figure 15: AAEC/P.m² against floor area (m²)

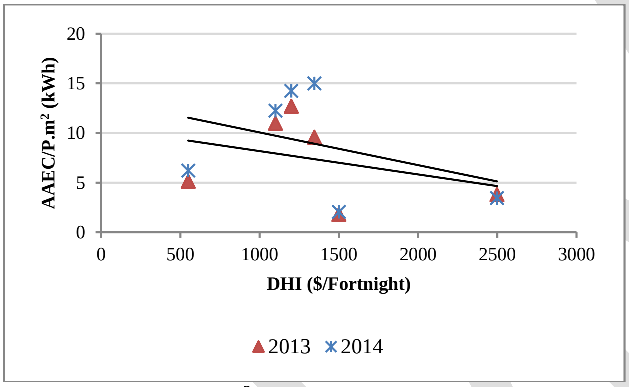

Figure 16: AAEC/P.m² against DHI excluding the high-income household

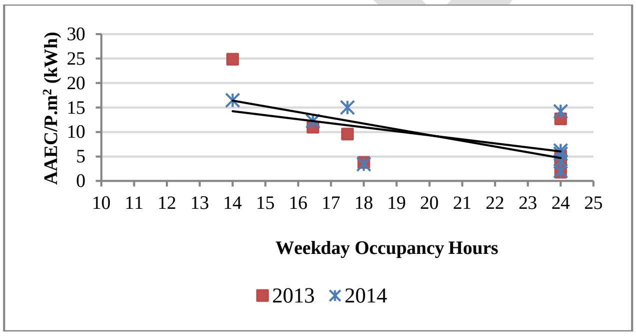

Figure 17: AAEC/P.m² against occupancy hours on a typical weekday

Table 1: Socio-Economic and Technical Characteristics of the Surveyed Households

HH	Building Type	Year of Construction	No. of Bedrooms	Floor Area (m^2)	Years of Residency	HH size	HoH Gender	HoH Education Level	Average Electricity Consumption in 2013 (kWh)	Average Electricity Consumption in 2014 (kWh)	Electricity Analysis
X_1	SD	2008	4	150	2	6	M	3	3412.2	3088	✓
X_2	SD	2011	2	101.35	3.5	2	F	3	2398.1	2415.5	*
X_3	SD	2011	4	198	3	4	F	2	4345	4842.6	✓
X_4	SD	2008	3	125	1.3	4	F	2	DA	DA	-
X_5	SD	2010	3	233.69	1.3	8	M	2	3805.8	3326.1	✓
X_6	SD	2010	5	142.57	3.8	6	M	2	5312.3	4383.3	✓
X_7	SD	2010	3	118.56	2.3	3	M	3	3613.8	3601.3	*
X_8	SD	2010	3	144.19	4	2	F	3	7163	4747.3	✓
X_9	SD	2008	4	122.63	6	2	F	2	3111.2	3489.8	✓
X_{10}	SD	2008	5	145.63	0.33	8	M	3	RM	RM	-
X_{11}	SD	2008	3	125.83	2.4	4	F	2	4820.6	7548.6	✓
X_{12}	SD	2011	3	193.88	3	5	M	2	3815.5	5381.9	✓
X_{13}	SD	2008	4	201.88	3	6	F	0	5612.1	4830	✓
X_{14}	TH	2008	2	104.26	4	1	M	2	3961.8	4093.7	-
X_{15}	SD	2008	3	107.87	5	2	F	2	DA	DA	-
X_{16}	SD	2010	3	111.91	4	2	F	3	2777.3	2525.6	*
X_{17}	SD	2008	4	192.77	0.83	6	M	2	RM	RM	-

HH: Household, SD: Single Detached, TH: Town House, DA: Did not Agree, RM: Recently Moved
HoH Education: None = 0, Primary = 1, Secondary/High School = 2, University Degree = 3
*These households are removed from electricity analysis as they either used the gas heating system or electric water heater.

Table 2: A comparison of average annual electricity consumption between the households with a male and a female HoH

		Male HoH	Female HoH
Year	**Number of Households**	4	5
2013	AAEC/P (kWh/2013)	619.53	1890.02
	AAEC/m^2 (kWh/2013)	21.85	32.62
	AAEC/P.m^2 (kWh/2013)	3.66	12.54
2014	AAEC/P (kWh/2014)	738.04	1846.4
	AAEC/m^2 (kWh/2014)	19.92	33.95
	AAEC/P.m^2 (kWh/2014)	4.31	12.38