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SOME COMPUTATIONAL RESULTS ON THE IMPACT OF SOCIO-ECONOMIC AND OCCUPANCY FACTORS AFFECTING RESIDENTIAL ENERGY USAGE IN NEW ZEALAND

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Abstract

In this study, the socio-economic and occupancy consequences affecting households and its impact on efficient energy use in the New Zealand residential sector are estimated. Also, factors impacting on efficient appliance usage in households are considered. Household appliance use surveys were conducted to obtain information about the activities occurring in New Zealand homes regarding the use of their household electrical appliances. Demographic factors considered include income bracket and the number of occupants in households. Household appliance use was modelled as a function of households turning off lights with no presence; households that consider efficiency as the most decisive factor when buying home appliances; occupants limiting heating consumption and the frequency of having hot showers in households.. This was achieved with the aid of questionnaires/interviews administered on 57 households in Hamilton and 35 households in Auckland. Demographic factors were analysed using frequency distribution to investigate the spread of household appliance usage. Hypothesised interactions between the factors in the model were tested and interpreted using correlation matrix andp-values to investigate their impact on efficient appliance usage in households. The factors considered in this research impacted positively on energy use, hence the need to improve efficiency in appliances use in households.

Keywords**:** Efficiency, Surveys, Consumer behaviour, Income bracket, Occupancy

1. Introduction

Households are highly dependent on electricity and is generally impossible for them to live without it. As a result, electricity is seen as a tool for socio-economic development; it increases economic activities in the society. There is a desperate need to reduce energy consumption in households[1].Energy consumption has a major impact on the economy, people and the environment. In controlling electric appliance use, problems in global warming can be lessened, energy resources well managed and the future of our energy well taken care of[2]. With the introduction of energy-efficient electric appliances, global energy savings has improved to about 83%, except in Asia, Africa and the Middle East[3]. According to [4], by 2050, power consumption could be reduced by one third through improvements in energy efficiency in buildings, industrial processes and transportation. Reducing energy use has the potential of reducing electricity consumption costs and thus increasing energy savings. In the 1990s, the US Environmental Protection Agency (EPA) created the Energy Star Program to reduce energy consumption by consumers. According to [5], 50 million kilowatt-hours (kWh) was saved through measures taken by consumers to reduce electricity consumption in 2014. The program has been adapted in other countries such as Australia, New Zealand and Japan.The application of energy efficiency and resource productivity paradigm offers a new ground for business invention, sustainable growth and economic development. The application of energy-efficiency programs to stimulate economic development was discussed in [2]. The paper presented that the use of energy-efficient initiatives reduces carbon emissions associated with energy use, with the primary goal of improving the environment, reducing energy spending and increasing savings.

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During the last 30 years, there have been a number of publications, concerning energy saving measures in various types of building. A small part of these publications examined the economic dimension of energy saving measures. The cost-effectiveness of energy-saving measures in buildings was discussed in [6], and provided examples for buildings in the United Kingdom. He mentioned that these measures can be regarded as investments, which should be evaluated using some general indicators of cost-effectiveness of energy usage. The paper proposed the internal rate of return and produced a ranking by cost-effectiveness of all the measures considered. Kuwait's approach and experience in the development, introduction and implementation of energy-saving standards in buildings was presented in [7]. Although Kuwait is rich in energy resources, a review of the growth in energy consumption revealed the need for energy savings, particularly in the building sector. The ministry of electricity and water of Kuwait responded by introducing guidelines and a set of regulations and mandatory standards for energy saving in buildings. The paper presented the potential energy as well as economic savings of their implementation. Other countries that have such guidelines include the United Kingdom, Australia, China, etc.

In essence, electricity efficiency and introducing control mechanisms to electricity consumption plays important roles in minimizing electricity wastages and reducing the cost of electricity. Applying control techniques to electric appliances would improve efficiency in the use of electricity. However, the lack of sufficient control for electric appliances' use is a key limiting factor for developing enough efficiency in electricity consumption in order to minimize electric costs [8]. To illustrate the application of control techniques on electric appliances for efficient electric use, data was collected from more than 300,000 detailed single-family house sale records in the Greater Chicago area to investigate the spatial effects neighborhood adoption of energy-efficient heating, ventilation, and air conditioning (HVAC) systems [9]. The control variables affecting the demand of energy-efficiency, taken as parameters in the spatial error model were neighborhood amenities, distance to the central business district, vacancy rate, population density, and percentage of households that were renters. According to the results from the full sample models, neighbourhoods with more newly constructed or recently rehabilitated houses, with larger square footage, and with higher median income and lower population density areas tended to adopt energy-efficient HVACs. Using the results from the repeat-observations models, neighbourhoods with homes experiencing larger remodels and expansions tended to have greater adoption rates for energy-efficient HVACs. Moreover, neighbourhoods of houses with larger lot sizes and square footage, with greater wealth, but paying lower tax rates on their properties were more likely to adopt energy-efficient HVACs. Simulation results of this study obtained from all the models suggest that households paying lower property taxes promote energy-efficient HVAC adoption than households making mortgage payments with lower interest rates.

A research paper in [10] provided a relationship between energy consumption and growth, in terms of human, environmental, and global health. The research paper suggested that achieving energy efficiency will greatly have a profound transformation effect on economic development, hence impacting on reducing energy costs. These factors will significantly reduce health costs, environmental pollution, production and global warming. As a result of findings from this paper, houses were made more energy efficient. For example, installation of wall and roof insulation, energy-efficient windows and doors, ultra-efficient lighting technologies, energy-saving appliances, solar power to heat water, etc. led to more efficient use of electricity. The research also suggested the introduction of light-weight hydro-electric motor vehicles to reduce energy costs and the protection of human and environmental health. a model based on patterns of active occupancy (i.e. when people are at home and awake) was presented in [11]. The domestic electricity demand model developed in the study mapped occupant activity to appliance use, where "appliance" refers to any individual domestic electricity load, such as a television, washing machine or vacuum cleaner. Each appliance in the model had two states: either on or off. A model generating activity sequences of individual household members, including occupancy states and their domestic electricity demand was presented in [12]. The activity-generating models were converted to empirical time-use data set creating a realistic spread of activities over time. The research developed a model for generation of occupancy patterns in households comprising of three states; 'absent', 'present and active', and 'present and inactive'.

The contributions of this paper are summarized as follows:

1. Improving efficiency in behavioral appliances use in households.
2. The reduction of wastages in the consumption of electricity, resulting in efficient allocation of energy resources from the electricity network.
3. Load matching and shifting strategies by consumers, whereby consumers can use their electric appliances in a more efficient manner.
4. Consumers can maintain significant energy savings over time.

Accordingly, the main objective of this paper is to analyse the impact of consumer behaviour, income level, number of occupants and location of households on efficient appliance usage. In Section 2, the methodology used to determine efficiency in appliance use is described. In Section 3, results are analysed, outlined and discussed. Finally, Section 4 is devoted to conclusion and discussion of the outcomes from this study.

2. Methodology

This research collected an array of information at the household level, which relies on questionnaires to collect data from households in New Zealand. In addition to the questionnaire, this research also conducted in-person interviews to collect socio-economic and household occupancy data to perform computational analysis for multivariate estimates and the examination of statistical relationships among the key variables.

A binary variable captures whether household is Hamilton (coded 1), or in Auckland(coded 2). Socio-economic variables are coded from options in the questionnaire. In order to capture household income, four income level groups ranging from one to four are given, with lower levels representing lower income. Number of occupants in a house is included as a key driver of efficient household appliance usage, coded according to the number of adults or children that live in the apartment on most part of the year. A series of Likert scale questions are included to capture behavioural factors that may influence efficient usage of household appliances, with lower values reflecting a greater commitment to efficiency in appliance usage. Electricity efficiency is represented by questions that represents a variety of measures that are commonly undertaken to reduce household electricity consumption and ranges from one to six. Examples include turning off lights in rooms with no presence, price as a factor when using appliances, limiting heating consumption, limiting hot water consumption and frequency of hot water baths.

A total of 92 respondents were interviewed out of an expected number of 100 households that were expected to be interviewed in Hamilton and Auckland. This represents a return rate of 92%. A total of 57 respondents were interviewed in Hamilton and 35 respondents were interviewed in Auckland. This represents a return rate of 95% and 87.5% for Hamilton and Auckland respectively. Questionnaires were randomly administered on these households. Households were identified and selected equally across the cities used in the survey. The sample design is given in Table 1.

Table 1.Sample design of study

Location	Expected number of respondents	Respondents interviewed	Percentage response (%)
Hamilton	60	57	95
Auckland	40	35	87.5
Total	100	92	92

The data collected from the survey was analysed to obtain descriptive statistics and multivariate models. These include frequency distribution, correlation matrix, and *p*-values of the various variables. The relationship between data collected for variables considered in the questionnaire is analysed using statistical package for social sciences (SPSS).

3. Analysis and Results

This section consists of results obtained from analysis carried out on requisite data. It consists of demographics and multivariate estimates for achieving efficiency in household appliance usage.As explained in the previous section, the efficiency of household appliance usage in New Zealand homes was determined by using the information recorded in a survey. The computation of frequency distribution, correlation matrix and *p*-values was conceptualized to observe relationships between factors related to efficiency in the use of household appliances considered in this research. This approach allows for intra-group relationships, rather than assuming that observations within the groups are independent.

3.1 Demographics of households

The demographics of households in this study are classified into two categories; (i) Households in Hamilton, and (ii) Households in Auckland. Households in Hamilton and Auckland were selected for this survey because it was relatively easy to collect data from these households compared to other cities in New Zealand, and also because of cost constraints. The demographic factors considered are location of household, number of occupants in a household and household's income bracket.

3.1.1 Demographics for households in Hamilton

The following variables were considered:

A. Number of household occupants in Hamilton

Table 2 and Fig.1 shows that majority of the houses in Hamilton have 4 occupants living in them, i.e. 31.6% of the population in Hamilton.

Table 2.Number of occupants

Value	Frequency	Percent	Cumulative percent
1	12	21.1	21.1
2	12	21.1	42.2
3	9	15.8	57.9
4	18	31.6	89.5
5	6	10.5	100
Total	57	100	

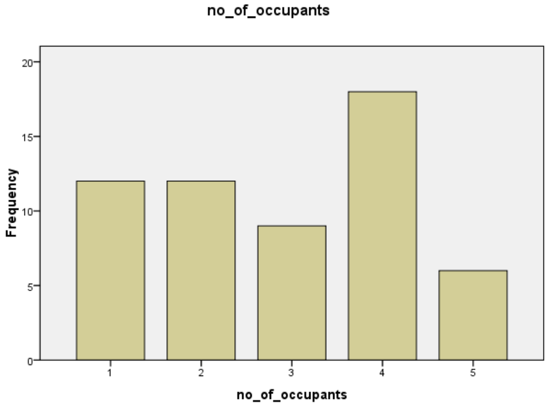

Fig. 1. Frequency of household occupants in Hamilton

B. Household income of households in Hamilton

A high percentage of the households in Hamilton lie within the income group $2,000-$3,000, which are 28 households (49.1%). This consists of the average income earners. This is shown in Table 3 and Fig.2 respectively.

Table 3. Household income

Value	Frequency	Percent	Cumulative percent
Less than $2,000 a month	11	19.3	19.3
$2,000-$3,000	28	49.1	68.4
$3,000-$5,000	12	21.1	89.5
Above $5,000 a month	6	10.5	100
Total	57	100	

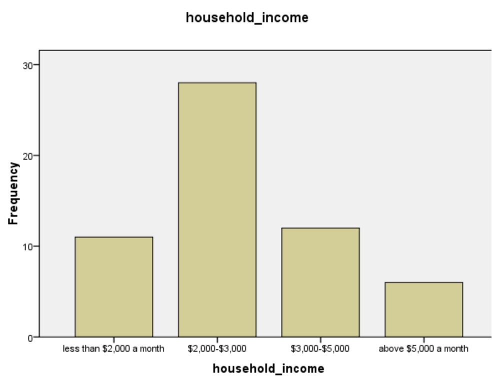

Fig.2.Frequency of household income in Hamilton

3.1.2 Demographics for households in Auckland

The following variables were considered:

A. Number of household occupants in Auckland

Table 4 and Fig.3 shows that majority of the houses in Auckland have 3 occupants living in them, i.e. 36.1% of the population in Auckland.

Table 4.Number of occupants

Value	Frequency	Percent	Cumulative percent
2	13	36.1	36.1
3	13	36.1	72.2
4	7	19.4	91.7
5	3	8.3	100
Total	36	100	

Fig. 3.Frequency of household occupants in Auckland

B. Household income in Auckland

A high percentage of the households in Auckland lie within the income group $2,000-$3,000, which are 20 households (55.6%). This consists of the average income earners. This is shown in Table 5 and Fig. 4 respectively.

Table 5.Household income

Value	Frequency	Percent	Cumulative percent
$2,000-$3,000	20	55.6	55.6
$3,000-$5,000	8	22.2	77.8
Above $5,000 a month	8	22.2	100
Total	36	100	

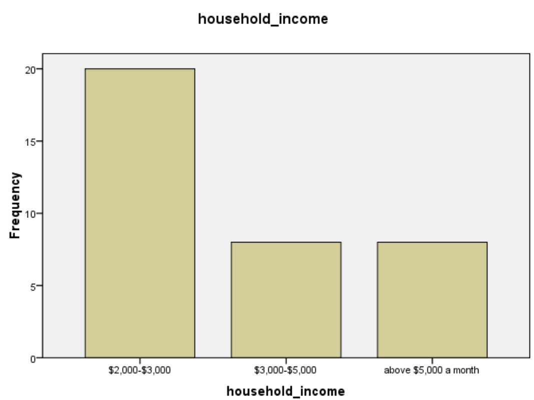

Fig. 4.Frequency of household income in Auckland

3.2 Correlation matrix and *p*-value table for factors impacting on efficient appliance usage for households in Hamilton and Auckland

The variables considered for the survey undertaken in this study include households turning off lights in rooms with no presence; efficiency is most decisive factor when buying home appliances; occupants limiting heating consumption andthe frequency of having hot showers in households. The correlation matrix and *p*-value are used to investigate the impact of socio-economic and occupancy factors on energy usage. The computations for correlation matrix and *p*-valuesare given in Equation (1).

$$\text{Correlation } (r) = \frac{n(\sum xy - (\sum x)(\sum y)}{\sqrt{(n\sum x^2 - (\sum x)^2)(n\sum y^2 - (\sum y)^2}} \qquad (1)$$

$x$is independent variable
$y$is dependent variable
A Correlationcoefficient (r) of 1 means that for every positive increase in one variable, there is a positive increase of a fixed proportion in the other.

A correlation coefficient (r) of -1 means that for every positive increase in one variable, there is a negative decrease of a fixed proportion in the other.

A Correlationcoefficient (r) of zero means that for every increase, there isn't a positive or negative increase. The two just aren't related.

The *p*-value, or computed probability, is the probability of finding the observed, or more extreme, results. The results are accepted if the computed *p*-value is greater than the level of significance value $\propto$at $100\ (1-\propto)\%$ significance level, otherwise the result is rejected.The significance level $(\propto)$ is refers to a pre-chosen probability. Conventionally the 5% (less than 1 in 20 chance of being wrong), 1% and 0.1% (*p*-value< 0.05, 0.01 and 0.001) levels can be used.

The correlation matrix and *p*-value table showing the relationship between these variables are given in Table 6 and Table 7 respectively.

Table 6.Correlation matrix for factors affecting appliance usage of households

		1	2	3
	Correlation (r)	**Households turning off lights in rooms with no presence**	**Efficiency is most decisive factor when buying home appliances**	**Frequency of having hot showers**
1	**Households turning off lights in rooms with no presence**	1		
2	**Efficiency is most decisive factor when buying home appliances**	0.847802	1	
3	**Frequency of having hot showers**	0.431791	0.663791	1

Table7.*p*-values for factors affecting appliance usage of households

		1	2	3
	p-value	**Households turning off lights in rooms with no presence**	**Efficiency is most decisive factor when buying home appliances**	**Frequency of having hot showers**
1	**Households turning off lights in rooms with no presence**	1		
2	**Efficiency is most decisive factor when buying home appliances**	0.0634	1	
3	**Frequency of having hot showers**	0.0018	0.0607	1

From Table 6, there is a positive correlation between households turning off lights in rooms with no presence and consumers that consider efficiency as the most decisive factor when buying home appliances (r= 0.847802). This is due to consumers taking efficiency in appliance usage serious. Also, frequency of households having hot showers and consumers that consider efficiency as the most decisive factor when buying home appliances is highly correlated (r= 0.663791). This indicates that households consider efficiency as an important factor when consuming electricity. There is no significant relationship between households turning off lights in rooms with no presence and households having hot showers (r= 0.431791). The results and interpretations from Table 6 can be confirmed by the *p*-values obtained from the data. From Table 7, at $\propto = 0.01$, the *p*-value between households turning off lights in rooms with no presence and consumers that consider efficiency as the most decisive factor when buying home appliances (p = 0.0634) indicates a linear relationship since p = 0.0634 $> \propto = 0.01$.

Similarly, at $\propto = 0.01$, the *p*-value between frequency of households having hot showers and consumers that consider efficiency as the most decisive factor when buying home appliances (p = 0.0607) show there is a significant relationship since p = 0.0607 $> \propto = 0.01$. There is no significant relationship between households turning off lights in rooms with no presence and households having hot showers (p = 0.0018), since p = 0.0018 $< \propto = 0.01$.

4. Conclusion

This research investigates socio-economic and occupancy factors affecting energy usage in New Zealand's households. It is important to recommend some factors contributing to household energy use. Such factors as consumer behaviour, income, age, geographical location, that has an effect on power consumption for household appliances. In terms of improving efficiency in appliances use in households, it is important to identify target behaviours that have a relatively large energy saving potential.

The positive relationship observed between households turning off lights in rooms with no presence, frequency of households having hot showers and consumers that consider efficiency as the most decisive factor when buying home appliances is consistent with arguments in favour of their impact on efficient appliance usage. The number of occupants in a household is also an important factor in understanding efficiency in residential electricity usage. Households that are more compact are likely to reap the benefits in the form of reduced electricity consumption.

There are two methods that can be used to minimize the use of energy in households. Firstly, is human behaviour, i.e. curtailing energy wastage while using electric appliances. This is achieved by turning off lights, fans, air-conditioners, etc. on a frequent basis in households. human behaviour is affected by sociological and psychological factors. Secondly, is the use of energy efficient appliances. This requires investments in energy efficient devices. By keeping efficiency in use of household appliances in mind, researchers can focus on consumer behaviour that significantly influences appliance efficiency use qualities.

References

[1] World Energy Outlook (2016, May 31). Retrieved from. doi:10.1787/weo-2013-en/

[2] Roulet, E.: Climate Control of Terrestrial Carbon Exchange across Biomes and Continents. Environmental Research Letters 5(3) (2010).

[3] Bergen, A.: Towards Software-Adaptive Green Computing Based on Server Power Consumption. Proceedings of the 3rd International Workshop on Green and Sustainable Software, 9–16 (2014).

[4] International Energy Agency. (2016, May 31). Retrieved from http://www.iea.org/publications/

[5] United States Environmental Protection Agency. (2016, May 31). Retrieved from http:// https://www3.epa.gov/

[6] Freund P.: The Cost-Effectiveness of Some Measures for Energy Conservation in Buildings in the UK. Build. Service & Environment Engineering, 6, 69–79 (1979).

[7] Kellow, M.: Kuwait's Approach to Mandatory Energy-Conservation Standards for Buildings. Energy, 14(8), 491–502 (1989).

[8] Mishra, S., Usmani, J. A. & Varshney, S.: Energy Saving Analysis In Building Walls Through Thermal Insulation System, 2(5), 128–135 (2012).

[9] Noonan, D. S., Hsieh, C. &Matisoff, D.: Spatial Effects in Energy-Efficient Residential HVAC Technology Adoption. Environment and Behaviour, 45(4), 476–503 (2011).

[10] Fontana, L., Atella, V. &Kammen, D. M.: Energy Efficiency as a Unifying Principle for Human, Environmental, and Global Health. F1000Research, 2, 101 (2013).
[11] Richardson, I., Thomson, M., Infield, D. & Clifford, C.: Domestic Electricity Use: A High-Resolution Energy Demand Model. Energy and Buildings, 42(10), 1878–1887 (2010).
[12] Widén, J. & Wäckelgård, E.: A High-Resolution Stochastic Model of Domestic Activity Patterns and Electricity Demand. Applied Energy, 87(6), 1880–1892 (2010).