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EVALUATION OF BUILDING ELECTRICITY CONSUMPTION OF RESIDENTIAL DWELLINGS IN OSHAWA

Andrew Lukomski[1], Kamiel Gabriel[1], Yaolin Lin[1,*], Don Pitman[2]

[1]Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, Oshawa, Ontario, Canada
[2] Manager of Communications and Energy Conservations, OPUC Networks Inc.
[*] Corresponding author: yaolinlin@gmail.com

ABSTRACT

In this paper, the principle component analysis was applied to find the most important factors that affect the electricity consumption in 55 houses in Oshawa. The long-term trends of electricity consumptions of 270 houses located in Oshawa, currently being monitored by smart meters, were generated for several types of houses with different mechanical systems. Occupants' behavioral factors that contribute to the electricity consumption were examined and analyzed. Simple correlation models were developed to predict the electricity consumption for a number of houses.

INTRODUCTION

This paper presents a summary of the progress in investigating energy consumption trends in Oshawa's Residential Dwellings project during the summer of 2007. The majority of analysis is directed towards *Phase II* of the project, involving the monitoring of electricity consumption of over 260 homes in the Oshawa area using smart meters. *Phase I* involved monitoring of 55 homes in the Oshawa area. One of the focal points for this study was to ensure that the consumption data from the Oshawa PUC Networks Inc. (OPUCN) smart meters was received accurately. The process of collecting the consumption data was automated using a MATLAB based code to simplify the extraction process. The metered data was also coupled with household surveys and home energy audits for some of the homes. The three group parameters being considered as most influential factors are the building envelope, mechanical systems and consumer habits. Each group contributes to electricity consumption differently. All data is stored electronically.

Analysis was limited, mainly due to the focus on smart meter data acquisition. Principle component analysis was conducted on data from *Phase I* to verify the technique for implementation on *Phase II data;* preliminary results are presented. Consumption trends are also investigated for various home combinations to indicate the widespread energy use patterns that exist in the residential sector.

The smart meter data that is received at UOIT is through a data communications company, Tantalus Systems Corporation, using the TUNet™ software. The data is transmitted by radio signals to a communications tower and is stored in aggregate files. A rough estimate for the number of meters involved in the study is 260 as select meters do not operate on a continuous stream. The first set of metered data came to UOIT as a single file with consumption data between February 27, 2007 and May 30, 2007. The installation of the study's smart meters was completed over several months which left only a small number of homes with enough data to move ahead with trend analysis. Nearly all meters were accounted for at the end of May. After establishing a data transfer web space at UOIT, Tantalus was able to update the database on a daily basis. Useful data was then extracted at UOIT. Periodic updates are carried out on the data and the files in place are capable of handling incoming data until August 2008.

Using long term trend analysis, a periodic use of electricity was observed in certain homes which could be used to establish relationships between consumption and factors attributed to consumer habits. Homes with similar characteristics have been grouped and can be analyzed together to help identify the impact of consumer habits or other expected factors based on the observed differences in consumption patterns. This is an effective technique in identifying consumer habits.

To gather information regarding the individual habits within the studied homes, a detailed 35 question survey was conducted in all participating homes. Questions targeted topics such as type of outdoor lighting, work schedules, number of inhabitants, level of education and vacation period for individuals within the home. Additionally, the age, housing type and type of heating was listed to provide general information about housing characteristics for each home. Residents were also presented with a series of habitual changes to help reduce consumption within their homes and asked which actions they would be most willing to adapt to their routines. Select actions have already been promoted by distribution companies; however, it is necessary to find which of those capture the interest of consumers resulting in conservation. Current analysis clearly depicts energy consumption as being an interdependent variable.

Information gathered as part of the energy audit includes housing characteristics, such as floor and wall areas, R-values for walls and windows, and HVAC capacities. The Canadian home energy use modeling software HOT2XP was used to generate reports for 82 homes as part of the study database. The regression model developed for this project is centered on this group of homes since only select information is available for the homes without energy audits as mentioned previously. Simulations made by the software can be loosely used as a comparison to predictions made by the software currently being developed.

PRINCIPLE COMPONENT ANALYSIS

The statistical technique was used to identify the importance of different parameters towards electricity consumption based on consumer habits. The goal was to simplify the studied relationship to a select group of variables having the largest impact on the dependent variable (Aggarwala et al. 2004). The PCA analysis was carried out on homes from *Phase I* of the project. This was done to test the feasibility of the method and provide some preliminary results for comparison with expected values. Twenty five homes were part of the data set based on the survey results obtained from those homes. The survey consisted of nine questions, as summarized in Table 1.

The survey from *Phase I* consisted of building and internal systems related questions while *Phase* 2 survey focuses more on consumer. This was ideal in testing whether or not the PCA would properly identify the significant variables from the data set. *Phase I* data was received during the period from June 2005 to May 2006 (approximately 11 month). Homes were divided into above and below average consumption homes based on a calculated average value of 9990.6 kWh/year.

Table 1 - Questions Included for PCA Analysis from Phase I Survey

	Survey Question
1	What type of building do you live in? (Single, Semi, Town)
2	When was your home built?
3	What is the square footage of your home?
4	What type of space heating does your home have? (Electric, Natural Gas, Oil)
5	What type of water heater does your home have? (Electric, Natural Gas)
6	Do you have any programmable thermostats?
7	How many people live in your home?
8	Do you own or rent your home?
9	Indicate your highest level of education

Results obtained showed that similar household factors had an impact on both the below and above average consumption homes (Table 2). Each analysis produced nine eigenvalues with corresponding eigenvectors of which the most significant is presented for each case. The largest components are bolded and indicate the most important questions to the type of households. For the below average consumption homes, in order, the *number of residents, floor area* and the *age of the home* were the most important criteria. For the above average homes the largest impact was, in order, the *floor area*, the *type of home* and the *type of space heating equipment* inside the home.

Table 2 - PCA Results for 25 Homes (Part of Phase I Set)

Below Average Homes		**Above Average Homes**	
λ	1.2947915	λ	2.60796035
Ques.	**x1**	**Ques.**	**x1**
1	0.1244	***1***	***-0.4733***
2	***0.3356***	2	-0.0223
3	***-0.6309***	***3***	***0.6843***
4	0.0724	***4***	***0.3898***
5	0	5	0.2012
6	-0.0750	6	0.0315
7	***0.6685***	7	0.2145
8	0	8	-0.2299
9	0.1265	9	0.1212

PCA identified the important factors for both the below average and above average homes. Although these factors were important for both groups of homes they do not necessarily indicate why these homes differ in consumption to such a great extent. Identifying which factors were important for only a single group, i.e. the above average consumption homes was completed by conducting t-test statistics for each question that was answered by the households. As a result, the questions which were demanded most significant for the two separate categories are identified, as shown in Figure 1.

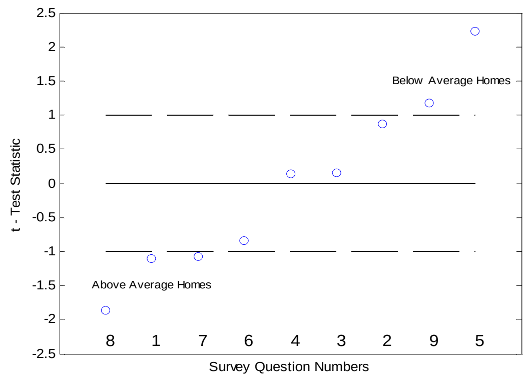

Figure 1. Survey Questions Ranked According to Home Category Importance - Phase I

Tests greater than 1 in magnitude are all statistically significant on, at least, 80% confidence level. The results show that above average consumption homes tend to depend on questions 8, 1 and 7 the most, while the below average consumption depend on 5, 9 and 2. Referring to the responses to questions, some above average homes are rented town homes and are usually occupied by several inhabitants. On the other hand, below average consumption homes have natural gas water heaters and tend to have a high education. Questions of high importance to each category would be considered for focused programs, while those having a relatively equal importance could be included as part of general programs focusing on the entire residential base.

The PCA analysis will be carried out on homes as part of *Phase II* study, when a larger data set is received. It is expected that with a larger data set of homes and the survey having up to 35 questions the results will identify some of the lesser known factors and rank their importance towards above and below average consumption homes. The analysis will not include building characteristics to provide a clear indication of the habitual factors which influence electricity consumption.

ELECTRICITY CONSUMPTION ANALYSIS

Analysis of certain factors with electricity consumption was carried out to identify general trends, similar to analysis during *Phase I* (Gabriel and Willis 2006). The parameters studied included the consumption over a selected monitoring period affected by the number of inhabitants in a home, the total home income bracket and house type. Only a fraction of data for homes was extracted for this analysis since not all homes and consumption have readings from early stage of the study.

The impact of number of inhabitants on consumption had a positive trend in both the electrically and natural gas heated homes as shown in Figures 2 and 3. The sample size for the electric heated homes (ELEC) is noticeably smaller as the majority of the homes are natural gas heated homes (NG). The increase in electricity consumption per additional individual in the home (including children) is approximately 300 kWh (Apr. 11/07- Aug. 6/07) in both styles of homes while the baseload consumption for electric homes is slightly larger. Also, the data is widely ranging, which shows that other parameters are influencing consumption.

Multiple variables will be needed to give a reasonable prediction of electrical consumption in a typical home. Generally, the effect of space cooling and/or heating will not change drastically with the addition of individuals into a home but rather with the home size. The increase in consumption is therefore a result of increased appliance usage, hot water consumption and other electronic gadgets used in increasingly modernized homes. Additionally, the consumption patterns of children differ from adults adding uncertainty to actual consumption patterns per individual.

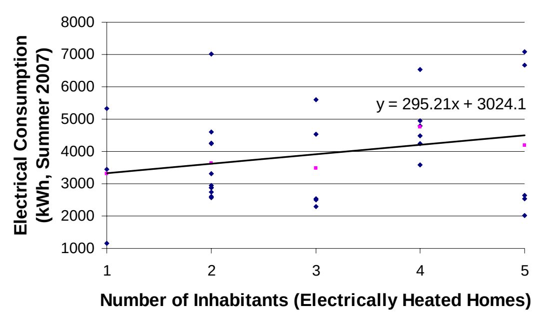

Figure 2. Number of Inhabitants Impact on Electricity Consumption (Electrically Heated Homes)

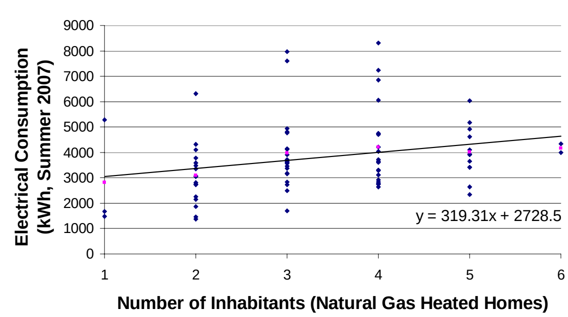

Figure 3. Number of Inhabitants Impact on Electricity Consumption (Natural Gas Heated Homes)

Next, the income analysis provided results based on the average values of consumption for each income bracket (Figures 4 and 5). Similar to the inhabitants' trends, the data is widespread and outliers exist for all brackets. The increase in consumption per income bracket is noticeably different with natural gas homes consuming more per unit increase. It is necessary to mention that the endpoints for some of the brackets do not vary significantly between one another suggesting that the income level is not a very strong factor. Further analysis should be conducted to account for all seasons within a year having different impact on homes, as the period in the current analysis (spring/summer) naturally affect more electricity consumption because of the use of central air conditioning systems in those homes. It is possible that the varying size of the A/C units could have a major effect during the summer period as cooling plays a major role in the electricity consumption during the summer months.

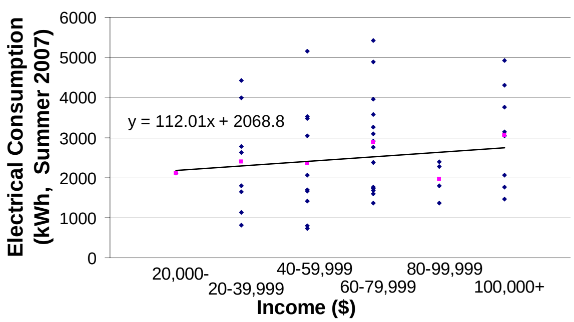

Figure 4. Effect of Income on Electricity Consumption (Electrically Heated Homes)

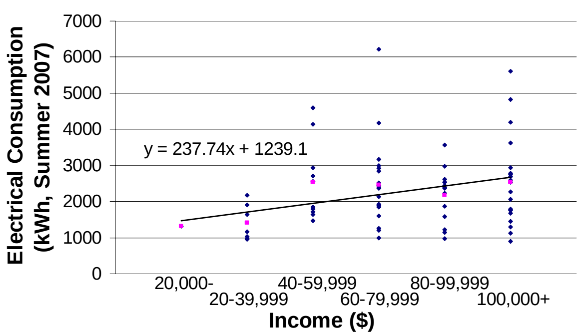

Figure 5. Effect of Income on Electricity Consumption (Natural Gas Heated Homes)

Housing type plays a role in energy consumption as is seen in Figures 6 and 7, which account for the period Apr. 11 – Aug. 6, 2007. The row end homes as included in this study are either semi-detached or an end unit town-house. That is, only 3 of 4 walls are open to the external environment where a large fraction of thermal energy is lost (winter) or gained (summer). For the homes considered, there is an approximately 1600 kWh lower electrical consumption for the row end homes compared to the single detached homes over the spring/summer period. The single homes in both the electric and natural gas groupings generally have larger areas to cool, either with larger central systems or window units. This may be an additional factor which places those consumption readings above the row end homes. Analysis during the winter period would provide a different scenario as the natural gas homes would not be relying on electricity for heating and so the large consumption patterns may level off.

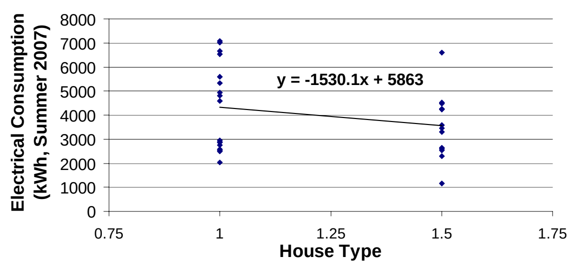

Figure 6. Electrical Consumption for Electric Homes

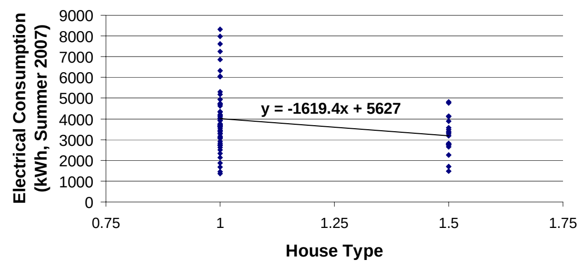

Figure 7. Electrical Consumption for Natural Gas Homes

As part of the occupants' survey, questions concerning conservation actions were asked to understand which habits households were most willing to adapt to help conserve electricity (Figure 8). Over 60% of occupants surveyed were willing to implement most of the activities listed. Notably, approximately 90% of respondents were willing to use a full cold water wash cycle for their laundry and turn off lights in empty rooms. On the other hand, the use of electronic equipment in households draws a large amount of standby electricity consumption which is essentially wasted electricity. As only 40% of respondents are willing to remove these electronics from the grid when not in use, it is necessary that manufacturing standards be adjusted to reduce this consumption component. Raising the summer time set point to 25°C is only considered by about 55% of households and so utility controlled reductions in air conditioning units should be pursued. Distribution companies should consider action to implement programs which limit air conditioning use during peak hours. It is not possible to validate whether these individuals have since implemented such actions.

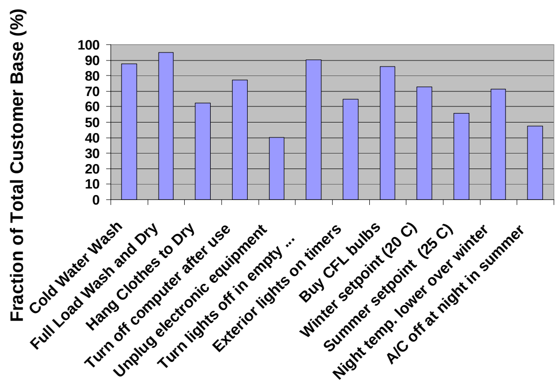

Figure 8. Results of Consumers' Willingness to Implement Change to Conserve Electricity

Survey data suggest that consumers are widely concerned with investing in conservation efforts (Figure 9). Small scale initiatives are more attractive to engage in with over 50% of respondents willing to spend a maximum of $250 on actions that will help reduce electricity usage. Many households are hesitant to invest large amounts of money into such activities as the paybacks benefits are often not clear to them. The most appealing programs for households should make such benefits clear to consumers and come at lower costs. Having a large response to smaller conservation programs will result in widespread implementation and the possibility that households will carry on with further conservation efforts in the future.

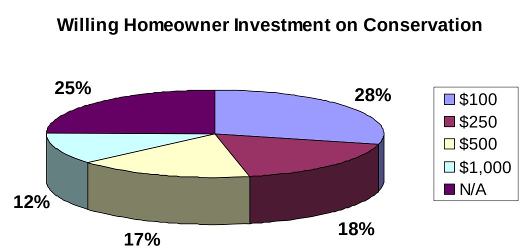

Figure 9. Homeowner Investment towards Conservation Actions

Each home reported in this study has characteristics that coincide with other homes being monitored. By comparing these groupings and identifying some of the common factors that contribute to electrical consumption, we can then focus on those homes with the largest differences (Table 3). Figure 10 shows various homes with the cumulative energy consumption for nearly a 5 month period between February 27 and August 6, 2007. The transitional months of May and June, listed as day numbers 64 through 124 have the largest fluctuations in consumption trends. As summer approaches, the NG-homes begin to use central air conditioners, thus increase the daily electricity consumption. On the other hand, the ELEC-homes, such as home *1*, see a leveling of consumption since baseboard heaters are not operating during summer months and a central air conditioner is usually unavailable. Homes such as *4* and *8* are of concern due to their high consumption even though they are heated by natural gas during winter months. Additionally, home *4* experiences consumption ranging between 40-60 kWh per day with a shift occurring around day 55 (with daily readings listed at 60-80 kWh for the rest of the monitoring period). This may be attributed to an early start of the cooling season for this house (end of April), or another type of behavioral change. The electrical consumption per number of inhabitants in a home (Figure 11) is considered a good way to distinguish between the homes which may be high consumers from those who have many individuals living inside. It is necessary to note that the consumption for heating and cooling is not known explicitly and may not provide a true representation of the actual consumption per individual. Homes such as *#2* have a very small consumption total per individual for a four-person household ranking below several two-person households. On the other hand, three person homes (such as *#4*) need to be evaluated more closely since consumer habits evidently contribute to the observed high consumption.

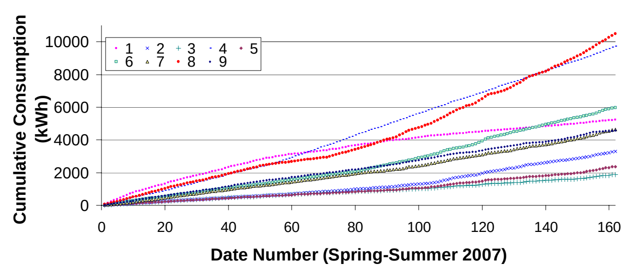

Figure 10. Seasonal Effects of Electricity Consumption for Several Homes

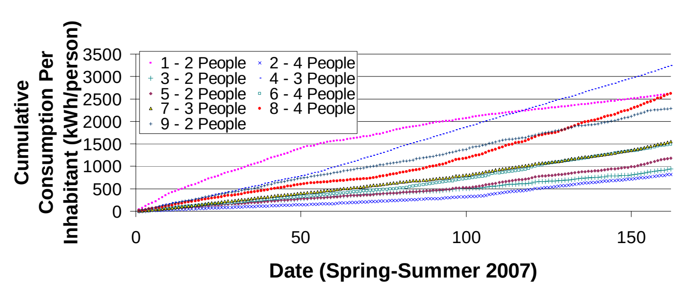

Figure 11. Effect of Number of Inhabitants on Consumption

Table 3 – Homes Involved in Long Term Analysis

House #	Code	Type	Heating Type	Water Heating Type	A/C
1	39843	Single-73 1-storey	Electric	Natural Gas	N/A
2	40431	Single-87 2-storey	NG-Continuous Pilot	Natural Gas	Central
3	66208	Single-94 2-storey	NG-High Efficiency	Natural Gas	Central
4	66968	Single-96 1-storey	NG-High Efficiency	Natural Gas	Window
5	79463	Single-95 2-storey	NG-Mid Efficiency	Natural Gas	Central
6	79488	Single(76-87) 2-storey	Electric	-	-
7	79716	Single-84 2-storey	NG-Continuous Pilot	Natural Gas	Central
8	79717	Single-85 2-storey	NG-Continuous Pilot	Natural Gas	Central
9	79734	Single-58 1-storey	Oil Furnace	Electricity	Central
10	28380	Single(76-87) 1-storey	NG	-	-
11	41057	Row-End-81 2-storey	NG-Continuous Pilot	NG	N/A
12	79742	Single(76-87) 2-storey	NG	-	-

Electricity consumption, to a large extent, depends on the external environment, mainly contributing to the heating and cooling requirements of a home. For the set of homes monitoring and reported in this study (February 27 – August 6, 2007), the effect of degree days on electricity consumption is presented in Figure 12. Two separate linear trends are observed over the study period for the NG heated homes. In summer, the rise in consumption occurring in these homes is even more prominent due to the consumption of electricity for cooling. The electrically heated home *1* maintains a linear trend over the entire monitoring period. A degree day is defined as the average value of the difference in temperature between the outdoor air and indoor set-point temperature of 18°C, for each day. It is possible to assume that the habits of individuals living in those homes do not change significantly during the transition from the winter to summer season.

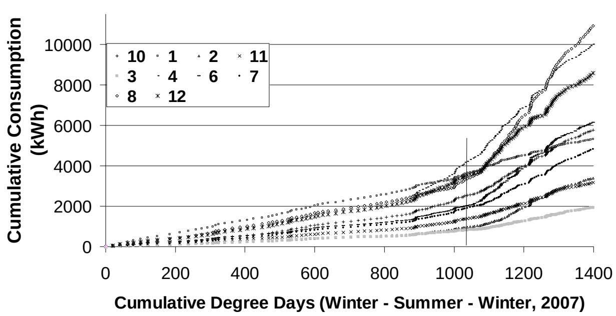

Figure 12. Consumption Relative to Degree Days (Based on indoor set-point temperature of 18°C)

This provides means to approximate the consumption due to the use of air conditioning based on degree days. As shown in Figure 13, home *8*, electrical consumption with A/C can be as large as 7.4 times the base consumption with roughly 20 kWh consumed per degree day in this four-person household. The other homes, *10* and *2* experience a similar increase due to air conditioning requirements of 7.5 and 7.1 kWh, respectively. Each home includes four individuals with different lifestyle patterns. Based on this type of composition, long term actions can be taken to reduce A/C consumption by limiting usage during peak demand hours.

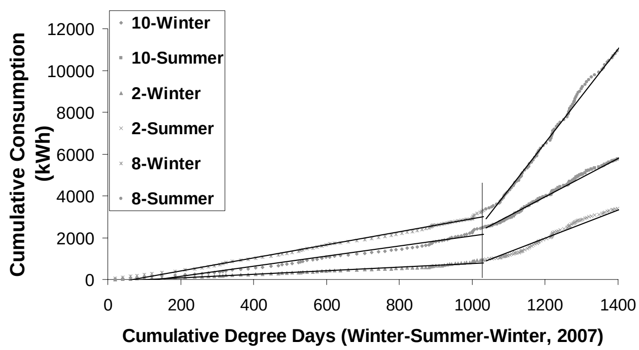

Figure 13. Identifying Cooling Consumption for Natural Gas Homes (Transition 1030.5 DD – May 15)

The correlation models for each house are presented in Table 4, where y is the total electricity consumption (kWh), and x is the accumulative degree days. Strong linear relationships with R-square value of 0.90 are observed. This means that the occupants' behaviors are strongly affected by the outdoor air temperature. Houses #2, 3 and 5 have the lowest electricity consumption in winter, and houses #1, 3, 5 have the lowest electricity consumption in summer.

Table 4 Correlation models for each house

House #	Summer (x_0=1037.7)	Winter (x_0=0)
1	y = 4.974x - 1476.9 R^2 = 0.9893	y = 3.3413x R^2 = 0.9974
2	y = 8.0505x - 7666.1 R^2 = 0.9863	y = 0.7516x R^2 = 0.9369
3	y = 3.3409x - 2730.2 R^2 = 0.9951	y = 0.6996x R^2 = 0.966
4	y = 17.816x - 14438 R^2 = 0.9953	y = 3.1239x R^2 = 0.9037
5	y = 4.9367x - 4446.8 R^2 = 0.9935	y = 0.6784x R^2 = 0.9614
6	y = 13.281x - 11995 R^2 = 0.9942	y = 1.6547x R^2 = 0.9499
7	y = 8.7875x - 7417.3 R^2 = 0.9947	y = 1.5179x R^2 = 0.9392
8	y = 23.208x - 21279 R^2 = 0.9946	y = 2.8561x R^2 = 0.9831
9	y = 8.0627x - 6301 R^2 = 0.9953	y = 1.8165x R^2 = 0.9607
10	y = 9.9519x - 7960.9 R^2 = 0.997	y = 2.0014x R^2 = 0.9258
11	y = 5.5263x - 4450.9 R^2 = 0.9936	y = 1.1279x R^2 = 0.9558
12	y = 15.568x - 12850 R^2 = 0.9938	y = 2.8171x R^2 = 0.9378

The general trend for the natural gas homes shows that base-load consumption increases during the summer season by as much as 1.66 kW (House 8), while in electric homes it may drop by 1.8 kW from winter to summer. Air conditioning may contribute to this increase in consumption, with even only a fraction of a kilo-watt. The change in base-load consumption depends on the house being studied; a universal value is unavailable. The two electric homes (1 & 6) show opposite trends which will require more investigation to explain the difference. In some homes, overnight standby consumption can contribute a reasonably large electrical load which many homeowners are likely unaware of, or unconcerned about. Informing consumers of this standby consumption may lead to rethinking the operation of certain electronics/appliances over night. These results can greatly assist in obtaining the daily habitual consumption routines in different homes which will further allow us to learn the actual consumption by occupants. This should be replicated for more homes in the future.

CONCLUSION

Samples from a study being conducted at UOIT in partnership with Oshawa PUC Networks, Inc. and OCE are about 12 homes, but data are collected from a wider range of homes in the Oshawa area.

The principle component analysis of *Phase I* data provided useful results to be replicated in the second phase (currently being studied). This data was collected over 11 months, which gave a nearly complete consumption profile for each home accounting for the seasonal differences and the types of home studied. Ultimately, the findings from *Phase I* provide insight into two different home groupings. Incentives may also be included to help reduce the consumption within households. Each of the homes in the above average consumption bracket can also be approached to undertake certain renovations to reduce the heat loss and gain among the buildings.

The homes which are part of this study will continue to be monitored this year allowing for more defined patterns of electricity consumption. The results have shown that the consumption trends vary from season to season with completely different profiles for each home with the effects of weather and heating/cooling changes. The analyses of electrically heated and natural gas heated homes were conducted separately because of the unique profiles that are generated by each type of home based on seasonal changes. The majority of this analysis was centered on the late spring and summer seasons. Based on the data, it is clear that many of the natural gas heated homes have increased electrical consumption during the summer period and as such appeared to be high consumers. For the individual factor analysis, the type of home produced the largest change in consumption with single homes consuming nearly 1600 kWh more electricity compared to row-end homes over a four month period in the spring/summer seasons. Thus we can safely conclude that the type of home is a primary factor in electrical consumption in a home. The number of inhabitants played a much smaller role in the collected samples, yet, it is noted that age of inhabitants varies and personal routines are unique for each individual. For this reason, the survey data must play a greater role in further analysis of the data.

The impact of degree days on the heating and cooling of buildings is significant since the peak demand periods in Ontario occur during the summer months. Accounting for the changes in electricity demand between winter and summer seasons can give an approximate figure for the cooling demand in each house per degree increase in outdoor temperature. The different seasons make it possible to identify the consumer habits and the electricity requirements in all homes.

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