A COMPARISON OF ELECTRICITY 'SMART METER' DATA WITH HIGH RESOLUTION MEASURED RESIDENTIAL LOADS

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ABSTRACT

In the Canadian residential sector, the end-uses of appliances, lighting, and plug loads account for 16% of total end-use energy consumption (NRCan 2012). In an effort to reduce the impacts of this energy consumption, electricity technologies such as solar photovoltaics and smart appliances are being adopted. Their evaluation requires an understanding of residential electricity use patterns. Building simulation tools can estimate the time-step performance of such technologies, but require accurate and representative appliances, lighting and plug-load (ALP) electricity profiles as an input. Sub-metered datasets lack in quantity and thus overall representativeness of the sector. Meanwhile, large, representative datasets are becoming available through electricity smart-metering programs, but usually consist only of whole-house electricity load and lack summary household characteristics (e.g. occupancy, floor space, appliance descriptions). However, homes which are not electrically heated, cooled and without electric water heating may function as ALP load profiles for simulation. This paper addresses two of these loads with a new method of distinguishing non-electrically heated and cooled homes from a broad dataset of whole-house profiles. The method originates from a comparison of two electricity load datasets: (i) "smart-meter" 15-minute time-step whole-house data for 160 homes spanning up to three years, and (ii) "sub-metered" 1-minute time-steps for 23 residential homes. This comparison also speaks to the usefulness of whole-house electricity smart-meter information to building performance simulation.

INTRODUCTION

There is currently a strong focus on designing net-zero energy buildings and communities which use on-site electricity generation such as combined heat and power and solar photovoltaics (PV) to supply energy end-uses. These buildings presently rely on the electricity grid as an infinite source and sink, and their proliferation necessitates a better understanding of timestep electricity demand. In net-zero communities, distributed generation from solar PV may cause severe peaks and valleys in the community electricity load on the grid. Utilities seek to understand these short-term loads so that they can procure sufficient generating capacity and install adequately sized and placed distribution equipment (e.g. pole transformers).

Existing models which employ building simulation software are capable of time-step energy demand estimation of buildings and communities. These typically rely on engineering principles to model space-heating and space-cooling, but appliances, lighting, and plug loads (ALP loads) are largely driven by occupant behavior and modelling relies on measured or synthetic time-step load profiles. Examples of ALP loads are shown in Figure 1. Since ALP electricity use varies widely across households, community scale modeling requires a sufficient number of ALP load profiles for individual houses to represent a greater community.

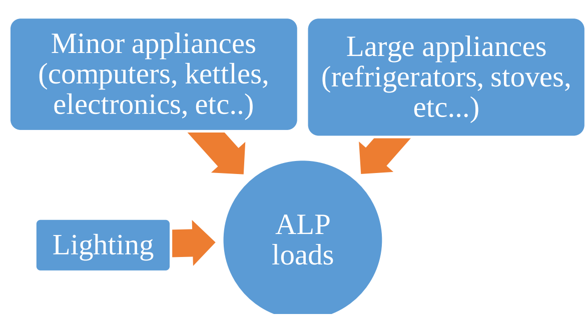

Figure 1 Examples of ALP loads

Currently, ALP profiles at high time-step resolution remain few in Canada. However, new datasets are increasingly available through utility "smart metering" programs. These usually consist of only the whole-house electricity load for homes, including ALP and ventilation, and potentially domestic hot water (DHW) heating and space heating/cooling, as shown by Figure 2.

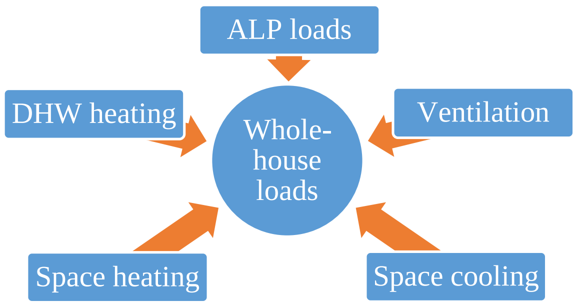

Figure 2 Example of whole-house loads

However, many homes rely on non-electric energy sources for DHW and space heating and do not cool or ventilate their spaces. These whole-house load profiles may be candidates to represent ALP loads only. This paper addresses the space heating and space cooling components by providing a new method of distinguishing houses which do not rely on electric space heating or electric DHW heating from a database of whole-house electricity load profiles. The method is applied to a new dataset of 15-minute time-step whole-house electricity load measurements from 160 houses in Nova Scotia. The method relies on comparisons made with an existing research-grade dataset consisting of sub-metered 1-minute time-step electricity load measurements for 23 houses in Ottawa, Ontario. We explore the benefits and limitations of this method based on additional comparisons between the newly distinguished profiles and the existing research grade profiles. Our future research will aim to elaborate on this method to address the space cooling and ventilation loads to ultimately distinguish profiles from the whole-house database that can adequately represent ALP loads for building simulation purposes.

BACKGROUND

In an effort to design buildings with minimal environmental impact, the implementation of net-zero energy buildings at a community scale may have economic advantages and utilitarian benefits. For example, smart grid technologies may allow for power sharing technologies which can help control utility demand. To date, performance evaluations of net-zero energy communities are still uncommon, but it is expected the electrical grid interaction with these communities will present new challenges. For example, on-site solar PV electricity generation and community electricity demand of net-zero energy communities may not align, causing dramatic changes in the community load profile (Hachem-Vermette et al. 2015).

Previous community scale modelling endeavours have relied on a limited number of electricity profiles, scaled up to represent a larger number of homes (Swan et. al. 2011). This may allow for accurate estimation of annual, monthly, weekly or even daily energy consumption, but does not allow for time-step demand modelling at hourly, 15-minute or 1-minute time-steps. This is because the scaling up of a limited number of profiles will result in unrealistic peaks and valleys in demand which follow the temporal patterns of the limited profiles. This is demonstrated in Figure 3 where an ALP profile for 1 house is scaled by a factor of 23, and compared to the sum of 23 unique house profiles. It is evident summing unique profiles produces far less dramatic changes in total demand than by scaling a single profile.

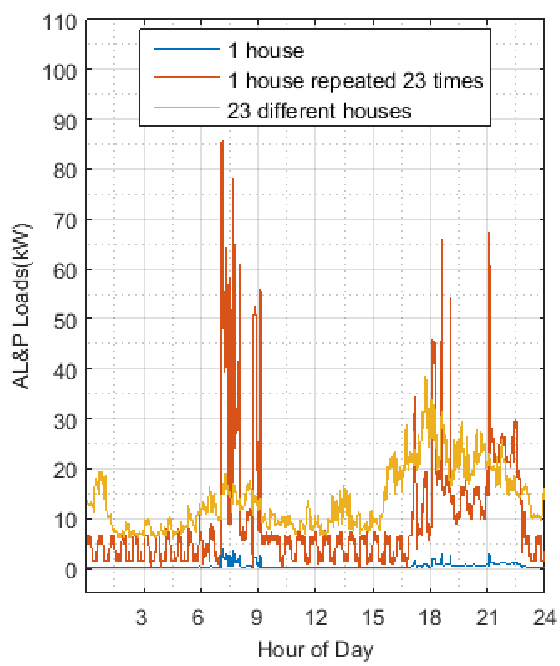

Figure 3 Electricity demand comparison of scaling one house by 23 versus summing 23 unique houses

As an alternative to expensive field studies needed to collect distributed electricity load measurements, researchers have generated synthetic electricity load profiles for building simulation. For example, Armstrong et al. (2009) created a set of nine, 5-minute time-step ALP electricity demand profiles designed to represent 'typical' detached Canadian households. The purpose of the profiles, however, was not to examine grid effects or demand side management with building simulation tools, but instead to look at system performance in terms of ability to meet heating and electrical requirements of the house. In constructing these profiles, engineering assumptions were made; for example, to better represent detached homes as opposed to row housing, the quantity of appliances per household and its associated electricity use were adjusted upwards from the values drawn from appliance stock surveys. In comparison to measured profiles, the synthetic profiles showed a higher concentration of small loads below 200 W and should likely have a higher constant baseload to match the measured profiles. These profiles have since been applied in many building energy models (Leadbetter & Swan 2012, Obrien et. al. 2011, Swan et. al. 2011). While they are good for aggregate electricity consumption analysis, their limited number does not provide for community time-step demand analysis because of the scaling issue previously demonstrated.

In recent years, many studies have emerged in Canada and abroad examining measured residential electricity loads. ALP loads have been shown to be primarily behavior driven with a weak relationship to outdoor temperatures and can vary significantly across households (Aydinalp-Koksal et al. 2015, Chen et al. 2015, Lee et al. 2014). These observations reinforce the need for a variety of unique and representative profiles, especially for community-scale simulation. Furthermore, plug-loads are constantly changing as new electricity consuming devices become available or more affordable to various demographics (Firth et al. 2008). Such trends strongly support the continued collection and publication of up-to-date electricity consumption profiles for building simulation. Sub-metered, strictly ALP load measurements are still uncommon and existing profile disaggregation techniques require intrusive appliance specific knowledge (Basu et al. 2015, Zeifman and Roth 2011). However, the increasing availability of whole-house load profiles presents an opportunity to satisfy the demands of building simulation with a selection of these profiles. The remaining sections of this paper explore this possibility.

DATA SOURCES

SUB-METERED ELECTRICITY DATA FOR OTTAWA, ONTARIO FROM CARLETON UNIVERSITY

The Ottawa dataset was provided by the Sustainable Building Energy Systems research group at Carleton University. A complete description of the dataset measurement techniques, quality and processing can be found in Saldanha and Beausoleil-Morrison (2012) and Johnson and Beausoleil-Morrison (2015).

Beginning in 2009, measurements of whole house and individual device consumption (DHW, furnace, space cooling) were taken for more than a full year at 1-minute time-steps for 12 Canadian homes in Ottawa, Ontario. The instruments were then recommissioned in 2011, and an additional 11 houses were added for another full year. All gaps and data quality issues were addressed to create continuous annual profiles. For all houses, furnace auxiliary, air conditioner (for space cooling) and DHW consumption were subtracted from whole house consumption to produce a 'non-HVAC' or ALP equivalent electrical consumption profile for each house. Additionally, for three homes, sub-metering was conducted on the dryer, stove and dishwasher. In the study, there is no mention of whole-house ventilation systems such as heat recovery ventilators. With 7 of the homes being constructed in 2000 or later, a ventilation system load is likely included in the ALP load profiles.

As part of their study, Saldanha and Beausoleil-Morrison (2012) conducted a comparison analysis of the derived ALP profiles with the synthetic profiles generated by Armstrong et al. (2009). It was found that the synthetic profiles did not adequately capture the temporal variability within each of the measured profiles or the variation between household.

Johnson and Beausoleil-Morrison (2015) examined the factors influencing ALP consumption levels across all of the 23 houses and found that house size (floor area) had weak influence while occupancy strongly influenced annual ALP electricity consumption. They also compared the 23 house dataset with the Ontario housing stock data published by Natural Resources Canada (NRCan 2012, NRCan 2013) and found that the ALP electricity consumption of homes between the 25^{th} percentile and 75^{th} percentile (i.e. half of the measured houses) are in close agreement with the Ontario housing stock data.

WHOLE-HOUSE "SMART METER" DATA FOR NOVA SCOTIA FROM NOVA SCOTIA POWER INCORPORATED

The Nova Scotia dataset is whole-house electricity demand measurements at 15-min time-steps obtained from smart meter data provided by electricity utility Nova Scotia Power Incorporated. Data was labeled and divided into three categories of homes:

- All-electrically heated (AEH) homes which rely on electricity as the primary heating energy source, either via resistance strip heaters or heat-pump systems.

- Non-electrically heated (NEH) homes which rely on natural gas, oil, propane, or wood as the primary heating fuel. Electricity may still be used as a secondary heating source.

- Time-of-use electrically heated (TOU) homes which rely on electricity as the primary heating energy source via an electric-thermal-storage unit. The unit charges overnight during off-peak pricing hours, and discharges during the day on-peak pricing.

Houses were assigned to a category based on the status of the heating system at the time of the smart meter installation and the information may no longer be valid if a new system has been subsequently installed. Such evolution of the housing stock is typical, and must be expected to influence the results of whole-house electricity consumption datasets. Furthermore, an air conditioning system for space cooling may be present in any category for space cooling.

While the TOU homes had a 'smart meter' installed in order for them to participate in the TOU pricing scheme, it is unknown how the remaining houses were selected to have 'smart meters' installed. Any biases associated with the selection process are unknown for this study.

Meta-data was provided for 34 of the homes based on a telephone survey conducted by Nova Scotia Power Incorporated at an unknown date. Primary and secondary heating system type and energy source, cooling system (e.g. ceiling fan, portable fan, air conditioner), occupancy, main living area size, and location (town) were recorded. Of these homes, 24 relied on electricity as the primary heating source, 7 relied on oil and 3 relied on wood or wood pellets. Three of the 7 homes which relied on oil for heating also had plug-in electric heaters as a secondary source. Thirteen of the homes (38%) had an air conditioner for space cooling, 16 of the homes (47%) had only portable or ceiling fans for cooling, and 5 of the homes (15%) had no cooling system. Total occupancy averaged 2.7 people per house. Only 25 homes provided a main living area estimate and the average house size is 184 m^2 (1983 ft^2). The 34 homes were located in various cities, towns and villages spread throughout Nova Scotia.

Data was provided for the years 2012, 2013 and 2014 for a total of 161 house profiles. Not every house participated for all three years. Table 1 summarizes data availability.

Table 1 Availability of Nova Scotia data by home category

House Category	Year 2012	Year 2013	Year 2014
	Number of Homes		
AEH	74	62	53
NEH	53	42	32
TOU	29	28	24
Total	156	132	109
Full years of data	One	Two	Three
Number of houses	28	29	104

The electricity measurement instruments were electronic ALPHA PLUS® Meters. Each measurement datapoint is the average real-power value (units of W) measured over the preceding 15-minute period. These meters are utility-grade and operate with a measurement accuracy of 0.2%.

METHODOLOGY

First, the datasets are compared with the intention of identifying homes from the Nova Scotia dataset that do not use electricity for space heating and cooling, so that these whole-house profiles may be treated as ALP loads and used in building performance simulation. The obvious starting point is to use the NEH homes from the Nova Scotia dataset. Because space conditioning strongly depends upon ambient air temperature, the seasonal variations are compared in Figure 4. Nova Scotia AEH and TOU homes have also been added for comparison.

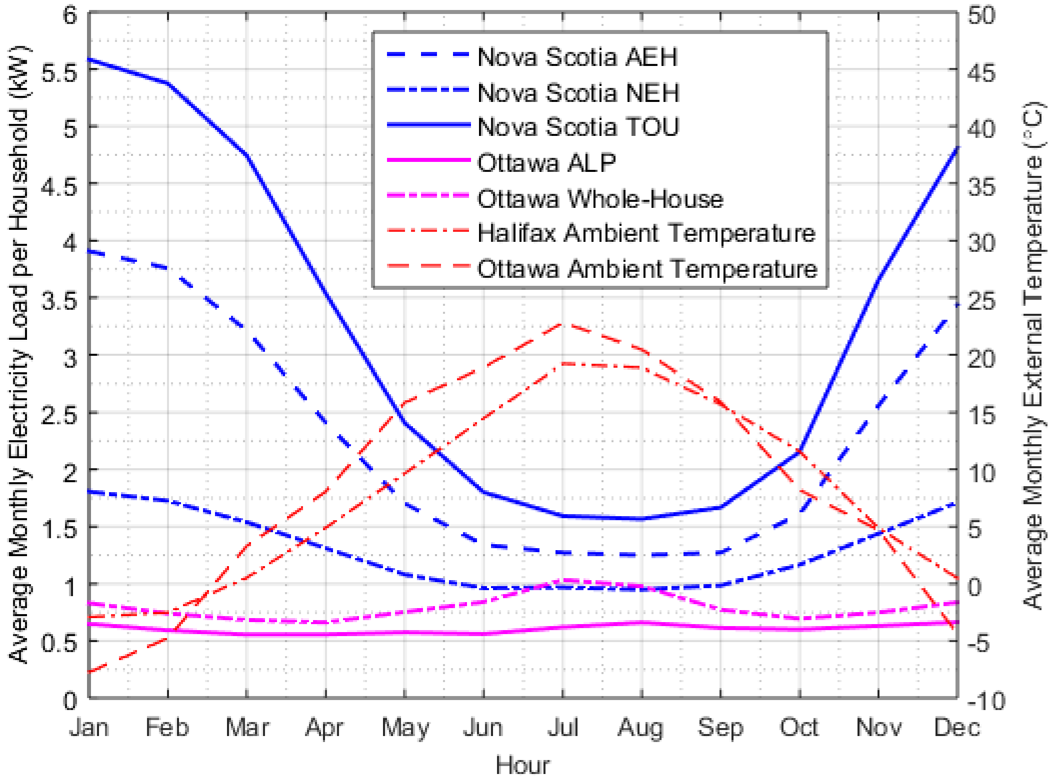

Figure 4 Average monthly electricity demand and ambient temperatures for both datasets

In Figure 4, the monthly average ambient temperatures in Halifax and Ottawa have been plotted to demonstrate the relationships with measured electricity usage. There is only a minor correlation between external temperatures and the Ottawa ALP electricity loads (R = -0.19). The whole-house loads show a clear relationship to outdoor temperature (R = 0.46). This is expected, since the whole-house load includes power supplied to air conditioning units. However, an increase in electricity demand occurs during the colder months as well, because the whole-house loads include the power draws from the heating system auxiliaries such as furnace fans and boiler pumps. There is a strong negative correlation between the external temperature in Halifax and the Nova Scotia whole-house NEH electricity loads (R = -0.96) suggesting that as the temperature drops, the electricity demand increases. On average, electricity use for the NEH homes increases by about 80% from the warmest months to the coldest months. These results suggest that some of the NEH houses from the Nova Scotia dataset still rely on some form of electric heating. This effect is much more dramatic with the with Nova Scotia whole-house AEH and TOU electricity loads, which increase by about 250% (AEH) and 350% (TOU) from the warmest months to coldest months.

After generating a monthly average load profile for each individual house in the Nova Scotia dataset, it is revealed that many of the houses had a relatively constant load across the seasons, following the ALP trend of the Ottawa data. However, some of the monthly profiles of homes in the NEH category were strongly affected by ambient temperatures. As well, some homes in the AEH category were not affected by outdoor temperatures, likely caused by them changing their heating system type during renovations.

IDENTIFICATION OF HOMES WITH ELECTRIC SPACE HEATING

This section describes the method used to distinguish homes from the Nova Scotia dataset that do not rely on electric space heating, based on trend observations from 22 Ottawa dataset ALP profiles.

To distinguish these houses, the average load for the milder summer months of June and September was subtracted from the average winter load (Nov - Feb for each house in both datasets. Due to the mild temperatures, it is assumed that there is the least likelihood of space heating or cooling during the selected summer months and so they are chosen as the 'baseline months'. The results are plotted in histograms, shown in Figure 5.

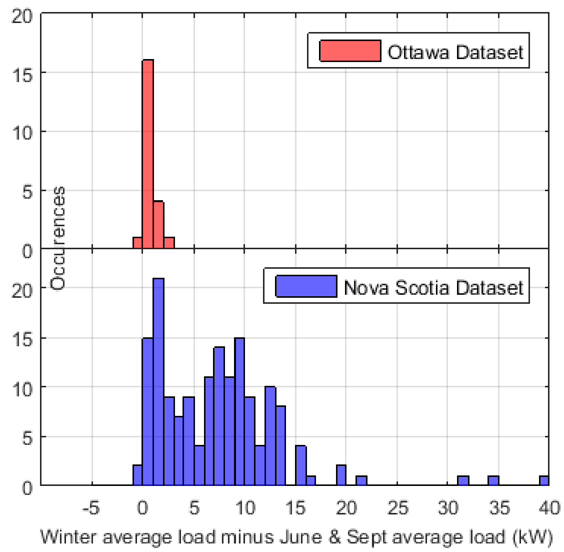

Figure 5 **Histograms of average winter load minus average June & Sept loads for Ottawa and Nova Scotia datasets**

The upper histogram in Figure 5 shows that the Ottawa ALP winter load does not vary greatly from the shoulder season load, with a difference between the averages ranging from -1.2 kW to +1.7 kW. In the lower histogram, the Nova Scotia dataset differences range from -0.2 kW to +40 kW. There are two major peaks, one occurring at about a +1 kW difference and the other occurring at about +9 kW. The distribution in proximity to the 9 kW is a relatively normal distribution, likely representing electrically heated homes of various sizes and with various heating system efficiencies. The homes distributed around the +1 kW peak are likely the homes which do not rely on electric heating.

All Nova Scotia homes which showed an average load difference between -1 kW and +2 kW were thus assumed to be homes which do not rely on electric heating, and were taken to represent non-electrically heated home profiles.

IDENTIFICATION OF HOMES WITH ELECTRIC SPACE COOLING

To distinguish homes from the Nova Scotia dataset that do not rely on electric space cooling, the above method is applied against the selected non electrically heating homes using a different selection of monthly average load observations. Since space cooling is likely to occur during the warmer daytime hours of the hottest months, the average daytime (11 am and 5 pm) load for the milder summer months of June and September was subtracted from the average daytime load for hottest months of July and August for each house in both datasets. The results are plotted in histograms, shown in Figure 6.

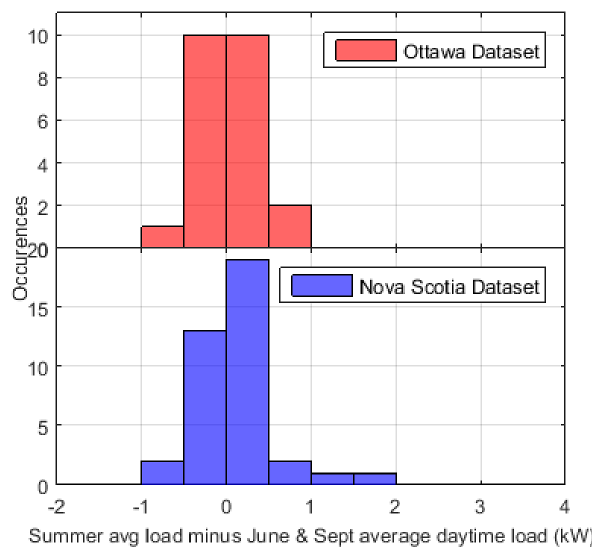

Figure 6 **Histograms of average July & Aug daytime loads minus average June & Sept daytime loads for Ottawa and Nova Scotia datasets**

The upper histogram in Figure 6 shows that the Ottawa ALP July and August loads do not vary greatly from the June and September loads, with a difference between the averages ranging from -0.8 kW to +0.9 kW. In the lower histogram, the Nova Scotia dataset differences range from -0.7 kW to +1.9 kW. This range is much less than the range in Figure 5 since the effect of electric space cooling is much less significant than that of electric space heating. Air conditioners may only draw approximately 0.5 kW (e.g. window mount) to 4 kW (e.g. split-type) and may only operate in short bursts, depending on the ambient outdoor temperature. Furthermore, they may not operate every day during the cooling season.

All Nova Scotian homes which showed an average load difference between -1 kW and +1 kW were thus assumed to be homes which do not rely on space cooling. Note that these homes may still employ ceiling fans or portable fans during the warmer months. Only 2 of 38 homes (5%) were found to rely on space cooling. This is much less than the average in Nova Scotia where the penetration of air conditioners in homes is approximately 28% (NRCan 2014). It is suspected that homes which engage only a minimal amount of space cooling using small window type air conditioners may not have been identified by this method.

RESULTS

Using the above methods, a total of 38 profiles were from the Nova Scotia dataset were selected to be non electrically heated and from these, 36 homes were selected to be non air-conditioned. These came from two categories AEH and NEH, demonstrating the importance of re-evaluating metadata each few years. The resulting average monthly load of the Nova Scotia ALP profiles is shown in Figure 7, along with the Ottawa the ALP profiles.

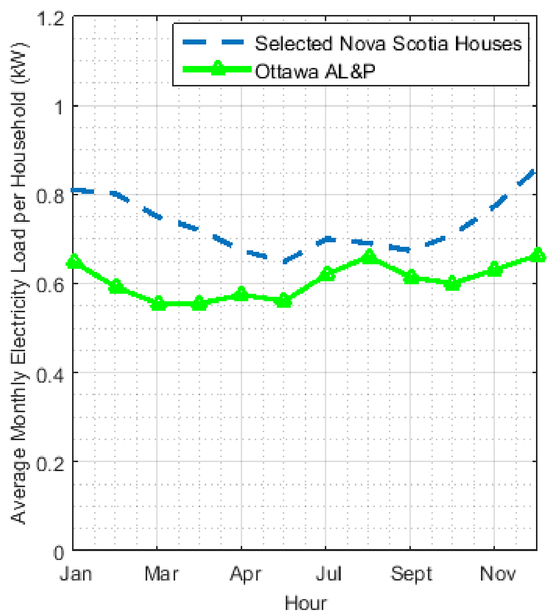

Figure 7 Monthly average load profile comparison of Ottawa profiles and selected Nova Scotia homes

From Figure 7, the average seasonal variation of the selected Nova Scotian homes is less than 0.2 kW. External temperature does still have an influence on the load (R = -0.82) and this is could be partially due to the use of fans/pumps in homes during the heating season, or simply the longer runtime of lighting during winter. More importantly, it could be attributed to the presence of DHW heating in some of the homes. In Nova Scotia, approximately 27.1% percent of homes rely on electricity for DHW heating (NRCan 2012). The seasonal influence on the load could also be partially attributed to DHW heating. George et. al. (2015) found that DHW consumption in a sample of Nova Scotian homes was on average 9.6% higher during the winter season than during the summer season.

The daily statistics of the ALP loads for each dataset are shown in Table 2. These values are generated by determining the statistic for each house individually taking into account the entire measurement period (1 to 3 years) and then averaging across all of the households of each dataset.

Table 2 Statistical summary of the average daily electricity consumption per household for two datasets

Statistic	Nova Scotia Selected (kWh/day)	Ottawa ALP (kWh/day)	Ottawa Main (Whole-House) (kWh/day)
Mean	17.3	14.3	19.0
Median	16.9	12.6	17.0
Maximum	36.1	30.1	44.7
Minimum	4.4	5.9	8.5
5^{th} Percentile	6.0	6.3	9.0
20^{th} Percentile	11.6	8.5	11.5
80^{th} Percentile	22.2	20.5	25.4
95^{th} Percentile	32.2	28.3	38.4

From Table 2, the selected Nova Scotia homes consume 20% more electricity annually than the Ottawa ALP consumption. This difference is assumed to be partially due to DHW heating and aligns well with the national estimate of 20% (NRCan 2014). The Nova Scotia dataset also has a comparable range of per household annual electricity consumption than the Ottawa datasets suggesting, that homes with large heating loads have been successfully distinguished.

The values in Table 2 compare well with the result of a national survey of ALP loads conducted in 2011 and 2012 by Natural Resources Canada (Parekh et. al. 2012). This survey estimates an average ALP load of 19 kWh per day per household which is 9% higher than the mean Nova Scotia ALP value and 25% percent higher than the mean Ottawa ALP value. However, the survey included ‘supplementary’ space conditioning loads such as portable heaters in the ALP load.

Daily average ALP loads such as those presented in Table 2 are of value to building simulation tools which produce low resolution energy estimates. Hot2000 is a widely used whole-house building simulation tool developed by Natural Resources Canada (CETC 2008). The default ALP load assumption applied by this software is 24 kWh per day, which is 38% higher than the mean daily Nova Scotia ALP value in Table 2 and 68% higher than the mean daily Ottawa ALP value.

CONCLUSION

With smart metering programs growing rapidly in install base, new opportunities present themselves for using this data. However, this data is typically limited 15-minute time-steps and is a whole-house electricity measurement. Present disaggregation techniques struggle to identify the ALP component of the load, which is of significance to building performance simulation as it is used to represent occupant driven electricity consumption.

This research presents a method of distinguishing non electrically heated and cooled home load profiles from whole-house data at 15-min time-steps from a dataset that includes homes of various heating energy sources and sparse and sometimes inaccurate metadata. It is expected that some non-ALP loads remain included in the distinguished profiles, such as DHW heating and potentially even minimal amounts of space heating or cooling. Future research on this dataset will focus on distinguishing profiles which include DHW heating.

Once the DHW component has been addressed, these profiles will be recommended for building simulation purposes. Moving forward, this method can be applied to much larger datasets of whole-house load profiles as they become available across Canada, thus inexpensively generating geographically representative datasets of ALP load profiles for building simulation.

While the method was based on observations from a very limited dataset of only 23 houses located in one region of Canada, it is suggested that as future sub-metered datasets become available, the method is revisited to insure validity. For example, because the Ottawa ALP dataset revealed little correlation to outdoor temperature, this method excludes all Nova Scotian profiles with temperature dependent ALP loads. Homes with unusual consumption characteristics may be excluded using this method but may still be statistically significant and therefore useful for community energy modelling.

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REFERENCES

Armstrong, M. M., Swinton, M. C., Ribberink, H., Beausoleil-Morrison, I., & Millette, J. (2009). Synthetically derived profiles for representing occupant-driven electric loads in canadian housing. Journal of Building Performance Simulation, 2(1), 15-30. doi:10.1080/19401490802706653

Aydinalp Koksal, M., Rowlands, I. H., & Parker, P. (2015). Energy, cost, and emission end-use profiles of homes: An Ontario (Canada) case study. Applied Energy, 142(0), 303-316. doi:http://dx.doi.org/10.1016/j.apenergy.2014.12.077

Basu, K., Debusschere, V., Douzal-Chouakria, A., & Bacha, S. (2015). Time series distance-based methods for non-intrusive load monitoring in residential buildings. Energy and Buildings, 96, 109-117. doi:http://dx.doi.org/10.1016/j.enbuild.2015.03.021

Birt, B. J., Newsham, G. R., Beausoleil-Morrison, I., Armstrong, M. M., Saldanha, N., & Rowlands, I. H. (2012). Disaggregating categories of electrical energy end-use from whole-house hourly data. Energy and Buildings, 50, 93-102. doi:http://dx.doi.org/10.1016/j.enbuild.2012.03.025

CANMET Energy Technology Center (CETC). (2008). HOT2000 (10.51st ed.). Ottawa: Natural Resources Canada. Retrieved May 4, 2015, 2015, from: https://www.nrcan.gc.ca/energy/software-tools/7421

Chen, V. L., Delmas, M. A., Kaiser, W. J., & Locke, S. L. (2015). What can we learn from high-frequency appliance-level energy metering? Results from a field experiment. Energy Policy, 77, 164-175. doi:http://dx.doi.org/10.1016/j.enpol.2014.11.021

Firth, S., Lomas, K., Wright, A., & Wall, R. (2008). Identifying trends in the use of domestic appliances from household electricity consumption measurements. Energy and Buildings, 40(5), 926-936. doi:http://dx.doi.org/10.1016/j.enbuild.2007.07.005

Gaiser, K., & Stroeve, P. (2014). The impact of scheduling appliances and rate structure on bill savings for net-zero energy communities: Application to west village. Applied Energy, 113, 1586-1595. doi:http://dx.doi.org/10.1016/j.apenergy.2013.08.075

George, D., Pearre, N. S., & Swan, L. G. (2015). High resolution measured domestic hot water consumption of canadian homes. Energy and Buildings, 109, 304-315. doi:http://dx.doi.org/10.1016/j.enbuild.2015.09.067

Hachem-Vermette, C., Cubi, E., & Bergerson, J. (2015). Energy performance of a solar mixed-use community. Sustainable Cities and Society, doi:http://dx.doi.org/10.1016/j.scs.2015.08.002

Johnson, G., & Beausoleil-Morrison, I. (2015). Electrical-end-use data from 23 houses sample each minute for simulating micro-generation systems. Microgen 4, the 4th International Conference on Microgeneration and Related Technologies, Tokyo, Japan.

Leadbetter, J., & Swan, L. (2012). Battery storage system for residential electricity peak demand shaving. Energy and Buildings, 55, 685-692. doi:http://dx.doi.org/10.1016/j.enbuild.2012.09.035

Lee, S., Whaley, D., & Saman, W. (2014). Electricity demand profile of Australian low energy houses. Energy Procedia, 62, 91-100. doi:http://dx.doi.org/10.1016/j.egypro.2014.12.370

Natural Resources Canada (NRCan) (2012). Comprehensive energy use database, 1990 to 2012.

Natural Resources Canada (NRCan). (2013). Survey of household energy use 2011 - detailed statistical report

Natural Resources Canada Office Energy Efficiency (NRCan). (2014). Energy use data handbook tables (Canada). Retrieved 01/16, 2015, from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/handbook_tables.cfm?attr=0

Pietila, A., Beausoleil-Morrison, I., & Newsham, G. R. (2012). Zero peak housing: Exploring the possibility of eliminating electrical draws from houses during periods of high demand on the electrical grid. Building and Environment, 58, 103-113. doi:http://dx.doi.org/10.1016/j.buildenv.2012.06.019

O'Brien, W., Athienitis, A., & Kesik, T. (2011). Thermal zoning and interzonal airflow in the design and simulation of solar houses: A sensitivity analysis. Journal of Building Performance Simulation, 4(3), 239-256. doi:10.1080/19401493.2010.528031

Parekh, A., Wang, P., & Strack, T. (2012). Survey results of user-dependant electricity loads in Canadian homes. ACEEE Summer Study on Energy Efficiency in Buildings.

Powers, J., Margossian, B. and Smith, B. (1991). “Using a Rule-Based Algorithm to Disaggregate End-Use Load Profiles from Premise-Level Data,” IEEE Computer Applications in Power, 42-47.

Saldanha, N., & Beausoleil-Morrison, I. (2012). Measured end-use electric load profiles for 12 Canadian houses at high temporal resolution. Energy and Buildings, 49, 519-530. doi:http://dx.doi.org/10.1016/j.enbuild.2012.02.050

Swan, L. G., Ugursal, V. I., & Beausoleil-Morrison, I. (2011). Occupant related household energy consumption in Canada: Estimation using a bottom-up neural-network technique. Energy and Buildings, 43(2–3), 326-337.