Mech 6340 Project
High time-step resolution measured domestic hot water consumption profiles of single detached Canadian homes

Presented by:
Dane George
dane-george@dal.ca

Presented to:
Dr. Ugursal
Department of Mechanical Energy
Dalhousie University

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Abstract

In 2011, domestic hot water (DHW) heating accounted for 22% of Canadian residential energy use, making residential water heating a significant opportunity for energy conservation. Technologies such as solar DHW heating and solar combi-systems are being installed in an effort to reduce DHW heating energy consumption and their performance is greatly influenced by the DHW consumption patterns of home occupants. To accurately predict the energy saving potential of these systems it is important to employ representative DHW consumption profiles during the simulation process. However, due to the expensive nature of field studies, previous DHW consumption profiles have been generated synthetically using probabilistic modelling techniques or they have been generated using measured but limited datasets. Recently in Halifax, Nova Scotia, the municipal pilot program Solar City has made DHW consumption measurements available for over 200 homes at high a time-step of 1 minute. Furthermore, a home survey of each participant includes information about occupancy rates, appliance ownership, mechanical systems and approximate house area. Ultimately, an analysis of this data will investigate consumption characteristics such as average daily consumption per household and per occupant as well as seasonal, monthly and daily variations in usage patterns. Based on these findings, new DHW consumption profiles representative of the Canadian residential housing stock will be generated from the dataset. This class project includes an extensive review of previous DHW consumption studies and DHW consumption estimates and profiles currently being used. Furthermore, a preliminary analysis was conducted on 35 homes of the Solar City dataset which will make the basis of the larger study.

Contents

1 Introduction

With increasing instability and uncertainty of energy costs in Canada, energy saving retrofits are an attractive way for home owners to reduce energy consumption and increase their energy security. Furthermore, as governments strive to reduce greenhouse gas (GHG) emissions, within the residential sector there are many opportunities for energy conservation programs and incentives. Energy consumed for water heating is significant; in 2011 the heating of domestic hot water (DHW) accounted for 20% of residential energy use and 3% of total Canadian secondary energy use (OEE 2013).

Simulation using energy modelling software is an important part of the pre-implementation of many technological applications such as residential solar DHW systems, solar combi-systems, combined heat and power systems, net-zero energy building design and 'smart-grid' applications. Factors such as the duration and flow rate of a DHW draw can influence the performance of these technologies and therefore the use of representative profiles and consumption characteristics may impact the accuracy of simulations (Jordan and Vajen 2000). However, measuring domestic hot water consumption at high temporal resolution requires a flow meter and a data acquisition system which are expensive to purchase and install. Historically, measured data at time-steps under 5 minutes have been unavailable and researchers have instead relied upon synthetic profiles or have utilized profiles based on limited or dated datasets. The Solar City program in Halifax, Nova Scotia has made available temperature and DHW flow measurements at 1 minute time-steps and provides an excellent opportunity to generate measured representative daily and yearly profiles at high temporal resolution.

Solar City is a municipal government pilot program which provides financing, sourcing and installation of up to 1,000 solar water heating systems to home owners in Halifax Regional Municipality (HRM). Optional to the system installation is a data monitoring system which measures flow rates, air and fluid temperatures and solar power at one minute intervals. By October 2014, over 200 systems had been installed that include data monitoring. Data is available ranging from 2 to 544 days of measurements. Furthermore, through an initial survey, participants have provided information such approximate house area, occupancy, water heating system type and appliance ownership.

This study examines several DHW consumption characteristics such as mean daily DHW use and time-of-use influences. Due to the time constraint associate with this class project, only a preliminary analysis was conducted on 35 homes of the Solar City dataset. The tools generated during this project will form the basis of a more comprehensive study.

1.1 Background and Literature Review

1.1.1 Measured DHW consumption

Several studies of DHW consumption have been in conducted in Canada and the U.S. Beginning in 1981, Perlman and Mills (1985) collected over two million DHW flow measurements at 15 minute time-steps in 59 homes throughout Ontario. In A survey of 58 of the households gathered data to examine households DHW consumption based on family size, presence and age of children, average family age, average age of adults, presence of people home during the day, opinion of water use level and opinion of run out frequency. Daily, monthly, seasonal (winter/summer) average usage patterns were analyzed and representative profiles were generated for the entire population and what was deemed to be a 'typical' family of 2 adults and 2 children. In order to aid with DHW system sizing, 'probabilistic' profiles were developed to represent DHW requirements of 95% of the sample population.

Becker and Stogshill (1990) compiled a database from nine studies totalling more than 30 million DHW consumption measurements at 15 minute time-steps for both apartment buildings and homes throughout Canada and the U.S. The Perlman and Mills (1985) study is included in this database and although many of the same factors of influence were investigated it was possible to expand on these factors due to the breadth of data. It was found that climatic location also had a major influence on DHW consumption and that this might be due to differences in outdoor temperatures.

Over the past three decades, factors influencing DHW consumption have changed: faucet and showerhead flow standards have decreased and 'low-flow' faucets are being installed through many energy and water conservation programs such as Efficiency Nova Scotia's Product Installation program wherein home owners receive faucet aerators and low-flow showerheads free of cost (Efficiency Nova Scotia 2015). Furthermore, the frequency of ownership of household appliances such as dishwashers and clothes washing machines may have changed. Perlman and Mill (1985) found that only 79% of their sample households owned an automatic dishwasher. Attitudes may have changed as well; a large proportion of Perlman and Mills (1985) survey participants 'considered automatic dishwashing as only an occasional alternative to manual dishwashing'. Finally, Canadian demographics have also changed; the average number of persons per private household in Canada has decreased from 2.8 in 1986 to 2.5 in 2011 (Statistics Canada 2012).

A more recent study by Edwards and Beau-Soleil Morrison (2015) included measured DHW consumption data from 73 households in Quebec at a 5 minute time-step. The data was collected at each home for between 60 and 165 days between early November 2006 and mid-April 2007. Based on a statistical analysis, 12 profiles were chosen to represent the combinations of the average, median, sparing and profligate consumption levels with three temporal demand patterns for those who consumed primarily in the mornings, in the evenings or evenly throughout the day. Since only fall, spring and winter measurements were available; winter measurements were used populate the missing summer months but were reduced by 13% based on the observations of Becker and Stogsdill (1990). Three of these profiles were then incorporated into the TRNSYS 17 simulation program to analyze the performance of a typical solar DHW heating system.

Thomas et al. (2011) conducted a study of 74 households in Ontario aimed to evaluate the daily draw profiles used in current water heater performance test standards. Measurements were taken for two to three weeks at each house at time-steps of 2-4 seconds over periods of 2-3 weeks. It was found that average daily DHW consumption was lower than current test standards but that the number of DHW draws per day was higher. A new number of 79 draws per day was suggest to replace the current standard of 6 draws. It was also found average daily consumption was lower than those employed by the standards.

1.1.2 Synthetically generated DHW consumption estimates

Edwards and Beau-Soleil Morrison (2015) and Perlman and Mills (1985) both developed DHW consumption profiles based on measured DHW consumption. While these profiles capture the temporal variability in consumption patterns, they rely on a relatively small sample of homes (73 and 58 respectively) to potentially represent a larger population. Alternatively, researchers have also generated consumption estimates based on historical energy end-use data and other surveyed information such as occupancy, appliance ownership. A weakness of this approach is that individual end-use energy consumption (i.e. DHW, appliance, lighting, etc.) is derived by accounting for the differences in end-use energy uses a sample of homes. There is a risk that energy consumption is inappropriately applied to the correct end-use, especially since the estimate may rely on subjective occupant descriptions of appliance use (Swan and Ugursal 2009). The strength of this method is that data collection is less intrusive and does not rely on expensive data collection equipment and therefore a larger sample of the population may be incorporated into the calculations. This section highlights several usages of this method that are relevant to the current research.

Evans and Swan (2013) estimated average daily DHW consumption based on a sample of homes in the Halifax Regional Municipality. This sample consisted of the initial applicants to the Solar City program and may include overlap with the current Solar City sample. A survey of each home gathered location, occupancy, water source, method of DHW heating, energy use and energy costs. Of 1594 homes, 1019 used fuel oil for DHW, space heating or both. Assuming that residential fuel oil is used only for space heating, the average amount of oil consumed for space heating and DHW heating was isolated from and subtracted from the average amount of oil consumed for space heating only thereby estimating the average amount of fuel/energy used for DHW heating. By assuming an average seasonal efficiency of stand-alone oil-fired DHW heaters and fixed inlet and outlet temperatures, this energy estimate was converted into an annual DHW draw volume. Average consumption was estimated for occupancies of 1 to 6. Since the sample set of homes in this study were initial applicants to the Solar City program, it provides an excellent opportunity to compare the results of this method with the findings of the current study of measured data.

Jordan and Vajen (2001) used a probability approach to model DHW demand based on data gathered in Germany and Switzerland (Knight et al. 2007). The model produced a different profile for each day of the year at 1, 6 and 60 minute time-steps and for mean daily consumption levels of 100, 200, 400 and 800 litres/day. A method was also given to superimpose profiles in order to generate a new profiles at different increments (i.e. a profile for a mean daily consumption of 300 l could be generated by superimposing 100 l and 200 l profiles). The model assumes 4 categories of loads: short loads (i.e. washing hands, etc.), medium loads (i.e. dishwasher), baths and showers. Within each category, assumptions are made for the mean flow rate, load duration, incidences, and the statistical distribution of different flow rates. Days of the week, seasons and holidays are also considered.

For Subtask 42 of the IEA Energy Conservation in Buildings and Community Systems Programme, measured DHW profiles at 5 and 60 minute time-steps from the U.S., Canada and various countries in Europe were compiled and used to calibrate the model created by Jordan and Vajen (2001). The DHW consumption data used in Subtask 42 did not include information on occupancy levels, data collection methods nor date of data collection. The DHW consumption levels and patterns from in different regions varied greatly: average daily DHW consumption in North American was over 200 litres per day while European consumption was 100 litres per day. Using these daily estimates as the basis, the probabilistic model developed by Jordan and Vajen's (2001) was then employed to generate annual profiles at 1, 5 and 15 minute representative of Europe and North America for use in the assessment of residential cogeneration systems. The 5 and 15 minute profiles were created by aggregating the 1 minute profiles over the longer time intervals.

In a similar fashion, Swan et al. (2011) generated a set of DHW consumption profiles to match the homes in the Canadian Single-Detached and Double/Row Housing Database (CSDDRD). An existing residential end-use energy consumption model was coupled the synthetic DHW consumption profiles generated by Jordan and Vajen (2001). Energy for DHW heating for each house in the CSDDRD was estimated using a neural networks model developed by Aydinalp et al. (2001) which was calibrated for the Canadian residential housing stock using data from the Survey of Household Energy Use (SHEU) 1993. The model was then populated with data from the CSDDRD (soil temperature and DHW system energy factor), from the SHEU 1993 (storage tank age), the SHEU 2003 (clothes washer use, ownership, income, storage tank size, pipe insulation, insulating blanket, no. of low flow shower heads and no. of tap aerators), and from the Census 2006 (no. of children). The resulting annual DHW energy consumption was then converted to an annual DHW draw volume by assuming a fixed delivery temperature. DHW consumption profiles were then generated by adjusting Jordan and Vajen's (2001) profiles by a 'multiplier' so that the integrated annual consumption of each profile was identical to estimates for each home in the CSDDRD.

Both probabilistic and measured estimates of DHW consumption have their strengths and weaknesses. Measured profiles produce objective, real results but might lack statistical relevance. Statistically generated profiles are more likely influenced by the subjective nature of surveys.

1.1.3 DHW consumption and energy simulation

Building and energy simulation software may accept various resolutions of temporal input. Energy consumption of buildings and energy output of technologies may be estimated at sub-hourly, hourly, daily or monthly intervals and the occupant load input profiles may be required at intervals of equal or less resolution.

Natural Resources Canada has developed two widely used programs: HOT2000 for residential energy analysis (CETC 2008) and RETScreen for energy efficiency, renewable energy and cogeneration energy performance analysis (CETC 2013). HOT2000 has been used for many Canadian government programs such as the R-2000 and ecoEnergy retrofit programs. Among many features, HOT2000 allows for estimation of energy requirements for space heating and cooling and water heating. CanmetENERGY and Natural Resources Canada have used HOT2000 for research studies such as the modelling of residential cogeneration systems (NRCan 2014a). HOT2000 incorporates an average daily DHW consumption to estimate energy required for DHW heating. RETScreen has been used as part of the Solar City program to estimate the energy and greenhouse gas emissions savings potential and to help screen possible installations at each participating home (NRCan 2014b). RETScreen also incorporates a value for average daily DHW consumption.

Other building simulation software such Energy Plus, TRNSYS and ESP-R are capable generating higher resolution energy end-use estimates, thus requiring occupant load profiles at more frequent time-steps. Several research studies have incorporated daily DHW consumption profiles into building energy simulations. Perhaps due to the lack of availability and accessibility of annual draw profiles, some researchers have used repeated daily profiles for annual simulations. For example, Fung and Gill (2011) simulated seventeen different residential DHW systems using the TRNSYS simulator. The simulation spanned an entire year using the repeating daily DHW draw profile developed by Perlman and Mills (1985).

Swan et al. (2013) developed the Canadian Residential End-Use Energy and GHG Emissions Model (CHREM) which is also based on the CSDDRD. Currently, CHREM employs the DHW consumption profiles developed by Swan et al. (2011). CHREM is designed for research applications that analyze the potential impacts of residential technologies on the Canadian housing stock. For example, Nikoofard et al. (2014) utilized the CHREM to evaluate the techno-economic feasibility of solar domestic hot water heating.

2 Data Sources and Methods

All of the Solar City data is the result of a data acquisition system being installed with a solar DHW heating system on single-detached homes in the Halifax Regional Municipality. There are two concerns about using the Solar City data to represent the DHW use patterns of a wider region. First, all measurements were conducted for houses with solar DHW heating systems. There is a risk that occupant behavior adjust to better utilize the system (i.e. showering in the morning versus the evening). Alternatively, since less energy would be consumed than for an equivalent system without the solar component, an occupant might consume more DHW. Additionally, since a larger store of heated water is available to some occupants with the additional solar 'pre-heated' tank, occupants may tend towards prolonged draws. Perlman and Mills (1985) encountered the same problem and determined that DHW consumption was affected primarily by social and demographic factors rather than a solar DHW system.

Secondly, during the on-site survey, low-flow faucets and showerheads were installed in the homes. These devices could significantly reduce DHW consumption in these homes. After the installations, the occurrences of low-flow devices amongst the solar city sample may not represent the larger population. However there is the possibility that the solar city sample does represent the Canadian housing stock as the use of low-flow devices is become more widespread on account of government and utility sponsored efficiency programs.

2.1 Solar hot water and data collection systems

All data acquisition and solar DHW heating systems in the Solar City program were supplied and installed in the same configuration as a component of a solar water heating system. A typical system schematic is shown in Figure 1. Note that the auxiliary tank is a pre-existing component in the homes and that some homes may have an instantaneous DHW heater instead. All new components were sourced from a common supplier.

The system components utilized in this study are the flow meter and the temperature sensor measuring T_{hot}. The specifications and measurement uncertainty of each device remain to be investigated. The data acquisition tool used on all systems were Web Energy Loggers (WEL). A WEL is an HVAC monitoring system capable of logging temperature and pulse signal count. All sensor and meter data are recorded into monthly log files which can then be downloaded online (Malone & Malone 2013). In this study each home is be denoted by its associated WEL number (i.e. WEL 707).

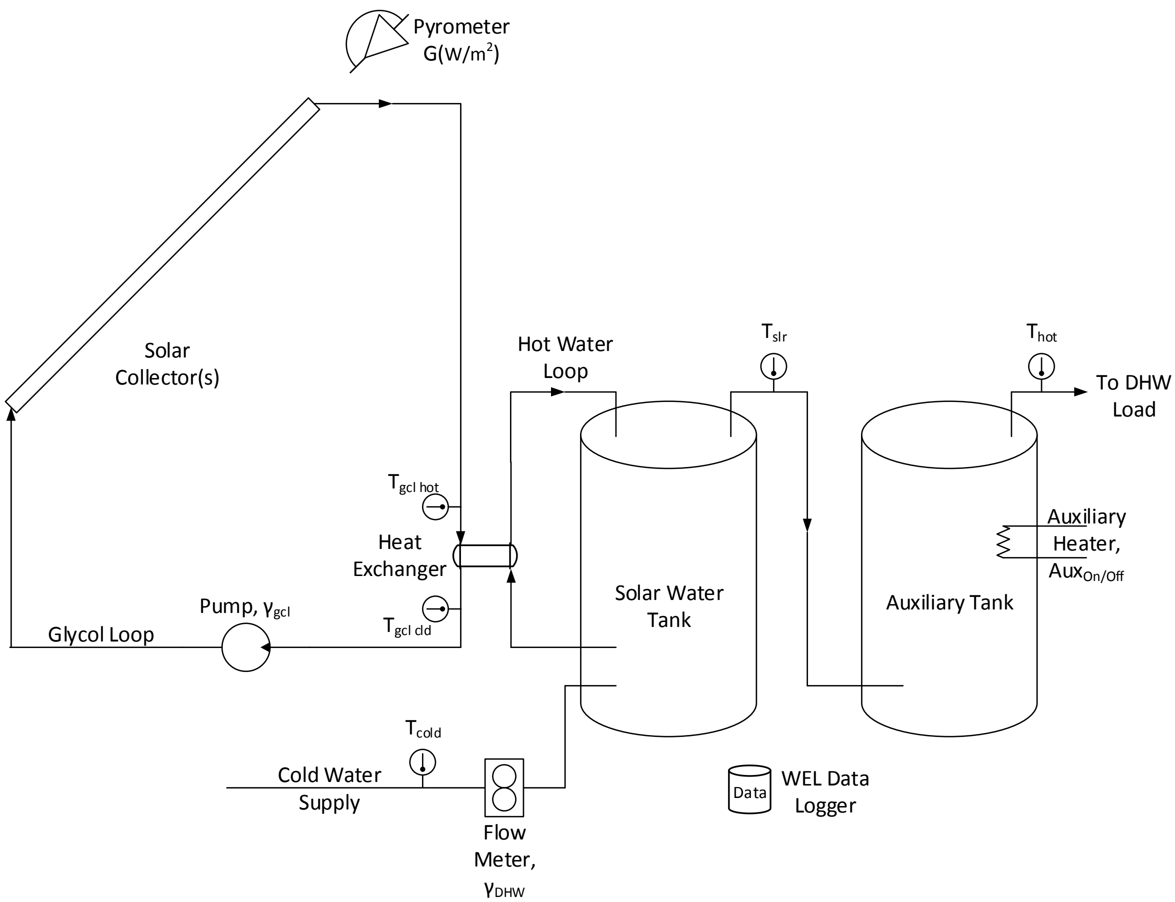

Figure 1 **Schematic of a typical Solar City solar hot water heating system**

2.2 Household surveys

Data associated with each participating home was also collected in a household survey conducted during a preliminary site visit to the home. The following relevant information was collected: the approximate house size, number of adults, seniors and children per household, DHW conversion system type and fuel type, presence of DHW consuming appliances and faucet/showerhead flow rate measurements.

2.3 Data processing

Initial analysis of the flow measurements revealed two major concerns: an excessive number of very small flow measurements (0 to 0.23 litres/min) and gaps in measured data. A flow measurement of 0.23 litres would equate to a low flow faucet with a flow rate of 2.5 litres/min to run for 5.5 seconds. It is not unreasonable that a homeowner would draw DHW in small amounts for 1 to 5 seconds many times throughout a day in order to satisfy simple requirements such as washing hands or rinsing dishes. However, there also exists the possibility that there is error in the flow meter measurements. Thomas et al. (2011) also noted an excess in single pulse DHW draw occurrences. It was thought that these occurrences were likely due to water pressure changes and/or convection currents in the water pipes which triggered the flow meter. Figure 2 demonstrates the difference in occurrence trends for flow measurements below 0.23 litres/min and above 0.23 litres per minute. As there may be measurement uncertainty associated with the flow meter and data acquisition system, further investigation will be necessary to determine the cause of the 'small' flow measurements.

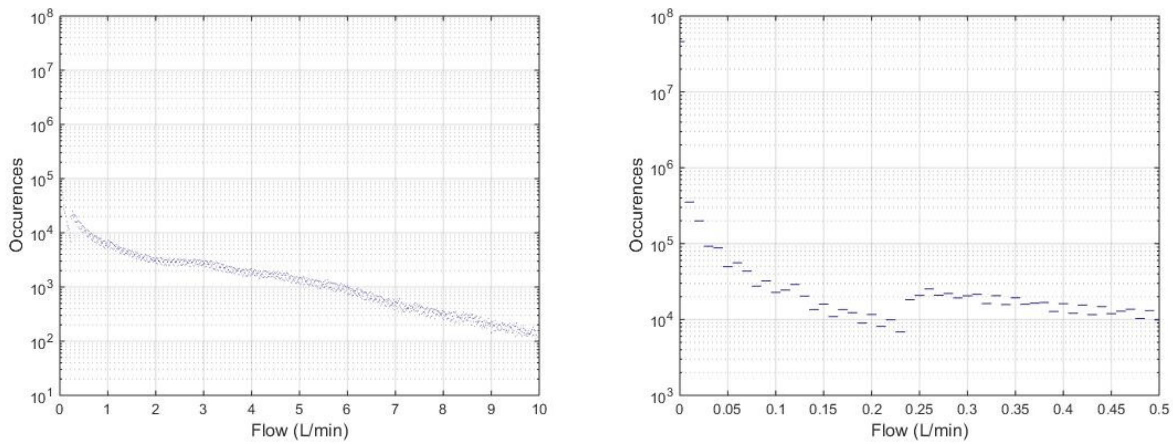

Figure 2 Occurrences of flow measurements (log scale)

A preliminary analysis has revealed that 'pockets' of data were missing from the data log files. For example, WEL742 was missing complete measurement data from October 2nd, 2013 to October 6th, 2013, from July 12th, 2014 to July 21st, 2014 and from July 23rd to August 4th, 2014. The reason for these gaps is unknown but could be on account of the data acquisition system going 'offline' due to a fault with the modem. In the generation of annual DHW consumption profiles, the gaps in data will also need to be addressed.

Also associated with the missing data are incomplete 'days' of data at the edges of the missing 'pockets'. Using the example above, on July 11th there were measurements for less than the entire day before the data acquisition system went offline. These was insufficient time to address this issue for this class project and therefore the results described below will be affected.

Edwards and Beau-Soleil Morrison (2015) used a data-filling procedure to populate missing periods. Assuming that weekly and seasonal DHW use had a significant impact on DHW consumption levels, missing data for autumn and spring seasons was populated with other data from the equivalent season and an equivalent day of the week. No measured data existed for the summer months which were instead populated with winter data and reduced by 13% based on observations by Becker and Stogsdill (1990).

3 Results

Previous studies have identified that occupancy and time-of-use have significant impact on DHW consumption. The effects of these factors of influence will be explored in the following sections.

3.1 Average daily hot water use

3.1.1 Comparison of findings

Average daily hot water use is used by some building simulation software including RETScreen and HOT2000. This value is also simple and accessible for comparison between the results of other studies and can be an indicator of changes in trends over time. The average daily hot water use for the 35 Solar City homes is shown in Table 1 along with the results from other studies. The recommended/default values used in both RETScreen and HOT2000 software are also listed.

Table 1 Average daily DHW consumption

Source	Average Daily DHW Use (L/day)	Average Occupancy	DHW Temperature (°C)
Solar City (35 homes)	176	3.2	(to be determined)
Perlman and Mills (1985)*	236	3.8	-
Becker and Stogsdill (1990)	238	-	-
Evans and Swan (2013)	209	3.2	55 (assumed)
Swan et al. (2011)	208	-	55 (assumed)
Thomas et al. (2011)	186	3.35	-
Edwards et al. (2015)	189	-	-
RETScreen (2015)**	225	-	55
Hot2000 (2015)	225	4 (Default)	55

* This value corresponds to the average for 'all families' in the study, as opposed to the typical family of 2 adults and 2 children.
**RETScreen also suggests a value of 60 litres/day/person at 60 °C or 1/3 of the total water use shown on the water bill.
***For occupancy levels other than 4 people, HOT2000 recommends a value of 85+(35 × number of occupants) litres/day.

From Table 1, it is clear that over the past three decades consumption has decreased. Current default estimates of both RETScreen and Hot2000 software over-estimate DHW consumption. It is also interesting to note that the more recent values based on measured studies (Thomas et al. 2011, Edwards et al. 2011 and Solar City) are less than the more recent values determined from DHW heating energy consumption (Evans and Swan 2013 and Swan et al. 2011).

The Solar City value is less than all others. The installation low-flow faucets and showerheads of during the on-site survey may contribute to this difference. It should also be noted that this value is based on only 35 homes and may not be representative of the entire Solar City sample. As well there are remaining data quality issues with the dataset that may have affected this value.

Distribution of average daily consumption across the 35 homes is shown in Figure 3 and the associated statistics are shown in Table 2. It should be noted that although the average consumption is 176 liters per day across all homes, the majority of consumption is less than the average. The mean values are weighted due to profligate consumption by two houses.

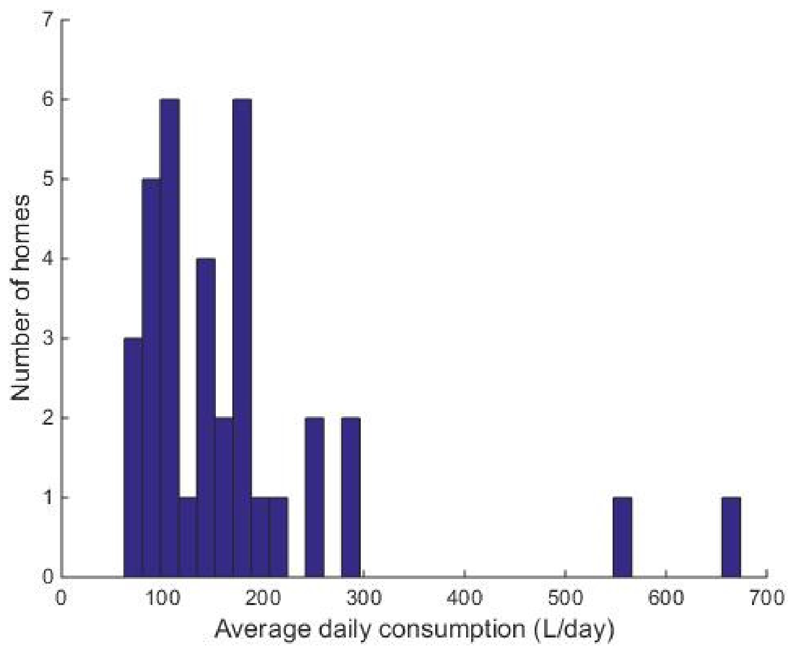

Figure 3 Distribution of average daily consumption

Table 2 Statistical summary of the average daily DHW consumption for 35 homes

Statistic	Value
Mean	176
Median	142
Max	674
Min	61
20th percentile	98
80th percentile	205

3.2 Effects of occupancy

Occupancy has been shown to be a significant factor of influence on DHW use. Both RETScreen and HOT2000 include recommendations for daily DHW consumption inputs if the occupancy is known (see Table 1 footnote) For Solar City, the effects occupancy will be investigated and if possible a trend (likely linear) will be generated which can be applied in simulation programs. Below, Table 3 lists the occupancy rates for the 35 homes based on 4 classifications: children, teenagers, adults and seniors. Previous studies have shown that households with senior occupants may consume drastically less DHW than the average household (Becker and Stogsdill 1990). However, the fraction of households with only seniors in the Solar City sample may not be large enough to investigate this effect.

Table 3 Average occupancy

	Average
Total occupants	3.2
Adults	2.2
Seniors	0.1
Teenagers	0.5
Children	0.5

Figure 4 shows the distribution of occupancy levels across the 35 home sample set and the average daily DHW consumption corresponding to the each occupancy level. As expected, consumption increases with occupancy between 1 and 4 occupants. However, consumption then decreases at 5 occupants. Once the entire Solar City sample of over 200 homes is included, the increasing trend is expected to be consistent for homes with 2 or more occupants.

It should also be noted that the distribution of occupancy is not even. In order to match the needs of research studies, it may be useful to present profiles as an average daily total (representing the larger population), but also as average consumption per person (normalized by occupancy). This may be helpful in an analysis where the building occupancy is known.

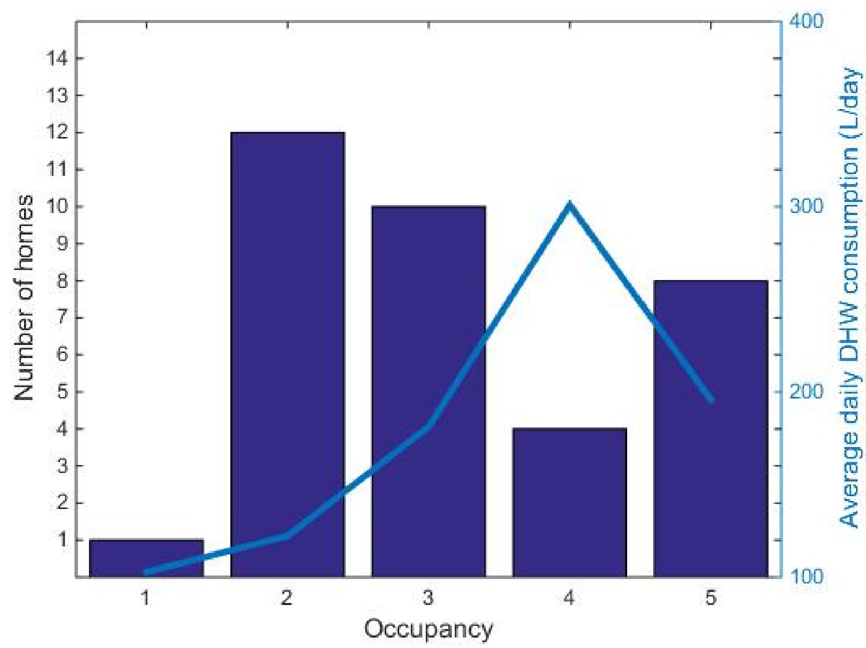

Figure 4 Occupancy levels of homes and average daily DHW flow

3.3 Time-of-use variations

Previous studies have identified that time-of-use has a significant impact on DHW consumption. Time-of-use patterns can be analysed in on several scales and this study will investigate daily, weekly, monthly and seasonal variations. Thus far, no time-of-use analysis of the Solar City data has been completed and the findings of other research will be presented instead.

3.3.1 Hourly variations

The importance of using realistic profiles was demonstrated by Spur et al. (2005). Using the TRNSYS simulator, it was shown that the number of daily draw-offs and temporal draw-off patterns (i.e. morning vs. evening) could affect the efficiency of storage type water heaters by as much as 13%.

Perlman and Mills (1985) identified three categories of users: high-morning, high-evening and low-user. The latter user type was identified by low daily use while the first two were identified by the time of peak use. Edwards and Beau-Soleil Morrison (2015) distinguished three similar categories: predominantly morning consumption, predominantly evening consumption and relatively dispersed consumption. Annual profiles were developed for these three temporal consumption patterns and used in the TRNSYS simulation program to demonstrate their impact on the performance of a typical solar DHW heating system similar to the illustrated system in Figure 1. Predominantly morning vs. predominantly evening consumption strongly influenced the functioning of the systems auxiliary heater. For predominantly morning users, the auxiliary heater would operate primarily during the day, corresponding to a higher demand period for an electric utility. For a predominantly evening user, the auxiliary heater would function primarily overnight. The annual performance of a solar hot water heating system was also analyzed. For equal consumption at two different temporal consumption patterns, dispersed consumption resulted in an annual solar fraction of energy 2.4% higher than predominantly morning consumption.

3.3.2 Weekly variations

It is likely that weekly variations in hot water use will be discovered, especially between weekday and weekend use. Perlman and Mills (1985) found Sunday to be the most demanding hot water use day and attributed this to the presence at home of occupants on Sundays. The average hourly variations for each day of the week were also presented, showing that on Sundays, consumption was more evenly distributed throughout the day.

3.3.3 Seasonal variations

The performance of many technologies may vary seasonally. For example, since available solar radiation and the trajectory of the sun through the sky both vary throughout the year, so will the performance of a solar water heating system. While DHW consumption may also vary seasonally. Perlman and Mills (1985) found that winter consumption can be up to 45% higher than summer consumption. Becker and Stogsdill (1990) found that the winter average consumption was 13% higher than summer average consumption.

The average seasonal trends in the Solar City data will be investigated by averaging across all a homes in the sample. Figure 5 demonstrates that the patterns may vary across households. WEL 707 follows the expected trend, consuming more in the winter, than the summer while WEL 719 consumed more during the winter months. It may be useful to distinguish homes with common seasonal consumption patterns such as 'high winter' and 'high summer' and investigate their distribution across the sample. If major categories are present, then representative annual profiles might be generated for each.

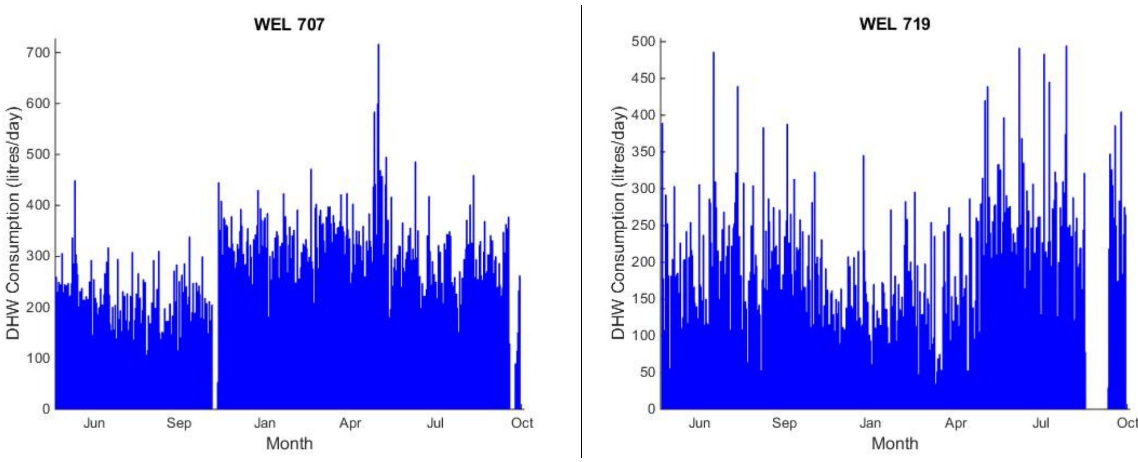

Figure 5 Seasonal variations in flow for WEL's 707 and 719

While previous studies have simply investigated 'summer' and 'winter' trends. The analysis of the Solar City data will investigate the trends across all seasons as defined in Table 4.

Table 4 Definition of seasons

Season	Definition of seasons	# days in the season
Summer	June 22 to September 22	93
Fall	September 23 to December 21	90
Winter	December 22 to March 20	89
Spring	March 21 to June 21	93

3.4 Peak and probabilistic consumption

In performance simulation, average trends in DHW consumption are useful when evaluating the average performance factor of a technology. However, DHW consumption patterns also are considered for water heating system design and probabilistic consumption is more relevant. Perlman and Mills (1985) developed hourly, daily, weekly and monthly probabilistic DHW consumption levels at a 95% percent confidence level. These values are still the basis for the Service Water Heating: Hot Water Requirements and Storage Equipment Sizing section of the 2011 ASHRAE Handbook: HVAC Applications (ASHRAE 2011). Since these values are over three decades old, it will be useful to examine the any discrepancies from the Solar City data.

3.5 Effects of DHW temperature

Historically in research and building simulation, DHW temperature leaving the heating system has been assumed based on average heating system set points. This value is important in energy simulation, because energy consumed to heat DHW is proportional to the temperature difference across a heating system. By the same principle DHW consumption estimates in studies such as Evans and Swan (2013) and Swan et al. (2011) have relied on the assumed temperature of 55°C to derive DHW consumption from DHW heating energy use. Both RETScreen and HOT2000 assume a default temperature of 55 °C. The Solar City data provides an excellent opportunity to determine an average DHW temperature leaving the heating system and compare it with the previously assumed value. Furthermore, if any variations in temperature are present across the sample, there will be an opportunity to investigate the relationship between DHW temperature and consumption.

4 Conclusion

The Solar City data presents a unique opportunity to investigate new trends in DHW consumption. While other studies have measured DHW consumption, most are either dated or incomplete. Trends in hot water consumption based on factors such as time-of-use and occupancy are not expected to have changed over the past decades, but the magnitude of flow is expected to have decreased with the adoption of more efficient water consuming devices.

Since computational power has increased significantly over the past decades, higher resolution building simulation has become more commonplace in research and industry. This has created the need for high resolution, representative occupant load profiles for electricity and DHW consumption. Historically, these models have relied on synthetically derived occupant load profiles which attempt to model occupant behavior but fail to capture the large variability of DHW draws. With over 200 sample homes with up to 16 months of measurements at a time-step of 1 minute, the Solar City data is an excellent source of data from which to generate annual DHW load profiles for single-detached homes.

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