Energy and Buildings 58 (2013) 58–65

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Domestic hot water consumption estimates for solar thermal system sizing

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ARTICLE INFO

Article history:
Received 14 June 2012
Received in revised form
21 September 2012
Accepted 13 November 2012

Keywords:
Domestic
Residential
Water
Consumption
Energy
Solar
Occupancy
Survey
Model
Hot-water

ABSTRACT

Accurate domestic-hot water (DHW) consumption information is useful for solar-thermal-hot-water-system designers and policy makers supporting solar-thermal-incentive programs. Conducting field studies of DHW-consumption patterns is difficult and costly, and as a result, there are few studies available in the body of literature. Several DHW models exist, however these aggregate models are often dated and most fail to identify the influence of the number of occupants in the dwelling, instead relying on a standard-per-capita consumption. The standard of 60 liters/capita/day (lcd) is found to be accurate for households of 4 or more occupants, but significantly under estimates per-capita-hot-water consumption for households with 3 or fewer occupants, consequently, under estimating the energy and GHG-emissions savings of solar-DHW programs [1]. The new estimate presented here addresses these issues. This study was conducted using utility-billing data, and occupant responses from a survey of 1594 residences. The data includes annual total-water use, energy consumption, costs, and basic information about the residence and occupants. The method isolates average-oil used in water heaters and then estimates system performance to calculate the volume of hot water heated. The findings include total-water use, oil consumption for water heating, and DHW use based on occupancy for households of 1 through 6 occupants.

1. Introduction

This paper estimates domestic hot water (DHW) consumption from an interpretation and analysis of survey data from Halifax Regional Municipality Solar City pilot program. Solar City is a municipal program that provides installation management and financing of solar-DHW systems for residential-property owners. The intent of the program is to encourage adoption of residential-solar-DHW systems to reduce conventional-energy consumption, greenhouse-gas (GHG) emissions, and ultimately residential-energy bills for participants. 1594 residential-survey participants provided annual-total water and energy-consumption data from utility bills, as well as basic information about the residence and occupancy. These new estimates can be used to expand, refine, and update existing DHW models.

DWH heating is roughly 30% of residential-energy use, which is a reasonable incentive for understanding consumption trends for DHW-system design, as well as water and energy conservation efforts [2]. Standard dwellings are not equipped with meters to provide flow and temperature for energy-balance calculations used in determining DHW use and so the data are not directly available in most cases. Total-water use is measured at the interface between the supply main and the house, which unfortunately does not differentiate the hot from the cold-water consumption. DHW consumption information is needed to design effective, yet efficient, solar-thermal systems for residential DHW, district-energy planning, combined DHW and space-heating systems, net-zero-energy-building design, and “smart-grid” applications.

The difficulty, in obtaining DHW-consumption data, is the principal reason behind the lack of availability, especially when considering regional and cultural influence on water consumption, for which it is likely that no relevant study is available. Literature concerning DHW-use patterns is limited and often relies on data gathered prior to the widespread use of energy efficient appliances and water-conserving fixtures [3]. The analysis is complicated by the many factors that influence DHW consumption patterns, including: flow rate, occupancy, household composition, the installed appliances, and the regional climate [3]. Additionally, residential water and energy, including electricity, fuel oil, natural gas, propane, and firewood, are typically supplied by different vendors; some may be municipally operated or government regulated, while others are private businesses, with each having their own method of cataloguing consumption data. The vendor data also does not include demographics such as the number of occupants in the house or the DHW appliance types and heating schema. Finally,

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http://dx.doi.org/10.1016/j.enbuild.2012.11.020

Table 1
Annual-daily-hot-water use from previous studies.

Merrigan [11]			Pearlman and Mills [5]	
Occupants (occurrences)	Residential DHW use (l/d)	Per capita DHW use (lcd)	Occupants (occurrences)	Per capita DWH use (lcd)
2 (18)	166	83	2 (6)	69
3 (17)	213	71	3 (18)	86
4 (25)	257	64	4 (19)	63
5 (13)	272	54	5 (15)	46

consumption data for water and energy in individual residences are often considered privacy-protected information and not publically available.

The Solar City survey provides a unique and rare aggregation of household data at a significant sample size, which enables a meaningful statistical comparison of water consumption, energy inputs, and household occupancy to produce DHW-consumption estimates. DHW volume is determined by isolating the average quantity of oil used in water heaters and then converting to DHW consumption through system-performance modeling. The survey data set did not support a similar analysis for electrical, propane, and natural-gas-DHW heating, although a modified survey design may allow such an analysis in the future. The findings indicate average-total-water use of 200 liters-per-capita-per day (lcd), which is significantly less than national average of 274 lcd. The average DHW use was found to be 65 lcd, a 12% increase over the national design standard of 60 lcd [1] and [4]. Additionally, when distributed by the number of occupants in the residence, the findings indicate a significantly higher DHW consumption for households with 3-or-less occupants, while 4-or-more-occupant households more closely agree with national-design standards. These findings will be useful for residential-solar-hot-water-system design and program analysis.

2. Literature review

The seminal Pearlman and Mills [5] study measured and analyzed the DHW-use and time-of-use patterns in 58 Ontario, Canada residences. The Pearlman study forms the basis for the *ASHRAE HVAC Applications Handbook* 2003, a widely-referenced North American standard for DHW-system design [6]. In this study the average-household-DHW use was 236 l/d and per-capita use was 47 lcd to 86 lcd, varying by number of occupants in the household, peaking at 3 occupants, and then decreasing for larger families [5]. The study considered only 2 through 5-occupant households. Seasonal variation, adult age (maximum consumption for 30–35 year olds) and presence of children under 6-years old were considered to be significant "influencing factors" on DHW-use patterns.

Becker and Stogsdill [7], [8] reviewed and compared nine DHW studies across North America with an averaged finding of 239 l/d per residence. Becker and Stogsdill found factors of seasonal variation, renting/owning, and presence of seniors to be significant. Per-capita estimates were not provided.

Swan, et al. used a bottom up approach based on a neural network and statistical model. The analysis modeled 16,952 houses, representing typical Canadian housing stock. The result was 208 l/d residential-total-DHW use and individual use of 67 lcd [9].

An example flow trace study is the work conducted by DeOreo and Mayer [10] in the Seattle area, during which DHW use was measured for 10 residences over a period of two weeks. The method interprets water flow events by volume and duration, to categorize them to specific end-uses, such as dishwasher or faucet. The residences grouped as "high-use" consumed 248 lcd of total water and 95 lcd of DWH (38% of the total water use). The DeOreo study analyzed time-of-use, end-use, and aggregated use of cold water and DHW over a small sample size in one region. Per-capita use was calculated by the average occupancy of 2.6 occupants per residence. The DeOreo study, while detailed, had a relatively small sample size.

The Merrigan [11] study of 74 North Carolina DHW systems in family residences produced daily-DHW-use profiles and average-daily use distributed by occupants residing in the house. Merrigan found that daily-DHW use increased linearly by approximately 45 l/d for each additional person in the house above 2, but also noted a large variability in use. The findings from the important studies of Merrigan and Pearlman and Mills are detailed in Table 1. It can be seen that estimates are similar for 4-occupant residences but diverge by 10% or more for other occupancy levels.

3. Data and survey information

1594 surveys were received for this study from the Solar City program with data from the year 2010, representing approximately 1% percent of the 165,153 normally occupied dwellings and 1.3% of the 2010 population of Halifax Regional Municipality [12]. The pilot program survey contained 35 data fields from each participating household. The fields included residence location, occupancy, water source, method of heating DHW, as well as water, oil, electricity, natural gas, and propane use and costs. Sufficient information is present in the surveys to conduct an in-depth analysis of water use, and through energy consumption, to determine the DHW-use trends of this medium-sized-metropolitan area. Table 2 provides a statistical description of the key-data fields from the survey. Appendix A provides further statistical details of relevant data fields employed in the survey.

Households contained between 1 and 9 occupants with 2 to 4 occupants per household being most frequent as shown in Fig. 1. There were few households with 7 or more occupants, so they were not included in the analyses that used groupings by the number of occupants in the household, although the larger households are included when determining means. The mean number of occupants per household is 3.2. Of the 1589 residences reporting a method of DHW heating, 49% used oil and 47% used electricity. Natural gas, propane, and a mix of other sources including wood, comprised a negligible remainder of the DHW-heating systems. That most residences rely on either oil or electricity as the primary heating source for DHW is typical of Atlantic Canada.

4. Water-use analysis

The program survey was initiated to provide screening for participation in the Solar City program and to investigate acceptance criteria for wider participation in subsequent program stages. Finally, the survey is to set a baseline of metrics to validate the success of the program. Of the 1594 survey respondents, 1044 provided water use and cost data based on municipal-water bills. The remainder of the respondents reported an on-site well as the water source, and are thus not metered. For the metered group, unusually large and very small uses were validated, or rejected, by comparison of the reported water cost with billing-rate cost-bin information from Halifax Regional Water Commission [13]. 1019

Table 2
General statistics of Solar City survey data fields (annual values unless otherwise specified).

	Water use (m^3)	Occupants per household	Age of house (yrs)	Total oil (l)	Total electricity (kWh)	Total natural gas (GJ)	Total propane (l)
(Occurrences)	(1019)	(1583)	(1589)	(917)	(1485)	(17)	(172)
Minimum	21	1	0.1	200	1972	17	33
Maximum	1824	9	340	7510	114,217	111	8365
Mean	215	3.2	37	2326	13,924	58	592
Mean-per-capita use	72 (200 lcd)			840	4901	19	216

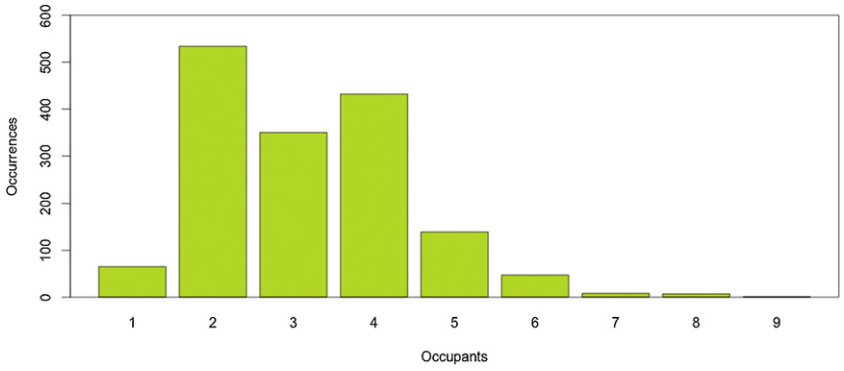

Fig. 1. Household-occupant distribution.

records (97.6%) were suitable for water-use-related analysis. Of the 1019 records suitable for water-use analysis, 1012 are suitable for distribution by occupancy, and 7 records were missing occupancy information. 1001 records populated the 6-occupant or less fields.

Table 3 shows the summary results of the records considered for water-use analysis distributed by occupancy. Percent difference from the 1-occupant household was also calculated as another method to demonstrate patterns with increasing number of occupants in each household. The percent difference was repeated using the Canadian-average-per-capita-water consumption of 274 lcd [14]. Fig. 2 shows the data distribution for total-water-use. On the boxplot, the black bar represents the median, colored box the middle quartiles, and circles represent outliers. Fig. 3 graphically shows the total-water-use pattern with increasing occupants in the residence.

4.1. Discussion of total-water use

Macro estimates of residential-daily-average-per-capita-water use in 2009 were 274 lcd across Canada; 292 lcd for Nova Scotia; and, 280 lcd for municipalities of 50,000 to 500,000 population across Canada [14]. The Solar City population using municipal-water-supply averaged 200 lcd, 27% less than the Canadian mean and 32% less than the Nova Scotia mean. This brings into question that citizens interested in solar DHW may already practice water conservation and that penetration of water conserving appliances, fixtures, and consciousness has started to make an impact on residential water consumption.

The 1-occupant households show higher use than the national average for per-capita-water use while residences with 2 or more occupants showed less-than-predicted use from the national average. An interesting result from this view of the data is the trend of reduced per-capita use with increasing occupancy from 1 to 4 people in the house, becoming more or less constant after 4 occupants. This result is likely due to an "economy of scale" effect with DHW conservation from shared laundry, dishwasher, and cleaning demands, but may also indicate habit changes with changing family sizes.

4.2. High-water-users

The data set included a small group of residences with high-annual-water use, which were included in the analyses of this paper. The water-use chart given in Fig. 4 is a distribution of the 1019 municipal-water-supplied residences by consumption

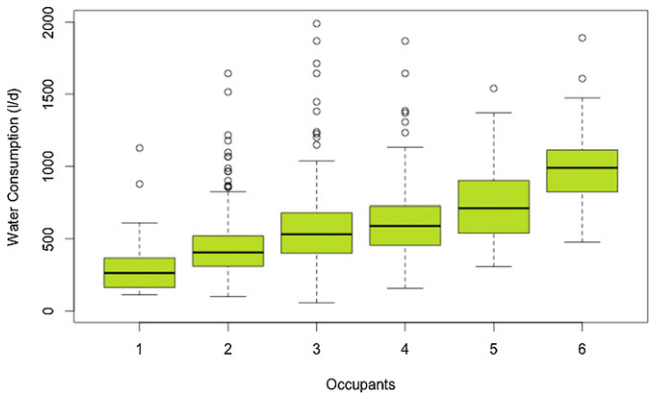

Fig. 2. Residential-total-water-use distribution.

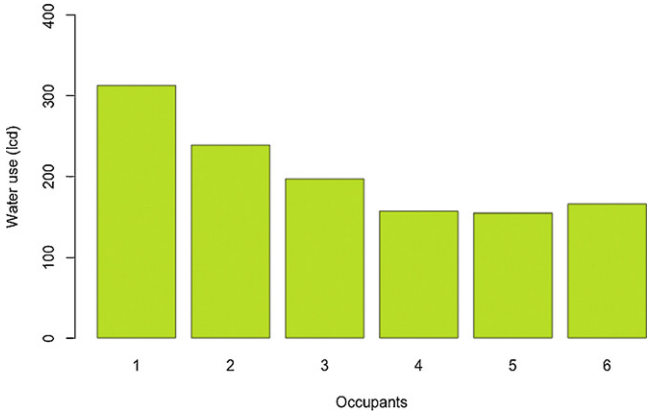

Fig. 3. Average-per-capita-total-water use.

Table 3
Average-per-capita-water use by occupants in the household.

Number of people in household (occurrences)	1 (39)	2 (341)	3 (231)	4 (272)	5 (89)	6 (29)
Daily-residential-mean-water use (l/d)	313	478	591	627	774	995
Daily-per-capita-mean-water use (lcd)	313	239	197	157	155	166
% difference in daily- per-capita-mean-water use from 1-occupant household	0%	−23.6%	−37.0%	−49.8%	−50.5%	−47.0%
% difference in daily- per-capita-water use from Canadian average (274 lcd) [14]	+14.1%	−12.8%	−28.2%	−42.8%	−43.5%	−39.5%

levels along the bottom axis. 97% of the residences used less than 500 m^3/yr; the mean was 215 m^3/yr. The remaining 30 residences, representing just under 3% of the municipal-water-supplied residences, used a range of 502 m^3/yr to 1824 m^3/yr. The high-water-users group had a higher than average number of occupants in the household at 4.1 as opposed to 3.2 for the entire population of municipal-water users, yet this alone does not compensate for their use of over 300% more water on average. Swimming pools, irrigation, and habit may contribute to the high-water consumption but the survey did not capture the characteristics, so the cause is not known.

5. Energy used for DHW heating

The analysis presented here develops a DHW-use pattern by isolating and calculating the average amount of oil consumed for space heating (SH) and DWH compared to the average amount of oil consumed for SH heating only. It is assumed that: i) residential oil is used only for SH and/or DHW, allowing for comparison of those with oil-DHW heaters and those with electric-DHW heaters; and, ii) there is a similar pattern between the two groups of auxiliary SH use from sources other than oil. This second assumption is reasonable given the small number, less than 20, of oil-using respondents that reported an auxiliary heat source.

This analysis indirectly calculates household-DHW use, isolating DHW-energy consumption by subtracting average-oil consumption for SH from total-oil consumed. The result is an average amount of oil consumed for DHW heating. The oil-users group is further analyzed by the number of occupants in each residence, as per-capita-water use is directly affected by the number of occupants in the household. Then an average-DHW-system-performance factor is applied to determine DHW use. An overview of the primary methods for DHW heating and the number of occurrences in the data set, are presented in Table 4. It can be seen that the average-water-use-per residence among the groupings are very similar, indicating that water-use patterns are independent of primary-DHW-heating source.

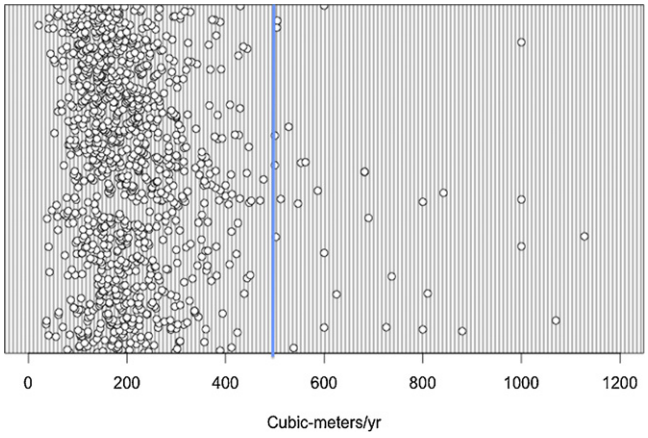

Fig. 4. Distribution of household-annual-water consumption.

5.1. Method of determining oil consumed for DHW

The method of determining oil-consumption attributable to DHW heating is based on an analysis of separating oil consumers into two groups, those using oil-DHW heaters and those using electric-DHW heaters. The consumption distributions for each of the two groups are shown in Figs. 5 and 6 for oil- and electric-DHW heating. Those using oil for DHW consume it for both SH and DHW heating; those using electric-DHW heating use oil only for SH. The mean oil consumption was calculated as 2450 liters/yr for the oil-DHW group and 1706 liters/yr for the electric-DHW group. The difference between the two means, oil SH and DHW minus oil only for SH, is the mean quantity of oil consumed for heating DHW as shown by Equation (1). The groupings were large enough to support an analysis of the means conducted this way, with 758 occurrences for oil-DHW heaters and 146 occurrences for electric-DHW heaters. This was from a total of 917 occurrences reporting oil consumption; the remaining 13 occurrences for oil consumption reported another primary form of DHW heating such as wood or propane, or did not report a value for DHW-heating method. Although this method does not provide insight into the exact DHW patterns of each household, the analysis does provide an avenue to

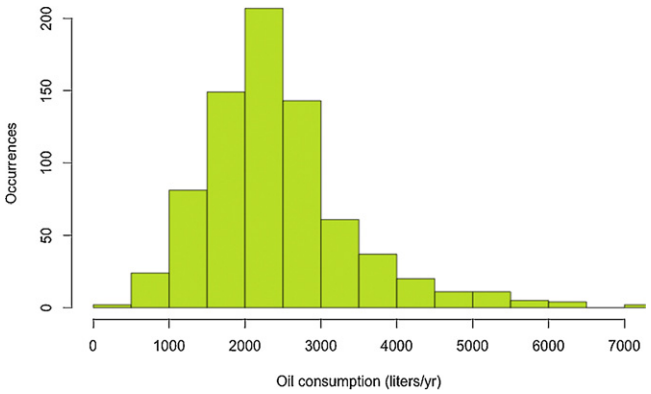

Fig. 5. Oil consumed for SH and DHW.

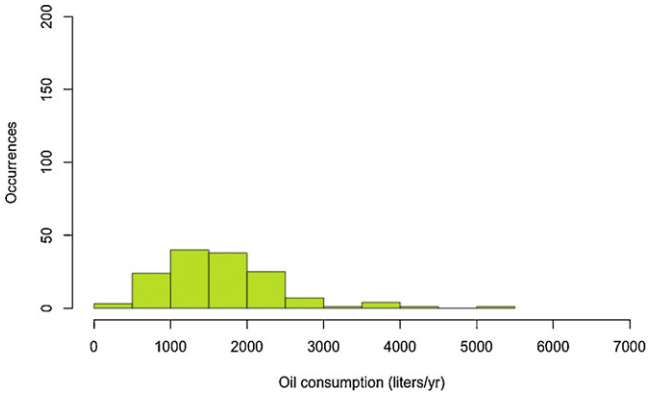

Fig. 6. Oil consumed for SH only.

Table 4
Primary DHW heating summary.

Primary hot water heating (occurrences)	Electric (753)	Oil (784)	Natural gas (12)	Propane (19)	Other (21)
Average household water use (m/yr) (occurrences)	218 (428)	212 (557)	221 (11)	208 (1)	198 (8)

Table 5
Average household oil consumption by oil and electric DHW heating.[a]

Number of occupants	1	2	3	4	5	6
Oil for SH + DHW (l/yr) (occurrences)	1842 (31)	2324 (251)	2369 (161)	2507 (217)	2714 (62)	3220 (25)
Oil for SH (l/yr) (occurrences)	1348 (6)	1725 (48)	1646 (35)	1638 (30)	1656 (16)	1961 (5)
Oil for DHW (l/yr)	494	599	723	869	1058	1260
% oil for DHW	27%	26%	30%	35%	39%	39%

[a] This table represents oil-consumers. Households with 7–9 occupants were not included in this analysis. Occurrence numbers vary with occurrence numbers in Table 6 since many of the oil-consumers supplied their water from a private well with no metering and thus did not report water consumption.

develop average annual DHW use, which can be used for program and policy evaluation and solar-DHW-system planning and sizing.

$$Oil_{DHW} = Oil_{DHW+SH} - Oil_{SH} \quad (1)$$

The same analysis was then applied across the oil-using group but distributed by the number of occupants in the house. This was done to determine if DHW use was also affected by number of occupants, as was the case with total-household- and per-capita-water use. Two outlier data points were removed in this part of the analysis. The first was a low-outlier in the 1-occupant oil-for-SH-only group. The oil consumption was 377 l/yr, just 22% of the average for SH-only users. This was likely due to a supplemental heating source, such as a wood stove. The occupant in this residence also demonstrates electricity and water use well below population average. The second data point was in the 2-occupant oil-for-SH-only column from a high-oil user, consuming 5000 l/yr, nearly three fold the average of 1706 l/yr. This user may be heating an attached rental unit or have a very large space to heat. Table 5 shows the findings of distributing the mean oil use calculation across households with 1 through 6 occupants. 1-occupant and 6-occupant groupings for households using oil for SH and electric-DHW heating were sparsely represented with sample sizes of 6 and 5 respectively, which reduces the reliability of the calculations as compared to groupings with larger sample sizes. Fig. 7 illustrates the oil consumed for DHW, showing a base load for a 1-occupant household and incremental increases for each additional person occupying the household.

5.2. Discussion of DHW energy use

The oil consumed for DHW increases with the number of occupants in the residence, as can be expected, with each person contributing to DHW use. The percentage of oil consumed for DHW heating increases with occupancy as DHW load grows faster than SH requirements. The 1-occupant household uses a slightly higher percentage of oil for DHW than the 2-occupant household due to lower SH demands and higher per-capita-DHW-heating requirements. It can be seen that between 25% and 40% of oil consumption supports DHW heating, trending upward with occupancy increase.

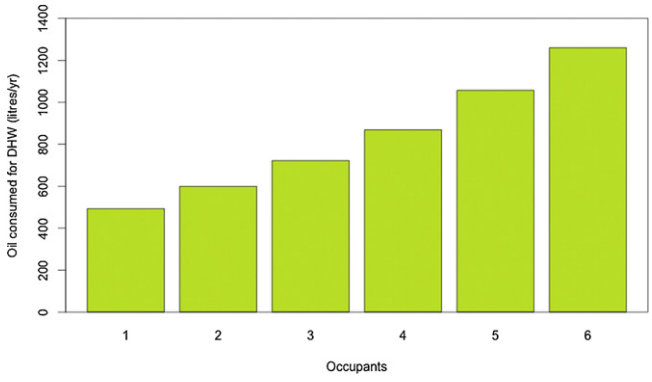

Fig. 7. Oil consumption attributed to DHW heating.

The Office of Energy Efficiency (OEE) estimates provide information for SH and DHW energy consumption. Of the total-residential-energy consumption in Canada, SH consumes 893 PJ and DHW-heating consumes 246 PJ, which are 55% and 15% of the total-residential-energy consumption, respectively [2]. For the OEE estimates, DHW is 22% of the total energy consumed for SH and DHW. The OEE numbers include all forms of energy such as electric, oil, and natural gas. For the analysis conducted above, to determine oil consumed for DHW heating, the mean of the group using oil for SH and DHW is 2450 liters/yr and for those using oil for SH and electricity for DHW the mean is 1706 liters/yr. The difference of the means is 744 liters/yr, representing 30% of the total-oil consumed, which is the fraction of oil consumed for DHW heating. The Solar City data are taken from oil used for DHW and SH in Nova Scotia climate, while the OEE estimates consider all forms of DHW heating, location energy price variation, and different climatic conditions across Canada.

6. Determining DHW use

A simple system performance model can be used to determine the volume of DHW heated from the oil consumed in DHW heaters. For this calculation, a single average-seasonal-energy-efficiency of 55% was used to model a stand-alone-oil-DHW-heating system with storage tank, which is representative of the majority of oil-DHW-heating systems in the region [14] and [15]. The equation below relates the energy of the combusted fuel oil to the amount of water heated:

$$nQ = cm(T_{out} - T_{in}) \quad (2)$$

The terms are as follows:

n = seasonal energy efficiency = 55% [16]

Q = energy used to heat DHW in Joules at 38.68 MJ/liter of light fuel oil [17]

T_{out} = 55 °C

T_{in} = 5 °C

m = mass of heated water. Assume avg density ~1000 kg/m^3

c = 4184 J kg^{-1} K^{-1}

Given this calculation, with appropriate unit conversions, every liter of oil heats 102.6 liters of water from 5 °C to 55 °C. Using the oil consumed in DHW heaters from Table 5 and Equation (2), the average-DHW-use per capita can be calculated. Table 6 shows the results of this calculation. Table 6 also includes water use

Table 6
Calculated-average-daily-DHW use for oil-DHW-heating group.

Number of occupants	1	2	3	4	5	6	Mean[c]
Oil consumption for DHW (l/yr)[b]	494	599	723	869	1058	1260	744 (146)[a]
Residential total water use (l/d) (occurrences)	368 (22)	469 (178)	567 (123)	622 (162)	840 (42)	1007 (16)	581 (557)
Per capita total water use (lcd)	368	235	189	156	168	168	184 (557)
Residential DHW use from Eq. (2) (l/d)	139	168	201	242	294	351	209
Per capita DHW use (lcd)	139	84	67	60	59	58	65
DHW as % of total household water use[d]	38%	36%	35%	39%	35%	35%	36%

[a] This difference of the means was developed using the oil DHW heating group of 758 occurrences and electric-DHW-heating group of 146 occurrences.
[b] From Table 5.
[c] Mean calculations included larger households of 7–9 occupants and the two outliers discussed in Section 5.1.
[d] The values in the last row of Table 6 can be obtained directly by dividing the value in row 1 (oil consumption for DHW) by the value in row 2 (residential total water use) and multiplying by the conversion factor 102.6/365, where 102.6 is the result of Eq. (2), and 365 is the number of days in a year.

distributed by the number of occupants for the oil-users group. There are similarities in the water-use patterns between the whole of the Solar City population and the population subset of the oil-DHW-heating group, as evidenced by comparing results in Tables 3 and 6, yet evidence was not available to determine if the DHW-consumption patterns were consistent with groups that heated DHW with other methods such as electricity, natural gas, propane and firewood. Solar City is a program designed to promote residential-solar-thermal-hot-water systems, and residences participating in Solar City were distributed across the municipality consistently with local population densities, as correlated by a postal codes. Specific evidence was not available to determine if the participant group represents a more generalized pattern of DHW consumption regionally, although climate, energy prices, and, to a degree, regional culture and attitudes would be common throughout the province. To the extent that the per-capita-DHW-consumption results obtained here for households that use oil for obtaining DHW can be generalized to the broader population, they will be useful.

6.1. Discussion of results

Analysis of daily-DHW use shows significant deviation about the normal 60 lcd DHW-use assumed by RETScreen calculations [1]. Households, with 4 or more occupants, were similar to the 60 lcd average estimated by RETScreen. The "economy of scale" trend seen in per-capita-water use was also present in per-capita-DHW use and the oil consumed to heat that water. Overall, 60 lcd is a reasonable mean rule-of-thumb for DHW requirements for high-occupancy residences. Tailoring the size of the solar-thermal system according to current use patterns for the Solar City population, will require considering the number of occupants in the residence and adjusting system capacity to match the actual demand. The 1-, 2-, and 3-occupant households consume more DHW per capita than the 60 lcd average typically used for sizing residential-thermal-DHW systems. For the national average model, 60 lcd of DHW is only 22% of the total national per-capita-water use of 274 lcd. The total water consumption in the Solar City population is less than statistical averages across NS and Canada, but the percentage of DHW to total-water use is higher than the national standard [14], [1]. For Solar City the ratios of DHW to total-water use is 35% to 40%, depending on occupancy. These findings should be considered for solar-DHW-system sizing if no change is made to occupant-water consumption. Programs, such as Solar City, may be able to capture additional energy and GHG savings in their accountings with the DHW estimates determined in this analysis versus the RETScreen design standard of 60 lcd [1].

This study updates and supplements previous DHW water studies including those of Pearlman and Mills [5], Merrigan [10], and the national design standard for DHW-use presented in RETScreen [1]. Fig. 8 shows a comparison of the predicted-residential-water use

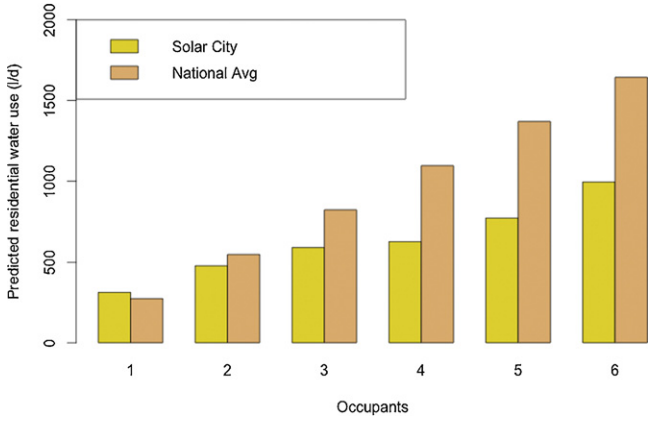

Fig. 8. National avg. and Solar City total-water-use [1].

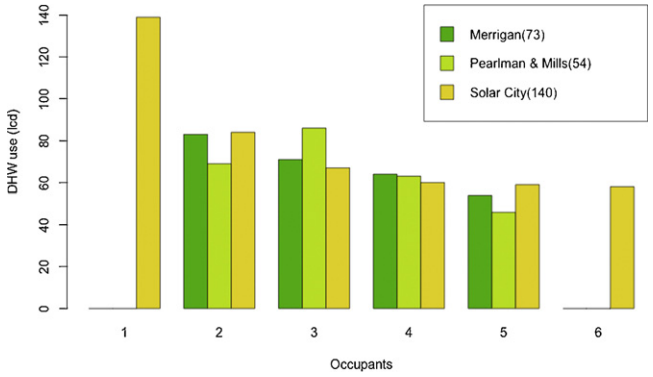

Fig. 9. Per-capita-DHW-use comparison (140 is the sample size of the oil-for-SH-only group, the smaller of the two groups used to determine DHW. The original group was 146 but 2 outliers were removed as discussed above and 4 records were from households greater than 6-occupants which were not considered in the analysis of DHW use by number of occupants in the household. This number can also be determined by adding the sample sizes across line 2 of Table 5).

using the national-average model and the Solar City findings. The national average significantly over-estimates water use for residences with more than 2 occupants. Fig. 9 compares the DHW-use findings for the same three studies and the number of samples suitable to determine DHW-use for each of the studies, Solar City, Merrigan [10], and Pearlman and Mills [5].

7. Conclusions

The Solar City survey provides detailed data of residential-water use and energy consumption in Halifax Regional Municipality. The energy-billing data and total-water-use data are easily available to municipalities via survey or opt-in programs. From the data,

patterns of water use and heating-oil consumption were determined, and high-residential-water consumers were identified. With over 1000 samples, sufficient variety existed to isolate energy used for DHW by comparing residences consuming heating oil for DHW and SH versus those only consuming heating oil for SH. Many energy services are used for DHW heating and are shared with other end-uses, making direct methods impossible. A simple fixed efficiency model of the DHW system was used to identify a pattern of DHW use in the Solar City population. The Solar City population represents approximately 1% of residences and population within Halifax Regional Municipality with a relatively even distribution throughout the various neighborhoods, and are probably representative of residential water, energy, and DHW consumption throughout the region. The findings indicate that the national-DHW-use-design standard of 60 lcd is sufficient for large households but does not capture increased use of DHW in smaller households. Planners must insure systems are not undersized for smaller occupancy, or they can pair reduced capacity with a targeted-water-conservation program. If energy and GHG savings estimates are done on the basis of 60 lcd, then additional opportunities for savings exist in the lower-occupancy categories, representing a majority of the population. This paper presents a method using oil, but the method could be applied to natural gas or propane in suitable service areas with slight modification of the survey design. The findings also provide a water and DHW reference for engineers, contractors, and municipal planners to refine solar DHW system sizing, costs, return on investment calculations, greenhouse-gas offsets, and solar energy policies. This study developed the following:

1. An updated and expanded estimate for residential-total-water use according to the number of occupants in the household
2. A method for estimating DHW use by determining oil consumption used for DHW and converting the energy input into DHW volume, and
3. An updated and expanded estimate of residential-per-capita DHW use according to the number of people in the household.

Additional analysis is possible with the Solar City data to include electricity-consumption patterns, total-energy-use patterns, and spatial analysis of the residences for solar-access mapping, among others. Future surveys will ideally be designed to identify house square footage and specific space heating modes within the household so electricity consumption can be more accurately quantified to its specific end-uses.

Acknowledgements

The authors are grateful to Julian Boyle of Halifax Regional Municipality for the provision of the Solar City survey data. The first author would also like to acknowledge Sam Stewart of Dalhousie University Mathematics Department for his guidance and assistance in programming with the statistics program R.

Appendix A.

Tables A1 and A2.

Table A1
Data description.

	Min	1st Quartile	Median	Mean	3rd Quartile	Max	Missing or N/A
Water consumption (m^3/yr)	21	139	187	215	256	1824	575
Energy							
Oil consumption (l)	200	1637	2221	2326	2796	7510	667
Electricity consumption (kWh)	1972	7246	11,600	13,920	18,420	114,200	109
Natural gas consumption (GJ)	17	38	56	58	75	111	1577
Propane consumption (l)	33	198	305	592	544	8365	1423
Occupants	1	2	3	3.2	4	9	11
Age of house (years)	0	12	27	37	55	340	5
Cost (CDN dollars 2010)							
Oil cost	175	1324	1800	1899	2262	7000	655
Electric cost	228	1034	1524	1792	2350	10,920	21
NG cost	360	793	976	978	1200	1588	1577
Propane cost	25	210	347	584	571	7951	1425
Miscellaneous use							
	Yes	No					
Well water	531	1063					
Oil use	955	639					
NG use	29	1565					
Propane use	187	1407					
	Electric	Oil	NG	Propane	Other		Missing or N/A
Primary DHW heat	753	784	12	19	21		5

Table A2
Solar city population energy and water consumption by type of DHW heating.

Primary DHW Heat	Electric	Oil	Natural Gas	Propane	Other	Grand Total
Occurrences	753	784	12	19	21	1589
Avg. oil consumption (l/yr)	1706	2450	0	3050	1942	2328
Avg. electricity consumption (kWh/yr)	18,974	8950	8049	15,039	17,403	13,904
Avg. number of occupants	3.1	3.2	3.2	3.7	3.0	3.2
Avg. age of house	29	43	51	58	24	37
Occurrences with municipal water supply	428	557	11	11	8	1015
Avg. water consumption (m^3/yr)	218	212	221	208	198	214

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