Survey Results of User-Dependent Electricity Loads in Canadian Homes

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ABSTRACT

During 2010-2012, Natural Resources Canada performed detailed assessments of electricity consumption in over 700 Canadian homes. These field assessments were conducted using the Residential Electricity Audit Tool (REAT). This electricity assessment method complements and extends features of the whole house energy evaluation procedures. A REAT assessment combines various data elements to produce a customized estimate of electricity usage and customized savings opportunities for a specific household. These elements include: (1) an inventory of electrical devices in the house; (2) historical energy-use characteristics of residential appliances and devices; (3) occupant-based estimates of operating hours and schedules of various appliances and lighting; (4) customized analysis of electricity use; (5) reconciliation of estimated usage with utility bills; (5) 'what if' analysis for various equipment upgrades and operational changes; and (6) homeowner advisory report.

The audit process includes a walk-through survey of the home to gather an inventory of energy consuming devices, a homeowner interview to assign appropriate operation schedules, a reconciliation of estimated and actual electricity use data from utility bills, the identification of appliance replacement opportunities and operational changes to reduce electricity consumption, and the preparation of a summary report for the homeowner.

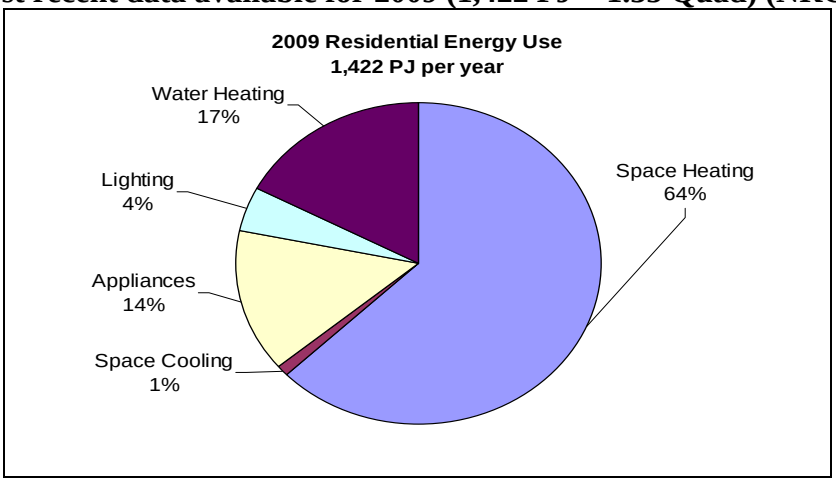
The nation-wide REAT evaluations showed an average base electricity use, excluding heating and cooling loads, of about 6,920 kWh per year. Historical comparisons showed that there is a significant increase in the energy use associated with plug loads; however, energy use associated with major appliances has reduced. The energy consumption due to stand-by usage accounts for about 9% of base-load electricity consumption.

This paper describes the REAT methodology, summarizes survey results and analysis of various usage components, and provides assessments of a number of doable scenarios for reducing electric energy consumption in Canadian homes.

Introduction

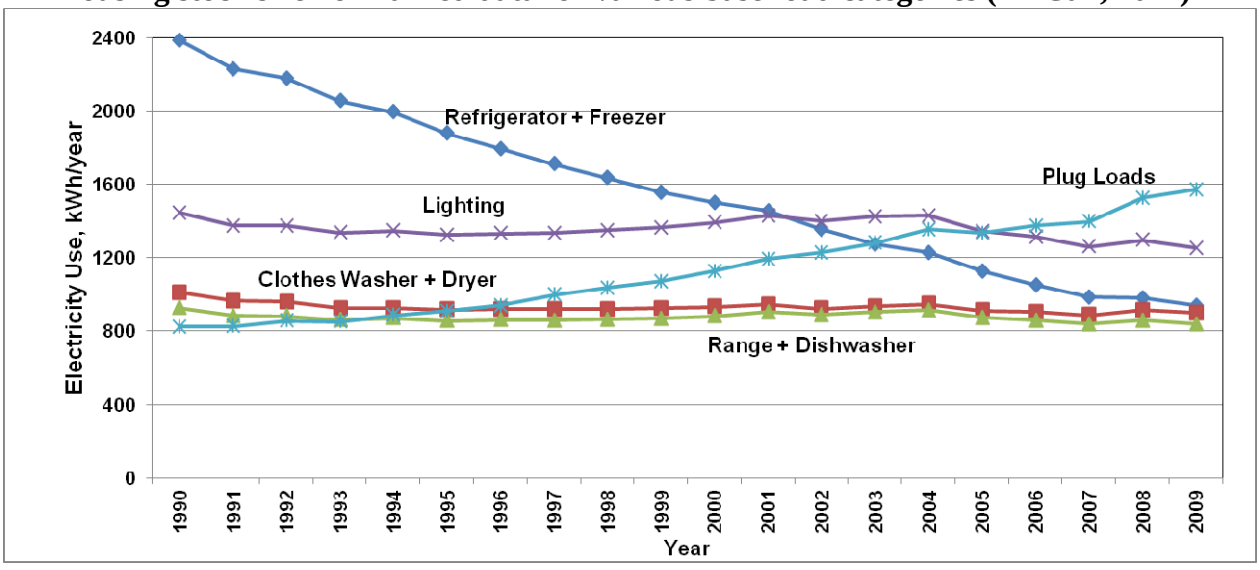
Canadian housing stock consists of 13.4 million dwellings with single-family dwellings (58%), semi-detached and row housing (17%), low-rise walk-ups and apartment buildings (15%) and mid- and high-rise apartment buildings (10%) (NRCan 2012). With sustained growth of the housing market, residential electricity use is increasing significantly. Base load electricity consumption attributed to lighting and appliances account for about 18% (266 million GJ) of the total residential energy usage of 1,422 million GJ [~ 1.35 quad] as shown in Figure 1 (NRCan 2012).

Figure 1. Canadian national inventory data for the annual residential energy use in the most recent data available for 2009 (1,422 PJ = 1.35 Quad) (NRCan 2012)



In the last couple of decades, residential electricity use has drastically changed. In addition to major appliances such as ranges, refrigerators, dishwashers, clothes washer and dryers, houses commonly have large numbers of small appliances, home entertainment, computer and communication devices, and other gadgets. These include such things as microwave ovens, counter-top appliances, flat-screen televisions, digital cable boxes, satellite tuners, video players, digital video recorders, home theatre components, I-pod™/MP3 docks, video games, computers, notebooks, tablets, in-home wireless networks, printers, multi-function devices, cordless telephone, cell phones, etc. The national inventory tracking of electricity uses in the residential sector, shown in Figure 2, indicated very interesting findings.

Figure 2. Annual energy use profile of a typical home in Canada; housing stock size normalized data for various base-load categories (NRCan, 2012)



Refrigerators and freezers have significantly improved in energy efficiency since 1990 (-61% change). The energy used for lighting has decreased modestly over the years (-13% change), as has the energy used by clothes washers and dryers (-11% change), and ranges and

dishwashers (-10% change). In contrast, there has been a dramatic rise in plug-load consumption (+91% change) which includes entertainment devices, computers, cordless phones, cell phones counter-top appliances and other personal devices. The overall base-load electricity usage in homes has changed by about -17%. Much of the efficiency gains of major appliances have been offset by increases in user-dependant plug loads.

The national energy-use statistics capture the overall trends in electricity usage. However, there is a lack of recent data on the number and types of plug loads consisting of numerous small appliances and devices, and detailed base-load electricity consumption in Canadian housing. It is important to establish the current market penetration and the overall energy usage by this growing segment of electrical devices.

Canada being a northern nation with an inclement cold climate, homeowner electricity usage patterns are somewhat different than other jurisdictions, and it is imperative to develop electricity-usage profiles for Canadian homes which can be used to target efficiency improvements. The Natural Resources Canada's Residential Electricity Audit Tool (REAT) Project began in 2009 with the purpose of developing uniform and consistent procedures for gathering residential electricity end-use data and providing appropriate recommendations to homeowners on possible actions to reduce electricity usage in their homes. As a starting point, an Internet search was done to document existing residential energy audit tools. Approximately 40 different web-based or homeowner self-administered programs were captured, mainly from utilities and public or government energy agencies in North America, Europe, and Australia. Using this information as a starting point, the REAT Project proceeded to develop a new electricity evaluation procedure, pilot-test the new evaluation tool in 40 homes, modify and enhance the audit procedures, and finally conduct a nation-wide survey of over 700 homes in 2011 and 2012.

This paper describes the REAT methodology and then presents summary results from the nation-wide survey of user-dependant electricity usage in Canadian homes.

Methodology

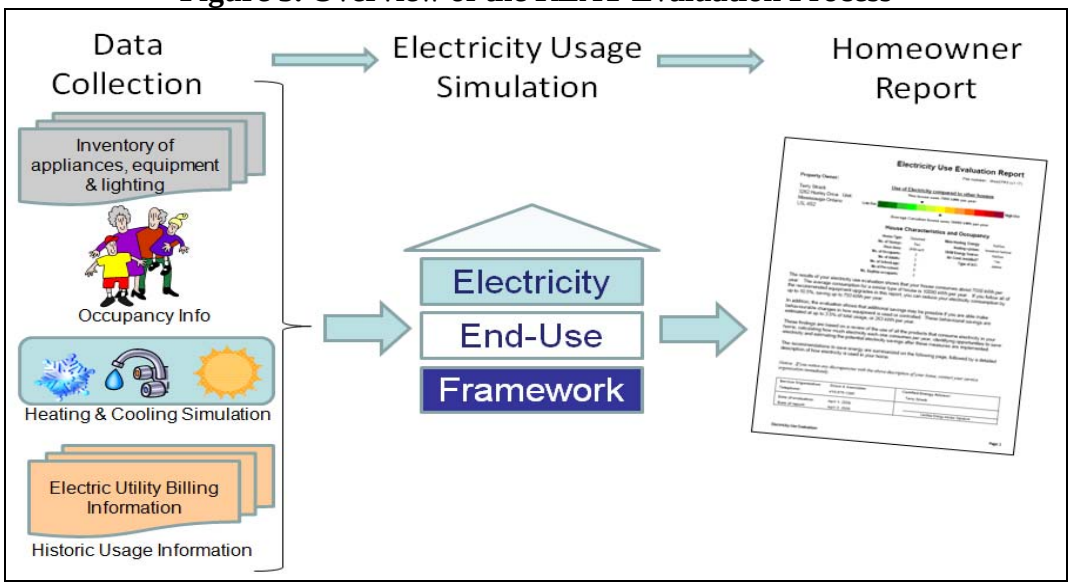
Residential housing energy assessments in Canada have historically used a "whole-house" energy evaluation procedure (NRCan 2007) which focuses on measuring the performance of the building shell, and space and hot-water heating systems. This procedure uses a weather-based building simulation which estimates the fuel and electricity consumption required to heat the home under standard operating conditions. In doing so the "whole-house" method makes some general assumptions about house occupancy and the base-load usage of electricity by appliances, lighting, plug loads in the house as well as outdoor uses. The standard base-load assumption is 24 kWh per day (HOT2000, 2007).

In contrast, the Residential Electricity Audit Tool (REAT) and data collection procedures are designed to quantify electricity usage in a specific household under actual "lived-in" operating conditions. The REAT evaluation uses the actual house occupancy and the actual inventory of electrical devices to predict the usage of electricity by the test house, and includes a built-in reconciliation process which results in an overall breakdown of electricity usage, that when summed, agrees closely with the actual billed electricity usage for the household. REAT also quantifies specific, actionable opportunities for reducing the consumption of electricity which cover both equipment replacement and behavioural changes.

Description of REAT Tool

REAT was developed as an extension to the "whole-house energy evaluation" and is intended to be undertaken after the completion of the "whole-house" evaluation. The REAT software works in conjunction with the HOT2000 building simulation model to predict the "as-lived-in" electricity consumption by the house (Strack 2010). An overview of the REAT evaluation process is illustrated graphically in Figure 3.

Figure 3. Overview of the REAT Evaluation Process



The REAT Software tool provides the necessary framework for collecting information from various sources and estimating the electricity usage by the household under evaluation. Information is collected on:

- the inventory of lighting, appliances and electrical devices in the home,
- the number of occupants and average occupancy patterns over a 12-month evaluation period,
- as-lived-in estimates of energy usage by the primary heating and cooling equipment in the home, and
- the historic electricity usage of the household over the 12-month evaluation period

The output from the REAT assessment is a 9-page "Electricity Use Evaluation Report" targeted at the homeowner, which breaks down the annual electricity usage by the test household into 10 subcategories; provides information on stand-by power usage; and, makes up to 11 recommendations, including estimated kWh-savings values, on practical ways to reduce electricity consumption. The 10 end-use subcategories are:

1. Major appliances (further sub-divided into eight appliance types)
   - Refrigerators
   - Freezers
   - Wine cellars

- Dishwashers
- Ranges
- Microwave ovens
- Clothes Washers
- Clothes Dryers

2. Lighting (further sub-divided into indoor/outdoor and light technology types)
   - Incandescent
   - Halogen
   - Fluorescent
   - Other types
3. Domestic water heating (if applicable)
4. Air conditioning
5. Space heating
6. Supplemental space conditioning (e.g. portable heaters, fans, dehumidifiers, etc.)
7. Home entertainment equipment
8. Office and communication equipment
9. Pumps, pools and spas
10. Other Miscellaneous Uses (e.g. small kitchen, cleaning and grooming appliances)

Field Data Collection and Simulation Procedures

The REAT process involves four parts:

1. Completing a survey of the house to note the number and location of all lighting sources, plug-in appliances, built-in appliances, outdoor light and outdoor electrical equipment.
2. Conducting a short interview with the occupants of the home to determine the number of residents, age-groups, occupancy of the house during the day and over the 12-month period, and occupancy patterns of the individual rooms. This information is used to calculate custom usage modifiers for lighting, built-in appliances and all plug-loads in the house.
3. Using the weather-based house simulation model (HOT2000, NRCan 2007), from the ecoENERGY Evaluation (NRCan 2007), to estimate the "as-operated" electricity usage by the primary heating, ventilating, air-conditioning (i.e. HVAC) and domestic hot water systems.
4. Inputting 12 consecutive months of kilowatt-hour usage from electric bills for the household, clicking a button to initiate the auto-reconciliation routines in the REAT software, and printing the homeowner report.

Training and Instruction Modules

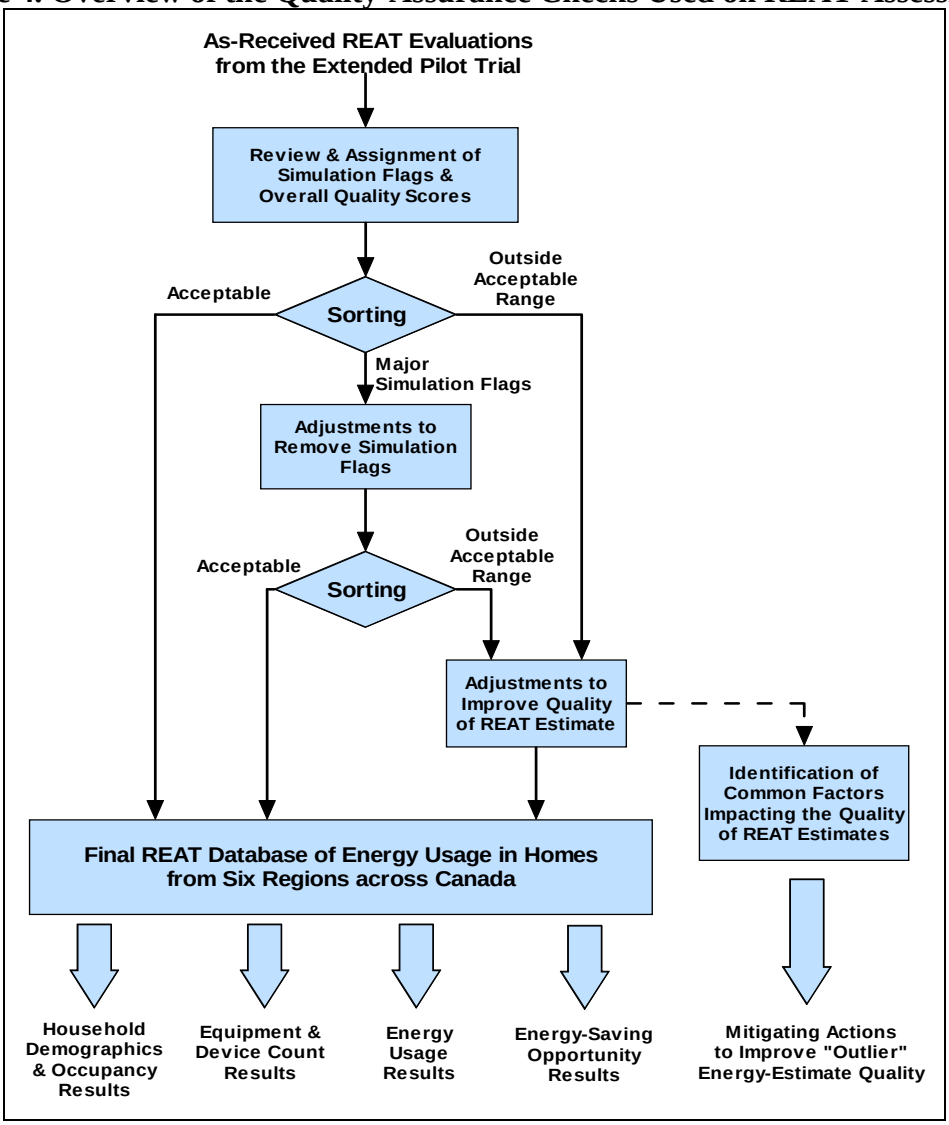
Training and instruction modules were developed and delivered to certified Energy Advisors (EAs) in 1-day training workshops in 6 regions across Canada. The first half-day involved classroom instruction on the background calculations used in REAT and usage of the REAT data collection procedures and software. The second half-day involved a trial REAT evaluation by the EAs of an actual house in the local area.

Field Assessments

In 2010, Natural Resources Canada (NRCan) field test the initial prototype REAT software and procedures in a limited trial (i.e. 40 sites) in Ontario. This initial field trial showed that the REAT method was feasible and could be completed within the expected timeframe. It also identified areas for improvement in both the data collection and simulation procedures, which led to the development of the second-generation REAT evaluation method.

In 2011 and 2012 NRCan engaged regional partners to field-test the second-generation REAT evaluation method in 6 regions across Canada. This effort produced over 700 REAT assessments.

Figure 4. Overview of the Quality-Assurance Checks Used on REAT Assessments



Quality Assurance & Data Extraction Process

Completed REAT assessments are processed to check for quality to ensure simulations meet a minimum quality before data is extracted and recorded in a master database of field results. This quality assurance (QA) procedure is shown graphically in Figure 4.

REAT Assessments are screened for their agreement with the actual billing data (±15%) and for the presence of any major simulation discrepancies. Assessments failing this screening process are manually reviewed and re-work to bring them within acceptable limits where possible. This usually involves resolving simulation discrepancies and adjusting setup values in the HVAC simulation software (HOT2000, NRCan 2007) to better represent actual operating conditions.

Information is also gathered from "outliers" to identify common factors contributing to poor assessment quality. This information is used to make future improvements to the REAT software and/or training material as part of the continuous quality improvement efforts.

Survey Results

The 2011 and 2012 extended field trials produced 720 REAT assessments from 6 regions across Canada, including British Columbia, Manitoba, New Brunswick, Nova Scotia, Ontario and Saskatchewan using the 2nd Generation REAT evaluation method. The results generated by these REAT assessments are discussed in the following sections. Table 1 and Table 2 show summaries of some of the device counts and annual energy consumption values.

Table 1. Summary of the Average Number of Electrical Devices found in Homes

No of Houses Sampled	Average Number of Devices by End-Use Area (count)									
	Lamps	Refrig.	Freezer	Dish-washer	Wine cellar	Home Enter't	Office & Comm.	Other Common	Suppl. Space Cond.	Other Misc & Seasonal
720	56.4	1.39	0.61	0.68	0.05	9.4	9.7	11.4	2.1	0.6

In addition there were on average one electric range, one microwave, one clothes washer and one clothes dryer per house surveyed. A minority of houses also have service pumps (26% of houses) and electric loads associated with pools, hot tubs and spas (16% of houses).

Table 2. Summary of Average Electricity Usage, Estimated by End-Use Area

No of Houses Sampled	Average Annual Electricity Usage by End Use Area (kWh/house)								
	Lights	Major Appl.	Home Ent't & Office	Other Common Loads	Suppl. Space Cond.	Other Misc & Seasonal	Pumps, Pools & Spas	Total Base Load	Standby Power
720	1088	2674	1547	704	230	184	492	6919	602

Quality of REAT Surveys from Six-Region Trial

About 82% of "as-received" REAT evaluations from 2011 passed the QA checks without any adjustments. In 2012 this fraction had increased to about 95% due to changes in the energy advisor training material as part of the continuous improvement process. Overall, about 88% of

REAT assessments were acceptable "as-received". Of the remaining 12%, about 7% triggered "simulation flags" and 5% had poor agreement (>15% difference) to actual billed electricity usage. After review and manual adjustments were made 99% of REAT assessments passed the QA checks.

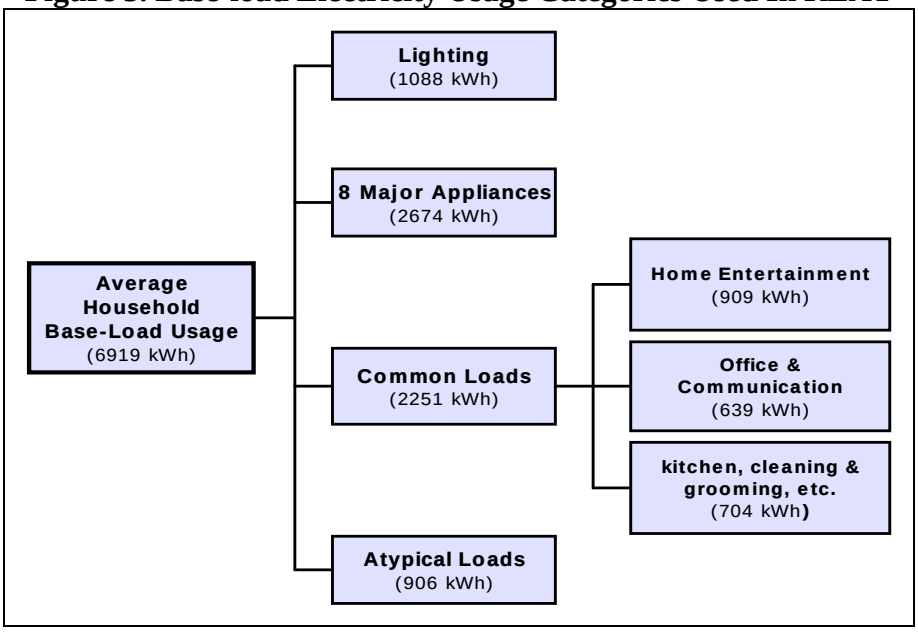
Household Demographics and Occupancy

The survey show that on average a household consisted of approximately 3.0 persons made up of 2.0 adults, 0.8 school-age and 0.2 pre-school children. On average, day-time occupancy on weekdays was 0.9 or about one person per household. Over the year, the average house was occupied about 95% of the time or for about 49-1/2 weeks. Occupancy variables are one set of parameters that are used by the REAT software to scale the electric usage of discretionary loads found in the house.

Base-load Electricity Usage

Base-load electricity usage consists of all uses within and outside the home that are not part of the primary space-heating, domestic hot water heating and space cooling systems. Base-load uses include lighting, major appliances, common-plug loads that are found in almost every home, plus "atypical" loads that are found in only some homes. This breakdown is shown graphically in Figure 5.

Figure 5. Base-load Electricity Usage Categories Used In REAT



The 720-house REAT survey estimated the average base load electricity usage at about 6920 kWh per year, or about 19.0 kWh per day.

Lighting. On average, houses had about 52 indoor lamps. Incandescent bulbs were the dominant technology type in 49% of houses followed by fluorescent (46% of houses) and halogen (5% of houses).

On average, houses had four outdoor lamps. An additional four outdoor lamps or strings[1] of seasonal lights were used during part of the year. Annual lighting energy usage averaged about 771 kWh for indoor applications and 317 kWh for outdoor applications for a total of 1088 kWh.

Major appliances. The eight major appliances considered are: refrigerators, freezers, wine cellars, ranges, microwave ovens, dishwashers, clothes washers and clothes dryers. These are discussed individually in the following sections. In most cases, two energy values are shown: the average household usage which equals the total energy usage by the population of houses surveyed divided by the number of houses surveyed (i.e. 720 houses); and the average energy usage per household by houses with at least one of the particular device-type present. The former energy value is similar to the energy usage reported by the national statistics (NRCan 2012) for appliances and represents the population average usage by a particular device type. The latter energy-usage value removes houses without the device from the equation, and is indicative of the average consumption by the particular device-type in a household. Per-unit energy values are also shown when they are significantly different from the per-household value.

Refrigerators. Survey data showed that 66.0% of houses had one refrigerator, 29.6% had two refrigerators and 4.4% had three or more refrigerators. On average there were 1.39 refrigerators per house surveyed. Annual refrigerator energy usage was estimated at 884 kWh per household or 638 kWh per refrigerator.

Freezers. Survey data showed that 50.6% of houses had one freezer, 5.3% of houses had two or more freezers, and 44.1% of houses had none. On average there was 0.61 freezer per house surveyed. Annual freezer energy usage was 274 kWh on average for all houses surveyed. In houses with freezers, the average annual usage was estimated at 491 kWh per household or 446 kWh per freezer.

Wine cellars. The survey data showed that self-contained wine cellars (aka wine coolers) are not very common, with only 33 houses (4.6%) reporting one or more units present, and the balance, 687 houses (95.4%) having none. On average there were 0.050 wine cellars per house surveyed. Annual wine-cellar energy usage was 19 kWh on average for all houses surveyed. In houses with wine cellars, the average annual usage was estimated at 410 kWh per household or 375 kWh per wine cellar.

Ranges. Houses surveyed had both electric and gas ranges, with electric ranges being more common, accounting for 711 (91.3% of ranges) of the 779 ranges identified in the survey. Fifty-nine houses (8.5%) had two ranges. The most common configuration was one electric range accounting for 610 houses (84.7% of houses). On average there were 1.08 ranges (0.99 electric and 0.09 gas) per house surveyed. Annual electricity usage by ranges was 579 kWh on average for all houses surveyed. In houses with electric ranges, the average annual electricity usage was estimated at 628 kWh.

Microwave ovens. The most common configuration for microwave ovens was one per house accounting for 638 houses (88.6%). An additional 46 houses (6.4%) had two microwave ovens,

[1] A string of seasonal lights was defined as having 35-lamps regardless of the actual string length.

and 36 houses (5.0%) had none. On average there were 1.01 microwave ovens per house surveyed. Annual microwave oven energy usage was 111 kWh on average for all houses surveyed. In houses with microwaves, the average annual usage was estimated at 117 kWh.

Dishwashers. The most common configuration for dishwashers was one per house accounting for 470 houses (65.3%). An additional nine houses (1.3%) had two dishwashers, and 241 houses (33.5%) had none. On average there were 0.68 dishwashers per house surveyed. Annual electricity usage by dishwashers was 175 kWh on average for all houses surveyed. In houses with dishwashers, the average annual electricity usage was estimated at 263 kWh.

Clothes washers. The most common configuration for clothes washers was one per house accounting for 703 houses (97.6%). An additional 12 houses (1.7%) had two clothes washers, and five houses (0.7%) had none. On average there were 1.01 clothes washers per house surveyed. Annual electricity usage by clothes washers was about 52 kWh per household (both all-house average and clothes-washer-house average).

Clothes dryers. Houses surveyed had both electric and gas clothes dryers, though electric dryers were more common, accounting for 689 (96.1% of dryers) of the 717 dryers identified in the survey. The most common configuration was 1 electric dryer accounting for 667 houses (92.6%). An additional 11 houses (1.5%) had two electric dryers; 28 houses (3.9%) had one gas dryer, and 14 houses (1.9%) had none. On average there was one clothe dryer (0.96 electric and 0.04 gas) per house surveyed. Annual electricity usage by clothes dryers was 580 kWh on average for all houses surveyed. In houses with electric clothes dryers, the average annual electricity usage was estimated at 614 kWh.

Home entertainment equipment. The category includes devices such as televisions, set-top boxes, video recording and playback equipment, audio equipment, video games and digital photo frames. On average there were 9.4 home entertainment devices per house surveyed. Average annual energy usage by home entertainment devices was estimated at 909 kWh per household. This included about 341 kWh of standby usage. Standby usage was estimated on a device-by-device basis using average standby power characteristics for each device type and, if applicable, accounting for the usage of switched power-bars to disconnect devices when not in use.

Computer and office equipment. This category includes devices such as desktop computers and monitors, notebooks, netbooks, tablets, printers, multifunction printer, modems, routers, cordless telephones, and other office equipment such as photocopiers and shredder. On average there were 9.7 office and communication devices per house surveyed. Average annual energy usage by office and communication devices was estimated at 639 kWh per household. This included about 142 kWh of standby usage. Standby usage was estimated on a device-by-device basis using average standby power characteristics for each device type and, if applicable, accounting for the usage of switched power-bars to disconnect devices when not in use.

Other common loads. The other common loads category includes devices such as small kitchen appliance (e.g. coffee makers, toasters, toaster-ovens, slow-cookers, rice-cookers, blenders, etc), cleaning appliances (e.g. vacuums, power heads, etc.), grooming appliances (e.g. clothes irons, hair dryers, styling iron, etc), and other items such as AC-powered clocks, CO detectors and

smoke detectors, garage-door openers, intercoms, home security systems, and water softeners. On average there were 11.4 other-common devices per household surveyed. Annual energy usage by other-common devices was estimated at 704 kWh per household.

Atypical base loads. Atypical base loads are ones that are less common and found in only a fraction of the housing population. This category includes items such as supplemental space conditioning loads (e.g. ceiling fans, portable fans, portable heaters, portable humidifiers, dehumidifiers, room air cleaners, etc.), aquarium pumps and heaters, water-bed heaters, seasonal loads (e.g. electric blankets, automotive engine heaters, in-car heaters, electric barbeques, electric lawn mowers, pipe trace heating, roof and gutter heaters, etc.). Atypical loads also include service pumps (e.g. sump pumps, well-water pumps and sewage pumps), pool, hot-tub and spa pumps and heater loads, and other recreational and life-style loads such as treadmills, saunas, steam showers, heated driveways and sidewalks, etc. The atypical load results from the REAT house surveys are summarized in Table 3.

Table 3. Summary of the Atypical Base-load Results from the REAT Surveys

ITEM	Suppl. Space Conditioning Loads	Misc & Seasonal Loads	Service Pumps	Pool, Hot-tub, Spa, & Sauna Loads	Load Summation
# of houses sampled	720	720	720	720	
Average Annual Electricity Usage for all houses sampled (kWh/house)	230	184	174	318	906
# of houses with non-zero usage (% of all sampled)	477 (66%)	256 (36%)	186 (26%)	121 (17%)	
Average Annual Electricity Usage for all non-zero houses (kWh/house)	347	517	675	1890	3429

Annual electricity usage by atypical loads was 906 kWh on average for all houses surveyed. Based on houses with non-zero atypical load, the average annual electricity usage was estimated at about 3,430 kWh. Pools, hot-tub and spa sub-category dominated the usage, with an average value of about 1,900 kWh based on a sample size of 121 houses.

Energy Saving Opportunities

The REAT software estimated energy savings potential on a house-by-house basis for up to 11 opportunities, six involving equipment upgrades and five involving behavioral changes by the occupants. Where appropriate, equipment upgrade recommendations involved changing the refrigerator, freezer, clothes washer, air conditioner, water heater (if electric) and lighting technology to energy-efficient ENERGY STAR™ models. On average, equipment retrofits are estimated to reduce annual energy consumption by 955 kWh per household (745 kWh base-load savings, 58 kWh electric water heater savings, and 152 kWh air-conditioner savings). Largest base-load savings opportunities involved lighting and refrigerator efficiency upgrades.

Behavioral recommendations involved removing and recycling the second refrigerator and freezer (if present), using an outdoor clothes line for 25% of clothes drying, reducing standby power usage by some home entertainment and office equipment by using an external power bar (based on a 50% reduction in standby), and using a timer to reduce pool, hot-tub and spa loads (based on a 50% reduction in pumping). On average, behavioral changes are estimated

to reduce electricity usage by 702 kWh per household. Largest base-load savings opportunities involve recycling extra refrigerators and freezers, using power bars on home entertainment devices, and using outdoor clothes lines.

Conclusions

The Residential Electricity Audit Tool (REAT) Project has developed a detailed, flexible and intuitive audit tool to conduct electricity audits and reconcile with utility bills. With over 100 energy advisors trained since 2011, a nation-wide electricity audit of homes is being undertaken. Survey results from over 700 homes have been analyzed and are presented here.

On an average, Canadian households consume about 6,920 kWh of electricity per year for the purposes of lighting, appliances, entertainment and other miscellaneous loads. This is about 19.0 kWh per day (or in terms of average electricity costs, about $2.20 per day). Lighting energy use is about 1,090 kWh per year. Electricity usage associated with home entertainment and communication devices is pegged at 1,550 kWh per year. About 9% of the annual electricity use is associated with stand-by power consumption.

The electricity savings opportunities included replacement of major appliances with energy efficient and ENERGY STAR® compliant products, replacement of conventional lighting fixtures with CFLs, LEDs or other efficient lamps. These measures alone can reduce electricity consumption by about 750 kWh per year or 11% of base-load usage. Additional savings are possible by upgrading electric water heaters and central air conditioners.

Interestingly, the survey results showed that potential changes in homeowner behaviour (e.g. shutting down internet modems, wireless routers and high power consuming devices when not in use, recycling extra refrigerators, and occasional use of outdoor clothes lines) can save 700 kWh per year or about 10% of base-load usage without changing or upgrading any electrical equipment in the house.

It is expected that the residential electricity audit tool will be integrated with whole house energy analysis modelling in the near future. This will allow energy advisors to provide comprehensive energy audits of homes and recommend how individual homeowners can reduce their electricity use and achieve benefits of significant cost savings.

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