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Residential Behavioral Savings: An Analysis of Principal Electricity End Uses in British Columbia

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ABSTRACT

Research on energy savings in residential dwellings has been dominated by an engineering economics paradigm, in which economic agents adopt practices and technologies which are cost effective. This paper challenges this paradigm and reports on a detailed behavioral study done with residential customers. Using data collected from a survey of 1,437 residential customers, we apply the conditions, capacity and commitment model. The model was applied to six residential energy end uses: (1) space heating, (2) lighting, (3) domestic hot water, (4) washing appliances, (5) refrigeration and (6) consumer electronics. In each end use area, respondents were asked a series of scaled questions dealing with their level of satisfactionwith the service level for the end use (conditions); their ability to modify or change service levels (capacity); and the extent to which they performed energy efficient actions or behaviors (commitment). Using simple engineering algorithms, the study also estimated potential behavioral energy savings at the end use level. The study found that refrigerator and freezer temperature control, defrosting freezers, checking the hot water tank temperature and turning off the hot water tank while away from home were particularly effective means of saving energy in residential buildings. Somewhat less, but still effective means of saving energy in residential buildings include using cold water to wash clothes, air drying dishes, turning off outside lights and lights in empty rooms, using low wattage bulbs, night and day temperature setbacks, keeping part of the house cooler, draft proofing, installation of storm windows and unplugging computers and entertainment equipment.

Introduction

Research on energy conservation policies has been dominated by an engineering economics paradigm, in which economic agents adopt those technologies and practices which are cost effective. Some key references to this literature include Duke and Kammen, Golove and Eto, Horowitz and Haeri, Jaffe and Stavins, Joskow and Marron, and Auffhammer et al. Within this engineering economics literature, analysis of energy savings opportunities typically proceeds by estimating net life cycle costs, and then assuming that the technologies and practices with the best life cycle costs will be adopted by economic agents, whether they are businesses or households. From a public policy perspective, the most effective policy initiative is one which most cost effectively promotes improvement in lighting, appliances, motor systems, HVAC systems and building shells. Demand side management programs have focused their attention on market barriers to the adoption of efficient technologies and the development and implementation of policy instruments to overcome these barriers. These instruments include codes and standards, labeling and information, conservation rates and financial incentives.

The behavioral literature on how customers actually make decisions on how they use energy has had, at least until recently, relatively little impact on energy efficiency policies. Some key references for this literature include California Energy Commission, Janda et al., Lutzenhiser, Stern, Moezzi et al., Sahota et al., Tiedemann et al. and Wilson and Dowlatabadi. This behavioral literature typically examines the actions of economic agents in specific and well-defined contexts with a view to understanding how and why they make decisions on energy use and on energy conservation behaviors. Interest in the behavioral literature began to increase both during and after the California energy crisis of 2000-2001, where the traditional hardware solutions to energy conservation were initially promoted. But the substantial energy demand reductions that were actually observed appeared to be, upon detailed examination, due primarily to conservation behaviors promoted by mass media and by social marketing. This suggests that it may be useful to try to more explicitly model the role of residential and business customers in securing conservation benefits, and to build a model that will help understand why some customers adopt energy efficient technologies while others do not adopt them.

This study has three main objectives: first, review recent estimates of residential end use electricity consumption for British Columbia households; second, apply the conditions, capacity and commitment model to a large sample of surveyed BC Hydro residential customers; and, third, estimate the potential impact of behavioral savings on residential electricity end use consumption in British Columbia households. A summary of this paper is as follows. The next section summarizes the study approach including the data collection and method. The third section provides detailed results by end use. The fourth section discusses key learnings and implications from this study.

Data and Methods

In this section, we summarize the major research issues, data and methods used in this study as shown in Table 1.

Table 1. Study Objectives, Data and Methods

Objectives	Data	Method
Estimate residential electricity consumption by end use	Customer survey (n = 1,126) Electricity billing data Weather data	Conditional demand analysis
Apply the conditions, capacity, commitment model	Customer survey (n = 1,437)	Cross tabulations Engineering algorithms
Estimate potential electric behavioral energy savings	Above information	Engineering algorithms

Data. Data was collected through a web-based, on-line survey of 1,437 residential respondents in 2008. Survey development proceeded in several steps. First, published literature on behavioral energy savings was reviewed. Second, a workshop was held with program staff and external experts to review and define possible approaches and researchable questions. Third, a draft survey was developed, circulated among stakeholders and revised in response to comments received. Fourth, data was collected though a web-based, on-line survey. Fifth, data was cleaned and a variety of cross tabulations were run in SPSS. The survey included a wide range of energy related attitudes, conditions and behaviors as well as detailed information on the respondent’s home. For each end use area, the respondents were asked a series of scaled questions dealing with their level of concern about the service level for the end use (such as lighting levels or temperatures); their ability to modify or change service levels; and the extent to which they performed energy efficient actions or behaviors. Since not all residential customers have a computer in their home, it was important to understand if there were potential biases introduced by using a web-based survey. The results of this work (Panel) were compared with BC Hydro’s 2008 Residential End Use Survey (REUS), a random mail-based survey of some 6,386 customers.

Although respondent characteristics for the Panel and REUS were similar, there were some differences. First, with respect to education, the Panel appears to under-represent those with less than a grade 12 education compared to REUS (Panel = 4%, REUS = 11%). Second, with respect to household composition, the Panel appears to under-represent the 65 years and over age group compared to REUS (Panel = 24%, REUS = 32%). Third, with respect to household income, the Panel appears to under-represent those with household incomes less than $40,000 per year compared to REUS (Panel = 21%, REUS = 33%). These differences were not judged to be large enough to reduce the validity and the usefulness of the data analysis and results.

End Use Consumption. We estimated residential end use electricity consumption using a conditional demand analysis (CDA) model with 24 monthly observations for 1,126 customers representing four regions and four dwelling segments. The basic idea of the CDA model is that total household consumption is the sum of consumption of various end-uses plus an error term or residual. Appliance saturations are modeled by an indicator variable to indicate the presence or absence of an end-use in a particular household or by a count variable to indicate the number of units present. The estimated regression coefficient is the UEC. The UECs are modeled as functions of appropriate exogenous variables. The detailed model uses a combined behavioral-thermodynamic approach. In other words, basic thermodynamic relationships are exploited to define equations reflecting energy consumption for major end-uses, and these are modified by behavioral characteristics such as the manner and frequency with which an end-use is employed.

$$HEC_{ht} = \sum_{all\ a} UEC_{aht}\, S_{ah}$$

Here, HEC_{ht} is the total energy consumption by household h in month t, UEC_{aht} is the energy consumption for end- use a by household h in month t, and S_{ah} is the stock of end-use a in household h. Stocks are represented by indicator variables to indicate the presence or absence of the end-use or by the counts of the number of the units of the end-use in the household. The UECs for the various end-uses are functions of appropriate exogenous variables, such as end-use features, dwelling characteristics, household characteristics and household income. The dependent variable in the model is daily energy consumption per household in a given month. Using customers' actual consumption by month allows consumption to be modeled as a function of weather in that month, including the impact of heating degree-days (HDD) on main space heating and supplementary space heating load and the impact of cooling degree-days (CDD) on central air conditioning and portable/room air conditioners.

Behavioral Model. Our behavioral model both builds on and simplifies the models used by previous authors [Ajzen, Fishbein and Ajzen, Lutzenhiser]. We argue that adoption of conservation and energy efficiency actions and practices has three main components. (1) **Condition** refers to the circumstances surrounding a customer's potential conservation actions, which include, in particular, the customer's satisfaction with the status quo. This satisfaction with the status quo could well have as its antecedents in mediation between attitudes and social norms, as in behavioral theories based on social psychology, but the mediation between attitudes and social norms is not necessary for this model. (2) **Capacity** refers to the customer's ability to act to undertake conservation actions, which may include both the presence of an enabling technology and the authority to act. This is essentially the same concept as perceived behavioral control and includes both the technical capacity to undertake a conservation action and the authority to undertake the action. (3) **Commitment** refers to the customer's acting to undertake an energy saving action or behavior, which may include the frequency with which an action is performed. In addition, we define (4) an (achievable) **behavioral target**, as the difference between capacity and commitment.

Savings Potential. Finally, our potential energy savings framework uses information from the conditional demand analysis and the conditions, capacity and commitment model to estimate the scope for additional behavioral energy savings. Potential savings for a particular end use are defined as the product of electricity consumption for that end use times the behavioral target times the potential savings share. Data sources for this algorithm are as follows: (1) end use electricity consumption comes from our conditional demand model; (2) behavioral target is defined as the difference between capacity and commitment as was just noted; and (3) potential savings share is taken from Sahota et al.[1]

Results

In this section we presentthe study results for: (1) end use energy consumption; (2) for twenty energy behaviors related to the six main residential energy end uses: space heating, lighting, domestic hot water, washing appliances, refrigeration and consumer electronics; and (3) for potential behavioral energy savings.

End Use Electricity Consumption

Table 2 shows the unit energy consumption (UEC) of electric end uses and weighted household average UECs for British Columbia, a winter peaking region. Weights were derived by actual proportion of residential accounts in the population, and penetration of each end use in (twelve) region and dwelling segments. As expected, the largest end uses are primary electric space heating at 4,767 kWh per year and electric water heating at 2,790 kWh per year. Other major end uses are secondary electric space heating (2,068 kWh per year), lighting (1,992 kWh per year), and refrigerator and freezer (1,120 kWh per year). Pools and hot tubs are also heavy users of electricity, but they have rather low saturation rates compared to other major end uses. Based on the UECs and the saturation of each end use, electricity consumption of each end use was also estimated for an average home in BC.

Table 2. Saturation Rates and Unit Energy Consumption (UEC) for Electricity by End Use

End use	Saturation (no. per household)	Unit Energy (kWh/y)	Average Unit Energy (kWh/y)
Primary electric space heating	0.36	4,767	1,716
Secondary electric space heating	0.27	2,068	558
Central air conditioning	0.09	230	21
Room/portable air conditioning	0.16	34	5
Electric water heating	0.38	2,790	1,060
Refrigerator or freezer	2.00	1,120	2,240
Electric range, cook top, stove	1.05	347	364
Dishwasher	0.72	372	268
Clothes washer or dryer	1.81	256	463
Lighting	39.47	50.48	1,992
Television	1.88	409	769

1A series of questions were included in the survey. Typically after a question about how often a respondent performed a specific behavior, respondents were provided with some data on the energy impact of that behavior. They were asked how likely they would be to do the behavior in the future. The answers were recorded on a five-point scale. To recognize that people often overstate future behavior,and in line with common market research practices, the response share was calculated by taking 80% of the "definitely will" and 20% of the "probably will."

Personal computer	1.25	415	519
Pool	0.004	1,597	6
Hot tub	0.03	2,881	86
Average kWh/y per household			**10,069**

Space Heating

Table 3 summarizes the five behaviors related to space heating included in the residential customer survey: temperature setback at night; temperature setback during the day when no-one was at home; keeping part of the house cooler when unused, draft proofing and installation of storm windows.

Respondents are more satisfied (69%) with the current level of service they obtain from night setback, day setback while no-one is in the home and keeping part of the house cooler, than with draft proofing and installation of storm windows (45%). For day and night temperature setback and draft proofing, it was assumed that all homeowners have the ability to undertake the action(s), while there are capacity issues regarding keeping part of the house cooler (54%) and authority issues with installing storm windows(e.g., for renters and condominium owners, 33%).In terms of commitment, respondents are most likely to engage in night temperature setback (67%), somewhat likely to engage in day temperature setback (58%) and draft proofing (53%), somewhat less likely to keep part of the house cooler (43%), and unlikely to install storm windows (5%).

The behavioral target, the difference between capacity and commitment, indicates potential to increase draft proofing (47%) and day setback (42%) actions, some potential to increase night setback actions (33%) and installation of storm windows (28%), and somewhat less potential to increase actions related to keeping part of the house cooler (11%). On average, the five space heating actions have a behavioral target of 32%, indicating potential share of those amenable to and capable of implementing the space heating energy efficiency actions.

Table 3. Space Heating Conditions, Capacity, Commitment, Behavioral Target (%)

Behavior	**Conditions**	**Capacity**	**Commitment**	**Behavioral Target**
Night setback	69	100	67	33
Day setback	69	100	58	42
Keep part of house cooler	69	54	43	11
Draft proofing	45	100	53	47
Install storm windows	45	33	5	28
Average	59	77	45	32

Lighting

Table 4 summarizes the three behaviors related to lighting included in the residential customer survey: turning off lights when the room is empty; using low wattage bulbs and turning off outside lights.

Respondents are quite satisfied with the current level of service they obtain from turning off lights in empty rooms and using low wattage bulbs (85%), have the ability to undertake the actions (100%), and are either very (86%) or somewhat (68%) committed to taking these actions. Respondents are somewhat satisfied that they turn off outside lights (64%), have quite high capacity to turn off outside lights (80%) and are somewhat (60%) committed to undertaking this action.

The behavioral target is highest for using low wattage bulbs (32%), and somewhat lower for turning off outside lights (20%) and turning off lights in empty rooms (14%). On average, the three lighting actions have a behavioral target of 22%, somewhat lower that the average for the five space heating actions (32%).

Table 4. Lighting Conditions, Capacity, Commitment, Behavioral Target (%)

Behavior	Conditions	Capacity	Commitment	Behavioral target
Turn off lights – empty room	85	100	86	14
Use low wattage bulbs	85	100	68	32
Turn off outside lights	64	80	60	20
Average	78	93	71	22

Domestic Hot Water

Table 5 summarizes the two behaviors related to domestic hot water included in the residential customer survey: checking the temperature of domestic hot water (DHW) tanks and turning off hot water tanks while away or on vacation.

In terms of current actions to check the temperature and turning off the hot water tank while away from the home respondent are satisfied (46%), have the ability to undertake these actions (100%) and are more likely to check the temperature of the hot water tank (43%) than they are to turn it off while away from home (20%).

The behavioral target is higher for turning off the hot water tank when away from the home (80%), but still reasonably high for checking the temperature (57%). On average, the two actions related to domestic hot water have a behavioral target of 69%, suggesting considerable more behavior change is possible from these actions, compared to actions related to space heating (32%) and lighting (22%).

Table 5. Domestic Hot Water Conditions, Capacity, Commitment, Behavioral Target (%)

Behavior	Conditions	Capacity	Commitment	Behavioral target
Check DHW temperature	46	100	43	57
Turn off DHW away/vacation	46	100	20	80
Average	46	100	32	69

Washing Appliances

Table 6 summarizes the two behaviors related to washing appliances (clothes washers and dishwashers) included in the residential customer survey: washing clothes in cold waterand air drying or using the energy savings setting on the dishwasher.

Respondents are somewhat satisfied (62%) with actions related to using cold water to wash clothes and air drying dishes. While all respondents have the ability to air dry dishes (100%), only 69% of loads or actions are appropriate for cold water washing. Nevertheless, respondents are somewhat more committed to washing clothes in cold water (62%) than to air drying the dishes (43%), while the behavioral target for air drying dishes is much higher (57%) than for washing clothes in cold water (7%).

On average, the two washing appliance actions have a behavioral target of 32%, compared to actions related to domestic hot water (69%), space heating (32%) and lighting (22%).

Table 6. Washing Appliances Conditions, Capacity, Commitment, Behavioral Target (%)

Behavior	Conditions	Capacity	Commitment	Behavioral target
Cold water clothes wash	62	69	62	7
Dishwasher air dry/energy saver	62	100	43	57
Average	62	85	53	32

Refrigeration

Table 7 summarizes the three behaviors related to refrigeration (refrigerators and freezers) included in the residential customer survey: checking and adjusting refrigerator and freezer temperatures; and defrosting the freezer more frequently.

In terms of current actions to check refrigerator and freezer temperatures and to defrost the freezer more often, respondents are satisfied (41%), have the ability to undertake these actions (100%), and are more likely to check the refrigerator temperature (59%) and defrost the freezer more often (54%) than to check the freezer temperature (33%).

The behavioral target is highest for checking the freezer temperature (67%) with more modest targets for checking the refrigerator temperature (41%) and defrosting the freezer more often (46%). On average, the three actions related to refrigeration have a behavioral target of 51%, compared to actions related to domestic hot water (69%), washing appliances (32%), space heating (32%) and lighting (22%).

Table 7. Refrigeration Conditions, Capacity, Commitment, Behavioral Target (%)

Behavior	Conditions	Capacity	Commitmen t	Behavioral target
Checkrefrigerator temperature	41	100	59	41
Check freezer temperature	41	100	33	67
Defrost freezer more frequently	41	100	54	46
Average	41	100	49	51

Consumer Electronics

Table 8 summarizes the five behaviors related to consumer electronicsloads included in the residential customer survey: unplugging brick chargers when not in use, turning off the TV when no one is watching, turning off all computer components, turning the computer monitor off and using power management software.

Respondents are quite satisfied (75% - 81%) with the status quo regarding five consumer electronic load actions and have the ability to undertake these actions (100%). Commitment is highest for using computer power management software (86%) and turning off the TV (80%), followed by turning off all computer components (57%) and turning off the computer monitor (47%), with less commitment to unplugging unused brick chargers (33%).

The behavioral targets for unplugging unused brick charges and turning the computer monitor off are high (67% and 53% respectively), followed by turning all computer components off (43%), turning off the TV when no-one is watching (20%) and using computer power management software. On average, the five actions related to consumer electronics have a behavioral target of 39%, compared to domestic hot water (69%), refrigeration (51%), washing appliances (32%), space heating (32%) and lighting (22%).

Table 8. Consumer Electronics Conditions, Capacity, Commitment, Behavioral Target (%)

Behavior	Conditions	Capacity	Commitment	Behavioral target
Unplug unused brick chargers	75	100	33	67
Turn off TV no one watching	81	100	80	20
Computer all components off	75	100	57	43
Computer monitor off	75	100	47	53
Computer power management	75	100	86	14
Average	76	100	61	39

Potential Behavioral Savings

Table 9 summarizes potential behavioral energy savings per dwelling. For each end use examined, potential savings are defined as the product of average consumption for the end use times the behavioral target share times the potential savings share. Overall, the potential energy savings per dwelling are 442 kWh per year or 4% of average dwelling consumption (10,069 kWh per year).

All six action areas provide effective means of saving energy in residential buildings. The largest potential energy savings and potentially the easiest to acquire are for:

- **refrigeration** actions (134 kWh/y) with high average unit energy consumption (2,240), a high behavioral target share (51%) and reasonable potential energy savings share (12%); and
- **domestic hot water** actions (110 kWh/y) with reasonable average unit consumption (1,060 kWh/y) a high behavioral target share (69%) and reasonable potential energy savings share (15%).

Both **lighting** and **washing appliance** actions have reasonable potential energy savings (61 kWh/yr and 68 kWh/y, respectively). However, lighting actions have a low behavioral target share (22%), while washing appliance actions has low average unit consumption (731 kWh/y) and reasonable, though not large behavioral target share (32%) suggesting potential challenges in terms of identifying households with potential energy savings, engaging these consumers and initiating and/or extending actions (e.g., increased frequency of action) within the household.

Space heating and **consumer electronic** actions have low potential energy savings per dwelling despite reasonably large average unit energy savings and reasonably large behavioral target shares (32% and 39%). The low potential savings share (9% and 4%) for these actions suggests challenges in terms of engaging a sufficient number of customers and/or actions to achieve the potential energy savings.

Table 9. Potential Behavioral Savings per End Use per Dwelling

End Use	Average Unit Energy (kWh/y)	Behavioral target share	Potential savings share	Potential savings (kWh/y)
Space heating	1,716	0.32	0.09	**49**
Lighting	1,992	0.22	0.14	**61**
Domestic hot water	1,060	0.69	0.15	**110**
Washing appliances	731	0.32	0.29	**68**
Refrigeration	2,240	0.51	0.12	**134**
Consumer electronics	1,288	0.39	0.04	**20**
Potential Energy Savings per Dwelling				**442**

Discussion

Using data collected from a survey of 1,437 residential customers, we apply the conditions, capacity and commitment modelto six residential energy end uses: (1) space heating, (2) lighting, (3) domestic hot water, (4) washing appliances, (5) refrigeration and (6) consumer electronics. In each end use area, respondents were asked a series of scaled questions dealing with their level of satisfactionwith the service level for the end use (conditions); their ability to modify or change service levels (capacity); and the extent to which they performed energy efficient actions or behaviors (commitment). Using simple engineering algorithms, the study also estimated potential behavioral energy savings at the end use level.

The study found that refrigeration and domestic hot water actions including refrigerator and freezer temperature control, defrosting freezers, checking the hot water tank temperature and turning off the hot water tank while away from home were particularly effective means of saving energy in residential buildings. While respondents were satisfied with the service level for these actions (41%, 46%) there is considerable room to improve satisfaction suggesting consumers may be responsive to messaging to improve their satisfaction (comfort) with these services. That is, consumers are interested in actions that will improve their comfort and/or satisfaction. In addition, these actions have high behavioral target shares indicating considerable (51%, 69%) potential to influence a large number of consumers or consumer actions, and represent reasonable (12%, 15%) average unit potential energy savings.

Somewhat less, but still effective means of saving energy in residential buildings were found for washing appliances, lighting, space heating and consumer electronics actions including using cold water to wash clothes, air drying dishes, turning off outside lights and lights in empty rooms, using low wattage bulbs, night and day temperature setbacks, keeping part of the house cooler, draft proofing, installation of storm windows and unplugging computers and entertainment equipment. Consumers are relatively satisfied with lighting (78%), consumer electronic (76%), washing appliances (68%) and space heating (59%) services suggesting consumers may not perceive a need for action or further action in these areas, and that different messaging strategies may well be appropriate for these four action areas, in comparison to messaging for lower satisfaction areas (domestic hot water and refrigeration) where consumers may already have an interest in improving their satisfaction and/or comfort.

There is a relatively low behavioral target share for lighting actions (22%) accompanying the high satisfaction levels (78%), suggesting challenges associated with the perceived need for action/improvement, and identifying and communicating with a small proportion households and/or a small proportion of actions within a household. There are relatively low potential energy savings shares for space heating (9%) and consumer electronics (4%) suggesting a large proportion of households will be required to change/improve actions in order to achieve these energy savings, potentially indicating the efficacy of mass media messaging versus targeted communication strategies.

The level of satisfaction with the service level for the end use (conditions); the consumers' ability to modify or change service levels (capacity); the extent to which consumers performed energy efficient actions or behaviors (commitment) and the (achievable) behavioral target share (the difference between capacity and commitment) and average unit potential energy savings share were used to examine and to estimate average unit potential energy savings for six residential energy end uses: (1) space heating, (2) lighting, (3) domestic hot water, (4) washing appliances, (5) refrigeration and (6) consumer electronics. While all six end uses were found to be effective means of saving energy in residential buildings the conditions, capacity, commitment model helped identify predictable challenges that may arise in developing messaging and programs to achieve the identified energy savings.

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