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USING CONDITIONAL DEMAND ANALYSIS TO ESTIMATE RESIDENTIAL ENERGY USE AND ENERGY SAVINGS

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Utilities require detailed end-use energy consumption for power system planning, load forecasting, marketing and demand side management. End-use consumption refers to the consumption of space heating, space cooling, water heating, lighting and other specific uses as opposed to total consumption. This report presents the methodology and results of a residential end-use study for British Columbia, Canada. The study used Conditional Demand Analysis (CDA) to estimate Unit Energy Consumption (UEC) values for several residential end-uses and for several energy conservation measures. Conditional demand analysis is a multivariate regression technique which combines utility billing data with weather information and customer survey data to produce robust end-use energy consumption estimates.

Introduction

End-use energy consumption information is becoming increasingly important for power system planning, load forecasting, marketing and demand side management. A key tool for estimating end-use energy consumption is conditional demand analysis, which uses energy billing data combined with weather data and customer survey data in a multivariate regression framework. The basic idea underlying the conditional demand analysis is that the total load can be disaggregated into the component or end-use loads. These in turn can be modeled using thermodynamic principles as appropriate. The conditional demand analysis framework has several advantages over its main rival of end-use metering. First, surveying customers is inexpensive compared to end-use metering, so that robust estimates can be produced at relatively low cost through conditional demand analysis. Second, the number of sites included in metering projects is often quite small, so that the metered estimates may have large standard errors compared to CDA estimates. Third, the conditional demand approach can be used to estimate end-use loads in residential dwellings or dwelling classes not included in the modelling, if appropriate survey-based information is available. A number of previous studies have used conditional demand analysis to estimate residential end-use consumption. These studies include Lawrence and Parti (1984), Parti and Parti (1989), Sebold and Paris (1987), and Tiedemann (1997a, 1997b). The present study extends the commonly applied conditional demand analysis framework in order to produce both end-use consumption and end-use savings estimates.

Method

This study applies the conditional demand model. The basic idea of the conditional demand 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 unit energy coefficient or 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.

The dependent variable in the model is daily energy consumption per household in a given month, which is obtained from customer billing data by dividing total consumption by the number of days in the billing cycle. 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 conditioning loads.

This study is based on a survey of residential customers in BC Hydro's service territory who participated in the 2004 Residential End-Use Survey. For this study, surveys were mailed to 3,639 residential customers in November 2004. This survey covering all major end uses, housing characteristics and demographics, as well as attitudes towards energy use. The total number of surveys returned was 928, with unusable ID numbers and missing billing data reducing the usable sample to 791 surveys. Survey information was merged with energy consumption information for the period January 2004 through December 2005 and with weather data from a weather station closest to their dwelling.

The condition demand model was estimated using ordinary least squares to increase comparability with previous studies. The regression results are summarized in Table 1, which shows the value of each regression coefficient, the standard error and the associated probability that the coefficient is different from zero. The overall regression performed well with an adjusted R-squared value of 0.83. All coefficients had the expected signs, and 34 of 37 coefficients were significant at the 5% level or better.

Table 1. Regression results

Component	Coefficient	Standard error	P-value
HDD*Area*MainElecspacheat	0.047	0.002	0.00
HDD*Area*Duplex*MainElecspacheat	-0.015	0.002	0.00
HDD*Area*Apartment*MainElecspacheat	-0.046	0.003	0.00
HDD*Area*Mobilehome*MainElecspacheat	0.059	0.004	0.00
HDD*Area*Highinsulation*MainElecspacheat	-0.013	0.001	0.00
HDD*Area*Effwindows*MainElecspacheat	-0.0040	0.002	0.01
HDD*Area*Income*MainElecspacheat	0.00000023	0.000	0.00
Area*Winter*Mainelecspacheat	6.48	0.586	0.00
HDD*Area*Nonelecsecspacheat*MainElecspacheat	-0.0019	0.001	0.14
HDD*Area*Secondarvelecspacheat	0.017	0.001	0.00
HDD*Area*Duplex*Nonelecsecspacheat	-0.013	0.003	0.00
HDD*Area*Apartment*Nonelecsecspacheat	0.056	0.008	0.00
HDD*Area*Mobilehome*Nonelecsecspacheat	-0.00083	0.003	0.79
CDD*Area*Central space cooling	0.059	0.011	0.00
CDD*Area*Room or portable space cooling	0.066	0.012	0.00
HDD*Elecwaterheat	0.153	0.077	0.05
HDD*log(NoPeop+1)*Elecwaterheat	0.934	0.186	0.00
HDD*log(NoPeop+1)*High insulation*Elecwaterheat	0.464	0.129	0.00
HDD*Dishwasher loads per week*Elecwaterheat	0.091	0.008	0.00

HDD*Clotheswasher loads per week*Elecwaterheat	0.017	0.007	0.02
HDD*No lowflow showerheads*Elecwaterheat	-0.083	0.040	0.04
HDD*No instant hotwater taps*Elecwaterheat	0.366	0.056	0.00
HDD*No waterheaterblankets*Elecwaterheat	-0.195	0.051	0.00
No refrigerators and freezers	92.7	5.21	0.00
No electric ranges and cooktops and ovens	60.1	8.69	0.00
No dishwashers	3.20	10.6	0.76
No clothes washers and dryers	54.0	7.88	0.00
No incandescent lamps	3.35	0.302	0.00
No fluorescent lamps	5.72	0.904	0.00
No compact fluorescent lamps	-3.88	0.904	0.00
No halogen lamps	14.2	0.908	0.00
No other lamps	-0.053	0.582	0.90
No televisions	73.2	4.57	0.00
No personal computers	54.7	6.08	0.00
Pool	326.0	28.0	0.00
Indoor hot tub	136.4	16.6	0.00
Outdoor hot tub	362.1	17.0	0.00
R-squared	0.83		
F-statistic	2367		

Note. HDD is number of heating degree-days; CDD is number of cooling degree-days; no is number; log is logarithm; elec is electric; nonelec is non-electric; unless otherwise indicated the variable is an indicator variable.

End-use energy consumption

The regression coefficients were used to calculate unit energy consumption values for major residential end-uses. This involved the following steps:

- (1) calculate the UEC for each household possessing that end-use for each month by substituting household values and normal heating degree-days and cooling degree-days into the end-use equations;
- (2) calculate weighted average UECs across all households possessing that-use for each month; and
- (3) calculate the aggregate results across months.

Table 2 provides the saturation rates, unit energy consumption and end-use intensities, as well as total end-use intensity per household. The saturation rate is the average number of that end-use per household. The end-use intensities are the product of saturation rates multiplied by unit energy consumption. In other words, the unit energy consumption is average electricity consumed by that end-use if it is present, while the end-use intensity is the average consumption of that end-use across all households. The largest UECs include primary electric space heating (5,037 kWh per year), secondary electric space heating (2,310 kWh per year), electric water heater (3,186 kWh per year), lighting (1,937 kWh per year), swimming pool (3,912 kWh per year) and hot tub (2,612 kWh per year).

Table 2. Saturation rates, unit energy consumption and end-use intensity

	Saturation (number per household)	Unit energy consumption (kWh per year)	End-use intensity (kWh per year)
Primary electric space heating	0.28	5037	1410
Secondary electric space heating	0.29	2310	670
Central air conditioning	0.07	346	24
Room or portable air	0.14	207	29
Electric water heater	0.42	3186	1338
Refrigerator and freezer	2.11	1112	2346
Electric range, cook top and oven	1.07	721	771
Dishwasher	0.77	38	29
Clothes washer and clothes dryer	1.80	648	1166
Lighting	1.00	1937	1937
Television	1.93	878	1695
Personal computer	1.11	656	728
Swimming pool	0.05	3912	1956
Hot tub	0.17	2618	445
Total consumption			12744

End-use energy savings

The regression coefficients were also used to calculate unit energy savings values for major residential energy conservation measures. This involved the following steps:

- (1) calculate the unit energy savings for each household possessing that measure for each month by substituting household values and normal heating degree-days and cooling degree-days into the end-use equations;
- (2) calculate weighted average unit energy savings across all households possessing measure for each month; and
- (3) calculate the aggregate results across months.

Table 2 provides the saturation rates, unit energy savings and end-use savings, as well as end-use savings per household. The saturation rate is the average number of that measure per household. The end-use savings are the product of saturation rates multiplied by unit energy savings. In other words, the unit energy savings is average electricity saved by that measure if it is present, while the end-use savings is the average savings of that measure across all households. The largest unit energy savings include high insulation levels/insulated doors (1,649 kWh per year), energy efficient windows (618 kWh per year), low flow shower heads (256 kWh per year), and water heater blankets (616 kWh per year).

Table 3. Saturation rates, unit energy savings and end-use savings

	Saturation (number per household)	Unit energy savings (kWh peryear)	End-use savings (kWh per year)
High insulation levels/insulated	0.26	1649	429
Energy efficient windows	0.12	618	74
Low flow shower heads	0.40	256	102
Only full laundry loads	0.90	162	146
Water heater blanket	0.14	616	86
Compact fluorescent lamps	3.9	47	183
Total savings			1020

Conclusions

Utilities require detailed end-use energy consumption for power system planning, load forecasting, marketing and demand side management. End-use consumption refers to the consumption of space heating, space cooling, water heating, lighting and other specific uses as opposed to total consumption. This report presents the methodology and results of a residential end-use study for British Columbia, which uses Conditional Demand Analysis (CDA) to estimate unit energy consumption (UEC) values for several residential end-uses and for several energy conservation measures. CDA is a multivariate regression technique which combines utility billing data with weather information and customer survey data.

The study produced unit energy consumption estimates for 14 end-uses and four energy conservation measures based on a sample of 791 residential customers. The results were weighted to the population of B.C. Hydro customers. As expected, the largest end-uses are primary electric space heating at 5,037 kWh per year and electric water heating at 3,186 kWh per year. Other major end-uses are secondary electric space heating (2,310 kWh per year), lighting (1,937 kWh per year), refrigerator and freezer (1,112 kWh per year), television (878 kWh per year) and electric range, cook top and oven (721 kWh per year). Major conservation measures included insulation and draft proofing (1,649 kWh per year), energy efficient windows (618 kWh per year), low flow shower heads (256 kWh per year) and water heater blankets (616 kWh per year).

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