The Dynamics and Advantages of Using Billing Analysis to Evaluate New Residential Construction Programs

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ABSTRACT

Establishing appropriate and accurate baseline energy consumption is critical to evaluating energy savings of conservation programs. However, it is not always possible to establish an a priori baseline when pre-program metering is unfeasible. Such is the case with BC Hydro's new residential construction program. Since these homes are newly constructed, there is no opportunity to measure the pre-construction baseline of energy consumption and evaluations often rely on engineering calculations. This method of estimation has shortcomings that can lead to inaccurate or unreliable estimates. First, it is unknown of the accuracy of baseline energy consumption that are determined by existing building code and standard, building quality and code and standard compliance; second, the engineering calculations assume a certain set of occupancy and building characteristics which could differ from reality.

This paper presents an alternative evaluation approach adopted in the evaluation of BC Hydro's new residential construction program that addresses these shortcomings. The methodology established baseline energy consumption by randomly selecting non-participant single family detached homes constructed in the same period as program participant homes. Home assessment and program data was used to match non-participant homes with program participant homes on characteristics such as home size, space heating source, location and year of build. Such a non-participant group will represent the counter-factual energy consumption to be compared with the participant group's energy consumption. This approach features a dynamic baseline that reflects changes in building quality over time, accounts for the factors that impact the energy performance of newly constructed homes, and provides analytical flexibility.

Introduction

The Power Smart New Home Program was launched by BC Hydro[1] between 2006 and 2016 to encourage the construction of energy-efficient homes and to prepare the residential construction industry for the advancement of more energy-efficient building codes planned by the provincial government. The New Home Program included the Home Performance offer which provided financial incentives to residential home builders (from owner-builders to large scale developers) to adopt higher energy efficiency standards and install more energy-efficient technologies and products. Large scale developers were specifically targeted in an effort to increase the supply of energy-efficient homes in the new residential construction market. Builders could participate in the program multiple times without a cap. The New Home program was evaluated in 2016. A key objective of the evaluation of New Home Program was to measure its energy savings impact. Literature in the energy efficiency field reveals that the preferred evaluation methodology for new construction programs would be to meter the electricity consumption of program participant and baseline homes built around the same time and at proximate locations. This method requires a substantial number of inputs from the metering study as well as data

[1] BC Hydro is one of the largest energy suppliers in Canada, generating and delivering electricity to 95 per cent of the population of British Columbia. It operates an integrated system backed by 30 hydroelectric and two thermal generating stations as well as 79,000 kilometres of transmission and distribution lines serving about 2 million customers.

on home occupancy and building characteristics. While this is the preferred methodology, such evaluations often require a significant amount of evaluation resources and a long timeline to complete.

The evaluation of the Home Performance Offer adopted a different approach that overcomes the challenges of the above methodology and also provides a realistic and credible estimate of program impact. The methodology allows for setting up a baseline by randomly selecting non-participant homes constructed in the same period as the program participant homes in nearby locations, and matching them on certain characteristics.

The remainder of the paper is structured into three sections: Section 1 presents the evaluation methodology and data used for evaluating energy savings. Section 2 discusses the evaluation results and provides the variance analysis comparing energy performance of homes built by large and small builders, and the sensitivity analysis of one-to-one and one-to-many matching. Section 3 concludes the paper by discussing the merits and advantages of the methodology used in the evaluation over the engineering method.

Section 1. Evaluation Methodology and Data

1. Methodology and data for evaluating energy savings of attributed to the Home Performance Offer

Energy savings of newly constructed single family detached homes eligible for the Home Performance offer were evaluated using a quasi-experimental design with a matched comparison group. The critical step of using this methodology was to set up a comparison group that represented credible and realistic baseline consumption.

Since new residential homes had no energy consumption history to compare between the participants and non-participant groups, when constructing a comparison group, other matrices or indicators had to be used to establish the comparability of the two groups. To the extent of the data availability, the following matching criteria were used to ensure reasonable comparability of energy consumption between homes in the participant and non-participant groups:

- housing type (single family detached home);
- same year of build: obtained from program tracking data for participant homes and from BC Assessment for non-participant homes;
- region: broken into Lower Mainland, Vancouver Island, Southern Interior and North within the province of British Columbia; obtained from the BC Hydro billing system;
- space heating source (electric): obtained from the BC Hydro billing system; and
- home size (within ±15 square feet): obtained from BC Assessment.

In order to mitigate the impact of any extreme energy consumption cases being randomly selected into the comparison group, each participant home was matched with up to three non-participant homes. The one-to-many matching method is a standard approach often used in propensity scoring or nearest neighborhood matching in quasi experimental designs. Another reason for using multiple matches was that the selection of matching criteria was limited by the data availability and these criteria did not guarantee comparability of the participant and non-participant groups as other factors could influence home energy consumption (such as occupancy and household's social-economic status) that were not included in the matching criteria. One-to-many matching is a way to limit the impacts of factors not being considered in the matching. A sensitivity analysis revealed that the one-to-many matching produced more stable and smooth estimates, especially in the early evaluation period, than did one-to-one matching (see section 2 for results).

The evaluation included the majority (77% or 454 out of 592 homes) of the participating single family detached homes in the analysis. With some repeated draws from the non-participant pool, the one-to-many matching produced a total of 1,178 pairs of which 797 were matched with unique non-participants homes. Once the comparison group was constructed by computer matching, the net energy savings for the Home Performance offer were calculated through the following steps:

Step 1. Calculate average monthly energy savings per participant

The monthly net energy savings due to the impact of the Home Performance offer was calculated for each matched participant as the difference between the energy consumption of participating and non-participating homes for each month in the evaluation period.

Equation 1. Monthly Net Energy Savings

Monthly Net Energy Savings$_i$ =

$$\left[\sum_{\substack{Participant-\\Non-participant\\match=1}}^{n} (Energy\ Consumption_{non-Participant} - Energy\ Consumption_{Participant})\right]/\mathrm{n}$$

where *Energy Consumption* is monthly consumption and *n* equals the total number of matched pairs.

The Student's t-test on the pair matches between participant and non-participant was performed on the monthly basis for all the participants that were matched with non-participant. If the average difference between the participant and non-participant group was statistically different than zero at the 80% confidence level, it was included in the annual evaluated savings. This test was performed on both the single match and the three matches. The results were different, which will be discussed later in the paper.

Step 2. Adjust energy savings for weather

Since the calculation of net energy savings was based on actual billing data and the Home Performance offer focused mainly on energy efficiency and building shells, energy savings were dependent on space heating requirements and weather. Therefore, a weather adjustment was made to understand monthly energy savings under normalized weather conditions.

Monthly heating degree days and cooling degree days were compared to the long run (10 year) average of heating and cooling degree days obtained from Environment Canada. Then the average monthly savings were adjusted by the ratio of the long run average heating and cooling degree days to the actual monthly heating and cooling degree days.

Equation 2. Weather Adjusted Monthly Net Energy Savings

Weather Adjusted Monthly Net Energy Savings$_i$ =

*(Long Run Average Monthly Heating and Cooling Degree Days$_i$ /Actual Monthly Heating and Cooling Degree Days$_i$) * Monthly Net Energy Savings$_i$*

This approach to weather normalization assumes a linear relationship between energy savings attributable to the Home Performance offer and weather, or in other words that all savings are weather related. This assumption was supported by the fact that energy savings from this offer were due to space heating measures and previous work that demonstrated linearity in the relationship between residential energy consumption and heating and cooling degree days over a range of temperatures.[2]

Step 3. Calculate total energy savings attributable to the Home Performance Offer

Total energy savings attributable to the Home Performance offer was calculated by multiplying average annual energy savings per home by the number of participating homes per fiscal year. The number of participating homes was obtained from program tracking data.

2. Methodology and data for variance analysis of energy performance of homes built by large and small builders

Large (multi-unit) home builders and small (single-unit) home builders may have different practices in constructing energy-efficient buildings. The selection and composition of large and small builders in the comparison group could have an influence on the energy savings results for single family homes.

Information on residential home builders is collected and maintained by BC Assessment in a third party database. A total of 428[3] participants and 714 non-participants were identified in the database and classified as either large or small builders based on their construction activities over a one-year period. As shown in the table below, the composition of large builders and small builders in the participant and comparison groups was not the same: There was a larger share of large builders in the participant group than in the comparison group (53% vs 31%).

Table 1. Composition of Large and Small Builders in Participant and Comparison Groups

Participant Group			Comparison Group		
	Number	Percent		Number	Percent
Large-home builders	227	53%	Large-home builders	219	31%
Small home builders	201	47%	Small home builders	495	69%

Since the composition of large and small builders in the participant and non-participant groups was not the same, it was of interest to determine whether the difference in builder size in the participant and non-participant groups had an impact on the results. Once the composition of large and small builders was identified in the participant and non-participant groups, a variance analysis was conducted to identify the impact of builder size by using regression analysis.

The regression analysis was conducted using the following model to show the impact of two factors—program participation and the builder size –as fixed effects in monthly energy consumption:

[2] It is recognized that the linear relationship between energy savings and heating/cooling degree days may be weak considering that improved building shells lead to longer time lags between outside weather change and the activation of heating/cooling equipment. The linearity would likely be more noticeable in more extreme climates. In milder climates, non-linear relationships could exist.

[3] This number is different from 454 participants that were used for matching as some of the participants were not identified as large or small builder due to lack of information on their construction activities

Equation 3. Electricity Consumption as a Function of Builder Size

$$Energy\ Consumption_i = a + b*(Builder_i) + c*(Participant) + d*(Builder_i*Participant_i) + error,$$

Where *i* represents the house built by builder *i;*
Builder$_i$ indicates the size—whether builder *i* is a large (multi-unit) builder or a small (single-unit) builder; *Participant*$_i$ indicates whether or not builder *i* participates in the Home Performance Offer;

To see whether the impact of the composition difference existed, a third factor was added: the Interaction term of the large builders participating in the program ($Builder_i*Participant_i$). The results (presented in section 2) reveal that the cross impact was not significant confirming that the difference in the composition of large and small builders in the participant and non-participant groups did not affect the savings estimate when controlling for builder type's effect on consumption. Furthermore, although statistically significant, the coefficient associated with builder type was small relative to the savings.

Section 2. Results

1. Energy savings

The calculated monthly savings from April 2010 through March 2013 are detailed in the Appendix . As the table shows, energy savings were generated mostly in winter months, from October through February/March, since heating is a major electricity end-use for BC Hydro's residential customers who live in a winter climate zone. Table 2 shows average annual energy consumption of the non-participant and Non-participant groups for each of the three fiscal years from 2011 to 2013

Table 2. Average Annual Consumption of Participant and Non-participant group (F2011 - F2013)

Annual Consumption (kWh/year)	F2011	F2012	F2013
Non-participant (Baseline) Annual Consumption	20,330	17,685	16,891
Participant Annual Consumption	15,919	15,020	14,189

Table 3 shows the actual and weather-adjusted per participant energy savings attributed to the Home Performance Offer over the same three fiscal years.

Table 3. Annual Energy Savings per Participant Home (F2011 - F2013)

Annual Energy Savings per Participant Home (kWh/year)	F2011	F2012	F2013
Actual	4,007	2,665	2,242
Weather Adjusted	4,261	2,875	2,427

As can be seen in Table 2, participant homes were more energy efficient than non-participant homes across all three years and baseline consumption declined much more significantly over the period than did participant homes. These results indicate that non-participant homes were becoming more energy efficient over time, although less so than the participant homes. The changing baselines were the major reasons for the smaller energy savings attributed to the Home Performance offer in the second and third year than in the first year.

Based on the unit energy savings and the total number of new program participants in each fiscal year, the total evaluated energy savings generated by new participants are calculated and shown in the following table as compared to the program reported savings based on the original engineering estimates.

Table 4. Total Energy Savings for Home Performance Offer (F2011 - F2013)

Fiscal Year	**Units**[4]	**Annual Energy Savings (GWh/year)**		
		Program Reported Energy Savings	**Evaluated Energy Savings**	
			Actual	**Weather-Adjusted**
F2011	125	0.5	0.5	0.5
F2012	263	1.0	0.7	0.8
F2013	437	1.9	1.0	1.1

The difference between evaluated and reported savings was due to three factors. First, the unit savings per home were smaller than expected because the actual size of homes built under the program was smaller than assumed in the reported savings (180m^2 vs 205m^2). Second, the regional mix of program participation was different than assumed in reported savings (i.e., all participants were located on Vancouver Island and in the Lower Mainland, with a relatively mild climate, rather than dispersed across the entire province, so that unit savings were less). Lastly, non-participant homes built during the program period were more energy-efficient than assumed in the reported savings as many of them adopted heat-pumps as a space heating source (which are more efficient than electric baseboards) and the growing heat pump penetration was not considered for in the reported savings[5].

2. Sensitivity of results to matching method

Analysis was performed to examine the sensitivity of energy savings estimates to the adoption of a one-to-one matching approach and a one-to-three matching approach. A comparison group was constructed using one-to-one matching in three different ways:

- randomly selecting one from the three matches for each participant home,
- using the maximum consumption of the three matches for each participant home, and
- using the minimum consumption of the three matches for each participant home.

The sensitivity analysis indicated that using multiple matches for each participant home had less volatile results than matching just with one comparison home.

[4] The total units over three years are bigger than what is used for matching as some of the units could not be identified in the utility billing system due to different address registered by occupant.

[5] Our Residential End Use Tracking Study shows that the overall installation rate of air-source heat pump increased from 3% to 5% from 2010 to 2014 across the entire province. In the region of Vancouver Island and Lower Mainland, where most of new program participant units were located, the installation rate increased from 9% to 12% and 1% to 3%, respectively.

As illustrated in Figure 1, there was a difference in the results for the early evaluation period between the one-to-three and one-to-one match comparisons, but they started to converge later in the evaluation period. This is most likely due to the increased sample size in the later part of the evaluation period. Given the small participant numbers in the early evaluation period, it was more prudent and reliable to derive the results with the larger comparison group comprised of one-to-three matches instead of the one-to-one matched comparison group.

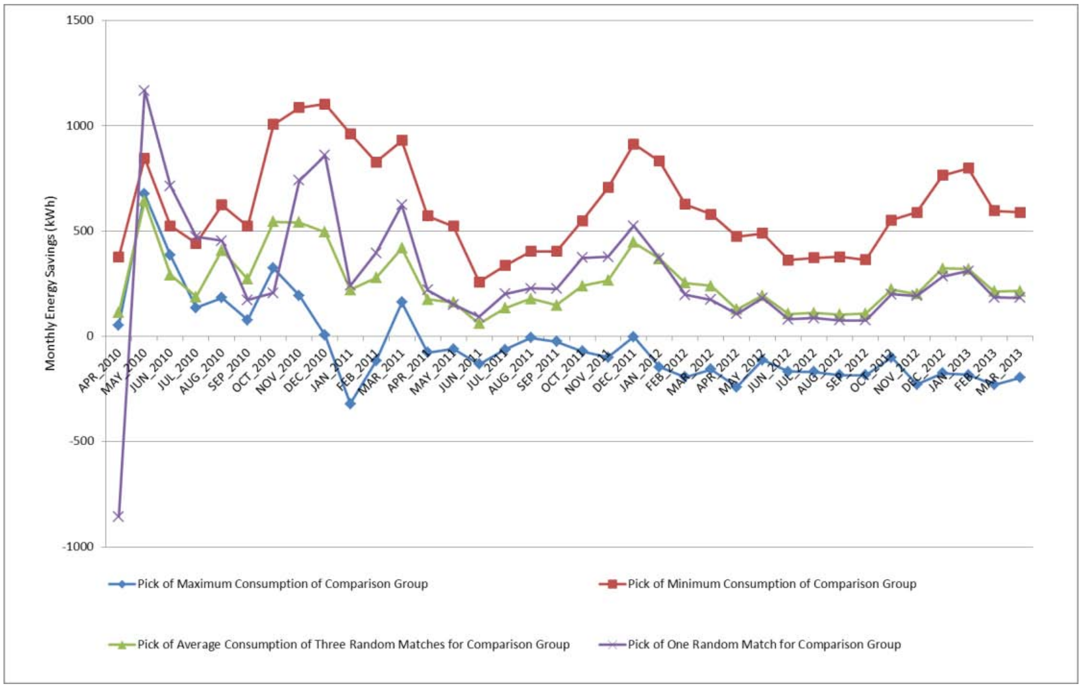

Figure 1. Impact of Comparison Group Construction on Energy Savings Results

3. Energy performance differences due to builder size

Large home builders and small home builders may have different practices in terms of constructing energy-efficient buildings. Therefore, the composition of the participating home and non-participating home groups was checked for differences in builder size and, if there was a difference, how much the difference would affect the net savings estimate.

Table 5 shows the results of the regression analysis, based on the model presented in Equation 3. They indicate that, on average, homes built by large builders consumed 42kWh/month (504kWh/year) less than a home built by a small builder. Program participants' home energy consumption was about 205kWh/month (2460kWh/year) more efficient than non-participants' homes. The coefficient of the third factor in Equation 3, the cross impact of the large builders participating in the program ($Builder_i$*$Participant_i$), was not statistically significant, which means that among the program participants, energy savings of the homes built by the large builders were not different from homes built by small builders.

Table 5. Results of Builder and Program Effect Regression Analysis

Parameter Estimates				
Variable	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	1441.0	9.0	160.76	<.0001
Builder	-41.8	13.55	-3.09	0.0020
Participant	-204.8	13.5	-15.18	<.0001

Conclusions

This paper discusses the quasi experimental design incorporating one-to-many matching and statistical analysis adopted in the evaluation of BC Hydro's residential new home construction program as a viable alternative to conducting a metering study and engineering analysis of energy consumptions of newly constructed homes.

In summary, the major advantages of this evaluation methodology over metering and engineering analysis are: 1) using a quasi-experimental design with a matched comparison group allowed us to account for changing energy consumption profiles in the residential construction market and to make an appropriate estimate of energy savings based on the realistic baseline consumption; 2) it created a dynamic baseline that could vary over time, by location, or could be impacted by varying building characteristics and weather conditions 3) the one-to-many matched comparison group adds statistical power and flexibility by increasing the size and variety of comparison group, rendering more credible evaluation results, and 4) it provided the flexibility to further analyse subgroups of program participants, such as single-unit builders versus multiple home developers.

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Appendix. **Actual and Weather Adjusted Monthly Net Electricity Savings (kWh per Participant)**

Month-Year	Actual Monthly Net Energy Savings (kWh)	Actual HDD & CDD	10 Year AVG HDD&CDD	Factor =10year AVG HDD&CDD / Actual HDD&CDD	Weather Adjusted Monthly Net Energy Savings (kWh)
APR10	0	300	328	0.92	0
MAY10	642	228	194	1.18	546
JUN10	0	124	107	1.17	0
JUL10	188	52	80	0.65	289
AUG10	408	73	74	0.98	418
SEP10	271	150	135	1.11	245
OCT10	544	248	304	0.82	666
NOV10	541	464	441	1.05	514
DEC10	494	471	564	0.84	592
JAN11	221	529	614	0.86	256
FEB11	278	493	523	0.94	295
MAR11	418	428	453	0.95	442
APR11	175	361	328	1.10	159
MAY11	161	238	194	1.23	131
JUN11	60	127	107	1.19	50
JUL11	133	88	80	1.11	120
AUG11	178	56	74	0.76	235
SEP11	147	108	135	0.80	184
OCT11	240	303	304	1.00	240
NOV11	265	450	441	1.02	260
DEC11	445	507	564	0.90	495
JAN12	368	551	614	0.90	410
FEB12	253	451	523	0.86	294
MAR12	240	367	453	0.81	296
APR12	127	300	328	0.91	139
MAY12	193	220	194	1.13	170
JUN12	107	147	107	1.37	78
JUL12	110	54	80	0.67	164
AUG12	104	56	74	0.76	137
SEP12	108	139	135	1.03	105
OCT12	223	330	304	1.09	205
NOV12	201	425	441	0.96	209
DEC12	321	520	564	0.92	348
JAN13	319	550	614	0.90	357
FEB13	213	402	523	0.77	278
MAR13	215	410	453	0.91	238