Coding Conservation: Does a Residential Energy Code Significantly Reduce Electricity and Natural Gas Use?

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ABSTRACT

BC Hydro has provided support for the development and implementation of a residential energy code and related energy efficiency standards, which have reduced energy use and energy efficiency in new residential construction in the jurisdiction. The purpose of this study was to evaluate the impact of the Code on energy use in residential dwellings. Key results were as follows: (1) Energy code features are consistent with those in leading jurisdictions; (2) On-site audits were used to build 16 archetypes, which in turn were used to estimate end use savings by fuel; and (3) Estimated net program electricity savings were 4.0 GWh per year, estimated net peak electricity savings were 0.8 MW, and estimated net natural gas savings were 31.7 TJ per year.

Introduction

BC Hydro has provided support for the development and implementation of residential energy codes and related energy efficiency standards, which have affected energy use and energy efficiency in new residential construction in British Columbia. The purpose of this study was to evaluate the impact of the BC Building Code on energy use in residential dwellings constructed in British Columbia for the year ending March 31, 2011 (F2011). The study used information collected from site audits, developer interviews, and customer surveys to build a comprehensive database for the analysis. Whole dwelling energy modeling was then used to estimate electricity and natural gas end-use consumption.

Literature Review

A number of studies have examined energy use in new residential dwellings with a view to identifying and quantifying the factors driving energy use. These studies include Dimetrosky *et al*. (1999), Hynek *et al*. (2004), Purdy and Beausoleil-Morrison (2001), Tiedemann (1999), Tiedemann and Sulyma (2006) and Tsuji (2004). Much of this analysis is based on either bin-type models such as HOT-2000 or hourly simulation-type models such as DOE 2.1, which are used primarily to model space conditioning loads (heating, cooling) as well as the interaction between space conditioning loads and ancillary heat sources such as lighting and appliances. Simple engineering algorithms, sometimes supported by metered energy use information, are used to model secondary loads including water heating, ventilation, lighting, refrigeration and plug loads. The key factors affecting energy requirements for space conditioning are the size of space conditioning loads and the efficiency with which these loads are met. The literature suggests that the key drivers of space conditioning loads are as follows: (1) thermal bridging through ground contact, the opaque envelope, and the windows; (2) infiltration of outside air; (3) external temperature; (4) solar radiation absorption and reflection; and (5) set-point temperature, set-back temperature and internal gains. This literature also suggests that the key drivers of heating, ventilation and air conditioning (HVAC) efficiency are as follows: (1) furnace and air conditioner steady-state efficiency and part-load curves; (2) air conditioner efficiency and part-load curves; (3) duct work losses and gains; and (4) radiant to convective heat ratio.

Several recent papers have examined the extent of residential energy code compliance and related impacts on energy use. Yang (2005) summarized ten studies for which the share of new homes meeting the state energy code was available, and his study found that the average rate of compliance was 67%. Vine (2006) examined six studies of residential building code compliance and utility new construction programs in California, Oregon and Washington, and found that new homes may fall below full compliance due to noncompliance of prescriptive components. Jacobsen and Kotchen (2009) used a regression discontinuity model to analyze a code change in Florida, and for the city examined found a 4% to 6% decrease in energy consumption due to the code. Costa and Kahn (2010) estimated the impact of housing vintage on energy consumption for Sacramento, using models that focus on temperature responses. Chong (2010) used a large dataset of monthly household-level electricity data to study impact of housing vintage, and he found that newer buildings (1980-2000) have significantly higher responses to temperature changes than older buildings (pre-1979), rather than the anticipated lower response if energy codes are effective. Misuriello *et al*. (2010) used a detailed literature and regulatory review combined with a survey of state energy officials and other stakeholders to examine energy building code compliance and enforcement in the United States.

Several key lessons emerge from these studies. First, some jurisdictions, energy code enforcement activities are lax, depending, for example, on a statement by the contractor that the planned building is compliant. Second, as-built conditions in buildings often differ from the building plans which were the basis of initial approval. Third, substitution of non-compliant building products for complaint building products is common. Finally, training and education efforts to enhance energy code compliance need to be strengthened. These studies cast some doubt on the extent to which residential energy building codes are able, even in principal, to fully meet their objectives and targets.

Method and Approach

For this study, there were two main objectives and three evaluation issues. The first objective was to develop and apply methods for evaluating energy savings associated with residential energy building codes. The second objective was to develop estimates of the energy and peak savings as a result of residential building codes. The three evaluation issues were as follows: (1) describe relevant energy use-related features of the code; (2) estimate unit energy savings by dwelling type and main space heating fuel; and (3) estimate energy and peak savings by dwelling type and main space heating fuel for F2011. A summary of the study issues, data and methods for this study is shown in the following table.

Table 1. Evaluation Issues, Data Sources and Methods

Issue	Data	Method
1. Characterize key residential building code requirements	BC official documents	Documents review
2. Estimate unit energy savings	On-site visits Billing data	HOT-2000 models
3. Estimate energy and peak savings	Above information	Algorithms

The study used information collected from site audits, developer interviews, and customer surveys to build a database for the analysis, and then whole-dwelling energy modeling was used to estimate energy and peak savings. The basic study approach was as follows:

- To describe the energy use-related features of the building code, we reviewed the current and previous codes and key features of the codes were extracted and evaluated. These included minimum insulation levels, installation of an air barrier, installation of a dedicated ventilation system, and the installation of double-glazed thermally broken windows.

- To estimate unit energy savings by fuel (electricity in kWh and natural gas in GJ), we built sixteen prototype dwellings using HOT 2000. The data used for the modeling came from on-site audits in British Columbia sponsored by BC Hydro and by the Canadian Office of Energy Efficiency, based on some 800 audits.

- To estimate gross energy savings by segment, we used this algorithm: gross energy savings equals unit energy savings multiplied by the number of starts (lagged one quarter for that segment) times the compliance rate. Information on housing starts by dwelling type came from CMHC data. To estimate gross peak savings by segment, we used the peak-to-energy ratio obtained from previous work.

Results

Building Code. In the early to mid-1990s, a number of changes were made to the BC Building Code (BCBC) and to the City of Vancouver Building By-law (VBBL). These changes included the following: (1) The minimum insulation table 9.25.2.A was adopted in the BCBC in 1994; (2) The minimum insulation table 9.25.2.A for single-family dwellings was adopted in the VBBL in 1995; (3) The minimum insulation table 9.26.2.A for multifamily dwellings was adopted in the VBBL in 1991; and (4)Additional requirements in new residential housing included installation of an air barrier, installation of a dedicated ventilation system, and installation of, as a minimum, double-glazed windows.

As of September 8, 2008, the BCBC required an improvement in energy and water efficiency in BC, and the code applied to all new construction and renovation. The new requirements were as follows. First, a new Part 10 was added to the BCBC that reflected the two objectives of water and energy efficiency. Second, Part 9 of the code on thermal insulation table was relocated to Part 10, and its scope was expanded to include four-story (in building height) residential buildings. The insulation table was amended by several improvements including eliminating the allowance to use relatively low insulation levels for natural gas-heated buildings in the Lower Mainland; increasing the attic space insulation from RSI 7.7 to RSI 9.0 in the colder areas of the province (4500 and greater degree days); and developing mid-level climate zone regulations with increased attic insulation requirements. Third, achievement of an EnerGuide Rating System (EGH) rating of 77 is an acceptable solution that provides an alternative to compliance with the insulation table for residential buildings. Fourth, non-residential Part 9 buildings must provide thermal insulation in wall, roof and suspended floor assemblies: the amount of insulation is derived from ASHRAE 90.1-2004. Fifth, all other buildings (primarily Part 3) must comply with the ASHRAE 90.1 – 2004 standards. Sixth, the requirements of the existing Water Conservation Plumbing Regulation were relocated to Part 10 of the Building Code and are applicable province-wide. Note that RSI is a standard measure of resistance to heat loss, and it is the inverse of watts loss per metre squared per degree Celsius. The key requirements of the previous and the current codes are shown in Table 7.

These changes are believed to have resulted in reduction in heat losses and gains through opaque walls and roof; reduction in losses and gains through fenestration products; lower outside air infiltration rates, reduced drafts and improved ventilation, with a consequent significant reduction in electricity and natural gas consumption; and improved household occupant comfort and health. The new insulation requirements (RSI values) for small residential buildings are based on heating degree-days, as shown in the following table. The RSI values are the inverse of U values. Discussions with trade allies and on-site visits suggest that the code is rarely exceeded, so that it provides an approximation of actual construction practice.

Table 7. Minimum Insulation Levels for Small Residential Buildings

	BC Building Code					
	Less than 3500 HDD RSI $(W/m^2/°C)^{-1}$		3500 to 4500 HDD RSI $(W/m^2/°C)^{-1}$		Over 4500 HHD RSI $(W/m^2/°C)^{-1}$	
	Previous Energy Code	Current Energy Code	Previous Energy Code	Current Energy Code	Previous Energy Code	Current Energy Code
Attic spaces	7.0	7.0	7.0	7.7	7.7	9.07
Roof joists	4.9	4.9	4.9	4.9	4.9	4.9
Frame wall	2.45	3.5	3.5	3.5	3.85	3.85
Suspended floors: concrete	2.1	2.1	2.1	2.1	2.1	2.1
Suspended floors: framed	4.9	4.9	4.9	4.9	4.9	4.9
Foundation walls	2.1	2.1	2.1	2.1	2.1	2.1
Unheated slabs	2.1	2.1	2.1	2.1	2.1	2.1
Heated slabs	1.8	1.8	1.8	1.8	1.8	1.8
Windows	0.3	0.5	0.3	0.5	0.3	0.5

Note. The standard measure of heat loss is watts per metre squared per degree Celsius, so that the inverse of this measure of heat loss is a measure of resistance to heat loss.

A number of additional regulatory developments have influenced energy use in residential new construction markets. These include the following: (1) introduction of the EnerGuide for New Homes/EcoEnergy program and the associated EnerGuide for New Homes Rating; (2) regulation of furnace, water heater efficiency levels and window products under the BC Energy Efficiency Act and the Government of Canada Energy Efficiency Act; and (3) regulation of linear fluorescent tubes under the Energy Efficiency Act, which led to a reduction in demand from 40 watts to 34 watts for a four-foot T12 fluorescent tube.

Unit Energy Savings. To estimate unit energy savings by fuel (electricity in kWh and natural gas in GJ), sixteen prototype dwellings were built using HOT 2000. The reason for using prototype models is that modeling individual buildings, although preferable form some perspectives, exceeded the budget available for this work. The data used for the modeling came from 800 on-site audits in British Columbia sponsored by BC Hydro and by the Canadian Office of Energy Efficiency. These on-site audits covered homes built under the previous code but within five years of the most recent code change. These homes were viewed as appropriate representing the pre-code change baseline. The on-site audits collected comprehensive information on building size and geometry, building envelope, heating, ventilation, air conditioning, domestic hot water, refrigeration, cooking, other appliances, and fuel types. This information was used to build a set of detailed input files which were merged with weather files. A series of model runs was undertaken, until the models tracked actual consumption of electricity and natural gas appropriately. The archetypes were first modeled as representatives of typical new construction pre-code change. They were then modeled so that they just meet the post-code change requirements. Unit savings were then defined as the difference between pre-code and post-code unit consumption. The prototype results were aggregated across regions using regional shares of housing starts. Table 8 presents estimated unit electricity and natural savings for single family/duplex dwellings, while Table 9 presents unit electricity and natural gas savings for row houses/apartments.

Table 8. Unit Savings for Single Family/Duplex

	Electric space heated	Gas space heated	Gas space heated
	Electricity use (kWh/year)	Electricity use (kWh/year)	Gas use (GJ/year)
Lower Mainland			
Pre-code	23,991	10,759	98.2
Post-code	23,296	10,703	93.2
Change	-695	-56	-5.0
Vancouver Island			
Pre-code	23,241	11,009	90.2
Post-code	22,518	10,981	87.6
Change	-723	-28	-2.6
Southern Interior			
Pre-code	27,466	10,981	112.0
Post-code	26,382	10,925	107.8
Change	-1,084	-56	-4.2
Northern Region			
Pre-code	38,114	11,037	153.3
Post-code	36,418	10,981	146.6
Change	-1,696	-56	-6.8

Table 9. Unit Savings for Row House/Apartment

	Electric space heated	Gas space heated	Gas space heated
	Electricity use (kWh/year)	Gas use (kWh/year)	Gas use (GJ/year)
Lower Mainland			
Pre-code	13,316	7,673	52.6
Post-code	12,899	7,617	49.9
Change	-417	-56	-2.6
Vancouver Island			
Pre-code	12,899	7,562	51.6
Post-code	12,705	7,506	49.9
Change	-616	-56	-1.7
Southern Interior			
Pre-code	15,207	7,284	60.3
Post-code	14,539	7,284	57.6
Change	-668	0	-2.7
Northern Region			
Pre-code	19,905	7,284	80.0
Post-code	18,848	7,228	75.6
Change	-1,057	-56	-4.4

Energy and Peak Savings. A preliminary step in estimating energy and peak savings was to estimate a compliance rate which was used to deflate the modeled unit savings. During the in-site investigations, compliance data was collected for a number of measures for 187 of the 800 audited dwellings. The data appeared to be the most reliable for ceiling-attic insulation, so this was used as a proxy for overall compliance. Table 10 presents the results of this analysis and shows that the share of code compliant houses for the baseline study was 0.63. It is assumed that this share is appropriate for the 2008 residential building code changes.

Table 10. Compliance Rate

	Sample size	Number compliant	Share compliant
Lower Mainland	69	63	0.91
Southern Interior	41	14	0.34
Vancouver Island	49	28	0.57
North	28	13	0.46
Total	187	118	0.63

To estimate gross energy savings by segment, unit energy savings were multiplied by the number of starts lagged one quarter for that segment times the assumed compliance rate. Information on housing starts by dwelling type came from CMHC data. To estimate gross peak savings by segment, the peak-to-energy ratio obtained from previous work was applied. Table 11 presents estimated electricity savings by dwelling type. Estimated gross program electricity savings were 6.3 GWh per year, while estimated gross peak savings were 1.3 MW for F2011. Estimated net program electricity savings were 4.0 GWh per year while estimated net peak savings were 0.8 MW for F2010. Table 12 presents estimated gross natural gas savings by dwelling type. Estimated program gross natural gas savings were 50.4 TJ per year for F2011. Estimated net program natural gas savings were 31.7 TJ per year. These are substantial reductions in energy use.

Table 11. Electricity Savings F2011

	Single/duplex	Row/apartment	Total
Electric heat			
Units	2,980	8,680	3,148
Savings per unit (kWh/year)	820	380	
Projected electricity (GWh/year)	2.44	3.30	5.74
Projected peak (MW)	0.49	0.66	1.15
Natural gas heat			
Units	8,462	4,883	3,092
Savings per unit (kWh/year)	45	40	
Projected electricity (GWh/year)	0.38	0.20	0.58
Projected peak (MW)	0.08	0.04	0.12
Electric and natural gas heat			
Projected electricity (GWh/year)	2.82	3.50	6.32
Projected peak (MW)	0.57	0.70	1.27

Assumed compliance	0.63	0.63	0.63
Gross energy savings (GWh/year)			3.98
Net energy peak (MW)			0.80

Table 12. Natural Gas Savings F2011

	Single/duplex	**Row/apartment**	**Total**
Gross savings			
Units	8,482	4,883	-
Savings per unit (GJ/year)	4.5	2.5	-
Projected savings (TJ/year)	38.169	12.208	50.377
Assumed compliance	0.63	0.63	0.63
Net savings (TJ)			31.737

Study Limitations and Future Work

Although it points to a significant reduction in energy use as a result of implementation of the new code, the study has three limitations, as follows. First, we used a modeling approach which assumes that without the code change, there would be no improvements in residential shell measures. To the extent that there would have been improvements in shell measures due to changes in the market, this might mean that savings have been overestimated. Second, due to the post-2008 recession, there was a significant slowdown in residential construction activity in 2009 and 2010 in British Columbia. But in 2011, there was an increase in residential construction activity, so that the evaluation for F2012 will probably show a more dramatic reduction in residential energy use in the next evaluation. These limitations suggest that it might be useful in a future evaluation to collect detailed information on dwellings built under the new Building Code, and then compare energy use between vintages of houses, perhaps using regression modeling.

Summary and Conclusions

BC Hydro has provided support for the development and implementation of residential energy codes and related energy efficiency standards, which have affected energy use and energy efficiency in new residential construction in British Columbia. The purpose of this study was to evaluation the impact of the BC Building Code's energy codes provisions on energy and peak consumption for F2011. The main conclusions were as follows.

Energy Code. In the early to mid-1990s, a number of changes were made to the BC Building Code (BCBC) and to the City of Vancouver Building By-law (VBBL). As of September 8, 2008, the BCBC required an improvement in energy and water efficiency in BC, and the code applied to all new construction and renovation.

Unit Energy Savings. To estimate unit energy savings by fuel (electricity in kWh and natural gas in GJ), sixteen prototype dwellings were built using HOT 2000 based on 800 on-site audits. This information was used to build a set of detailed models: a series of model runs was undertaken, until the models tracked actual consumption of electricity and natural gas appropriately. The archetypes were first modeled as representative of typical new construction pre-code change, and then they were modeled to just bring them up to the post-code change requirements. Unit savings were then defined as the difference between pre-code and post-code unit consumption.

Energy and Peak Savings. To estimate gross energy savings by segment, unit energy savings were multiplied by the number of starts lagged one quarter for that segment times the compliance rate. To estimate gross peak savings by segment, the peak-to-energy ratio obtained from previous work was applied. To estimate net savings, the average compliance rate from the baseline study was applied. Estimated gross program electricity savings were 4.0 GWh per year while estimated gross peak savings were 0.8 MW for F2011. Estimated program gross natural gas savings were 31.7 TJ per year for F2011. These are substantial reductions in energy use.

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