Measuring the Impact of a Residential Energy Code

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Abstract

Rigorously enforced stringent building codes can cost effectively achieve energy savings, reduce energy bills and curb greenhouse gas emissions. This paper combines on-site data from some 800 dwellings, energy use information, survey data and computer simulations to evaluate the impact of the most recent energy efficiency provisions of the British Columbia Building Code on residential energy use in British Columbia. Key findings are as follows. First, the estimated compliance rate of 0.63 is in the mid-range of estimates for similar codes. Second, for natural gas heated single family dwellings and duplexes, the estimated gross unit savings were 4.5 GJ per year, while for natural gas heated row houses and apartments, the estimated gross unit savings were 2.5 GJ per year. Third, for natural gas heated single family dwellings and duplexes, total net savings were 24.0 TJ per year, while for natural gas heated row houses and apartments, total net savings were 7.6 TJ per year. Fourth, for electrically heated single family dwellings and duplexes, the estimated gross unit savings were 820 kWh per year, while for electrically heated row houses and apartments, the estimated gross unit savings were 380 kWh per year. Fifth, for electrically heated single family dwellings and duplexes, total net savings were 1.5 GWh per year, while for electrically heated row houses and apartments, total net savings were 2.1 GWh per year.

Introduction

Rigorously enforced building codes with stringent energy use provisions are sometimes seen as a relatively cost-effective means of achieving energy savings, reducing energy bills and curb greenhouse gas emissions (Mahone et al. 2005). Building codes may have several advantages over the policy alternatives of voluntary standards, labeling and utility financial incentive programs in ensuring that buildings are energy efficient. First, it may be more cost effective to install shell measures with higher insulation levels or HVAC equipment with higher efficiency levels at the time of construction rather than to subsequently retrofit these buildings with the most energy efficient measures (Jaffe and Stavins 1994, 1995). Second, some consumers may have inaccurate perceptions of present costs and future benefits of current investment decisions, which may lead them to reject cost effective current investments which they would accept if they accurately understood the investment issue (Deutsch 2007, Train 1995). Third, there may be split incentives, for example, when an apartment building owner pays the up-front costs of a more energy efficient building but the gains in terms of reduced energy costs are received by those renting her apartments (Gillingham et al. 2009).

Several studies have used rigorous engineering and economic methods to examine energy use in residential dwellings. This analysis often uses bin-type simulation models such as HOT 2000 or hourly simulation models such as DOE 2.1, which are used to model space conditioning loads as well as the interaction between space conditioning and secondary loads such as lighting or refrigeration. Secondary loads such as fans and pumps, lighting, appliances and electronics are typically modeled using engineering algorithms. Dimetrosky et al. 1999, Hynek et al. 2004, and Purdy and Beausoleil-Morrison 2001noted that key drivers of space conditioning energy use were the size of these space conditioning loads and the efficiency with which these loads were met. The size of these loads depends upon: (1) thermal bridging through the ground, the opaque envelope and windows; (2) infiltration of outside air; (3) external temperature; (4) solar radiation and absorption; and (5) set-point temperature, set-back temperature and internal gains due to occupants and equipment. The efficacy with which these loads were met depend upon: (1) furnace and heat pump steady-state efficacy and part-load curves; (2) air conditioning steady-state efficiency and part load curves; (3) duct work losses and gains; and (4) radiant to conductive heat ratio. Tiedemann and Sulyma 2006 combined discrete choice analysis with DOE 2.1 models to quantify the drivers of space conditioning, HVAC auxiliary and lighting loads at the measure level. Tsuji et al. 2004 confirmed the usefulness of bottom-up simulation models in tracking end use energy profiles.

Several others studies have examined residential energy code compliance and the impact on energy use. Chong 2010 found that newer California dwellings have an (unexpected) higher response to temperature than did older buildings, suggesting the code was not effective, Conversely, Costa and Kahn 2010 found a modest impact of housing vintage on energy use for Sacramento, California. Jacobsen and Kotchen 2009 found that for one jurisdiction in Florida, energy consumption fell by 4% to 6% due to the code. In a comprehensive study combining literature and regulatory review with detailed interviews of officials across the United States, Misuriello et al. 2010 found that enforcement efforts were sometimes lax, castings some doubt on whether residential energy codes significantly reduce energy consumption. Vine 2006 examined six studies of compliance with residential building code and of utility new consecution program compliance in California, Oregon and Washington states, and he found that non-compliance of prescriptive components can lead to overall non-compliance. Using ten studies where compliance with state energy codes were measured, Yang 2005 found that the average compliance level was about 67 percent. That is, on average 67% of dwellings were in compliance with the minimum requirements of the code. It's worth noting that compliance studies typically look at only a subset of code requirements, and a dwelling is viewed as either in (full) compliance or not.

The purpose of this paper is to report on an evaluation of the impact of the updated energy efficiency provisions of the British Columbia (BC) Building Code on energy consumption in new residential dwellings for fiscal year 2011. An outline of the paper is as follows. The next section briefly describes energy related aspects of the BC Building Code. The following section summarizes the research questions, data sources and method for the study. The section after that provides the detailed study results organized by research question. The last section provides a summary and conclusions.

Building Code Description

British Columbia's Building Code is an instrument of the Provincial Government, but enforcement is primarily the responsibility of various municipalities. In 1994, a number of changes were made to British Columbia's Building Code to encourage energy efficiency in residential dwellings. These included adoption of a minimum insulation table, installation of an air barrier, installation of a dedicated ventilation system, and installation of double glazed windows or better. The key requirements are shown in terms of resistance to heat loss (watts/square metre/degree Celsius)$^{-1}$ or RSI values by heating zone, where the heating zones are defined in terms of heating degree days using a base of 18 degrees Celsius. Zone 1 is less than 3500 degree days, Zone 2 is 3500 to 4500 degree days and Zone 3 is over 3500 degree days. Note that the RSI values are the inverse of the corresponding heat loss or U values.

In the mid-1990s the BC Ministry of Energy proposed to upgrade the energy efficiency of the BC Building Code. Various options were prepared and subject to a stakeholder engagement process including consultant studies of the technical and financial feasibility of various options. New regulations came into place on September 8, 2008. Table 1 compares the 1994 insulation requirements to those of the 2008 revisions which is the subject of the present study. The changes included the following. First, attic space RSI was increased from 7.0 to 7.7 in Zone 2, and from 7.7 to 9.07 in Zone 3. Second, frame wall RSI was increased from 2.45 to 3.5 in Zone 1. Third, window RSI values increased from 0.3 to 0.5 in all three Zones. It is worth noting that dwellings achieving the federal government's EnerGuide Rating System score of 77 are viewed as being in compliance with the insulation requirements of the revised BC Building Code.

Table 1. Insulation Requirements RSI (watts/square metre/degree Celsius)$^{-1}$

Component	**Less than 3500 HDD Zone 1**		**3500 to 4500 HDD Zone 2**		**Over 3500 HDD Zone 3**	
	Previous	Current	Previous	Current	Previous	Current
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
Concrete fl	2.1	2.1	2.1	2.1	2.1	2.1
Framed floor	4.9	4.9	4.9	4.9	4.9	4.9
Found wall	2.1	2.1	2.1	2.1	2.1	2.1
Unheated slab	2.1	2.1	2.1	2.1	2.1	2.1
Heated slab	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**

Based on interviews and documents review, it was determined that the revised BC Building code initiative has three main activities: building code development, building code training and building code compliance.

Building code development was supported through the development of technical and financial assessment of, and stakeholder consultation on alternatives. The result of this was that the BC Building Code and enabling regulations were revised and enacted. This is the responsibility of the BC Ministry of Energy.

Building code training was supported through technical workshops and on-line training. The result of this was increased stakeholder knowledge of and interest in the BC Building Code. This has been supported by the BC Ministry of Energy and by BC Hydro.

Building code compliance was supported through inspection of plans during the permitting process and targeted on-site inspections during construction. The result of this was increased compliance with building code requirements. This is primarily the responsibility of various municipalities.

Table 2 provides a program logic model for the energy efficiency components of the BC Building Code based on stakeholder interviews and a documents review. For each of the three program components, the program logic model provides the logic chain of inputs, outputs, purpose and goal for each program component, as well as critical assumptions. Since there are strong and credible linkages between the inputs, outputs, purpose and goal for each of the three components, it is reasonable to conclude that the program logic is sound.

Table 2. Program Logic Model

	Building Code Development	**Building Code Training**	**Building Code Compliance**	**Critical assumptions**
Inputs	Development, technical and financial assessment and stakeholder consultation on alternatives	Technical workshops and on-line training materials	Inspection of plans during permitting process and targeted on-site inspections	Stakeholders have technical and financial capability to implement changes
Outputs	BC Building Code revised and enabling regulations in place	Stakeholder knowledge of and interest in building code increased	Compliance with building code requirements increased	Changes represent material improvements over previous code
Purpose	Ensure that new residential construction meets energy efficiency requirements essentially equivalent to EnerGuide rating of 77 for low rise buildings and ASHRAE 90.1for high rise buildings			Rebound effect is not significant
Goal	Reduce energy use in new residential construction			

Data and Method

For this study there were five main research questions. First, what is the compliance rate with Building Code change insulation requirements? Second, what are the gross unit natural gas savings? Third, what are the net (additional) total natural gas savings? Fourth, what are the unit gross electricity savings? Fifth, what are the net total electricity savings? Evaluation questions, data sources and methods are summarized in Table 3.

The study approach was as follows. First, interviews were conducted with key stakeholders including architects, building developers, and building permit and enforcement authorities to understand the nature of the new housing market in British Columbia, the role played by energy efficiency considerations in housing design and construction, and the factors affecting code compliance.

Second, results of a large set of housing audits were obtained from BC Hydro and from the Canadian Office of Energy Efficiency of Natural Resources Canada. Interest centered on 800 audits completed for a national comprehensive retrofit program, including about 375 electricity heated houses and about 425 natural gas heated houses from British Columbia. A subset of 187 of the 800 dwellings were built during the five years before the implementation of the revised Code, and consequently viewed as a suitable pre Code baseline. For the sample of 187 pre Code dwellings it was possible to calculate a compliance rate with the key insulation requirements of the Code. The audit files included information on building location; building size and geometry;

building envelope including wall and ceiling construction, insulation and windows and doors; heating, ventilation and air conditioning; domestic hot water; appliances including refrigeration, cooking and other appliances; and fuel types and consumption. This information was used to build a set of detailed input files which were merged with appropriate weather files.

Third, computer models of sixteen prototype dwellings were built using HOT 2000 and the prototypes were remodeled until they accurately reflected typical energy consumption. The prototypes included two dwelling types (single family and duplex versus row house) and four regions (Lower Mainland, Vancouver Island, Southern Interior, Northern Region). The sixteen prototypes were then remodeled so that they just met the Code change insulation requirements. Unit savings were the defined as the difference between baseline energy consumption and post Code change energy consumption. Please note that compliance is viewed as a binary variable (i.e., compliant or not compliant) and does not consider degree of compliance due to data limitations. For the set of four savings estimates (two dwelling types times the two space heating fuels), the unit savings estimates were aggregated using the regional shares of housing starts for each of the four regions.

Fourth, engineering algorithms were used to estimate energy savings by segment for fiscal year 2012 using Central Mortgage and Housing Corporation (CMHC) data on housing starts, lagged one quarter to allow for the period of construction. For natural gas heated houses, the algorithm was:

(1) $\Delta TJ = \Delta \text{unit TJ Consumption} * \text{Compliance Rate} \cdot \text{Number of Segment Housing Starts}$

For electrically heated houses, the algorithm was

(2) $\Delta GWh = \Delta \text{unit GWh Consumption} * \text{Compliance Rate} \cdot \text{Number of Segment Housing Starts}$

Table 3. Research Questions, Data Sources and Methods

Research Question	**Data Sources**	**Methods**
What is the compliance rate with the revised code requirements?	Site audits (n = 187)	Cross tabulation
What are the gross unit gas savings?	Site audits (n = 425)	Hot 2000 models
What are the net total gas savings?	Site audits (n = 425) CMHC housing starts data	Engineering algorithms
What are the gross unit electricity savings?	Site audits (n = 375)	Hot 2000 models
What are the net total electricity savings?	Site audits (n = 375) CMHC housing starts data	Engineering algorithms

Table 4 shows baseline energy use in natural gas heated homes. For single family dwellings and duplexes, electricity use varies from 10,759 kWh per year in the Lower Mainland to 11,037 kWh per year in the Northern Region, while natural gas use varies from 90.2 GJ per year on Vancouver Island to 153.3 GJ per year in the Northern Region. For row houses and apartments, electricity use varies from 7,284 kWh per year for both the Southern Interior and the

Northern Region to 7,653 kWh per year in the Lower Mainland, while natural gas uses varies from 51.6 GJ per year on Vancouver Island to 80.0 GJ per year in the Northern Region.

Table 4. Baseline Energy Use in Gas Heated Homes

Region	**Single family and duplex**		**Row house and apartment**	
	Electricity use (kWh/year)	Gas use (GJ/year)	Electricity use (kWh/year)	Gas use (GJ/year)
Lower Mainland	10,759	98.2	7,673	52.6
Vancouver Island	11,009	90.2	7,562	51.6
Southern Interior	10,981	112.0	7,284	60.3
Northern Region	11,037	153.3	7,284	80.0

Table 5 shows baseline energy use in electrically heated homes. For single family dwellings and duplexes, electricity use varies from 23,241 kWh per year on Vancouver Island to 38,114 kWh per year in the Northern Region. For row houses and apartments, electricity use varies 12,899 kWh per year on Vancouver Island to 19,905 kWh per year in the Northern Region.

Table 5. Baseline Energy Use in Electrically Heated Homes

Region	**Single family and duplex**	**Row house and apartment**
	Electricity use (kWh/year)	Electricity use (kWh/year)
Lower Mainland	23,991	13,316
Vancouver Island	23,241	12,899
Southern Interior	27,466	15,207
Northern Region	38,114	19,905

Results

Table 6 presents the estimated compliance rate with the insulation requirements of the BC Building Code. The estimated compliance rate of 0.63 is in the mid-range of estimates from studies of other jurisdictions.

Table 6. Compliance Rate

Sample size	**Number compliant**	**Number non-compliant**	**Share compliant**	**Share non-compliant**
187	118	69	0.63	0.37

Table 7 provides the estimated gross unit savings for natural gas heated dwellings based on the differences in consumption between the baseline runs and the just in compliance runs for the HOT 2000 models. For single family dwellings and duplexes, the estimated gross unit savings are 4.5 GJ per year. For row houses and apartments, the estimated gross unit savings are 2.5 GJ per year.

Table 7. Gross Unit Savings for Gas Heated Houses (GJ/year)

Single family and duplex	Row house and apartment
4.5	2.5

Table 8 provides the net total savings for natural gas heated dwellings based on the engineering algorithm. For single family dwellings and duplexes, total savings are 24.0 TJ per year. For row houses and apartments, total savings are 7.6 TJ per year.

Table 8. Net Total Gas Savings

	Gross unit savings (GJ/year)	Units	Net to gross ratio	Total savings (TJ/year)
Single/duplex	4.5	8,482	0.63	24.0
Row/apartment	2.5	4,833	0.63	7.6
Total				31.6

Table 9 provides the estimated gross unit savings for electrically heated dwellings based on the differences in consumption between the baseline runs and the just in compliance runs for the HOT 2000 models. For single family dwellings and duplexes, the estimated gross unit savings are 820 KWh per year. For row houses and apartments, the estimated gross unit savings are 380 kWh per year.

Table 9. Gross Unit Savings for Electrically Heated Houses (kWh/year)

Single family and duplex	Row house and apartment
820	380

Table 10 provides the net total savings for electrically heated dwellings based on the engineering algorithm. For single family dwellings and duplexes, total savings are 1.5 GWh per year. For row houses and apartments, total savings are 2.1 GWh per year.

Table 10. Net Total Electricity Savings

	Gross unit savings (kWh/year)	Units	Net to gross ratio	Total savings (GWh/year)
Single/duplex	820	2,980	0.63	1.5
Row/apartment	380	8,680	0.63	2.1
Total				4.4

Summary and Conclusion

This paper reviews the results of an evaluation of the residential energy efficiency provisions of the British Columbia Building Code for fiscal year 2011. This initiative included building code development, building code training and building code compliance enforcement to improve energy efficiency in new residential dwellings.

The study approach was as follows. First, interviews were conducted with key stakeholders to understand the nature of the new housing market in British Columbia, the role played by energy efficiency considerations in housing design and construction, and the factors affecting code compliance. Second, the results of a set of 800 housing audits was used to calculate a compliance rate with the key insulation requirements of the code and was used to build a set of detailed input files which was merged with appropriate weather files. Third, computer models of sixteen prototype dwellings were built using HOT 2000. The prototypes were remodeled until they accurately reflected typical energy consumption, and then remodeled so that they just met the Code change insulation requirements. Unit savings were the defined as the difference between baseline energy consumption and post code change energy consumption. Fourth, engineering algorithms were used to estimate energy savings by building segment by space heating fuel segment for fiscal year 2011.

This paper has five main findings as follows. First, the estimated compliance rate of 0.63 is in the mid-range of estimates for similar codes. Second, for natural gas heated single family dwellings and duplexes, the estimated gross unit savings were 4.5 GJ per year, while for natural gas heated row houses and apartments, the estimated gross unit savings were 2.5 GJ per year. Third, for natural gas heated single family dwellings and duplexes, total net savings were 24.0 TJ per year, while for natural gas heated row houses and apartments, total net savings were 7.6 TJ per year. Fourth, for electrically heated single family dwellings and duplexes, the estimated gross unit savings were 820 kWh per year, while for electrically heated row houses and apartments, the estimated gross unit savings were 380 kWh per year. Fifth, for electrically heated single family dwellings and duplexes, total net savings were 1.5 GWh per year, while for electrically heated row houses and apartments, total net savings were 2.1 GWh per year.

This study has several limitations. First, gross energy savings are based on modeled energy use information rather than energy use for treatment and control groups. Since the code applies to new construction, there is no comparison group. Second, the compliance rate is based on a convenience sample rather than a random sample of new dwellings. Third, due to data limitations, no estimate of take or rebound was available. Fourth, the scope of this work did not include an estimate of natural occurring market adoption (NOMA). However, interviews with developers and municipal code officials suggested that in the absence of code changes improvements in energy efficiency are probably not significant, in part related to mild climate conditions in heavily populated areas of the province.

In conclusion, two conditions must be met if residential building codes are to have a significant impact on residential energy consumption. First, the requirements of the building code must be materially more stringent than existing building practice. Building codes which essentially reflect current building practice may weed out a limited number of poorly designed or constructed buildings and level the playing field for all market actors, but they are not likely to save very much energy. Second, achieving high levels of compliance with the code is essential. Compliance can be potentially increased by a combination of building code training and education for market actors and code enforcement activities targeted at areas of suspected non-compliance.

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