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Abstract

We assess realized energy and air leakage changes in homes constructed before and after new building energy code adoptions in three Canadian provinces: Ontario, New Brunswick, and Alberta. We find no energy or air leakage reductions attributable to more stringent code requirements. There is no evidence that natural gas consumption declined among houses built up to five years before or four years after a code change. Instead, a generalized improvement in residential electricity consumption and air leakage rates is observable at least three to five years before any new code adoptions, depending on the province. These pre-existing trends in electricity consumption and air leakage may point to changes in building industry practice preceding new building code adoptions, though further investigation is required to assess the drivers of these changes. The estimated energy savings are also not in line with ex-ante engineering projections, which predicted natural gas savings of about 10% and little to no electricity savings.

Keywords: Building Codes, Residential Energy Consumption, Building Simulation, Energy Efficiency Policy, Climate Change, Net Zero

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1 Introduction

Buildings are long-lived, with an average lifespan of over 50 years, and they account for about one third of global annual energy consumption and 26% of global annual greenhouse gas (GHG) emissions (Aksozen et al., 2016; Miatto et al., 2017; IEA, 2023). In most countries, including Canada, between half to two thirds of the energy and GHG emissions in buildings arise from space heating, with much of the current stock of heating equipment using fossil fuels (Natural Resources Canada, 2023; IEA, 2023). As a result, attaining net zero GHG targets by mid-century will necessitate a large-scale transformation of the buildings sector within the next 25 years (IEA, 2022).

Over the past 40 years, the development of increasingly stringent model energy codes has been a key pillar of the federal government's goal to achieve a more energy-efficient housing stock (Haysom and Lacroix, 1999). While early model code efforts focused on standards applying to new housing construction and attaining reduced consumption levels, new model code processes have evolved to include achieving net zero housing and new regulations applied to building alterations (National Research Council Canada, 2020, 2018; Lockhart, 2022).[1] Energy standards that shift building construction practices towards continuously improved energy performance are a potentially cost-effective and impactful approach to reducing GHG emissions in housing (Abdeen et al., 2021).

An important consideration in the current approach to energy standards is how effective they are in practice. The development of energy performance requirements is currently based primarily on simulation models, and recent work in the context of energy efficiency retrofit rebates and energy performance certificates has identified limitations from using purely model-based predictions of energy savings (Christensen et al., 2021; Andelkovic et al., 2021; Fowlie et al., 2018). These limitations fall into two broad categories. First, behavioral responses to new energy code adoptions are not reflected in purely ex-ante modeling approaches. For example, new energy codes may not be binding, either due to lack of adequate code enforcement or requirements that are less stringent than contemporary building industry practice (Enker and Morrison, 2017; Dolfsma and Seo, 2013; Berry et al., 2013; Pride, 2020). Second, both energy consumption and energy saving predictions in building simulation models have been documented to be systematically biased upwards when compared to realized consumption (Myers and Papineau, 2023; Christensen et al., 2021; Davis et al., 2020; Papineau et al., 2023; NYSERDA, 2015).[2] While some energy efficiency agencies have responded to these documented biases by calibrating simulation models using customer utility consumption data (NYSERDA, 2015), modeling undertaken during the code development process in Canada and the U.S. does not yet follow this practice.

A few studies have evaluated the realized energy savings from energy codes, mostly from the U.S. The evidence presented in these studies is mixed. Some authors point towards a decrease in gas and/or electricity consumption due to an energy code change (Jacobsen and Kotchen, 2013; Levinson, 2016; Papineau, 2017; Novan et al., 2022). On the other hand, Kotchen (2017) re-estimates the results obtained in Jacobsen and Kotchen (2013) using more billing data and

[1] Although incorporating energy-efficient technologies into new houses at the time of construction may enable economies of scale and lead to lower costs than retrofitting existing residential buildings (Davis et al., 2020), standards that apply to existing buildings recognize that much of the building stock standing today will still be in operation in 2050.

[2] Though more research is needed to identify the source of these biases, existing studies point to models not accurately accounting for heterogeneity in the quality of retrofit workmanship, incorrect modeling assumptions, and, to a lesser extent, the impact of energy consumer behavior as drivers of modeling bias (Christensen et al., 2021; Davis et al., 2020).

find gas savings only, whereas Bruegge et al. (2019) report no statistically significant changes in gas use and modest electricity savings that are mostly driven by reductions in house size among houses built after the adoption of an energy code. These studies have also examined if realized energy savings from energy code adoptions differ from engineering predictions. While Jacobsen and Kotchen (2013), Kotchen (2017) and Novan et al. (2022) conclude that realized savings are in line with the ex-ante modeled projections, Levinson (2016), Papineau (2017), and Bruegge et al. (2019) find that simulation models tend to over-predict energy savings, in some cases by a large margin.

The literature on estimating realized savings from energy codes using realized consumption skews heavily towards the U.S., particularly California and Florida, states with warm climates and low demand for space heating. This has resulted in a lack of representation from populations living in heterogeneous climates or in jurisdictions with different institutional structures. For example, Canadian demands for heating and cooling differ significantly from those in most of the U.S. In 2019, the share of residential energy demand arising from space heating was 50% higher in Canada, with space heating being the largest contributor to residential GHG emissions, and the share of residential energy use from space cooling was only one-sixth the U.S. level (Natural Resources Canada, 2019; U.S. Energy Information Administration, 2019).

This paper uses several unique datasets of realized energy consumption and building envelope air leakage rates (measured by blower door tests) in houses from three provinces in Canada with distinct climate characteristics: Alberta, New Brunswick, and Ontario. We assess if houses built after more stringent building energy codes came into effect are associated with reduced energy use and air leakage relative to houses built a few years before the changes. The building code changes we evaluate are housing insulation standards adopted as part of the 1990 Ontario Building Code, and the 2011 National Energy Code for Buildings adopted by New Brunswick in 2014 and Alberta in 2015.[3]

Our findings indicate that while houses built just after building energy code changes consume less electricity, in levels and per square foot, than houses built pre-code, we cannot attribute these changes to code adoptions. In Ontario and Alberta, we observe a statistically significant downward trend in electricity consumption in progressively newer homes that began several years before a new code came into effect. In New Brunswick, there is a small decline in electricity consumption per square foot in houses built after a code change, but the difference compared to houses built before the code came into effect is not statistically significant. Gas usage, which is observed in Ontario and Alberta, does not significantly change in houses built after a code adoption relative to houses built pre-code. Event studies produce results that are in line with the energy consumption analysis. We also compare our estimates to engineering (or ex-ante) modeled predictions and find that they differ substantially from predictions in all three settings.

To further investigate the potential drivers behind these results, we complement our energy consumption analyses with data on air leakage rates obtained from Canada's largest house-level database on energy-related characteristics. We use an event study framework to assess whether air leakage differs in houses constructed a few years before versus a few years after a new code change. Our results are consistent with the energy savings findings. In Ontario, air leakage rates decline in progressively newer homes over time and these declines begin several years before a new code was adopted. In New Brunswick, we do not observe statistically significant declines in air leakage rates in houses built pre- versus post-code adoption.

[3]The 1990 Ontario insulation standards are based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90-1975, "Energy Conservation in New Building Design".

While the results of our study point to disappointing outcomes from more stringent energy code adoptions in helping meet climate targets in Canada, with potential implications for other regions with cold climates, they are consistent with several concerns that have been raised about the effectiveness of energy code adoptions in the field (Haley and Torrie, 2021). This includes limited resources for ensuring code compliance, variations in training and qualification requirements across provincial and municipal jurisdictions in Canada, 'atomised' building trades that prevent optimizing whole-home savings during construction, the possibility that building industry practices may change exogenously or endogenously before building codes are adopted, and behavioral responses from industry to new code requirements (Pride, 2020; Maisonneuve, 2021; Bruegge et al., 2019). Identifying the factors driving these shortfalls between predicted and realized energy savings should be a priority for future research.

The rest of the paper is organized as follows. We discuss our data sources in Section 2 and report engineering predictions of energy savings and air leakage for the code adoptions we observe in Section 3. Section 4 presents our empirical framework, realized energy savings estimates, and event studies. Section 5 concludes.

2 Data

To study the effect of building energy code changes on residential electricity consumption, natural gas consumption, and building envelope air leakage rates in Canada, our analysis makes use of three distinct data sources. Our first data source is utility consumption data for several cities located in three Canadian provinces: Medicine Hat, Alberta; Milton, Ontario; Newmarket, Ontario; and cities across New Brunswick. All of the consumption datasets include electricity consumption, and the Ontario and Alberta data also include natural gas consumption. Data on house-level characteristics such as year of construction and house size are also included in each consumption file, though each sample has variations in observed variables.

In Medicine Hat, monthly consumption data are from the city-owned utility. The data include house-level monthly electricity and gas consumption for all single-family homes in the municipality from January 2007 to November 2019. In Ontario, we obtained data on daily electricity and annual gas consumption for single-family homes in Newmarket and Milton between January and December of 2006 to 2008 and 2012 to 2013, respectively. In New Brunswick, we utilize monthly electricity usage for 12 billing periods (approximately one year for most houses) that span from April 2017 to March 2018.

For the City of Medicine Hat, data on house characteristics are obtained from municipal property assessments provided by the city-owned electric and natural gas utility. For Ontario, we combine the data from the Simul Corporation survey completed on April 25, 2006, for houses in Milton with Municipal Property Assessment Corporation data for houses in Newmarket. Finally, for New Brunswick, we use survey data from the 2017 Administration of the Energy Planning Survey conducted by New Brunswick Power, the primary electric utility in the province. The survey collected responses from houses on dwelling and occupant characteristics, household appliances, fuel usage, and behaviours related to energy consumption.

In comparison to the Ontario and Alberta consumption samples, where we observe the precise year of construction for each house, year of construction in the New Brunswick data is recorded in the form of year ranges rather than the exact year of construction. Year of construction in New Brunswick is recorded in the following ranges: prior to 1961, 1961-1974, 1975-1989, 1990-1999, 2000-2009, 2010-2014, and 2015-2018. This prevents us from creating a comprehensive dataset for all the cities and provinces that we study. We utilize two datasets in our analysis: one sample includes the New Brunswick data with 5,064 monthly electricity observations for 422 houses constructed in 2010-2014 or 2015-2018, and the second sample combines Medicine Hat, Milton, and Newmarket, which we refer to as the "combined sample", containing 107,027 monthly electricity observations and 9,266 annual gas observations for about 2,000 houses constructed within 5 years before the new code adoption and 4 years after. Further details about data cleaning to obtain our analysis sample are included in Appendix A. Tables 1 and 2 present the summary statistics for the combined sample and the New Brunswick sample, respectively.

Table 1: Summary Statistics (Combined Sample)

	Mean	Std. Dev.	Min	Max
Monthly electricity (kWh)	732.06	434.93	1	12800
House size (ft^2)	195.94	360.98	47.19	4095
Year built	2012	4.63	1986	2019
Number of households			2,053	
Number of observations			107,027	
Annual gas (m^3)	2572.03	1141.59	2.78	16897.64
House size (ft^2)	193.13	349.56	53.5	4095
Year built	2012	4.56	1986	2019
Number of households			2,029	
Number of observations			9,266	

Table 2: Summary Statistics (New Brunswick)

	Mean	Std. Dev.	Min	Max
Monthly electricity usage (kWh)	1384.46	930.407	105	8041
Single detached home	0.597	0.491	0	1
House size (ft^2)	1624.408	612.45	600	2700
House age (years)	3.353	1.234	1	4
Number of occupants	2.438	1.108	1	6
Electric water heater	0.86	0.347	0	1
Number of refrigeration devices	2.164	0.6	1	4
Number of dehumidifiers	0.329	0.509	0	3
Well pump	0.379	0.485	0	1
Pool pump	0.081	0.272	0	1
Electricity as the primary source of heating	0.751	0.432	0	1
Number of window AC	0.201	0.515	0	3
Number of houses			422	
Number of observations			5,064	

Second, we obtained house air leakage rates from the National Research Council. These data originate from Natural Resource Canada's EnerGuide for Homes (EGH) database, and include houses in each of the three provinces we analyze. The air leakage observations are from home energy audits, during which a "blower door test" is completed in each participating house.

This test measures the number of air changes per hour at a pressure differential of 50 pascals (ac_{50}/hour), a common measure of envelope air tightness used by public energy efficiency programs and firms offering energy efficiency services (NYSERDA, 2015). This measure is also used as a performance metric in building energy code development, modeling and verification (Proskiw, 2011; City of Edmonton, 2014). In addition to ac_{50}/hour, we also observe several other variables that are correlated with air leakage and that we include as control variables in our analysis. These are year of construction, number of windows, number of doors, house volume, house type, and house geometry (or house shape).

Third, we combine the consumption and air leakage datasets with information on the effective date of code changes. In Canada, while federal agencies and working groups develop model building codes, code adoptions that mandate new building standards occur at the provincial level (National Research Council Canada, 2022). As a result, code change adoptions and effective enforcement dates were identified in each of the provinces in our data. We consider building code changes with provisions that improved energy efficiency and reduced GHG emissions. Table 3 shows a summary of the adoption and effective dates used in our analysis for Alberta, Ontario, and New Brunswick.

Table 3: Building Codes Adoption and Effective Date by Province

	Building code	Adoption date	Effective date
Alberta	2014 Alberta Building Code	Feburary 26, 2015	May 1,2015
New Brunswick	2010 National Building Code	August 12, 2014	January 1, 2015
Ontario	1990 Ontario Building Code	July 30, 1990	October 1, 1990

In Alberta, residential efficiency standards were introduced as part of the 2014 Alberta Building Code (ABC) and enforcement came into effect in May 2015. In New Brunswick, energy efficiency provisions for housing were introduced as an interim amendment to the 2010 National Building Code in 2012. New Brunswick adopted the provisions in Regulation 2014-108 under the Metric Conversion Act (O.C. 2014-298) in August 2014, which came into effect in January 2015 and included the new energy efficiency provisions for housing and small buildings (New Brunswick, 2014; National Research Council Canada, 2014).[4]

In Ontario, a pivotal update to energy efficiency requirements in new housing was implemented with the 1990 Ontario Building Code (OBC), which took effect on October 1, 1990. For the purpose of our analyses, we designate the year 2014 as the last pre-code change year of construction in Alberta and New Brunswick, and 1990 in Ontario.[5]

3 Engineering Predictions of Energy Code Savings

In this section, we discuss the engineering estimates of energy savings, which we compare to our realized savings estimates in Section 4. We were provided with model-simulated predicted energy savings from the 1990 OBC change from the National Research Council Construction Research Centre. These results were obtained by comparing the 1986 OBC and 1990 OBC code-minimum performance. The simulations were completed for eleven common housing

[4]The previous version of the building code in place in New Brunswick was the 2009 New Brunswick Building Code Act (Canadian Legal Information Institute, 2009).

[5]Our results do not change if we move the code change year forward or back one year in Alberta or Ontario. We can't test this in New Brunswick due to the vintage ranges.

archetypes and three climate zones commonly used in building modeling for predicting energy code savings. Two sets of simulations were conducted, one without air conditioning (AC) and one with AC.

The simple average of simulated energy savings across all archetypes predicts an 11% reduction in natural gas consumption, a 1% reduction in electricity consumption in houses without AC, and a 0.5% electricity reduction in houses with AC, on average across three climate zones.[6] The code requirement affecting electricity use in the 1990 OBC derives exclusively from furnace electric fan use, which is why the predicted electricity savings are very small. While the simulated electricity savings differ in houses with and without AC, this may be related to the HOT-2000 model used in the energy code development process being relatively poor at predicting cooling loads (Parekh et al., 2018). With this caveat in mind, since all but 20 of the houses we observe in Ontario have AC, we use the electricity savings predictions with AC to compare with our realized savings.

The simulated predictions for the 11 housing archetypes with AC are shown in Table B1. The archetypes vary based on building size, number of storeys, and the type of basement. Predicted natural gas savings range from 6.2% in a 1,500 square foot, 2 storey middle-unit of a row house with a full basement, to 12.4% in natural gas savings for a 1,900 square foot, 1 storey house with a crawl space. The electricity savings are all less than 1%, ranging from 0.2% to 0.9%. To compare our estimated electricity and natural gas savings with simulated predictions, we calculate weighted averages of the simulated savings, with weights defined based on the distribution of characteristics in the realized consumption data. We accomplish this by proceeding as follows.

First, we form groups of houses in the realized data that are similar to the 11 archetypes in the simulated predictions from Table B1, by forming seven groups based on archetypes with the same number of stories and similar building sizes, as summarized in the Archetype Group column in Table B2. Houses of the same size with different basement types are included in the same archetype group since there is no information on basement type in the realized data. Given the simulation archetypes listed in Table B1, this likely has minimal impact on the weighted averages. For example, a 2,100 square foot, 2 storey house, one of the most common house types we observe, the predicted saving with a walk-out, slab-on-grade, or full basement are 11.8%, 11.7%, and 11.6%, respectively.

Second, with these seven archetype groups defined, we calculate the share of buildings in the realized data with similar characteristics as each Archetype Group. The house characteristics from the realized data used to allocate each house to one of the seven archetype groupings, the number of houses we observe in this category, and the resulting shares used in the weighted average, are shown in the last four columns of Table B2. Using the shares as weights, we calculate the weighted average of simulated gas and electricity savings, as well as simulated gas and electricity consumption, across the 7 archetype groups in Table B3. The simulation results predict a 9.6% annual natural gas usage reduction from the 1990 OBC, and a 0.4% annual electricity use reduction.

To assess predicted savings in the New Brunswick sample, we refer to Proskiw (2011), a study commissioned by the National Research Council as part of the 2012 code development process. The study reports savings estimates for houses constructed in six climate zones across Canada. We focus on the savings prediction for Climate Zone 6 as it is by far the most prevalent climate zone in New Brunswick (ASHRAE, 2021). The Proskiw (2011) study differentiates savings between houses with and without heat recovery ventilators (HRVs). We assume that

[6] The predicted savings results do not change substantially if only one or two of the three climate zones are used.

all of the houses in the New Brunswick sample during our study period are equipped with HRVs because most homes built since 1977 have them (Natural Resources Canada, 2022b). The predicted outcome from the energy-related changes in the 2012 National Building of Canada in Climate Zone 6, for houses with HRVs, is an annual reduction of 12.8% in whole-house kWh equivalent (Table 18 in Proskiw (2011)).

Proskiw (2011) also includes predictions for house envelope air tightness improvements, measured by air changes per hour at 50 pascals of pressure (hereafter ac/hr_{50}). Baseline or pre-code air tightness is assumed to be 3.18 ac/hr_{50}, which is the national average obtained from a survey of air tightness in houses less than five years old conducted by Natural Resources Canada; the value for the Climate Zone 6, the typical climate zone for New Brunswick, is 3.1 ac/hr_{50}, and the value for Climate Zone 5 (Ontario) is 3.2 ac/hr_{50}. The post-code air tightness is 2.5 ac/hr_{50} (the value is not differentiated by climate zones). The post-code assumed value is consistent with Ismaiel et al. (2023), who find houses from the EnerGuide database in Canada built between 2015-2018 have a mean air tightness of approximately 2.5 ac/hr_{50}. The baseline air tightness assumption is consistent with Hamlin and Gusdorf (1997), who find an average ac/hr_{50} of 3.06 among a small sample of conventionally built houses in the late 1990s.

4 Empirical Framework and Results: Energy Savings

To study the effect of more stringent provincial energy code requirements on electricity and natural gas consumption, we compare consumption from residences constructed just before and just after an energy code change. As discussed in Jacobsen and Kotchen (2013), this minimizes variation in observed and unobserved factors that might affect household consumption, such as efficiency regulations on furnaces or major appliances, other changes to building codes (for example, changes to the design and construction requirements of new buildings) or economic shocks. This approach to empirical evaluation arises from the administrative characteristics of the code adoption process across Canadian jurisdictions.

As noted previously, the adoption and effective enforcement of more stringent energy code requirements occurs on discrete dates that apply to all new buildings. This means, by construction, that we do not have a comparison group of houses with the same year built and location that are not subject to the building code change. In this setting, the causal effect of a new building energy code can be recovered if we can empirically control for all potential factors that are correlated with energy consumption and the code change (Jacobsen and Kotchen, 2013; Bruegge et al., 2019); in other words, there are no unobserved confounding variables (due to occupant behavior, housing structure, or other factors) that covary with energy consumption in buildings constructed a few years before and after a new code comes into effect. As described further below and following past literature, to implement this approach we control for several observable house characteristics that likely correlate with energy consumption, such as house size, as well as unobservable time-varying characteristics at the provincial level.

4.1 Alberta and Ontario Sample

In our empirical analysis, for the Alberta sample, we define houses constructed between 2010 and 2014 as the pre-code change years, while those built from 2016 to 2019 are the post-code change years. In the Ontario sample, the pre-code change years include houses constructed between 1986 and 1990, while the post-code change years span houses built between 1992 to 1995.

We use the following regression model to estimate the effect of the code change on electricity consumption:

$$C_{imp} = \alpha + \beta \text{CodeChange}_{ip} + \gamma \text{HouseSize}_i + \theta \text{YearBuilt}_i + \lambda_{mp} + \epsilon_{imp}, \quad (1)$$

where i indexes the household, m indexes the calendar month and p indexes the province in which household i is located (Ontario or Alberta). The dependent variable C_{imp} represents electricity consumption measured in kWh for household i in calendar month m and province p. CodeChange_{ip} is a dummy variable indicating whether a house is built before or after the year of the code change in province p. The variable HouseSize_i is the square footage of house i, and YearBuilt_i is the year of construction. The term λ_{mp} indicates a month of sample by province fixed effect, which controls for common factors that shift over time and affect households distinctly in each of the two provinces – weather and electricity prices, for example.[7] Finally, α is a constant term, and ϵ_{imp} is an idiosyncratic error term. Specification (1) is estimated using standard errors that are two-way clustered by month-of-sample and province (i.e. the unit of clustering is month-of-sample by province).

For gas consumption, we aggregate the monthly gas observations in Alberta to the annual level in order to match the annual gas data in Ontario. We then estimate the effect of the code change on annual gas usage in a similar regression specification:

$$C_{iyp} = \alpha + \beta \text{CodeChange}_{ip} + \gamma \text{HouseSize}_i + \theta \text{YearBuilt}_i + \delta_{yp} + \psi_{iyp}, \quad (2)$$

where C_{iyp} is annual gas consumption measured in cubic meters for household i in year y and province p, and δ_{yp} is a year-by-province fixed effect.

In our results, we report other specifications with variations of the dependent variable including the logarithm of consumption and the logarithm of consumption per 1,000 square feet; the logarithmic model reduces the impact of data outliers on statistical estimates.

Panel A of Table 4 shows results of estimating Specifications (1) and (2) for the combined Alberta and Ontario sample. Column (1) reports Specification (1) estimates when the dependent variable is the logarithm of monthly electricity consumption in kWh, and Columns (2) and (3) report estimates when the dependent variable is the logarithm of monthly electricity consumption in kWh per thousand square feet. Columns (4) to (6) report Specification (2) estimates for the logarithm of annual gas consumption in cubic meters (in Column(4)) and cubic meters per thousand square feet (in Columns (5) and (6)).

[7] Since the consumption samples in Alberta and Ontario are composed of houses in either the same city (Alberta) or cities located close to each other in the Greater Toronto Area (Ontario), the province fixed effects will capture weather variations. In addition, all houses in the Alberta sample are served by the same utility and face the same prices, and the same is true for the Ontario houses in Newmarket and Milton.

Table 4: Realized Electricity and Gas Savings

	Monthly electricity consumption			Annual gas consumption		
Dependent variable:	Logarithm kWh (1)	Logarithm kWh/1,000 ft^2 (2)	Logarithm kWh/1,000 ft^2 (3)	Logarithm m^3 (4)	Logarithm m^3/1,000 ft^2 (5)	Logarithm m^3/1,000 ft^2 (6)
Panel A: Alberta and Ontario						
Code Change	-0.318***	-0.271***	-0.154***	-0.110*	-0.080	-0.006
	(0.013)	(0.015)	(0.025)	(0.047)	(0.059)	(0.062)
Controls						
House size	Yes	No	No	Yes	No	No
Year Built	No	No	Yes	No	No	Yes
Fixed Effects						
Month of sample by province	Yes	Yes	Yes	No	No	No
Year of sample by province	No	No	No	Yes	Yes	Yes
Standard Error Clusters						
Month of sample by province	Yes	Yes	Yes	No	No	No
Year of sample by province	No	No	No	Yes	Yes	Yes
Constant	6.360***	6.156***	52.55***	7.66***	7.455***	37.029
	(0.015)	(0.003)	(5.412)	(0.042)	(0.010)	(8.012)
R-squared	0.10	0.08	0.09	0.10	0.08	0.08
Number of houses		2,053			2,029	
Number of observations		107,603			9,314	
Panel B: New Brunswick						
Code Change	-0.038*	-0.046				
	(0.019)	(0.03)				
Controls						
House size	Yes	No				
House type	Yes	Yes				
Occupancy	Yes	Yes				
Appliances, HVAC and behavior	Yes	Yes				
Fixed Effects						
Billing period	Yes	Yes				
Region	Yes	Yes				
Standard Errors Clusters						
Billing period and region	Yes	Yes				
Constant	5.763***	5.858***				
	(0.097)	(0.121)				
R-squared	0.57	0.43				
Number of houses	422					
Observations	5,064					

Notes: In Panel A, Columns (1)-(3) show the estimates of Specification (1), while Columns (4)-(6) present the estimates of Specification (2) with 2 different variations of the dependent variable: logarithm of consumption and logarithm of consumption per 1000 square feet. Panel B presents estimates of Specification (3). Clustered standard errors are in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

In Columns (1) and (4), we include house size in square feet as a control variable. The house size control is not included in the other specifications since the dependent variable is in consumption per thousand square feet. In Columns (3) and (6), we add year of construction as a control. We include month of sample by province fixed effects and month of sample by province clustered standard errors in Columns (1) to (4). In Columns (5) to (8) we include year of sample by province fixed effects and year of sample by province clustered standard errors.

The point estimates for electricity consumption suggest that houses built a few years after a code change consume 31% less electricity overall, and 27% less electricity per square foot, relative to houses built a few years before the code change. However, once year of construction is controlled for, the point estimate for the effect of the code falls by more than half, to 15.4%. This is a substantial difference in electricity consumption, and significantly higher than modeled predictions of a 0.4% electricity saving[8].

Natural gas consumption, on the other hand, does not significantly change in homes constructed pre-code change versus post-code change, in contrast to the modeled predictions of a 9.6% annual natural gas usage reduction from the 1990 OBC. After controlling for year of construction, the point estimate for gas savings is a 0.6% decline in gas consumption per square foot, and it is statistically insignificant.

4.2 New Brunswick Sample

In our empirical analysis for New Brunswick, the pre-code adoption sample consists of houses constructed from 2010 to 2014, while the post-code adoption sample encompasses houses built between 2015 and 2018.

To study the effect of the code change year on monthly electricity consumption, we adopt the following fixed-effects model that controls for durable appliance ownership or house and occupant characteristics that might affect energy use:

$$C_{itr} = \alpha + \beta \text{CodeChange}_i + \sum_{j=1}^{3} \nu_j \text{HouseControls}_{ij} + \sum_{k=1}^{7} \chi_m \text{Appliances}_{im} + \kappa_t + \eta_r + \mu_{itr}, \quad (3)$$

where i indexes the household, t indexes the billing period, and r is the region which household i's house is located.[9] Outcome variable C_{itr} measures consumption for household i in region r in billing period t. As in Specification (1), we report results for two different consumption measures for C_{it}: the logarithm of electricity consumption in kWh and the logarithm of consumption in kWh per 1000 square feet.

CodeChange_i is a dummy variable that takes the value 1 for houses built after the code change year and 0 otherwise, and β is the coefficient of interest that shows the effect of CodeChange on household electricity consumption. $\text{HouseControls}_{ij}$, where $j = \{1, 2, 3\}$, includes variables for house type, house size, and occupancy. Appliances_{im}, where $m = \{1, ..., 7\}$, controls for appliances and large equipment in house i that might be correlated with energy consumption: the number of refrigeration devices, humidifiers and/or window ACs, and dummy variables that take the value of 1 for houses with an electric primary heating system, electric

[8]The predicted electricity and gas savings are calculated for Ontario, whereas the majority of houses in the combined sample are located in Alberta. However, the comparison between the modeled and actual estimates is still valid. If the sample contained more houses from Ontario, the actual electricity savings could likely be even higher since average AC penetration is almost two times higher in Ontario than in Alberta (Statistics Canada, 2021), but the realized gas savings would not change because the average share of houses heated with gas is around 20% lower in Ontario than in Alberta (Natural Resources Canada, 2022a) Additionally, the results provided in Panel A of Table 4 do not change substantially if we estimate Specifications (1) and (2) for the Ontario and Alberta sub-samples separately.

[9]Billing period is the set of roughly 12 periods per year over which the utility measures consumption that is billed to customers once a calendar month. While billing period does not coincide with calendar month, all customers in the sample face the same billing period. Region is defined by the first three digits of the residence's postal code, also known as the Forward Sortation Area (Canada Post, 2022).

water heater, a well pump and/or a pool pump. α is the regression constant term, κ_t is a billing period fixed effect, η_r is the region fixed effect, and μ_{itr} is the error term. Standard errors are two-way clustered by billing period and region.

Panel B of Table 4 shows results of estimating Specification (3). As is the case with the combined sample, Columns (1) to (2) reflect the 2 different versions of the dependent variable. While the first column suggests that electricity levels declined statistically significantly in the post-code period in New Brunswick (the coefficient is only significant at the 10% level), normalizing the dependent variable by house size indicates that the energy code adoption had no statistically significant effect on electricity consumption per square foot in houses constructed after the new code.

The ex-post savings are not in line with the engineering predictions (an annual reduction of 12.8% in whole-house kWh equivalent). We acknowledge that the result of the comparison could be different if we had gas consumption data in New Brunswick since Proskiw (2011) calculates the overall change in energy consumption measured in kWh_e, irrespective of the type of energy source used in the house.

4.3 Event Studies: Energy and Air Leakage

The results presented in Sections 4.1 and 4.2 suggest that energy-related building code changes have had no discernible impact on gas usage in Alberta and Ontario and electricity consumption in New Brunswick, but are associated with significant reductions in electricity use in Ontario and Alberta. Our empirical strategy to identify these effects relies on evaluating energy consumption changes in houses constructed just after a new energy code change is adopted in each province, relative to those constructed just before the change. This empirical approach assumes that nothing but the new code affected energy consumption in these houses.[10] Behavioral responses in the construction industry in reaction to energy code requirements, such as changes in building size (as documented by Bruegge et al. (2019)) and poor compliance, or general innovation in construction materials and building practices unrelated to code changes, will each influence the realized effectiveness and evaluation of energy codes' impact.

Some of these factors may result in a generalized trend affecting energy use or air tightness patterns across years of construction before and/or after new code adoption, and, in that case, the change in electricity and gas consumption previously reported in Table 4 could be incorrectly attributed to the building energy code change (Jacobsen and Kotchen, 2013). In this section, we graphically assess whether pre-existing trends in energy consumption are drivers of the regression estimates documented above. We use event studies that illustrate year-by-year changes in both consumption and air tightness. The empirical approach and results are detailed below.

4.3.1 Energy Consumption

We start by conducting an event study for energy consumption in the combined sample using the following regression model:

$$C_{iyp}^{sqft} = \theta + \zeta(\text{YearBuilt}_i - \text{CodeYear}_{ip}) + \lambda_{yp} + \epsilon_{iyp}, \tag{4}$$

where C_{iyp}^{sqft} is the logarithm of annual electricity consumption per 1,000 square feet and

[10] Other than monthly or annual provincial shocks affecting electricity or natural gas consumption, respectively, which are also controlled for in our empirical specifications.

$CodeYear_{ip}$ is the year a code change became effective. As before, i indexes individual house, y denotes year, and p denotes province. In these event study analyses, we consider five years before a code came into effect and four years after. The omitted category in each event regression is the year the code was adopted (2015 in Alberta and 1991 in Ontario).

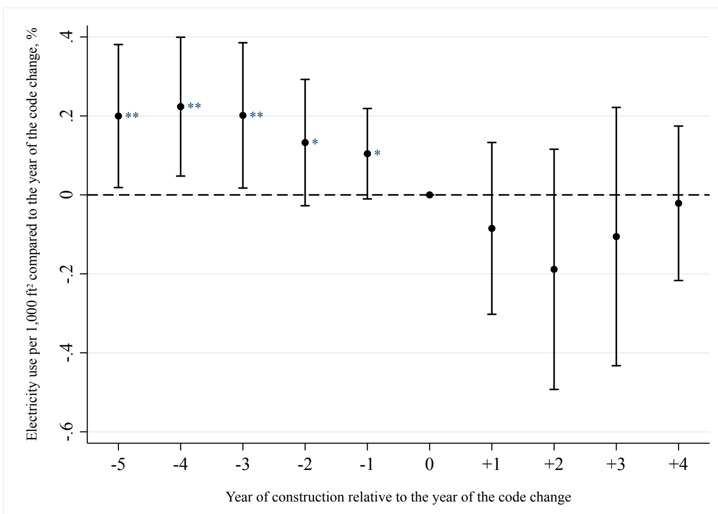
We also conduct an event study with annual gas consumption as the outcome of interest:

$$C_{iyp}^{sqft} = \theta + \zeta(\text{YearBuilt}_i - \text{CodeYear}_{ip}) + \delta_{yp} + \psi_{iyp}, \tag{5}$$

where C_{iyp}^{sqft} is the logarithm of annual gas consumption per 1,000 square feet.

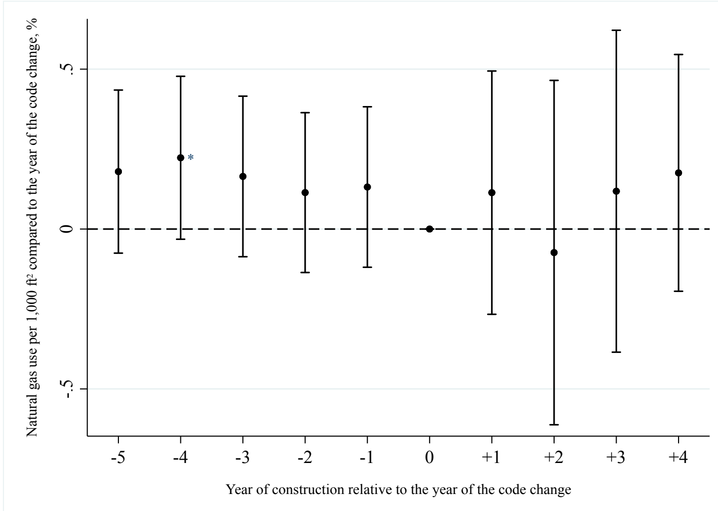
The point estimates from Specifications (4) and (5) are shown in Figures 1 and 2, respectively. In Figure 1, we observe a downward trend in electricity consumption per square foot that began about three years before the new code came into effect. The downward trend persists up to two years after the code became effective and then begins reverting back to zero, though none of the post-code electricity consumption changes are statistically significantly different from zero. Figure 2 indicates no statistically significant differences in gas consumption in houses constructed just before or just after the code change.

Figure 1: Realized Electricity Consumption by Year of Construction (Alberta & Ontario)



Notes: The figure shows the changes in electricity use per 1,000 square feet for different house vintages constructed before and after the code change (1991 for Ontario and 2015 for Alberta). The dependent variable is the logarithm of monthly electricity consumption in kWh per 1,000 square feet. The figure contains point estimates and 95% confidence intervals for the estimates from Specification (4).

Figure 2: Realized Gas Consumption by Year of Construction (Alberta & Ontario)



Notes: The figure shows the changes in natural gas use per 1,000 square feet for different house vintages constructed before and after the code change (1991 for Ontario and 2015 for Alberta). The dependent variable is the logarithm of annual gas consumption in m^3 per 1,000 square feet. The figure contains point estimates and 95% confidence intervals for the estimates from Specification (5).

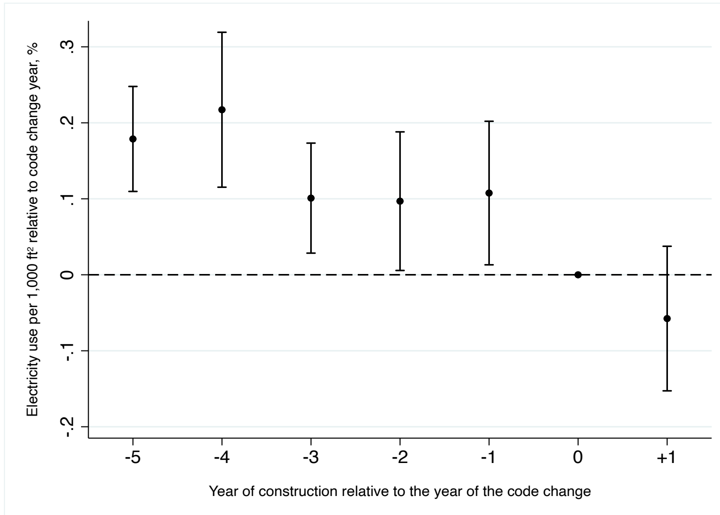
In the New Brunswick sample, where we observe a richer set of house-level covariates, we implement the following event study regression:

$$C_{iyr}^{sqft} = \theta + \zeta(\text{YearBuilt}_i - \text{CodeYear}_i) + \sum_{j=1}^{3} \nu_j \text{HouseControls}_{ij} + \sum_{k=1}^{7} \chi_m \text{Appliances}_{im} + \kappa_y + \eta_r + \mu_{iyr}, \quad (6)$$

where C^{sqft} is the logarithm of electricity consumption per 1000 square feet for household i in region r in billing year y, $\sum_{j=1}^{3} \nu_j \text{HouseControls}_{ij}$ and $\sum_{k=1}^{7} \chi_m \text{Appliances}_{im}$ are defined as in Specification (3).

As described in Section 2, in New Brunswick the year of construction is reported in year ranges rather than the exact years. In this context, the variable $YearBuilt_i$ for the event study is computed as the mean of the upper and lower bounds of each year range. For instance, the year range 1975-1989 is coded as a $Yearbuilt$ value of 1982. Figure 3 shows a discrete decline in electricity use per square foot beginning in this year range. In the post-code change years of 2015-2018, there is a small decline in the point estimate, but it is not statistically significantly different from zero (the same is true for the pre-code change years).

Figure 3: Realized Electricity Consumption by Year of Construction (New Brunswick)



Notes: The figure shows the changes in electricity use per 1,000 square feet for different house vintages constructed before and after the code change (where the latter is the 2015-2018 period in New Brunswick). The dependent variable is the logarithm of annual electricity consumption in kWh per 1,000 square feet, where a year corresponds to a billing year. The figure contains point estimates and 95% confidence intervals for the estimates from Specification (6).

4.3.2 Air Leakage

To assess how the adoption of a new building code might affect air leakage, we use a cross-sectional regression with house characteristics that correlate with air leakage and region variables as controls[11]. The EnerGuide for homes database observations do not include a sufficient number of houses built in the post-code period in Alberta (i.e. after 2015) and as a result we report air leakage results for Ontario and New Brunswick.[12] Since we observe slightly different covariates in each sample, we still proceed with two different regression specifications. The Ontario sample includes air tightness observations for 131,515 houses across the province, and the New Brunswick sample includes 484 houses. Unlike the electricity consumption sample, which reported ranges for the construction year of a given house in New Brunswick, we observe the precise year of construction for each house in this sample.

In the Ontario sample, the model is as follows:

$$\text{AirLeak}_{iw} = \theta + \zeta(\text{YearBuilt}_i - \text{CodeYear}) + \sum_{q=1}^{15} \gamma_q \text{HouseControls}_{iq} + \omega_w + \epsilon_{iw}, \quad (7)$$

where AirLeak_{iw} is the logarithm of measured air leakage at 50 pascals. We observe these measurements for each house i, and w is the nearest weather station, which corresponds to the location of the nearest city, with the exception of Toronto which includes a station for the City of Toronto and one for the Toronto Metropolitan area located between Vaughan and Brampton, Ontario. Point estimates for the pre- and post-code change years are captured by $(\text{YearBuilt}_i - \text{CodeYear})$, and $\text{HouseControls}_{iq}$ includes house-level control variables we observe

[11]We only conduct an event-study type of analysis for air leakage since the air leakage results are primarily used to corroborate the findings from the energy consumption analysis. In addition, the air leakage assumptions described in Proskiw (2011) are not modeled predictions.

[12]Air leakage rates are observed for only 3 or 4 houses in Alberta in each year spanning 2016-2019.

from the EnerGuide database.[13] The model contains weather station fixed effects, ω_w, and standard errors, ϵ_{iw}, are clustered by weather station location.[14]

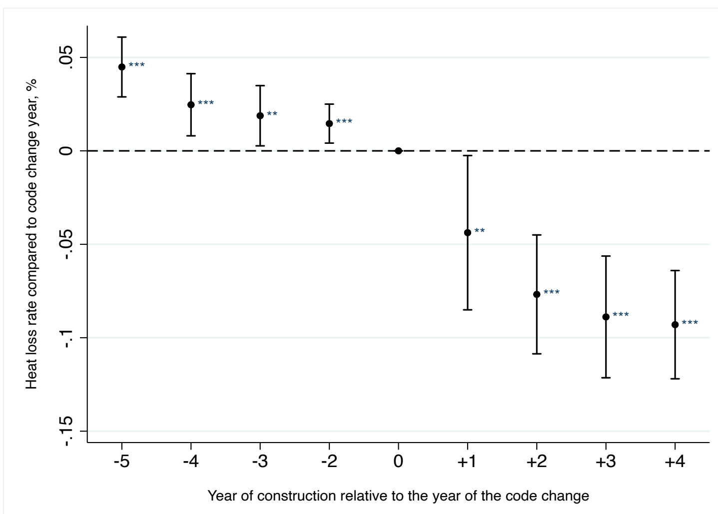
For the New Brunswick sample, we estimate the following specification:

$$\text{AirLeak}_{ic} = \theta + \zeta(\text{YearBuilt}_i - \text{CodeYear}) + \sum_{q=1}^{16} \gamma_q \text{HouseControls}_{iq} + \omega_c + \epsilon_{ic}, \tag{8}$$

Since the air leakage data for all houses in Canada derive from the same EnerGuide for homes database, our New Brunswick specification includes similar $\text{HouseControls}_{iq}$ variables as in Specification (7).[15] We observe the within-province county c for each house i. There are 15 counties in New Brunswick, which roughly capture different cities/population centers in the province (New Brunswick, 1998). The model includes county fixed effects, ω_c; standard errors, ϵ_{ic}, are clustered by county.

The air leakage event studies for Ontario and New Brunswick are depicted in Figures 4 and 5, respectively.

Figure 4: Realized Air Leakage Rates by Year of Construction (Ontario)



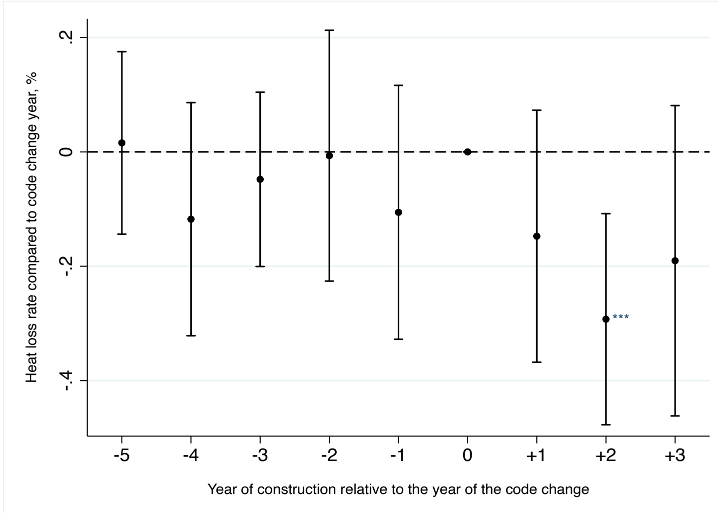
Notes: The figure shows the changes in air leakage rate for different house vintages constructed before and after the code change (1991 in Ontario). The dependent variable is the logarithm of measured air leakage at 50 pascals. The figure contains point estimates and 95% confidence intervals for the estimates from Specification (7).

[13] These are house volume, number of windows, number of doors, 5 dummy variables for the type of house, and 7 dummy variables documenting the house shape. Type of house includes attached duplex or triplex, semi-detached, detached, row house end unit, and row house middle unit. House shape includes L-shape, rectangular, T-shape, as well as other shapes (11 or more corners, 9-10 corners, 7-8 corners, and 5-6 corners). These dummy variables are included since both house type and plan shape can impact air leakage. For example, if a middle unit of a row house shares two walls with its neighbors, it will limit the total area susceptible to air leakages. Similarly, houses with a large number of corners may be leakier since corners are common areas that may include gaps through which outside air can enter.

[14] Clustering at the city level instead does not change the results.

[15] The New Brunswick sample also includes mobile homes, which are one of the house type dummy variables.

Figure 5: Realized Air Leakage Rates by Year of Construction (New Brunswick)



Notes: The figure shows the changes in air leakage rate for different house vintages constructed before and after the code change (2014 in New Brunswick). The dependent variable is the logarithm of measured air leakage at 50 pascals. The figure contains point estimates and 95% confidence intervals for the estimates from Specification (8).

The results mirror the consumption findings. In Ontario houses, there is a discernible downward trend in air tightness that begins at least four years before the new energy code came into effect. The average air tightness level over the sample period is 4.73 ac/hr$_{50}$, with an average of 4.95 ac/hr$_{50}$ pre-code and 4.56 ac/hr$_{50}$ post-code. These air tightness estimates are on the higher end of estimates from the literature on average air tightness values in Ontario. For example, as previously noted, Ismaiel et al. (2023) find post-code averages of approximately 3.1 ac/hr$_{50}$ in Ontario. Our air tightness estimates are also higher than the post-code (2.5 ac/hr$_{50}$, the value is not differentiated by climate zones), as well as baseline, or pre-code, values in Proskiw (2011), which assumes a baseline value of 3.2 ac/hr$_{50}$ for the southern Ontario climate zone (NAIMA, 2022). The pre-code difference in values could arguably be due to the time period under consideration, since Proskiw (2011) exploits studies from the 2000s for its baseline air change assumption, whereas the OBC change occurred in late 1990 and we focus on houses built up to 1995. However, if we make a sample of houses built between 2000 and 2003 (inclusive) in Ontario (around 500 houses), we still get the average air tightness of 4.75 ac/hr$_{50}$, almost identical to our estimates above.

In New Brunswick, there is little discernible change in air tightness over the sample period and most of the pre-code air tightness point estimates are higher than those for houses constructed after the code became effective (as shown in Figure 5). This is also consistent with the electricity consumption findings. The unconditional average air tightness level in the pre-code period is 2.54 ac/hr$_{50}$, and the post-code air tightness is 2.03 ac/hr$_{50}$. Both the pre- and post-code values are lower than those in Proskiw (2011), where the pre-code air tightness is assumed to be 3.1 ac/hr$_{50}$ and the post-code one is 2.5 ac/hr$_{50}$. At the same time, the post-code value is slightly higher than that reported in Ismaiel et al. (2023) who find the post-code average of approximately 1.9 ac/hr$_{50}$ in New Brunswick[16]. However, after controlling for observable

[16] As for the literature on average air tightness values in Canada overall, Hamlin and Gusdorf (1997) document an average of 3.06 ac/hr$_{50}$ among a sample of 222 Canadian houses constructed in the 1990s, while Khemet and Richman (2020) find a Canada-wide average of 5.7 ac/hr$_{50}$ in a large sample of single-family homes.

variables that correlate with air tightness, there is no statistically significant difference between the actual pre- and post-code levels.[17]

Past literature also documents significant inter-provincial heterogeneity based on regional construction practices, construction materials, climate zone of the house, house type and insulation type, among other factors (Khemet and Richman, 2020; Ismaiel et al., 2023; National Research Council Canada, 2015). Our empirical analysis controls for many of the drivers of this heterogeneity including location, house volume, number of windows and doors, house shape/geometry, and house type. Therefore, the air leakage estimates corroborate the energy consumption findings: the adoption of a new energy code does not cause a statistically significant impact of energy consumption or air leakage. In the next section, we discuss the implications of these findings for building energy code development and evaluation.

5 Conclusion

This paper contributes towards the evaluation of the ex-post effectiveness of building energy codes in Canada. We assess the realized energy savings from the adoption of more stringent energy codes in Canada over the last 30 years and compare our findings to engineering predictions. We use utility consumption data to estimate electricity and natural gas savings from energy codes in about two thousand homes constructed just before and just after the adoption of more stringent building energy codes, in a variety of municipalities spanning Ontario, Alberta, and New Brunswick. We corroborate our findings with air leakage measurements in over 130,000 houses.

We find that while homes built after a code change consume less electricity than the pre-code homes, these electricity savings are either not statistically significant, not robust to confounding variables, or driven by a pre-existing downward trend in electricity consumption. Natural gas consumption does not change significantly in Alberta and Ontario after the adoption of a new energy code. Air leakage rates in Ontario exhibit a downward trend pre-dating new energy code adoptions, similar to what we observe in the electricity sample, and there is no statistically significant change in air leakage in New Brunswick over the sample period.

These results contrast with engineering predictions of the change in energy consumption from the 1990 OBC modification and the more recent energy code adoptions in New Brunswick. The bulk of the savings from the OBC adoption of more stringent insulation measures were predicted to arise from reduced natural gas consumption, with a 9.6% predicted reduction. In the combined sample, where most of the houses are heated with natural gas (since the majority of the sample is located in Alberta), our point estimates are an 11% saving in gas consumption and 8% saving in gas consumption per square foot, and the estimates are not statistically significant. In New Brunswick, where a large share of houses heat their homes with electric baseboards or heat pumps, the point estimate is a 4.6% reduction in kWh per square foot, but it is not statistically significant, while predicted energy savings for the 2012 updated model energy code were a 12.8% reduction in whole-house kWh equivalent consumption.

Over the past several decades energy code development has been a key pillar of public policies enacted to lower energy use in the residential sector. The most recent iteration of model code development is the net zero energy ready (NZER) building code, which is expected to be published in 2024 (National Research Council Canada, 2022; Lockhart, 2022). Most provinces

[17] As determined on the basis of both an F-test for the equality of the pre- and post-code coefficients and the pair-wise significance of adjacent coefficients in Specification (8).

have committed to adopting a NZER code by 2030 as part of the Pan-Canadian Framework on Climate Change (Pride, 2020).[18]

The NZER code is one component of a tiered energy code that allows for differentiated levels of stringency in code standards. Tiered codes provide performance-based steps (tiers) for building energy efficiency, with higher levels of energy performance attained with each additional step. This tiered approach implicitly recognizes the high degree of heterogeneity in current energy code guidelines and procedures among municipalities across Canada, and by combining flexibility and stringency the hope is that a tiered framework may help provincial, territorial, and local governments accelerate the transition to net zero (Efficiency Canada, 2022).

However, as Canada moves towards enacting policies and programs to facilitate attaining a net zero economy, monitoring progress and evaluating the outcome of these initiatives will need to play a key role in ensuring targets are actually being met. While model predictions and laboratory or pilot-scale initiatives are important tools to assemble and test materials and equipment related to new energy code standards, as well as achieve proof-of-concept housing designs, scaling up these learnings from synthetic or small-sample settings presents unique challenges.

There is significant heterogeneity in housing stock characteristics, building industry practices, and occupant preferences that, fundamentally, cannot be captured in laboratory or pilot settings. Parameters capturing this multi-dimensional heterogeneity need to be estimated using realized energy consumption from samples that are large enough to attain high-powered statistical inference and reliable estimates. Unfortunately, there is relatively sparse large-sample evidence on the realized energy savings from building retrofits, and almost none from whole-house or deep energy retrofits (Giandomenico et al., 2022).[19] Two recent studies from Canada have documented that the energy savings from heat pumps, insulation measures, and energy-efficient windows and doors are significantly lower than engineering predictions Papineau et al. (2021, 2023).

Recent simulation-based work has noted the importance of accounting for realized behavior in engineering models of energy use (Abdeen et al., 2020, 2021). Inaccurate behavioral assumptions in simulation tools, such as set-point temperature and the number of occupants, may be one of the drivers of the existing gap between predicted and actual energy consumption in Canadian homes. However, the most robust and reliable approach to obtain accurate *ex-ante* estimates of energy savings that can ultimately be a good predictor of ex-post realized consumption needs to incorporate large representative samples of utility consumption in the population. Such approaches are conducive to assessing sources of model error and, more importantly, can provide reliable energy consumption estimates that embed both occupant preferences, heterogeneous housing stock attributes, and the interaction between these behavioral and structural characteristics.

[18] Saskatchewan is the only province that has not committed to this Framework.

[19] This problem is particularly acute in Canada. In a recent systematic review, Giandomenico et al. (2022) found no Canadian studies using realized energy savings to assess savings from housing retrofit programs, and most of the existing studies from other countries used inference approaches that are prone to statistical biases.

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A Data Cleaning

The original New Brunswick sample of houses included 6,941 houses. We undertook the following data cleaning steps to obtain our final sample. We removed houses with incomplete consumption data (30 houses), those with electric vehicles or on-site renewable energy generation (96 houses), outliers with extreme energy usage in any billing period (283 houses), as well as missing year built and house characteristics data (658 houses). Lastly, we limit our analysis exclusively to houses constructed within five years before the year of the code change and four years afterwards, resulting in a sample of 422 houses.

The combined sample initially contained 1,968 houses in Ontario (1,214 in Milton and 754 in Newmarket) and 20,956 houses in Medicine Hat, Alberta. After keeping the houses constructed within five years before and four years after the year of the code change, we were left with 159 homes in Ontario and 1,914 homes in Alberta. Then, in the Ontario sub-sample, we omitted houses with missing annual gas consumption (all the houses had non-missing monthly electricity consumption) and obtained 154 homes. In the Alberta sub-sample, we dropped 10 houses with a recorded house size of zero and omitted houses with missing annual gas consumption (all the houses had non-missing monthly electricity consumption); we obtained 1,894 homes with non-missing monthly electricity consumption and 1,875 houses with non-missing annual gas consumption.

B Simulated Energy Code Savings in Ontario

Table B1: Simulated Building Energy Code Annual Savings for 11 Housing Archetypes in Toronto

Archetype	Natural Gas Savings	Electricity Savings	Annual Natural Gas Consumption (m^3)		Annual Electricity Consumption (kWh)	
			1986	1990	1986	1990
1000sf_1storey_fullBsmt	8.4%	0.2%	4,100	3,758	16,387	16,353
1900sqft_1storey_crawlSpace	12.4%	0.2%	6,214	5,440	17,143	17,114
1300sf_2storey_fullBsmt	11.1%	0.4%	5,546	4,930	16,505	16,437
2100sf_2storey_fullBsmt	11.6%	0.7%	6,818	6,026	16,917	16,802
3500sf_2storey_fullBsmt	10.5%	0.9%	11,162	9,989	17,593	17,428
3500sf_2st_15%moreGlass_fullBsmt	10.0%	0.7%	11,393	10,250	17,664	17,535
2100sf_2storey_slabOnGrade	11.7%	0.8%	7,627	6,737	16,872	16,739
2100sf_2storey_walkOut	11.8%	0.7%	7,976	7,032	17,141	17,027
3000sf_2stry_walkOut	9.4%	0.7%	10,887	9,858	17,806	17,673
1500sf_2storey_rowEnd_fullBsmt	8.1%	0.4%	5,448	5,005	16,350	16,290
1500sf_2storey_rowMid_fullBsmt	6.2%	0.2%	4,663	4,373	16,301	16,260

Notes: The simulations are completed for the eleven archetypes across 3 climate zones within Ontario: Windsor, Toronto, and Big Trout Lake. In the paper, we exploit the simulation results for Toronto as the closest climate zone to Newmarket, one of the two cities in the Ontario sub-sample. We do not use the Milton actual energy usage data because the Milton dataset does not include gas consumption and the information on the number of storeys in a residential building (the latter is used to compare realized energy savings to the simulations, as explained in Section 3).

Table B2: Weights Calculation for 7 Aggregated Groups of Housing Archetypes

Archetype Group	Simulated Archetype	Realized Data			
		Building Size	Storeys	Number of Buildings	Share of Buildings
1000sf_1storey_fullBsmt	1000sf_1storey_fullBsmt	< 1900	1	20	0.0265
1900sqft_1storey_crawlSpace	1900sqft_1storey_crawlSpace	≥ 1900	1	23	0.0305
1300sf_2storey_fullBsmt	1300sf_2storey_fullBsmt	< 1500	2	172	0.2281
1500sf_2storey_fullBsmt	1500sf_2storey_rowEnd_fullBsmt 1500sf_2storey_rowMid_fullBsmt	[1500, 2100)	2	313	0.4151
2100sf_2storey	2100sf_2storey_fullBsmt 2100sf_2storey_slabOnGrade 2100sf_2storey_walkOut	[2100, 3000)	2	203	0.2692
3000sf_2stry_walkOut	3000sf_2stry_walkOut	[3000, 3500)	2	15	0.0199
3500sf_2storey_fullBsmt	3500sf_2storey_fullBsmt 3500sf_2st_15%moreGlass_fullBsmt	≥ 3500	2	8	0.0106
	Total			754	1.0000

Table B3: Simulated Building Energy Code Annual Savings for 7 Aggregated Groups of Housing Archetypes in Toronto

Archetype Group	Weights from Realized Data	Natural Gas Savings	Electricity Savings	Annual Natural Gas Consumption (m^3)		Annual Electricity Consumption (kWh)	
				1986	1990	1986	1990
1000sf_1storey_fullBsmt	0.0265	8.4%	0.2%	4,100	3,758	16,387	16,353
1900sqft_1storey_crawlSpace	0.0305	12.4%	0.2%	6,214	5,440	17,143	17,114
1300sf_2storey_fullBsmt	0.2281	11.1%	0.4%	5,546	4,930	16,505	16,437
1500sf_2storey_fullBsmt	0.4151	7.2%	0.2%	5,055	4,689	16,325	16,275
2100sf_2storey	0.2692	11.7%	0.7%	7,474	6,598	16,977	16,856
3000sf_2stry_walkOut	0.0199	9.4%	0.7%	10,887	9,858	17,806	17,673
3500sf_2storey_fullBsmt	0.0106	10.3%	0.8%	11,277	10,119	17,629	17,481
Weighted Average		*9.6%*	*0.4%*	*6,010*	*5,416*	*16,611*	*16,537*

Notes: The simulated percent energy savings and energy consumption for the archetype group are calculated as the simple average across the savings (consumption) for the corresponding archetypes the group includes.