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# **The Potential for Energy Efficiency Gains in the Canadian Commercial Building Sector: A Stochastic Frontier Study**

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**March 2005**

**CBEEDAC 2005–RP-01**

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*The Potential for Energy Efficiency Gains in the Canadian Commercial Building Sector:  
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**Abstract**

The achievement of energy efficiency in commercial buildings is a function of the activities undertaken, the technology in place, and the extent to which those technologies are used efficiently. We study the factors that affect efficient energy use in the Canadian commercial sector by applying a stochastic frontier approach to a cross-section of Canadian commercial buildings included in the Commercial and Institutional Building Energy Use Survey (CIBEUS). Structural and climate-control features of the buildings as well as climatic conditions are assumed to determine the location of the frontier, while management-related variables including such factors as ownership-type and activities govern whether or not the maximally attainable efficiency along the frontier is achieved. Our results indicate that although, on average, buildings appear to be fairly efficient, certain types of operations are more likely than others to exhibit energy efficiencies that are significantly worse than average. These results, along with those related to the effects of physical characteristics on the stochastic efficiency frontier, suggest that there is scope for focused policy initiatives to increase energy efficiency in this sector.

Keywords: Energy efficiency, commercial buildings, stochastic frontier

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## Introduction

Increases in energy efficiency are desirable for many reasons. For an individual consumer, an increase in efficiency can lead to lower overall energy costs. At a more aggregate societal level, due to the exhaustible nature of most energy sources, more efficient use can help to guarantee sufficient supplies for future generations. Furthermore, increased efficiency can have a positive impact on the amounts of greenhouse gases released into the earth's atmosphere.

The potential for gains in energy efficiency will vary across locations and activities. In this study, we focus on energy use in commercial buildings in Canada. Using data from the Commercial and Institutional Building Energy Use Survey (CIBEUS) conducted by Statistics Canada for the Office of Energy Efficiency at Natural Resources Canada, we use a stochastic frontier approach to examine how efficiently energy is being used in individual buildings. This approach allows us to determine which building, activity and owner characteristics play significant roles in the attainment of energy efficiency. It also allows us to consider which sorts of policy options might be utilized in order to encourage more efficient use of energy.

The stochastic frontier approach proposed by Aigner *et al* [1] explicitly recognizes that, given the activities undertaken in the building and the technology choices made, not all agents will use energy efficiently. There will be some hypothetical level of energy efficiency that is theoretically attainable, but not all buildings will use energy this efficiently, nor as efficiently as their best-performing counterpart. Some differences in energy use will be due to random factors such as unusually good or bad climatic conditions, occasional malfunctions of equipment, etc. Other differences may be due to differences in the incentives faced by building managers and other owner-specific factors that affect the way in which building occupants use the technology at hand. For instance, some owners may circulate energy-saving tips to building occupants and some owners may include utilities in the rent they charge to lessees. These types of decisions on the part of owners may have an impact on how efficiently occupants use energy.

To capture these two different types of impacts on energy efficiency, the stochastic frontier approach decomposes the random portion of energy use into two components. The first of these components, which is included in the stochastic frontier, is a general random shock that can be positive or negative. The second component consists of a non-negative random shock, which is a function of characteristics that determine the extent to which energy use in a particular building exceeds the efficient amounts indicated by the stochastic frontier.

Similar models that have been used to measure inefficiencies in applications ranging from production technology (Battese and Coelli [2]) to firm valuations (Habib and Ljungvist [3]) to sports performance (Hofler and Payne [4]) are easily adapted to the study of energy efficiency. In our context, the divergence from the stochastic frontier can be modeled, for example, as a function of building-owner characteristics. The information from this statistical modeling can be used to gauge what might be the best focus of policy-makers whose goal is to encourage increased efficiency in the use of energy inputs.

The structure of the paper is as follows. In Section II we review the literature on appropriate measures of energy efficiency for commercial buildings and on the impacts of technology choice on energy efficiency. This provides us with information on how to appropriately model the stochastic energy efficient frontier. Section III provides an overview of the stochastic frontier framework and details on its particular application to energy efficiency. The data are presented in Section IV along with a discussion of the summary statistics pertaining to the variables used in our model. The results and their implications for policy are dealt with in Section V. Section VI concludes.

## **II Energy Efficiency in Commercial Buildings**

Issues related to energy efficiency in commercial buildings have been addressed in numerous studies. However, in many cases, the issues are addressed indirectly or only play a secondary role in studies whose main focus is on other concerns. This includes

studies where the effects of specific building components on overall energy consumption are examined. Some interesting examples include assessments of exterior wall structure on energy consumption by Lindberg, Binamu, and Teikari [5], the effects of window glazing and daylighting on energy consumption by Winkelmann and Lokmanhekim [6], varying HVAC control methods in shopping centers and the resulting energy savings by Canbay, Hepbasli, and Gokcen [7], and the utilization of pre-cooling and ventilation strategies to reduce energy consumption by Becker and Paciuk [8].

There is also a substantial engineering literature that recommends specific energy conservation measures in commercial buildings. The literature runs the gamut from descriptions of simple, immediate energy conservation steps to consideration of more capital-intensive retrofits that can reduce energy consumption. Notable publications include Dubin *et al* [9], Baron [10], Chiogioji and Oura [11], Energy, Mines and Resources Canada [12], Patrick *et al* [13], Meckler [14], and Thumann and Younger [15]. There are also a myriad of online sources such as guides provided by Pacific Gas & Electric Company [16] and Younger [17]. These works provide important information regarding which types of technologies have the best potential, if used effectively, to lead to efficient use of energy resources.

The extent to which various technologies have an impact on overall energy efficiency will be a function of the importance of the related activity to overall energy usage. Natural Resources Canada [18], Energy, Mines and Resources Canada [12], and Baron [10] provide information regarding the percentage shares of energy consumption by end-use in commercial buildings. Space conditioning (heating and cooling) is the most significant factor in terms of energy consumption, accounting for more than half of all energy use. Heating, ventilation and air conditioning (HVAC) design is therefore a candidate to play a major role in terms of energy efficiency. While hot water plays a fairly minor role in energy consumption (4 to 6%), lighting may play a fairly important role (about 15%). For further information on lighting issues, see United States Department of Energy [19].

Since space heating comprises the majority of energy use in commercial buildings in Canada, it is expected that commercial buildings in Canada will typically follow an HVAC-dominated energy consumption pattern. Indoor climate control needs will be affected by a variety of factors. According to Monts and Blisset [20] and Dubin *et al* [9], the most important of these include the climate and location of the building, the level of comfort required, the number of occupants and the periods of occupancy, the physical characteristics of the building (such as roof and wall types), and the activities undertaken in the building.

In order to proceed with an evaluation of the energy efficiency of a building, an appropriate measure or indicator is needed. The United States Department of Energy (USDOE) defines energy efficiency as the “relative thrift or extravagance with which energy inputs are used to provide goods or services” (USDOE [21]). Energy-use rates, typically referred to as energy intensities, are the most common measures that are used as surrogates for energy efficiency. These energy intensities are further defined as the ratio of energy consumption to some measure of demand for energy. One of the most common energy-intensity indicators for the commercial building sector is energy consumption per square foot (USDOE [22]). Thus, the demand indicator in this measure is a building’s square footage.

This efficiency measure is used in a previous study of energy efficiency in commercial buildings (Monts and Blisset [20]). Their attempts to model energy-wasteful and energy-efficient buildings focuses on school and university buildings in Texas. Using a linear regression model, they find that 42% of the variation of a simple Energy Utilization Index is explained by climate, occupancy patterns, HVAC design, and building design. Another alternative method for gauging the energy efficiency of buildings is via a stochastic frontier approach. This approach allows the researcher to simultaneously examine the extent to which various technological factors and building characteristics determine the minimum attainable usage of energy and which other factors determine the extent to which any particular building achieves energy efficiency. A

stochastic frontier approach also allows the impacts on energy efficiency to be estimated more efficiently (in a statistical sense) than is possible using linear regression models.

### **III A Stochastic Energy Efficiency Frontier Model**

To apply the stochastic frontier approach of Aigner *et al* [1] to energy efficiency in commercial buildings, we assume that after controlling for location and climate, building characteristics, activities, and occupancy characteristics, measured energy efficiency will vary in response to random factors such as weather shocks and technological malfunctions, measurement errors in reporting, and differences in the care taken by building occupants to use technology as efficiently as possible.

If unusually inclement weather affects a particular building, energy use may be drastically increased beyond expected levels.<sup>4</sup> Similarly, unusually clement weather can reduce the need for heating or cooling, depending on the season. Technological malfunctions can either increase or decrease energy use. For example, if a major piece of heating or cooling equipment is out of service, there may be no energy use associated with it while it is down. On the other hand, if it continues to operate while malfunctioning, it may use more energy than usual to provide the same services.

In addition to the randomness inherent in the physical use of energy, it is also possible that there will be errors in measurement in the reporting of energy efficiency. Since energy efficiency is generally measured as a ratio of energy use to the square footage of a building, inaccuracies in the measurement of either component will lead to incorrect reporting of energy efficiency. Random errors associated with either physical influences such as those related to weather or malfunctions, or errors in measurement can be either positive or negative and are best captured via a two-sided error term.

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<sup>4</sup> For example, localized hail storms in Edmonton in the summer of 2004 placed massive strains on the systems of several buildings in the city, such as West Edmonton Mall.

The remaining type of influence on efficiency, once we control for building activities and characteristics, derives from the way in which building occupants deal with the technology in place. If occupants are not careful to use technology appropriately -- by correctly setting thermostats, turning lights off when not in use, and other such measures -- the building will not be as efficient in terms of energy use as a building that has similar physical characteristics and activities but whose occupants make more energy-aware decisions in their day-to-day operations. These types of divergences can be captured statistically with a one-sided error term that is non-negative. The larger the error term, the less efficient is the use of energy in that particular building. This one-sided inefficiency measure can be statistically modeled as a function of building owner characteristics and other relevant variables.

The stochastic energy efficiency frontier can be written as

$$(1) Y_i = x_i\beta + \varepsilon_i + v_i$$

where  $Y_i$  is the (log of) measured energy use per square foot for building  $i$ ;  
 $x_i$  is a vector of variables capturing the activities and physical characteristics of building  $i$ ;  
 $\varepsilon_i$  is a two-sided random error term capturing random shocks and measurement error for building  $i$ ; and  
 $v_i$  is a one-sided non-negative random error term capturing inefficiency effects for building  $i$

In this model, efficient energy-use behaviour for building  $i$  is defined as being on the stochastic frontier,  $y_i^E = x_i\beta + \varepsilon_i$ . The error term  $\varepsilon_i$  is assumed to be distributed normally with mean 0 and variance  $\sigma_\varepsilon^2$ . The variable  $y_i^E$  provides a benchmark for comparison as it measures the hypothetical efficiency that could be achieved by a building with these characteristics,  $x_i$ , given the random shocks faced by that building,  $\varepsilon_i$ . In other words, it provides a lower bound for (the log of) energy use per square foot for a commercial building of the type (in terms of physical characteristics and activities) observed in

observation  $i$ . Furthermore, the stochastic frontier parameters allow us to gauge, holding activities constant, which physical characteristics of a building contribute most to achieving energy efficiency through movements along the frontier.

Since it is not reasonable to assume that all energy will be used as efficiently as possible, the model includes a one-sided error term which can be used to distinguish between buildings which are actually on the frontier ( $v_i = 0$ ) and those which are not ( $v_i > 0$ ). It is assumed that  $v_i$  is distributed independently of  $\varepsilon_i$ , with a truncated normal distribution with mean  $\mu_i$  and variance  $\sigma_v^2$ . This is accomplished by specifying the one-sided error term as:

$$(2) v_i = z_i\alpha + \eta_i$$

where  $z_i$  is a vector of function of building-owner characteristics and incentives. It is assumed that  $\eta_i$  is distributed  $N(0, \sigma_v^2)$ , truncated at  $z_i\alpha$  such that  $\eta_i \geq -z_i\alpha$ .

This approach, given the composite error,  $\varepsilon_i + v_i$ , allows for a simple test to determine whether or not any inefficiencies exist. In the case where all buildings use energy efficiently, a model specification that omits the one-sided efficiency error term will not be significantly different from one that includes it. Additional tests can be applied to determine the overall significance of the variables included in the vector  $z$  in terms of their ability to pinpoint the sources of inefficiencies. One such test is based on the ratio,  $\lambda$ , of the variance of the one-sided error,  $\sigma_v^2$ , to the variance of the composite error  $\varepsilon_i + v_i$  (Aigner *et al* [1]). In the case where all sources of inefficiency are captured through the variables in  $z$ , nothing remains to be captured through  $\eta_i$ , and this ratio will be equal to zero.

In the case where there is evidence of inefficiencies, these inefficiencies can be measured on a building-by-building basis (see Battese and Coelli [2]) in terms of the ratio of actual energy use for the  $i^{\text{th}}$  building,  $\exp(Y_i)$ , to the frontier level of energy use for a building with characteristics  $x_i$ ,  $\exp(Y_i^E)$ . This can be written as:

$$(3) EI_i = E(\exp(v_i) | \varepsilon_i + v_i)$$

Empirically, this can be estimated by using the estimated values of  $v_i$ .

The selection of the particular variables selected for inclusion of  $x_i$  and  $z_i$  for our application is based on the literature on energy efficiency discussed earlier, insofar as it is permitted by the limitations of our data set.

#### **IV Data**

Our data on energy use in Canadian commercial buildings are extracted from the CIBEUS survey conducted by Statistics Canada in 2001 on behalf of the Office of Energy Efficiency at Natural Resources Canada. The CIBEUS data set contains detailed information pertaining to 4101 commercial and institutional buildings in major metropolitan areas of Canada. The information gathered includes data on several owner and occupancy characteristics, physical building characteristics, types of energy efficiency technology in place, recent retrofit decisions, and energy use. For our study, these data have been supplemented with city-specific degree-day data, available online from Environment Canada [23]. Heating degree day and cooling degree day information by city were matched to the census metropolitan area (CMA) as much as possible. In cases where such data were not available, the data for the closest CMA were used. In one case (Quebec City), hourly data were incomplete for a few dates, and missing values were interpolated in order to obtain annual totals. We retained Environment Canada's standard of 18C as the cut-off point for heating and cooling degree days.

For a variety of reasons, the data set used in this study contains substantially fewer than 4101 observations. For some buildings, data on one or more variables are not credible (such as buildings open for more than 24 hours in a day or built in the 1400s). Some observations are lost due to missing values for important variables. A large

number of observations are dropped from the sample because the energy usage data have been imputed based on the energy use characteristics of other similar buildings. Only observations with actual energy use data are retained for the purposes of our study. Buildings that are not heated or have no occupants are excluded, as are buildings for which the energy use data includes energy-intensive activities shared with other buildings. For highly specialized buildings such as hospitals and universities, for example, energy use per square foot might not be ideal measures of efficiency (Schipper [24]). Therefore, for the purposes of this study, we examine only a subset of the building types available in the CIBEUS data set. The types of buildings retained in our final sample of 1091 buildings and some summary statistics regarding their energy use are presented in Table 1.

Table 2 contains summary statistics, aggregated across all building types in our sample, for selected variables used in our stochastic energy efficiency frontier model. Figures 1 through 4 provide a partial snapshot of the buildings in terms of the types of technology in place. For heating, a variety of technologies are used, with standard furnaces or packaged heat units being used in about 60 % of buildings. Figures 2 and 3 present an overview of other characteristics related to the HVAC systems including the types of energy used and the presence of specific conservation features. The main fuels used for heating purposes are natural gas and electricity, with fuel oil a distant third. A substantial portion of buildings incorporate conservation features such as outdoor-air economizers and temperature setback systems. From Figure 4, we see that the most frequently used types of energy-efficient lighting technologies are energy efficient ballasts and energy efficient lamps. They are not, however commonly used. Less than 30% of buildings use energy efficient ballasts for over 50% of their lighting needs and only about 15% report widespread use of energy efficient lamps. Simple summary figures such as Figure 4 may be a little misleading in that some buildings may use a combination of energy efficient lighting technologies and therefore make substantial overall use of energy efficient lighting technologies.

In Table 1, energy usage is broken down by building activity. One can see, for example, that buildings where the main activity involves food preparation services or food retailing tend to use more energy per square foot than buildings housing other service or retailing activities. As can be seen from the standard deviations in Table 2, there are also large variations in energy efficiency within sets of buildings housing similar activities. Of course, this does not control for differences in other characteristics of the building, its owners or its occupants. To a certain extent, this may be capturing differences in desired thermal comfort in buildings, depending on the types of occupants and/or customers who are being serviced.

Although these summary statistics and figures provide a general idea of energy and technology use in Canadian commercial buildings, they are unable to shed much light on how efficiently energy is being used. In order to examine the efficiency of energy use and its determinants, we proceed to the estimation of a stochastic energy efficiency frontier model.

Our dependent variable is (the log of) energy use (GJ) per conditioned square foot per year. This square footage consists of the portion of the building that is heated, including heated parking areas. The variables included in the stochastic frontier ( $x_i\beta + \varepsilon_i$ ) are the exogenous factors that are expected to play a role in determining the amount of energy needed for commercial building operation. These factors include heating and cooling degree days (with the latter interacting with the indicators of the percentage of the building that is air-conditioned), variables related to the types of HVAC systems in place, variables related to building envelope thermal integrity (wall and roof types), lighting conservation features, occupancy characteristics and other general characteristics of the building such as age and size. The complete list of variables is provided in Table 3.

In terms of the factors that might be expected to affect the distance from the frontier for an individual building, we consider the ownership type, whether or not regular maintenance of the HVAC system is undertaken, stated incentives for undertaking

conservation measures, and the main activity undertaken in the building. Although it might be argued that the main activity should be included in the stochastic frontier portion of the model, convergence problems were encountered when the set of activity dummies were included in that portion of the model. It might reasonably be argued that the types of management decisions, especially with regard to thermal comfort, will differ across activities, and that these activity dummies belong in the one-sided error term portion of the model, at least to the extent that they capture management decisions as opposed to physical building characteristics.

## **V Results**

The stochastic frontier model was run in both Limdep 8.0 [25] and FRONTIER 4.1 [26]. Both programs, using different default starting values, yield identical values of the log-likelihood and model coefficients that coincide to several decimal places, the only difference being a different sign convention on the parameters of the one-sided error portion of the model. The inefficiency (EI) values reported were calculated in FRONTIER 4.1. The results from both an Ordinary Least Squares regression (which will be consistent but inefficient in the presence of a one-sided inefficiency error) and the Stochastic Frontier regression are presented in Table 3.1. In the Ordinary Least Squares version of the model, there is no statistical distinction made between the variables contained in  $x_i$  and those contained in  $z_i$ .

The LR test for the one-sided error calculated in FRONTIER 4.1 yields a value of 201.3, indicating that the stochastic frontier results provide a significant gain in efficiency over the Ordinary Least Squares regression. Also, the parameter  $\lambda$  (lambda), the ratio of the estimated standard deviation of the one-sided error to the estimated standard deviation of the composite error, is significantly different from zero. This indicates that not all of the sources of inefficiency are captured through the explanatory variables, thus providing further evidence of the (statistical) efficiency gains from a stochastic frontier approach.

The stochastic frontier portion of our model indicates which building and exogenous environmental characteristics have significant impacts on the intensity of energy utilization. The results indicate that larger buildings use energy less intensely. As would be expected, heating degree days have a positive impact on the intensity of energy use, while cooling degree days have an impact on energy use intensity only when interacted with the air-conditioning dummy. The more intensely the building is used, in terms of the number of hours of operation and the number of workers, the more intensely energy is used. Buildings which are partially vacant are less energy intensive, while those that are dedicated to a single use, tend to use energy more intensely.

It appears that only a few of the specific physical characteristics available in our data set have significant individual impacts on the location of the stochastic energy frontier. Buildings that use district hot water or packaged units for heating purposes, use energy more intensely than those using standard furnaces. Compared to fuel/heating oil, the use of electricity or liquid petroleum gas or propane leads to a lower intensity of energy use, while the use of natural gas increases energy use intensity. Some of these differences may be due to differences in fuel prices, allowing higher comfort level settings when less expensive fuels are used. Unfortunately, building specific energy cost data were not collected in the survey. While the type of heating equipment and the choice of main heating fuel matter, specific HVAC conservation features do not. Similarly, lighting conservation features have no significantly distinguishable impact on the location of the stochastic energy frontier.

In terms of building envelope thermal integrity variables, the window-to-wall ratio has an impact on the intensity of energy use, but the type of window chosen does not. Wall type matters, with concrete and curtain walls leading to increased intensity of energy use. Also, buildings with walls adjoined to other buildings tend to use energy less intensely. None of the roof type variables were significant, either individually or jointly. In fact, in all cases where no individual features in a group are significant, likelihood

ratio tests indicate that these variables are also not jointly significant at any standard level of significance.

Are Canadian commercial sector buildings energy efficient? The minimum possible inefficiency attainable according to equation (3) is 1, while the maximum is not bounded. Inefficiencies estimated from our stochastic frontier model range from 1.13 to 51.94 with 785 buildings (or more than two-thirds of the sample) having inefficiency ratings below the average of 2.70. The average inefficiency value by building classification is presented in the final column of Table 1. The building classifications associated with above-average inefficiency are: Retail- Food (4.32), Services- Food (5.59), Indoor Entertainment & Recreation (4.14) , Warehousing/ Storage (2.87) , Cultural Centres / Public Halls / Public Worship / Public Assembly (3.07). The least efficient building in the sample is from the Services – Food classification.

In terms of the factors that affect whether or not a particular building manages to come close to attaining the maximum achievable energy efficiency, as defined by the stochastic frontier, two distinct factors have significant impacts. First, building ownership matters. Both government-owned buildings and those owned by non-profit groups tend to be farther away from the frontier, with the difference being statistically significant for those buildings owned by non-profit organizations. This implies that privately owned buildings tend to achieve a higher level of energy efficiency, holding other factors constant. Second, as is evident from the average inefficiencies cited above, the main type of activity undertaken in the building also has an impact on the efficiency of energy use. Building management in situations with different client and worker requirements can lead to differences in energy use intensity. It seems to be primarily those buildings where customers tend to spend prolonged periods of time on the premises that use more energy per conditioned square foot, after controlling for physical building characteristics. This could be related to a strategy of providing for thermal comfort levels that will be conducive to retaining customers, comfort levels that go beyond what are standard in other types of business environments.

The results of this study have some potential policy implications in terms of appropriate targeting of efforts aimed at improved energy efficiency in the commercial sector in Canada. Non-private sector buildings, especially those owned by non-profit organizations, may be worthy of particular attention in terms of campaigns aimed at energy awareness. Given that these buildings comprise under 10 percent of our sample, the prospective for large-scale overall energy efficiency improvements from such a strategy may be limited. The other major group which might be targeted is those businesses whose customers spend significant amounts of time on-site, such as retail food and indoor recreation facilities. While some of the high energy requirements are likely to be due to energy requirements for the provision of services, some may be due to thermal comfort expectations of customers.

The stochastic frontier itself, is affected by the technological choices made by building owners. While increased adoption of structural features such as wall type or window-to-wall ratio can only be feasibly expected to occur as new buildings incorporate the most efficient types of structure, the adoption of other features through retrofit decisions may provide a strategy focus that could make inroads in terms of energy efficiency of the existing building stock. The major factors that may be adjustable, if considered to be cost effective by building managers, would appear to be those related to heating technology and fuel choice. When it comes to fuel choice decisions, whether or not decreasing energy use per conditioned square foot by switching fuels would be an overall positive move for the environment depends on factors such as the related greenhouse gas emissions, the impacts of extraction, and the method of generation.

## **VI Conclusions**

This study focuses on a determination of the physical and management characteristics that influence energy efficiency achievement in the commercial building sector in Canada. Using a cross-section of data from commercial buildings in the CIBEUS data set, we find that energy efficiency in this sector can be meaningfully

modeled in terms of a stochastic efficiency frontier. Physical characteristics relating to structural and climate-control features of the buildings determine the location of the frontier, while management-related variables concerning such factors as ownership-type and activities undertaken govern how close any particular building's energy efficiency is to that which is maximally attainable.

Using the numerical scale suggested by Battese and Coelli [2], the estimated efficiencies for the 1091 buildings included in our study range from a best score of 1.13 (which is quite close to the theoretical minimum value of 1) to a high of 51.94. Over two-thirds of all buildings are below the sample average of 2.71. Although on average, buildings appear to be fairly efficient, certain types of operations, including those housed in buildings owned by non-profit groups and those catering to a customer-base who spend significant amounts of time on-site, are the most likely buildings to exhibit energy inefficiencies that are significantly different from the average. These results, along with those related to the effects of physical characteristics on the location of a particular building along the frontier, suggest that there is room for focused policy initiatives to increase energy efficiency in this sector.

## Acknowledgements

<sup>1</sup> The authors gratefully acknowledge funding from Natural Resources Canada through the Canadian Building Energy End-Use Data and Analysis Centre (CBEEDAC).

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**Table 1: Building Types and Energy Use**

Building Classification	Energy use per heated square foot			Average Inefficiency
	Mean	Median	Standard Deviation	
1 Office Space (Gov't) (N=207)	.1215	.0950	.1083	1.87
2 Retail- Food (N=48)	.3105	.2516	.2331	4.32
3 Retail- Non-Food (N=178)	.1151	.0910	.0907	1.86
4 Services- Food (N=98)	.4678	.4285	.3243	5.59
5 Services- Non-Food (N=167)	.1559	.1069	.1679	2.08
6 Enclosed Mall (N=19)	.1020	.0723	.1337	2.24
7 Strip Mall (N=109)	.1581	.0901	.1761	2.56
8 Indoor Entertainment & Recreation (N=58)	.2869	.1472	.8281	4.14
9 Warehousing/ Storage (N=121)	.1822	.0893	.3170	2.87
10 Public Admin (Police, Fire, Courthouse, Jail) (N=37)	.1481	.0789	.2869	1.78
11 Cultural Centres / Public Halls / Public Worship / Public Assembly (N=49)	.1761	.0935	.2457	3.07

**Table 2: Selected Summary Statistics**

(N=1091)	Minimum	Maximum	Mean	Std. Deviation
Energy use per heated sq.ft. (%building heated x area + heated parking area)	.01	8.00	.19	.293
Year of construction	1830	1999	1967.33	29.228
Building area (excluding indoor parking and mechanical areas)	1000.00	1539203.00	27268.5948	76368.782
Number of floors (excluding indoor parking and mechanical areas)	1	21	2.14	1.861
Indoor parking Flag	0	1	.04	.195
Number of walls shared with another building (ground level or higher)	0	3	0.27	.588
Vacancy Flag (Partial)	0	1	.03	.164
Flag for single use occupancy	0	1	.53	.499
Number of people working in building during main shift 2000	1	1500	47.59	121.199
Total number of hours of operation per week	4.00	168.00	69.56	32.274
Building subject to seasonal activity (Yes=1, No=0)	0	1	.07	.253
Heating Degree Days	2741.40	5906.80	4343.58	876.157
Cooling Degree Days	14.00	393.80	155.76	95.520
Insulation Retrofits in 2000 (1=yes, 0=no)	0	1	.02	.124
Insulation Retrofits made prior to 2000 (Yes=1, No=0)	0	1	.12	.320
Lighting Retrofits in 2000 (1=yes, 0=no)	0	1	.03	.181
Lighting Retrofits made prior to 2000 (Yes=1, No=0)	0	1	.14	.350
Windows with reflective glass or shading film (Yes=1, No=0)	0	1	.26	.437
AC Flag (0=No, 1=Yes)	0	1	.84	.371
Regularly scheduled HVAC maintenance and repair	0	1	.79	.407
Private ownership Flag	0	1	.84	.365
Government ownership Flag	0	1	.07	.250
Non-Profit Organization	0	1	.09	.287

**Table 3: Regression Results**

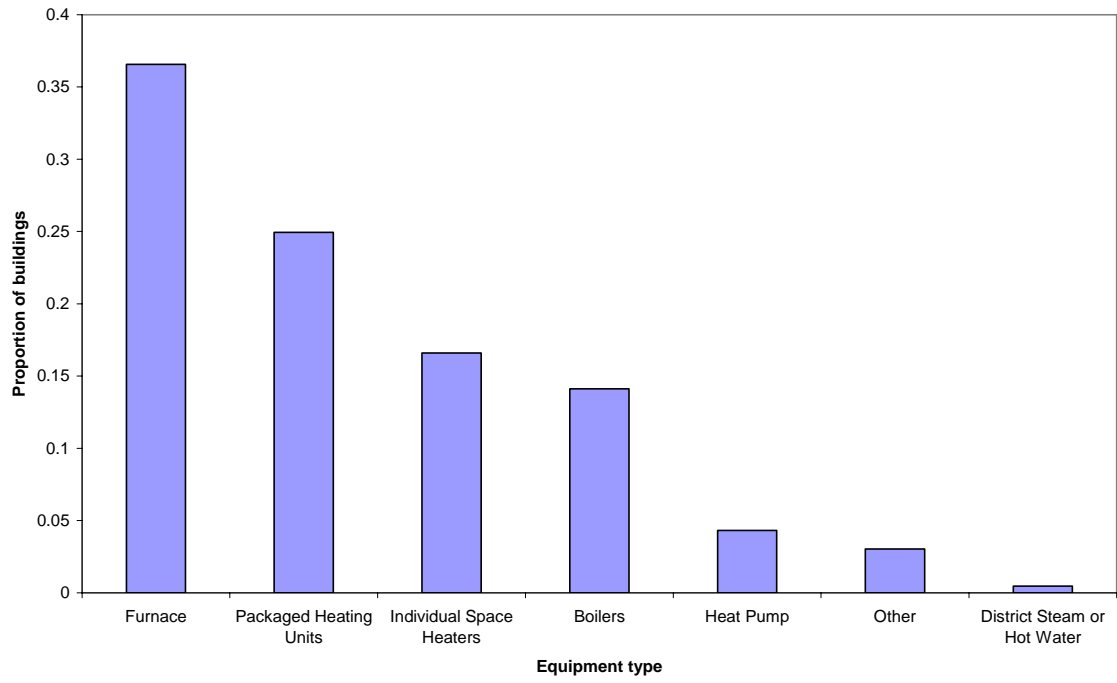
Variable	Stochastic Cost Frontier		OLS	
	<b>Primary Equation</b>			
Constant	-5.5436***	(1.0897)	-4.6544***	(1.0928)
log(size)	-0.3595***	(0.0258)	-0.3871***	(0.0301)
log(number of floors)	0.0397	(0.0497)	0.0568	(0.0531)
log(age)	0.0585	(0.0495)	0.0359	(0.0458)
log(cooling deg days)	-0.0156	(0.0392)	-0.0335	(0.0388)
log(heating deg days)	0.3703***	(0.1264)	0.3671***	(0.1213)
log(hours)	0.3971***	(0.0565)	0.4197***	(0.0585)
log(workers)	0.2328***	(0.0253)	0.2413***	(0.0270)
log(age:roofins retrofit)	-0.0236	(0.0370)	-0.0238	(0.0335)
log(age:wallins retrofit)	0.0177	(0.0432)	0.0197	(0.0406)
log(age:light retrofit)	0.0256	(0.0209)	0.0207	(0.0203)
Partial Vacancy Dummy	-0.2713**	(0.1287)	-0.3047**	(0.1355)
Single-use Dummy	0.1656***	(0.0474)	0.1388***	(0.0479)
Indoor Parking Dummy	-0.1461	(0.1159)	-0.1618	(0.1241)
Seasonal Activity Dummy	0.0258	(0.0808)	0.0937	(0.0895)
Air Conditioning Dummy	0.4986	(0.3586)	0.6200*	(0.3769)
AC Dummy x log(cdd)	-0.0676**	(0.0329)	-0.0504	(0.0323)
<b>AC type (omitted category: no AC)</b>				
residential	-0.1792	(0.3320)	-0.3785	(0.3538)
heat pump	-0.3522	(0.3643)	-0.5235	(0.3808)
individual room	-0.2250	(0.3440)	-0.3885	(0.3611)
central chillers	-0.0889	(0.3339)	-0.2919	(0.3610)
Packaged units	-0.1694	(0.3296)	-0.3661	(0.3502)
swamp coolers	0.0555	(0.5540)	-0.0491	(0.5458)
other	-0.0979	(0.3766)	-0.1605	(0.3967)
<b>Window features (omitted glazing category: double glazed)</b>				
Window-to-Wall Ratio	0.0039***	(0.0015)	0.0026*	(0.0013)
tint or shading	0.0478	(0.0535)	0.0304	(0.0545)
single glazed	-0.0512	(0.0675)	-0.1013	(0.0645)
triple glazed	-0.1735	(0.1647)	-0.1158	(0.1865)
double glazed: sealed	-0.0446	(0.0547)	-0.0398	(0.0573)
double glazed: low-E coat	-0.1408	(0.1047)	-0.1449	(0.1076)
triple glazed: low-E coat	0.2833	(0.9005)	-0.0315	(0.5145)
double glazed: low-E gas	0.1084	(0.1445)	0.0528	(0.1248)
triple glazed: low-E gas	-0.0921	(0.4162)	-0.0362	(0.3011)
<b>Heating, Ventilation, Air Conditioning Conservation features</b>				
variable air volume	0.0225	(0.0588)	-0.0086	(0.0560)
outdoor-air economizers	-0.0204	(0.0551)	-0.0295	(0.0541)
temperature setback	-0.0064	(0.0546)	0.0001	(0.0541)
equipment reset	0.0379	(0.0580)	0.0410	(0.0579)
heat recovery	0.0726	(0.0680)	0.0772	(0.0688)
<b>Heating Equipment Type (omitted category: furnace)</b>				
heat pumps	0.2068	(0.1765)	0.0684	(0.1828)
space heaters	0.0141	(0.0684)	-0.0036	(0.0766)
district steam	0.5568	(0.4886)	0.5958	(0.4200)
district hot water	0.1544*	(0.0826)	0.1344*	(0.0785)
boilers	0.0990	(0.0671)	0.0929	(0.0655)
packaged units	0.4190***	(0.1524)	0.3718***	(0.1322)
<b>Heating - Main fuel used (omitted category: fuel/heating oil) †</b>				
electricity	-0.3520***	(0.1273)	-0.2345*	(0.1245)
natural gas	0.2318*	(0.1191)	0.2711**	(0.1115)
bottled gas, lpg, propane	-0.6021***	(0.1793)	-0.4535**	(0.1987)
<b>Wall type (omitted category: metal stud with surface insulation)</b>				
curtain	0.2421*	(0.1335)	0.3032**	(0.1385)
metal stud, not insulated	0.1652	(0.2006)	0.1092	(0.1853)
wood frame, insulated	-0.0499	(0.0790)	-0.0250	(0.0816)
wood frame, not insulated	-0.0696	(0.1320)	-0.1199	(0.1362)
concrete block	0.0972	(0.0649)	0.0631	(0.0665)

concrete, interior finish	0.1505*	(0.0862)	0.1301	(0.0876)
pre-cast panel	0.1649	(0.1415)	0.1136	(0.1414)
<b>Other Wall features</b>				
One Adjoining Wall Dummy	-0.0055	(0.0654)	0.0195	(0.0677)
Two Adjoining Walls Dummy	-0.1453*	(0.0794)	-0.1082	(0.0943)
Three Adjoin Walls Dummy	-0.2831	(0.9964)	-0.5600	(0.4108)
<b>Roof type (omitted category: attic roof, not insulated)</b>				
attic, fully insulated	-0.1861	(0.1304)	-0.1803	(0.1531)
attic, partial insulation	0.0399	(0.1720)	0.0212	(0.1853)
wood truss, insulated	-0.1127	(0.1387)	-0.1203	(0.1528)
wood truss, not insulated	-0.0089	(0.1521)	0.0648	(0.1813)
metal truss, insulated	0.0453	(0.1309)	0.0530	(0.1530)
metal truss, not insul.	0.0631	(0.1727)	0.1562	(0.1911)
deck type, insulated	0.0004	(0.1229)	0.0205	(0.1452)
deck type, not insulated	0.0545	(0.1478)	0.1331	(0.1709)
<b>Lighting Features (&gt;50%)</b>				
specular reflectors	0.0718	(0.0797)	0.0361	(0.0734)
energy-efficient ballasts	0.0922	(0.0705)	0.0630	(0.0655)
daylight controls	0.1702	(0.1431)	0.2173	(0.1383)
occupancy sensors	-0.0057	(0.1352)	0.0641	(0.1744)
time switches	0.0695	(0.1000)	0.0442	(0.0969)
manual dimmers	0.0947	(0.1149)	0.1154	(0.1092)
energy efficient lamps	-0.0946	(0.0701)	0.0391	(0.0707)
other	0.0208	(0.1034)	0.0398	(0.0978)
<b>One-sided error mean</b>				
Constant	0.1418	(0.3514)		
Non-profit Owner Dummy	0.4112**	(0.1852)	0.1738*	(0.0950)
Government Owner Dummy	0.4737	(0.2890)	0.2289*	(0.1217)
HVAC Regular Maint. Dummy	0.1389	(0.1278)	0.1016*	(0.0586)
Economic Comp. Dummy	0.1310	(0.1501)	0.0790	(0.0608)
Environmental Concern	-0.0007	(0.1514)	0.0210	(0.0596)
Special Funding	-0.0353	(0.1427)	0.0351	(0.0579)
Other Incentives	-0.1141	(0.2028)	-0.0771	(0.0827)
<b>Main Activity (omitted category: strip mall)</b>				
Office Space	-0.7544**	(0.3078)	-0.2259**	(0.0987)
Retail: food	0.8845***	(0.3261)	0.5615***	(0.1323)
Retail: non-food	-0.6026**	(0.2982)	-0.1561*	(0.0943)
Services: food	1.0577***	(0.2801)	0.7142***	(0.1100)
Services: non-food	-0.3639	(0.2533)	-0.0783	(0.0956)
Enclosed Mall	-0.3823	(0.4695)	-0.1150	(0.1990)
Recreation/Entertainment	0.4199*	(0.2537)	0.3013**	(0.1316)
Warehousing/Storage	0.0886	(0.1948)	0.0695	(0.1026)
Public Administration	-1.2162*	(0.6784)	-0.4239**	(0.1788)
Public Assembly	-0.0787	(0.2989)	-0.0648	(0.1559)
<b>Lambda: <math>\sigma_v/\sigma_{\varepsilon+v}</math></b>				
	1.88792***			
$\sigma_v^2$	0.17236		0.47443	
$\sigma_{\varepsilon+v}^2$	0.61432			
N	1091		1091	
R-squared (adjusted)			0.4215	
Log-likelihood	-1071.973		-1094.348	

\*\*\* significant at 1% \*\* significant at 5% \* significant at 10%  
(standard errors in parentheses)

† district steam/hot water energy types are also omitted due to perfect multicollinearity with other variables in model.  
Jointly significant groups (LR test): wall type, heating equipment type, and main energy source - heating

**FIGURE 1: Heating Equipment**



**FIGURE 2: HVAC Conservation Features**

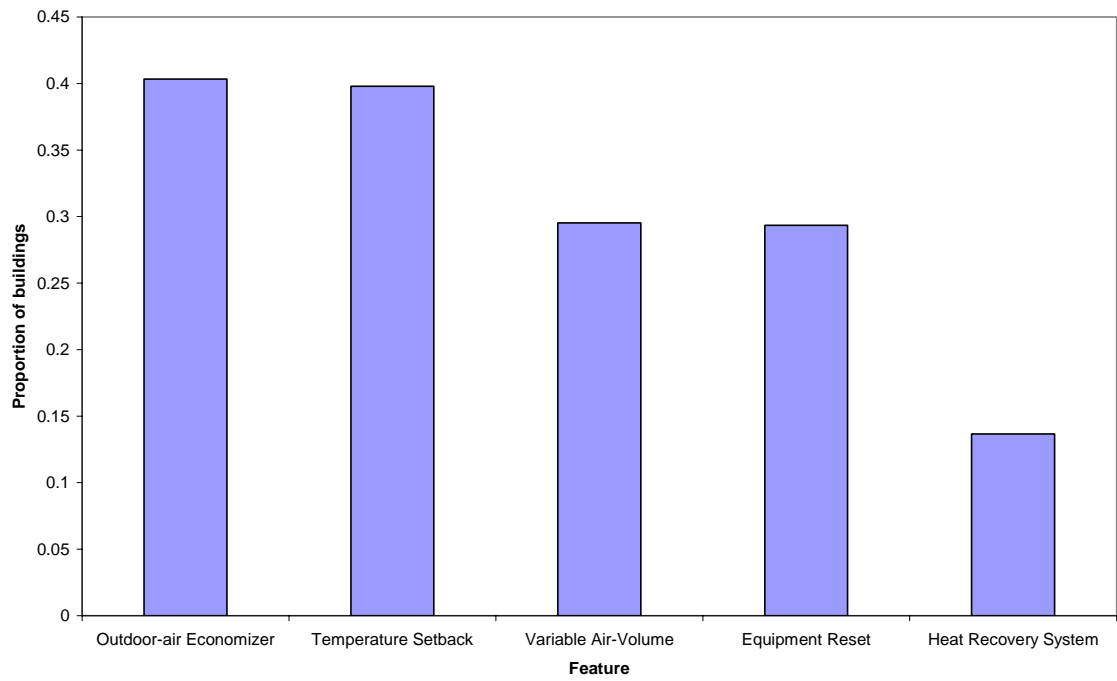


Figure 3: Main Fuel (Heating)

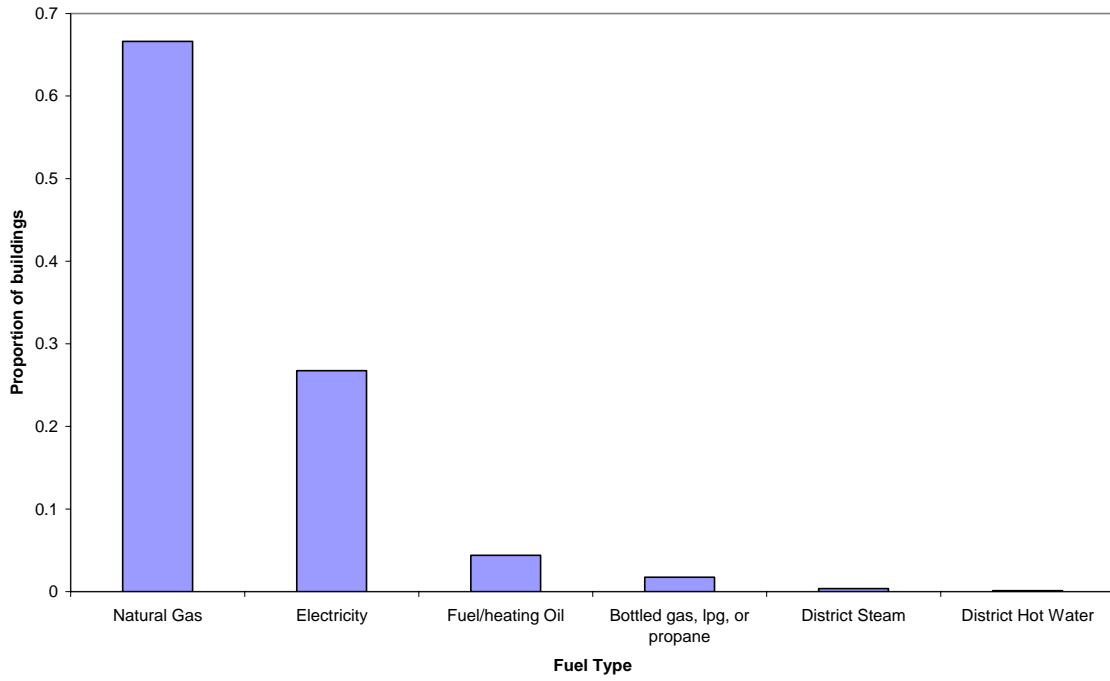
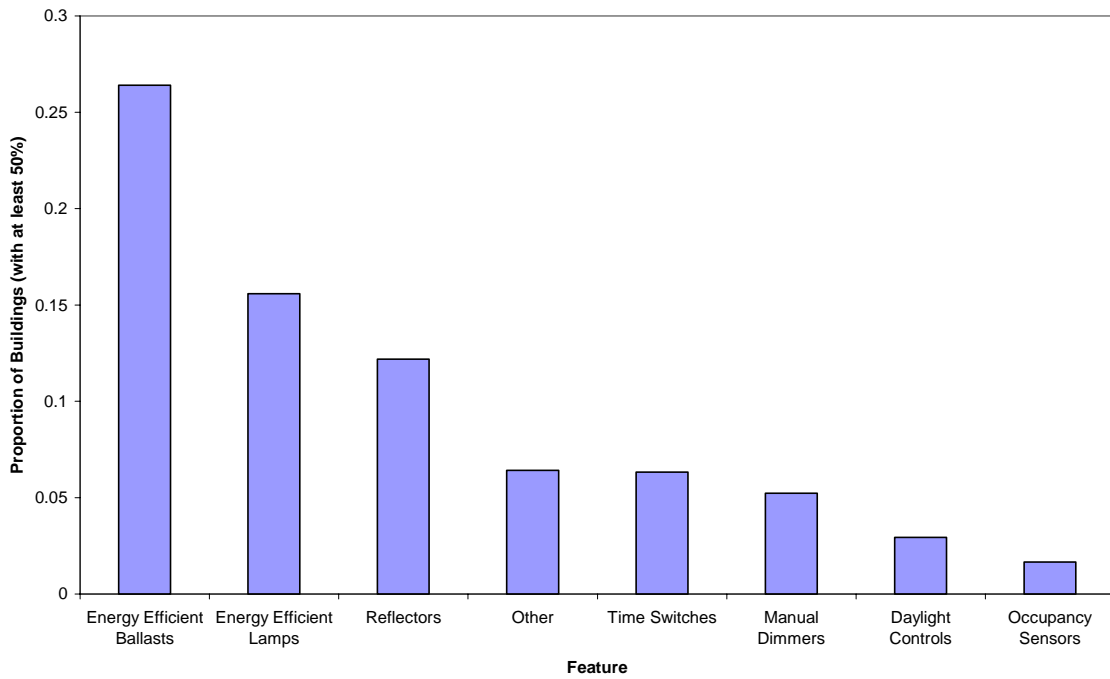


Figure 4: Lighting Conservation Features



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