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enerInfo BUILDING

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Evaluating Energy Efficiency in Commercial Buildings

A reduction in energy use can lead to lower costs, a slowing down of the depletion of exhaustible energy sources, and a decrease in the emission of greenhouse gases. These benefits may be available - without affecting activity levels - if there are inefficiencies that can be addressed in current patterns of energy consumption in buildings.

However, determination of whether energy inefficiencies exist, and the extent of any such inefficiencies in a particular building, cannot be readily ascertained simply by comparing the energy use or intensity in different buildings. Evidence that similar buildings use different total amounts of energy is not necessarily indicative of the presence of inefficiencies, since even where no such inefficiencies exist, energy will be used more intensely in some buildings than in others. For example, a building that is open for 24 hours per day will tend to use more energy than one that is only open for 10 hours per day, while some buildings are located in areas with more favourable climatic conditions than others.

In this newsletter we highlight a recent study by CBEEDAC researchers that examined the extent of, and the factors associated with, inefficiency in energy consumption in Canadian commercial buildings. In this analysis, which utilized energy consumption data and information on other building characteristics in 2000 from the Commercial and Institutional Building Energy Use Survey (CIBEUS), a "Stochastic Frontier" approach was utilized. This approach recognizes that there is a level of energy efficiency that is hypothetically attainable, but that not all buildings will use energy this efficiently, nor as efficiently as their best-performing counterpart. The methodology allows a determination of which building, activity, and owner characteristics play significant roles in the attainment of energy efficiency and what sort of policy options might be utilized in order to encourage more efficient use of energy.

EFFICIENCY FRONTIERS

J. Buck & D. Young

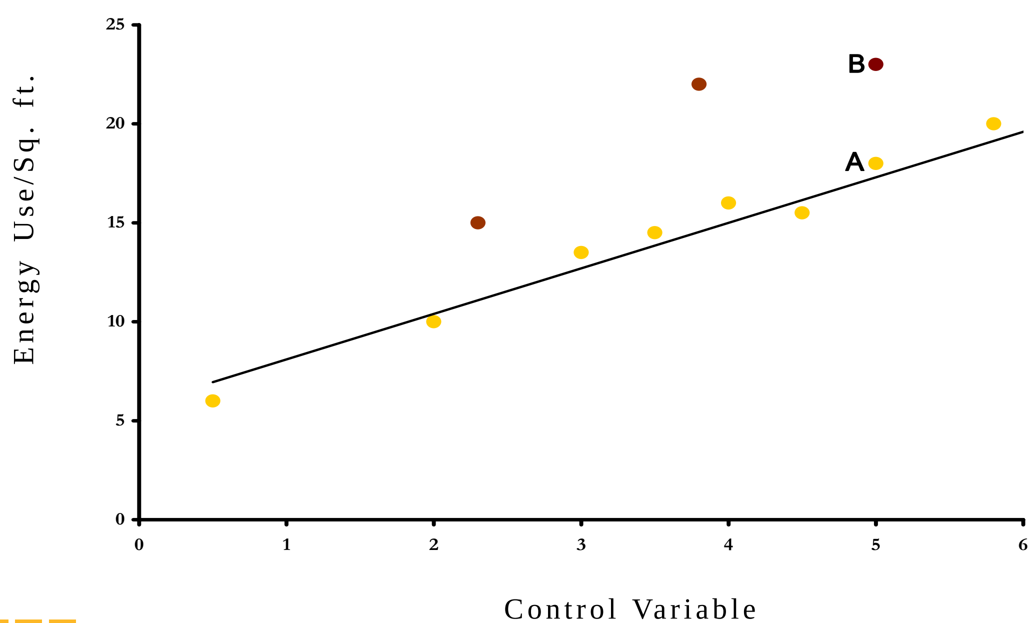
Stochastic frontier models, which have been used for many years to measure inefficiencies in applications ranging from production technology to firm valuations and sports performance, can be readily adapted to study energy efficiency in buildings. The stochastic frontier approach explicitly recognizes that, given the activities undertaken in a building and the technology choices made, not all agents will use energy efficiently. Some differences in energy use will be due to random factors (climate, equipment malfunctions, etc.) while other differences reflect the way in which building occupants use the available technology (thermostat settings, turning off lights, etc.).

The location of the stochastic energy efficiency frontier for commercial buildings is determined by estimating a function that relates measured energy efficiency (energy use per square foot) to variables that reflect location and climate, building characteristics, activities, and occupancy characteristics, as well as a usual two-sided (positive or negative) error term that reflects random factors such as weather shocks, technological malfunctions, measurement error, etc. However, in contrast to a typical specification, the equation that is estimated using a stochastic frontier approach also includes a non-negative random error term that indicates the extent to which building occupants use energy efficiently – the larger the error term, the less efficient is the use of energy in a particular building. This one-sided inefficiency measure, which depends on characteristics that determine the extent to which energy use in a particular building exceeds the efficient amounts indicated by the stochastic frontier, can be statistically modeled as a function of building owner characteristics and other relevant variables.

A two-dimensional stochastic frontier is represented by the yellow dots in Figure 1. Due to random positive or negative errors, these buildings – which use energy efficiently – do not lie along the non-stochastic part of the frontier depicted by the solid line. Buildings that are energy-inefficient – that use more than the minimal required amount of energy – are represented by the red dots (above the stochastic frontier).

For example, consider the building denoted by point A in Figure 1, which lies slightly above the non-stochastic part of the efficient frontier due to an unfavourable random shock. Another building which has the same characteristics and encounters the same random shock, but which uses energy inefficiently, is indicated by point B which

Figure 1: Stochastic Frontier



lies above A - an inefficient building will always be above the stochastic frontier. The extent of inefficiency is assumed to be related to, among other things, the commitment of building owners and occupants to energy conservation and the types of activities undertaken.

The CBEEDAC study uses energy consumption data and information on other building characteristics from the CIBEUS data set, a survey of Canadian commercial buildings conducted in 2001. These data are supplemented with city-specific degree day data from Environment Canada. The final sample consists of data for 1091 buildings for which 'energy use per square foot' can be considered as an informative measure. Summary information on the types of buildings included in the study and their average energy use is provided in Table 1.

Statistical tests on the model indicate that there are inefficiencies in energy use, and that the stochastic frontier framework is appropriate. The model implies a simple formula for an efficiency index (=1 for a fully efficient building). Average values for various building classifications are presented in Table 1. Based on the estimated frontier model, there are two main policy questions of interest that can be addressed:

(1) Can the frontier be shifted?
(2) Can building owners and occupants be induced to make decisions that will move (at least some) buildings closer to the frontier?

In response to the first question, 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.

The type of heating equipment and the choice of main heating fuel matters, but 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.

Table 1: Building Types and Energy Use

Building Classification	Mean Energy Use/sq. ft.	Avg. Inefficiency (Efficiency=1)
Office Space (Gov't) (N=207)	0.1215	1.87
Retail- Food (N=48)	0.3105	4.32
Retail- Non-Food (N=178)	0.1151	1.86
Services- Food (N=98)	0.4678	5.59
Services- Non-Food (N=167)	0.1559	2.08
Enclosed Mall (N=19)	0.1020	2.24
Strip Mall (N=109)	0.1581	2.56
Indoor Entertainment & Recreation (N=58)	0.2869	4.14
Warehousing/Storage (N=121)	0.1822	2.87
Public Admin (Police, Fire, Courthouse, Jail) (N=37)	0.1481	1.78
Cultural Centres/Public Halls/Public Worship/Public Assembly (N=49)	0.1761	3.07

(continued on next page....)

Also, buildings with walls adjoined to other buildings tend to use energy less intensely.

As for the second question, two distinct factors have significant impacts on how far a particular building is away from the efficient frontier. First, building ownership matters – 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 shown in Table 1, 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. Primarily, those buildings where customers tend to spend prolonged periods of time on the premises tend to 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 potential policy implications for the 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. However, these buildings comprise under 10 percent of our sample, so that 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 is itself 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.

Further details on the study and results are available from CBEEDAC.

BUILDING SERVICES

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If you house and/or collect data that could become a valuable addition to Canada's Building Energy End Use information system please consider contacting the Centre with your data information.