ANALYSIS OF ENERGY PERFORMANCE OF A SAMPLE OF 115 HOMES IN MONTREAL

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ABSTRACT

Information about the actual energy performance of different building types is essential for understanding how the energy is used and for developing the appropriate energy-efficient strategies. This paper presents the analysis of a sample of 115 homes in Montreal, Canada, which was performed using information from utility bills as well as general data on construction and occupancy. The distribution of homes in the sample in presented in terms of year of construction and size. The PRISM (PRInceton Scorekeeping Method) computer program was used to evaluate normalized energy consumption and cost. The results of this study are compared with information from a data base developed by a Canadian housing corporation and from the residential energy consumption survey performed by the U.S. Department of Energy.

INTRODUCTION

Information about the actual energy performance of homes is essential for understanding how the energy is used and for developing the appropriate energy-efficient strategies. A sample of 115 homes was used to evaluate the energy performance of homes in Montreal. Utility bills, which are, in fact, the only reliable source of information on the energy history of each house, were used in this study. In addition, some general construction and operation data were collected during the interviews with homeowners. To compare the energy consumption of homes using different fuels (e.g., electricity measured in kWh, oil in liters and natural gas in m^3), the oil or gas consumption was expressed in equivalent-kWh:

$$\text{Equivalent-kWh} = \frac{\text{Oil/gas consumption} \cdot \text{Hv}}{3.6} \qquad (1)$$

where oil/gas consumption is expressed in liters of oil or m^3 of natural gas; and Hv is the heating value of fuel, which was assumed to be equal to 39.0 MJ/(L of oil) or 37.3 MJ/(m^3 of natural gas).

The energy consumption and cost were first normalized in terms of heated floor area, which allows for the comparison of homes of different sizes, and were expressed in kWh/m^2·yr and \$/m^2·yr. The second type of normalization eliminated the impact of different climatic conditions to allow for the comparison of the energy performance of homes, which was monitored in different years. The reference weather conditions correspond to the long-term average from 1974 to 1993, as measured at the Dorval airport in Montreal. The weather-normalized energy consumption and cost were evaluated using PRISM (Fels et al. 1986). This weather-normalization method was initially created to calculate changes in energy consumption in a group of heated houses without cooling and then was developed to evaluate changes in electricity consumption in houses with cooling systems and using another fuel for heating. These options correspond to the heating-only and cooling-only models in the PRISM program. The PRISM program assumes a linear relationship between the energy consumption and the heating degree-days:

$$E_i = a + b \cdot H_i(T_{REF}) \quad [\text{kWh/m}^2 \cdot \text{day}] \qquad (2)$$

where

E_i = daily average energy consumption for the interval i;

a = base load or non-weather-dependent energy consumption (this term refers to the energy consumption that is assumed to be independent of outdoor air temperature, such as lighting, appliances, or domestic hot water);

b = slope of the weather-dependent energy use;

$H_i(T_{REF})$= heating degree-days per day computed with respect to the reference temperature T_{REF} within the interval i.

Initially, for a guess of the reference temperature T_{REF}, the least-square linear regression is used to evaluate the parameters a and b using the utility bills and the corresponding daily average outdoor temperatures. Then, using an iterative process based on Newton's method, the reference temperature, T_{REF}, is obtained as the value for which the mean-squared error is minimized. The corresponding values of parameters a and b are the best

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estimates of base-level and weather-dependent slope (Fels et al. 1986). The normalized energy consumption is then evaluated using the parameters a and b and the long-term annual average of the heating degree-days H_0 with respect to the reference temperature, T_{REF}:

$$\mathrm{NAC} = 365 \cdot a + b \cdot H_0(T_{REF}) \quad [\mathrm{kWh/m^2}] \qquad (3)$$

The second term of Equation 3 gives an estimate of the contribution of heating to the total energy consumption.

ANNUAL ENERGY PERFORMANCE

Annual total energy performance, expressed in equivalent-kWh/m^2·yr and \$/m^2·yr, is presented in Table 1 with respect to the year of construction and in Table 2 with respect to the heated floor area. Note an important reduction of total energy consumption of homes built after the oil crisis of 1973, from 253 to 162 kWh/m^2·yr, or a reduction of about 40%. For the same period, the reduction of energy cost was about 20%, from 11.6 to 9.2 \$/m^2·yr. In 1971, most homes in Quebec used oil as the main source for heating (83%), while only 8% of homes used natural gas and 7% used electricity (Observatoire 1994). In 1980, about 37% of homes used electricity for heating, 53% used oil, and 6% used gas. In 1992, electricity was used as the main source for heating in about 68% of homes in Quebec, while only 19% used oil and 8% used gas. Since 1980 the rate of penetration of electric heating in homes in Quebec, including new construction and the conversion to electricity in old homes, was between 90% and 96%.

TABLE 1 Energy Performance of the Sample Houses in Montreal vs. Year of Construction

Year	% of Total Number	kWh/m²yr	\$/m²yr
<1921	4	256.2	12.2
1921-1945	4	276.0	17.1
1946-1960	18	310.1	12.0
1961-1970	32	253.0	11.6
1971-1980	25	162.3	9.2
1981-1985	6	182.6	9.4
>1985	11	162.2	9.0

TABLE 2 Energy Performance of the Sample Houses in Montreal vs. Heated Floor Area

m²	% of Total Number	kWh/m² yr	\$/m² yr
<100	15	240.1	12.7
100-149	13	248.8	12.2
150-199	28	206.6	11.1
200-249	22	232.8	9.8
250-299	11	218.0	9.3
300-349	6	211.5	9.3
350-450	5	213.3	8.6

TABLE 3 Contribution of Heating to the Total Energy Performance (%)

Year	Before 1921	1921-45	1946-60	1961-70	1971-80	1981-85	>1985
Consumption	77.5	80.8	71.5	70.6	62.2	58.8	73.4
Cost	69.4	76.2	58.6	59.1	56.6	50.7	65.8

Large homes have a lower normalized energy consumption and cost, expressed in kWh/m^2·yr, than the smaller ones (e.g., about 215 kWh/m^2·yr for homes larger than 250 m^2 compared to 240 kWh/m^2·yr for homes smaller than 150 m^2). However, the difference in normalized energy consumption between large and small homes is only about 11%. When the normalized energy cost is compared, the difference between large and small homes is about 32%.

Heating contribution to the total energy consumption is evaluated to be between 60% and 80%, while the contribution to the energy cost is about 50% to 76% (Table 3).

The results of the present study were compared with a data base that contains information on the residential stock in Canada (Parekh et al. 1992). Approximately 205 homes of Quebec are included in this data base. The distribution of the Quebec sample in terms of year of construction is as follows:

- before 1920, 6%
- 1921-1945, 12%
- 1946-1960, 32%
- 1961-1970, 19%
- 1971-1980, 20%
- 1981-1990, 10%.

Figure 1 shows a comparison of the annual heating energy consumption that was evaluated in the present study, called CBS, and the corresponding values of an average home in Quebec from the housing data base.

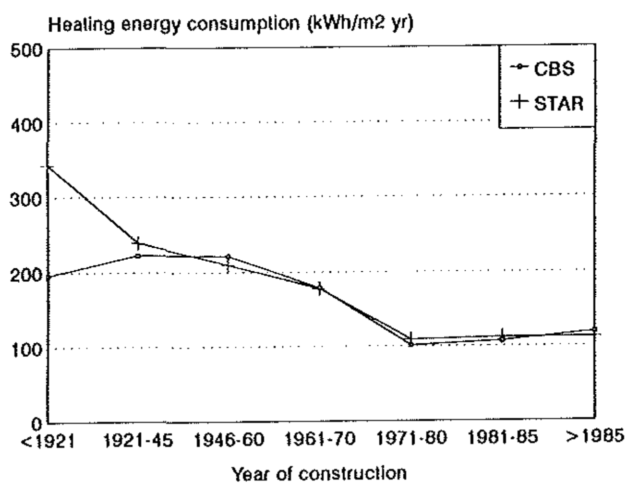

Figure 1 Annual heating energy consumption vs. year of construction. Comparison between the present study and the data base.

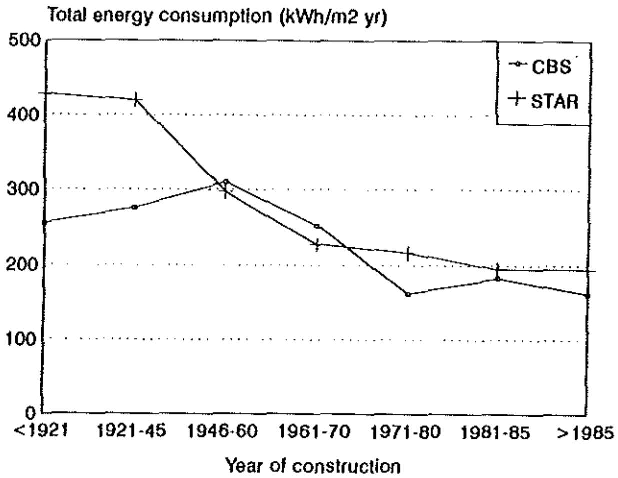

Figure 2 Annual total energy consumption vs. year of construction. Comparison between the present study and the data base.

There is good agreement for homes built after 1921. A comparison between the same two sources in terms of total energy consumption indicates a similar pattern for homes built after 1946 (Figure 2). The annual heating energy consumption of homes in Montreal was also compared with the corresponding values of homes in Ontario and with the average performance of homes in Canada (Figure 3). There is good agreement between the two sources concerning the contribution of heating to total energy consumption (Figure 4).

Table 4 shows a comparison of the energy performance of homes in Montreal, based on the present study, and the corresponding values of homes in the Northeast climatic region of the United States (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont) (EIA 1993a, 1993b). When the comparison regards only those locations in the northern United States with colder climatic

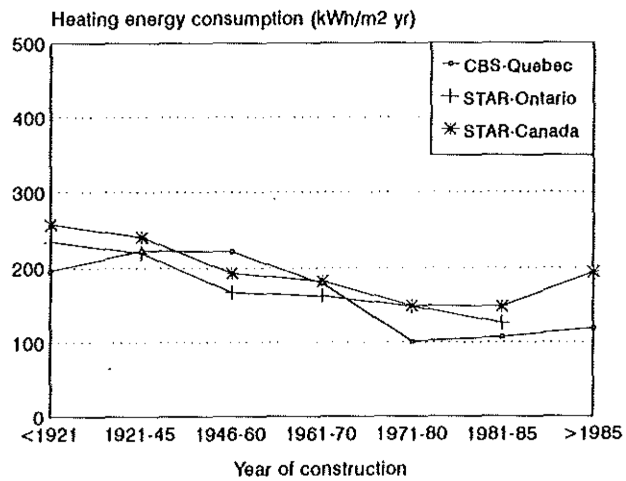

Figure 3 Annual heating energy consumption vs. year of construction. Comparison between the present study and the energy consumption of an average home in Ontario and of an average Canadian home.

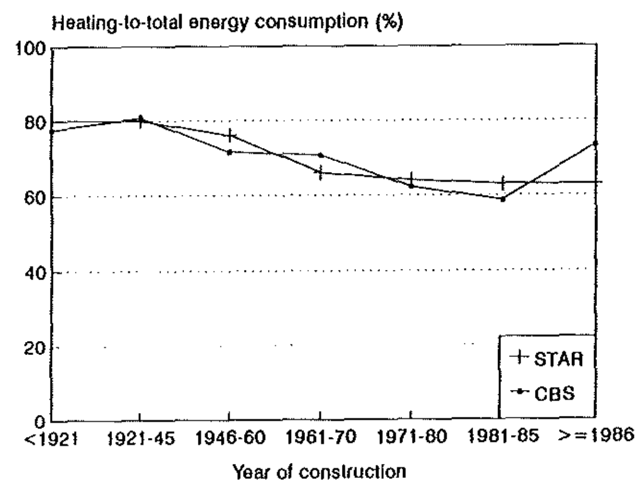

Figure 4 Contribution of heating to the total energy consumption. Comparison of the present study and the data base.

TABLE 4 Comparison of the Energy Performance of Houses in the Northeast Climatic Region of the United States and in Montreal

	Consumption (kWh/m^2 yr)		Cost* ($\$/m^2$ yr)		Heating-to-Total Consumption (%)		Heating-to-Total Cost (%)	
	USA	Montreal	USA	Montreal	USA	Montreal	USA	Montreal
Climate								
(>2800 HDD)	170.5	221.8	9.1	10.10	64.3	67.0	73.8	56.0
Heated floor area								
<100 m^2	322.0	240.1	17.9	12.7	57.4	65.0	38.6	50.0
100-199 m^2	198.9	220.3	10.8	11.4	60.6	66.0	39.6	60.0
>200 m^2	148.4	224.1	7.9	9.4	65.9	71.0	41.7	63.0
Year of Construction								
<1950	202.0	267.5	10.3	15.0	65.1	74.0	43.1	69.0
1950-1979	173.6	233.0	9.6	10.8	60.4	67.0	38.4	59.0
1980-1990	113.6	171.8	8.7	9.2	50.8	67.0	33.7	61.0

*Energy cost is presented in CAN$.

conditions (more than 2,800 heating degree-days [°C]), the contribution of heating to the total energy cost is lower in Montreal (56%) than in the U.S. (73.8%) for an almost equal contribution to the total consumption (67% vs. 64.3%). This is an interesting result, since one can expect a much larger contribution of heating to the total energy use in Montreal due to more severe climatic conditions (average heating degree-days is about 4500°C). The difference in heating cost between homes in Montreal and those in locations in the northern United States is mainly due to the energy cost for the residential sector: 5.26 cents U.S./kWh in Montreal, 12.36 cents U.S./kWh in Boston, and 14.96 cents U.S./kWh in New York (NRC 1994).

CONCLUSIONS

To better notice the potential for energy savings of the existing houses, their energy performance should be compared with that of some well-known energy-efficient houses in Canada, such as the R-2000 house (EMR 1987) and the Advanced House (ADV 1993). The average energy consumption of homes in Montreal that were built after the oil crisis of 1973 is about 160 to 180 kWh/m^2·yr (Figure 2). The energy performance of an energy-efficient home, known in Canada as "R-2000," has an average energy consumption of about 100 kWh/m^2·yr, and the "Advanced House" consumes only 50 kWh/m^2·yr. Therefore, there is a large potential for improving the energy efficiency of the existing homes in Montreal that were built after 1973. In the case of older homes, the potential for energy savings is even larger.

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