USE OF THE GLOBAL WARMING POTENTIAL INDEX TO EVALUATE THE IMPACT OF REDUCING THE AIR INFILTRATION RATES IN EXISTING HOUSES

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ABSTRACT

In a cold climate such as of Montreal the air infiltration through the exterior envelope of a house has a significant impact on the heating energy consumption and cost. Although the reduction of the air infiltration rate to the level of new well-built houses can lead to the reduction of heating energy cost, the present cost-effectiveness of its implementation in the existing houses is low. The evaluation of the environmental impact of this energy conservation measure is performed using the GWP (Global Warming Potential) index. This index is expressed in terms of carbon equivalent effect, and evaluates the combined global warming effect produced by several greenhouse gases.

INTRODUCTION

Existing houses should constitute an important target for the energy-related renovations, because their potential for improvement is much higher when is compared with houses built during the last 5-10 years, and also because of the large number of old houses in the residential stock.

In a cold climate such as of Montreal the air infiltration through the exterior envelope of a house has a significant impact on the heating energy consumption and cost. Consequently, the reduction of air infiltration rate is often used as an energy conservation measures. In most cases, the reduction of air infiltration rate does not exceed 1-2 ach, because of difficulties in implementing low cost renovations. The experience indicated that it is always easier and less expensive to built a new house in compliance with the building energy standards than to bring up the performance of an existing one to the same level of performance.

This paper evaluates the cost-effectiveness of this type of renovation, when the air infiltration rate is reduced up to the level of new well-built houses. The evaluation is performed with respect to two criteria: (i) the reduction of annual utility bills, and (ii) the reduction of Global Warming Potential (GWP) index; this index is expressed in terms of carbon equivalent effect, and evaluates the combined global warming effect produced by several greenhouse gases.

ACTUAL ENERGY CONSUMPTION OF HOUSES IN MONTREAL

The actual energy performance of a large sample of about 180 existing houses in Montreal is evaluated using a database of residential buildings in Montreal, developed by the author from several field studies [e.g., 1-3].

The utility bills were collected at each house along with some general construction and operation data. The annual energy consumption was normalized: (i) in terms of heated floor area, and (ii) with respect to the weather conditions of a long-term reference year. The weather-normalization technique is based on the assumption that the energy consumption of a house is composed of a non-weather-dependent component (e.g., for lighting and domestic hot water) which is almost constant throughout the year, and a weather-dependent component which varies linearly with the outdoor temperature. Annual normalized energy consumption, expressed in equivalent-kWh/m^2·yr, is presented in Table 1 with respect to the year of construction of the sample houses. Two trends are noticed: (i) the newer houses use less energy for heating than the older house, due to airtight and well insulated exterior envelopes and more efficient heating systems; and (ii) the fossil fuels, which are less expensive than the electricity per unit of thermal energy delivered into the houses, are mostly used in the older houses.

Table 1. Normalized annual energy performance of sample houses

Year of construction	Total energy consumption [kWh/m^2·yr] and cost ([\$/m^2·yr])	Contribution of heating [%]	Heating oil-to-total energy consumption [%]	Natural gas-to-total energy consumption [%]
< 1921	238 (11.1)	78	23.1	7.1
1921-1945	268 (15.0)	75	16.7	31.1
1946-1960	283 (11.6)	71	22.9	3.5
1961-1970	234 (10.8)	68	16.3	9.5
1971-1980	167 (9.4)	60	4.2	3.5
1981-1985	173 (9.7)	58	8.1	0
1986-1990	144 (8.5)	67	2.4	0
> 1990	124 (7.5)	60	0	0

EVALUATION OF POTENTIAL ENERGY SAVINGS

The air infiltration rate at 50 Pa pressure difference was measured, according to the Canadian standard CGSB-149.10, on a subset of 67 existing houses (Table 2). As expected, on the average, the new houses are tighter than the older ones. It is surprising to find out that most sample houses built after 1983 exceed the corresponding value for recently well-built houses, that is 3.0-3.3 ach. The target air infiltration rate of energy-efficient houses, which are known in Canada as R-2000 houses, is about 1.5 ach. Therefore, the reduction of air infiltration rate through the exterior envelope appears to have a significant potential for improving the energy performance of existing houses.

The impact of reducing the air infiltration rate was evaluated by computer simulation on a representative sample of 51 houses, for which detailed construction and operating data were collected during the field studies. A computer model for each house was developed using the HOT2000 program [4] and calibrated with the utility bills. Two levels of renovations were simulated: (i) the level 1, which corresponds to the reduction of the air infiltration rate to 3.3 ach; this is the target value used for new houses, since it corresponds to the average of new well-built houses; and (ii) the level 2, which corresponds to the target of 1.5 ach of a R-2000 house. If the house is brought to the level of a R-2000 house (level 2), a balanced mechanical ventilation system must be installed, with an air-to-air heat recovery ventilator to reduce the amount of energy used for the preheating of the ventilation air. The average expected energy savings are presented in Table 2. Although the potential energy savings is greater in the older houses, because they are leakier (e.g., 7.7 ach compared with the target of 3.3 ach), those houses use fossil fuels in a larger proportion, which are less expensive than the electricity per unit of thermal energy delivered. Therefore, the renovation of newer and older houses is expected to provide almost the same level of energy savings, expressed in dollars.

Table 2. Expected savings due to the reduction of air infiltration rate.

Year of construction	Average air infiltration rate measured at 50 Pa pressure difference [ach]	Expected savings due to the renovation [$/house□yr]	
		level 1	level 2
> 1921	7.3	93	131
1921-1945	7.7	112	126
1946-1960	7.7	145	280
1961-1970	6.9	58	90
1971-1980	6.9	111	280
1981-1985	5.3	188	130
1986-1990	4.9	128	223
> 1990	5.3	0	113

For the current cost of energy, materials and labour and including taxes, the reduction of air infiltration rate in existing houses up to the two levels 1 and 2 is not a cost-effective energy conservation measure: the simple payback period, for the renovation to level 1, is between 6 and 40 years, while for the second level is between 15 and 50 years.

EVALUATION OF GLOBAL WARMING POTENTIAL INDEX

The energy-related renovations contribute indirectly to the reduction of greenhouse emissions. The on-site emissions are due to the use of fossil fuels (e.g., heating oil, natural gas) as an energy source for the heating system. The on-site use of electricity does not generate greenhouse emissions. The pollution from the off-site generation of electricity depends on the contribution of different energy sources. In Quebec the hydro-electricity, which does not produce greenhouse gases, accounts for about 97% of electricity. The remaining 3% is produced mostly by the thermal generating plants using heating oil and natural gas.

The evaluation of the impact on the greenhouse gas emissions is performed using the pollutants coefficients developed by Liesen [5-6] (Table 3). The combined global warming effect produced by several gases is expressed, in terms of carbon equivalent effect, using the Global Warming Potential (GWP) index [7]. For instance, the instantaneous 20-year GWP for NO_x emissions is equal to 280, that is, one kg of NO_x emitted today will create the same global warming, every year of the next two decades, as 280 kg of CO_2.

Table 3. Coefficients used for the evaluation of GWP index.

	Pollutants coefficients [g/kWh]		GWP_{20} [kg of equivalent CO_2]
	Oil	Natural gas	
CO_2	263	178	1
NO_x	0.056764	0.212	280
HC	0.01321	0.0009	56

The emission of greenhouse gases is reduced proportionally to the GWP index as shown in Table 4. The calculations took into consideration the on-site contribution of fossil fuels to the annual heating energy consumption, and an overall efficiency of the power generating plants of 30%. Since significant amounts of fossil fuels are burned in the older houses for heating purposes, their renovation has a larger impact on the GWP index, than the renovation of newer houses.

Table 4. Environmental impact of reducing the air infiltration rate.

Year of construction	Renovation to level 1		Renovation to level 2	
	Average annual GWP [kg CO_2/house□yr]	Reduction [%]	Average annual GWP [kg CO_2/house□yr]	Reduction [%]
< 1921	382	1.5	542	2.12
1921-1945	502	2.4	563	2.7
1946-1960	495	1.9	941	3.5
1961-1970	191	0.9	301	1.4
1971-1980	103	0.4	258	0.9
1981-1985	251	0.9	174	0.9
1986-1990	83	0.2	146	0.3
> 1990	0	0	59	0

One can think that if environmental tax credits, evaluated in terms of the GWP index, can be deducted from the initial cost, then the investment in the reduction of air infiltration rate might become cost-effective for the homeowners. To evaluate this assumption, two values of the CO_2 tax were selected: (i) \$50/tonne of CO_2 [8], and (ii) \$200/tonne of CO_2 [9]. The results indicate that the CO_2 tax credits do not improve the cost-effectiveness of this type of renovation: the maximum reduction of the payback period is about one year.

The installation of a heat recovery ventilator in those houses which are renovated to the level 2 has a negative environmental impact due to the embodied energy of this equipment. For instance, a heat recovery ventilator of about 50 kg has about 1100 kWh embodied energy [10]. The GWP index, corresponding to this amount of embodied energy, is 200-400 kg CO_2 depending on the contribution of fossil fuels in the manufacturing process. Therefore, in most cases presented in Table 4, the negative environmental impact of manufacturing and installation of a heat recovery ventilator is expected to offset the positive environmental impact due to the reduction of air infiltration rate.

CONCLUSIONS

Although the reduction of air infiltration rate in existing houses to the level of new well-built houses can reduce the annual energy consumption and cost, this type of renovation is presently not cost-effective. This situation is due to the high costs of renovation, required to achieve the targeted level of air infiltration rate, and to the small energy savings, expressed in dollars, due to the low cost of energy for heating. Moreover, the application of the two levels of CO_2 tax credits will not improve the cost-effectiveness. Could one conclude that under these conditions it is not worth considering this type of energy conservation measure ? How the future changes in costs will affect the cost-effectiveness of this measure ? Is there any chance for the CO_2 tax credit to become a driving force in the renovation of existing houses ? A multi-disciplinary optimization research project will give some answers.

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