EVALUATION OF ENERGY PERFORMANCE OF AN EXISTING HOUSE IN MONTREAL USING FOUR ENERGY ANALYSIS SOFTWARE

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ABSTRACT
The purpose of this study was to evaluate the capabilities of four energy analysis software to predict the energy performance of an existing house. The discussion covers: (i) the modelling-related issues, and (ii) the impact of modelling accuracy on the prediction of energy and cost savings.

INTRODUCTION
The use of computer simulation is a cost-effective way to evaluate the potential energy and cost savings in buildings. The user develops the base model of the house using the available information about the physical characteristics, the operating conditions and the people's energy-related behaviour. The base model is then calibrated by modifying some parameters with unknown or uncertain values, based on a reasonable professional justification. The calibration is completed when an acceptable agreement is achieved between the predictions and the measured energy consumption, as obtained from the utility bills. The calibration of the base model is usually seen as a proof of an adequate simulation, or in other words that reasonable efforts were made by the user to accurately simulate the existing building. However, a perfect agreement between the predicted and measured energy consumption cannot be easily achieved. Moreover, a perfect agreement could cover some compensating errors.

ASHRAE (1991) recommended as acceptable the differences of 10 to 20% between the monthly predictions and measurements of energy consumption in existing buildings. Kaplan et al. (1990) proposed to use different levels of tolerances or acceptable differences in terms of the type of end-use and the interval of time used for comparison. The total energy consumption of an existing building should be predicted within 10% of the monthly metered values, and 15% of the daily values.

Great amount of time is usually spent to calibrate the computer model with the utility bills, assuming that the calibrated model will give accurate estimates of the potential energy savings due to renovations.

Zmeureanu et al. (1995) presented a study in which three researchers, each one using two or three software, evaluated the energy and cost savings due to the renovations in a large office building. They concluded that the results do not indicate a clear pattern: depending on the user or the software used for the simulation, the predicted savings vary significantly between simulations, regardless of the apparent accuracy of the calibrated base model.

A similar conclusion regarding the evaluation of energy savings was presented by Corson (1990): "On a percentage basis at least, differences recorded during ECM simulations were often greater than those associated with the respective base building models;... ECM results simulated with the same-building models constructed from different software packages often showed considerably more variability than the difference between the base building models."

In the case of an existing house, it could appear that the evaluation of energy performance is a much easier task, and therefore the predictions could be more accurate than in the case of large commercial buildings. The study presented in this paper is an attempt to explore this issue, using four energy analysis software: HOT2000, CODYBA, BLAST, and TRNSYS. The results should not lead to some conclusions about the relative accuracy of one software against another. The users have the major impact.

APPROACH
When an inter-program comparison is performed, in the first run, called "blind simulation", each user

develops his own base model without any feed-back from other users or a central manager, or without access to the previous utility bills. However, in the second run he has access to some information which can help him to improve the base model. The information about how another user has modelled a particular equipment, or how the features offered by another software have been used could be helpful. Finally, through a number of iterations the user is able to obtain a good agreement between his results and the utility bills.

For the purpose of this study, let us assume a different scenario: four companies are competing for the renovation of a large stock of houses; the housing agency will first test the capabilities of these four companies to accurately simulate the space heating loads of a model house; then some companies will be selected to predict the whole-house energy performance and the impact of cost-effective renovations. Each company receives the following information:

- a complete set of drawings and technical specifications of the model house,
- the utility bills over the past 12 months,
- the complaints made by the present homeowner,
- the results from a blower door test,
- the results from short-term measurements (e.g., up to 3-4 days of measurements of the indoor and supply air temperature in representative rooms, and measurements of electric current at the furnace).

Moreover, each company can visit the model house. Under this scenario, obviously there is no exchange of information between the competing companies. However, each user can adjust his model to fit the utility bills. The four companies used different approaches for the computer simulation of the model house:

- Company A uses the HOT2000 program.
- Company B uses the CODYBA program
- Company C uses the BLAST program.
- Company D uses the TRNSYS program. Two approaches were used in the simulation: single-zone model (type 19) and multizone model (type 56).

DESCRIPTION OF THE MODEL HOUSE

The model house has three floors above ground, plus a basement: partly finished, partly garage. The total heated floor area is about 230 m^2, and the heated volume is about 530 m^3. The technical specifications, concerning the thermal resistance of the exterior envelope, comply with the minimum requirements from the Quebec regulation for energy conservation in new houses: thermal resistance of exterior walls is about 3.6 $m^2 \cdot °C/W$, and that of windows is 0.35 $m^2 \cdot °C/W$ (double, clear glass, 13 mm air space). The windows account for about 30% of the gross exterior area. The air infiltration rate measured with a blower door at 50 Pa pressure difference is 4.79 ach. The equivalent leakage area is 31.6 cm^2/m^2 of exterior walls.

The heating is provided by a warm air furnace coupled with an air-to-air heat pump, working in heating mode: the V-shape condenser is installed before the blower in the same cabinet, and the evaporator and the compressor are in the back yard. Manufacturer's data indicate a Coefficient of Performance of 3.70 at design conditions. The heat pump is turned off only when the outdoor air temperature drops below -10°C. When additional heating is required, a heater element of 20 kW is turned on.

The ventilation air is supposed to be preheated in a heat recovery unit (HRU) by the warm exhaust air. Since this type of unit does not have fans to circulate the exhaust and outside air, the warm air stream comes directly from the supply outlet of the furnace. The outside air is preheated in the HRU and then is mixed with the return air, just before the furnace. In the model house, the dampers on both the outside air and the warm air were found to be closed. Moreover, the fresh air intake was not connected to the HRU. To make the things worst, the homeowner grows orchids in the master bathroom. Since the interior air is recirculated by the system, the relative humidity in the living room reaches 65%.

The furnace blower operates in the AUTO mode, that is, only when there is a demand for heating. The thermostat setpoint for heating is 22.2°C. The short-term measurements shown that the air temperature near the thermostat goes down to 19.5°C before the furnace turns on.

Supply diffusers are installed on the floor, under the exterior windows. The total supply air flow rate is about 380 L/s (53% on the first floor, 21% on the second, and 26% on the third). Some of the supply diffusers were found to be covered by furniture. Baseboard heaters are installed on the third floor (in the office), in the master bathroom, and in the finished basement, each one with its own thermostat. The owners declared that the use of baseboard heaters is very random. There is no fireplace in the house. Electricity is the only source of energy.

Most complaints concerned cold floors, cold drafts in rooms and on the staircase, condensation on some windows and deterioration of the frame, and nonuniform heating of the house (lower temperature in some bedrooms on the second floor and higher temperature in the living room on the first floor).

MODELLING-RELATED ISSUES

The following discussion refers to the capabilities offered by these programs to model some thermal phenomena, relevant to the model house. The accuracy of mathematical models used by these programs is beyond the purpose of this paper.

1. The only information about the air infiltration was obtained from a blower door test at 50 Pa pressure difference. HOT2000 program evaluates the natural infiltration rate using a given distribution of the equivalent leakage area around the house. The other three programs ask the user to input the peak infiltration rate for each zone. The users of these three programs used the results from the blower door test as the starting point, and then evaluated the peak values for each zone to be proportional with the interior volume or the surface area of exterior walls.

2. The maximum supply air temperature measured in the master bedroom, on the second floor, is lower than that on the first floor by more than 10°C, indicating important heat losses from the ducting system within the floors and vertical walls. None of these four programs can simulate this situation.

3. The simultaneous operation of the heat pump and the electric heater in a multizone forced air system can be directly modelled only with the HOT2000 program.

   Company C extracted the hourly heating coil loads from the BLAST program and the corresponding outdoor air temperature from a weather file, and performed additional calculations outside the program to take into account the operation of the heat pump. The coefficient of operation was corrected for operation at part load and in terms of outdoor air temperature. Moreover, if the outdoor air temperature drops below -10°C the heat pump is turned off, and the electric heater alone satisfies the heating demand.

4. The air movement and the corresponding convective heat transfer between thermal zones can be modelled, in a simple way, only by the BLAST and TRNSYS (type 56) programs. In both cases, the user has to define the coupling between zones, by using the value of air flow rate, which is evaluated by other means. The coupling between TRANSYS and COMIS programs was not used in the present study. Company A simulated the house as composed of two zones: one zone above grade, and the basement, without air movement between the two zones. Each zone has its own thermostat setpoint. Company B used a single zone approach. Company C used a multizone approach, with two versions: (i) without convective coupling between zones, and (ii) with convective coupling corresponding to 1 ach. Company D used the single-zone approach (type 19), and the multizone approach (type 56), with two versions: (i) without convective coupling, and (ii) with convective coupling.

5. Since the heat recovery unit cannot be directly simulated by the programs, it was modelled as a heat recovery ventilator without electric input for fans, and with an

average efficiency of 0.7.

6. During the site visit, on a cold winter day, the furnace was not working because the thermostat, which is installed in the leaving room facing the large South-East window, was under the direct solar radiation. This aspect cannot be directly simulated by the four programs.

ESTIMATED SPACE HEATING LOADS

Table 1 presents the annual and monthly space heating loads of the model house. All estimates of the annual loads, with one exception only, are between 31,400 kWh and 38,600 kWh. The space heating loads simulated with TRNSYS (type 56) are about 50% less than those simulated with the single-zone model (type19). The difference comes from: (i) in the multizone model the indoor air temperature of the two unheated spaces (basement and garage) is allowed to freely fluctuate, provided that it is not below the freezing point; therefore the heating loads are not calculated; in the single-zone model the whole house is supposed to be maintained at the setpoint temperature; and (ii) the convective coupling between the thermal zones has a significant impact. The simulation with the BLAST program indicated that the convective coupling between the thermal zones has a negligible impact on the estimated space heating loads. The space heating loads of the garage and the basement are not calculated since the indoor air temperature is not restricted.

Companies B and D calculated the space heating loads during the summer months, while companies A and C considered the heating system is normally off during the same period. If the summer heating loads are removed, the CODYBA estimates the annual loads at 38,585 kWh and TRNSYS at 37,439 kWh.

ESTIMATED WHOLE HOUSE ENERGY PERFORMANCE

Companies A and C were selected for the second phase, which comprises the following: (i) the modelling of the whole-house energy performance, (ii) the comparison with the utility bills, and (iii) the prediction of the energy and cost savings due to the house renovation.

Table 2 presents the annual and monthly electricity consumption, including heating, appliances, lighting and domestic hot water. For the sake of comparison, the annual electricity consumption, from the utility bills, is equal to 23,500 kWh.

SELECTION OF ENERGY EFFICIENCY MEASURES

The following energy efficient measures were selected to be evaluated:

ECM1. Installation of a programmable thermostat with a throttling range of 1.5°C. The thermostat setpoint is not changed.

ECM2 Installation of a programmable thermostat. The setpoint temperature is changed at night, between 23:00 and 6:00, from 22.2°C to 18°C.

ECM3. Air infiltration rate at 50 Pa is reduced from 4.79 Pa to 3.0 Pa.

ECM4. Combination of ECM1, ECM2 and ECM3.

ECM5. Replacement of the motorized dampers in the heat recovery unit, to control the position of dampers. Installation of an air duct to connect the heat recovery unit to the outside air intake. The outside air flow rate brought in the house corresponds to 0.3 ach.

The base models were then modified to simulate the five energy efficient measures. The predicted annual energy and cost savings are presented in Table 3 along with the initial cost of each energy-efficient measure.

One can notice the following:

- the first two energy-efficient measures are selected, regardless of the computer program used for the prediction of energy savings; the predicted annual energy savings are between $95 and $133 (ECM1) and between $67 and $133 (ECM2), for an initial cost of $80.0;

- the last energy-efficient measure should be selected for improving the air quality in the house, and not based on energy savings; under the worst predictions, the homeowner will increase the electricity bills by about $186/year, to improve the air quality and to avoid the deterioration of windows due to the condensation;

- the BLAST[1] model, which gives the highest estimate of the anual energy consumption, predicts also the largest savings, compared with the BLAST[2] model;

- in three cases (ECM3, ECM4 and ECM5) the

BLAST[2] model, which overestimates by about 20% the actual energy consumption, predicts larger savings than the HOT2000 model, which is within 7% of the actual consumption.

CONCLUSIONS

In spite of large differences in the modelling approaches used by the four companies, the estimates of space heating loads are within 18% of the average value of all estimates. The simulation with TRNSYS (type 56) is the only exception.

Although some thermal phenomena occurring in the house cannot be simulated by the four programs, or are only simulated in a simple way by some programs, the estimates of space heating loads or electricity consumption agree reasonable well.

Finally the differences in the estimation of energy and cost savings do not affect the decision on the implementation of energy-efficient measures.

It is also important to note that although much time and effort can be spent on developing an input file which accurately predicts the actual energy performance, assuming that the energy savings are also well predicted, there is nonetheless a large uncertainty associated with the prediction of renovation costs of existing houses.

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Table 1. Comparison of the space heating loads, in kWh.

	Company A HOT2000	Company B CODYBA	Company C BLAST	Company D TRNSYS (type 56)	Company D TRNSYS (type 19)
Jan	6947	6771	6890	3524	6634
Feb	5527	7770	6759	3985	7470
Mar	4048	5880	4591	3302	6048
Apr	2171	3901	2417	2341	4075
May	725	2273	0	1440	2565
Jun	4	742	0	387	866
Jul	0	105	0	33	186
Aug	0	66	0	0	135
Sep	398	1397	0	485	1392
Oct	1714	2871	2405	975	2526
Nov	3683	4621	4129	2062	4378
Dec	6215	6771	6613	3072	6309
Total	31430	43168 (38585)[1]	33854	21605	42583 (37439)[1]

[1]heating loads during the summer months are not considered

Table 2. Comparison of the whole-house electricity consumption, in kWh.

	Company A HOT2000	Company C BLAST[1]	Company C BLAST[2]
Jan	5750	7830	4580
Feb	4340	7630	4150
Mar	2430	5960	3577
Apr	1276	3570	2606
May	727	883	883
Jun	475	854	854
Jul	560	883	883
Aug	530	882	882
Sep	560	854	854
Oct	1076	3320	2513
Nov	1930	5290	3346
Dec	4636	7800	4209
Total	24290	45700	28490

[1]direct results from BLAST program; the heat pump is not considered.
[2]hourly heating coil loads are extracted from BLAST program; the impact of heat pump is separately estimated.

Table 3. Comparison of the predicted annual energy savings and the reduction of the space heating loads (within brackets), in kWh. **Annual cost savings (CAN$) are presented in bold.**

Energy efficiency measures	Company A HOT2000	Company C BLAST[1]	Company C BLAST[2]	Initial cost [$]
1	1915 (2741) **130**	1956 (1701) **133**	1405 (1701) **95**	80.0
2	**-**	1856 (2942) **126**	986 (2942) **67**	80.0
3	4279 (5877) **291**	9856 (10777) **669**	6923 (10777) **470**	1100.0
4	5283 (7867) **359**	12556 (13211) **853**	8491 (13211) **577**	1180.0
5	-1666 (-1328) **-113**	56 (0) **4**	-2741 (0) **-186**	200.0

[1]direct results from BLAST program; the heat pump is not considered.

[2]hourly heating coil loads are extracted from BLAST program; the impact of heat pump is separately estimated.