COMPARISON OF COST AND ENERGY SAVINGS IN AN EXISTING LARGE BUILDING AS PREDICTED BY THREE SIMULATION PROGRAMS

Radu Zmeureanu[1], Lora Pasqualetto[1] and Frederic Bilas[2]
[1]Centre for Building Studies, Concordia University, Montréal, CANADA
[2]Université de Liège, Liège, BELGIUM

ABSTRACT

Three energy analysis programs (BESA-Design, PC-BLAST and MICRO-DOE2. 1D) were used by three researchers to evaluate the energy and cost savings in a large existing office building located in Montreal. The purpose of this study was twofold: (1) to test the programs' capabilities to predict the energy performance of an existing large commercial building, using information normally available to an energy consultant, that is without additional and expensive monitoring, and (2) to tes t the programs' capabilities to evaluate the impact of several energ efficient measures.

INTRODUCTION

The use of computer simulation is a cost-effective way to compensate for the missing long-term monitoring and to improve the traditional practice, in order to evaluate the potential for energy savings in large commercial buildings. The building managers and owners usually ask for a quick and less expensive evaluation of the potential for improving the energy efficiency, and look for the estimates of initial cost and payback period. Therefore, the consultants have limited time and budget available to perform the building energy audit. The evaluation of the actual energy performance is mainly based on the analysis of utility bills, and the disaggregation of total energy use between the major end-uses is based on additional assumptions, statistical data or short-term measurements. The long-term monitoring of energy use is rather an exception than a current practice for the energy audit in large office buildings.

The impact of proposed energy efficient measures can be better evaluated by using a computer model of the existing building. The model is developed by using drawings, specifications, manufacturers catalogues, as well as on-site visits for interviewing the building manager and for verifying the equipment operation. The limited budget allocated for an energy audit usually does not allow for detailed measurements to define the "as-built" or "as-operated" values of some parameters. In addition, even the most sophisticated computer programs use some simplifying assumptions or default values. The computer model is then calibrated by comparing the predictions with the measured energy performance, as obtained from the utility bills. However, a perfect agreement between the predicted and measured energy consumption cannot easily be achieved. 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. For instance, the differences of 5% on a monthly basis and 15% on a daily basis are acceptable for evaluating the energy consumption for interior loads such as lighting, receptacles or domestic hot water. In the case of the energy consumption for HVAC systems, the proposed tolerances are 15-25% for monthly values, and 25-35% for daily values. The lower limits are recommended for periods of peak heating and cooling loads, and the upper limits for the mild weather conditions. The total energy consumption of an existing building must be predicted within 10% of the monthly metered values, and 15% of the daily values. It is beyond the scope of this paper to present all available validation studies. However, to better illustrate the user's acceptance of differences between simulation results and monitored energy use in <u>large existing commercial buildings</u>, a review of some studies was performed (Alereza and Hovander 1985, Clearly and Wong 1988, Diamond and Hun 1981, Diamond et al. 1990, Grenville and Phillips 1981, Haberl and Claridge 1985, Heidell and Taylor 1985, Herron et al. 1980, Jamieson and Harding 1989, Jamieson and Qualman 1990, Vaughn 1984):

1. In most projects, the difference between the measured and predicted total annual energy use was between 1% and 14%. Only in two projects, where the analysis was carried out for a group of

buildings, a lower accuracy in predictions was accepted.
2. The total annual electricity use was estimated within 15%.
3. The difference between the predicted and measured annual gas/oil use was between 1% and 78%.
4. The prediction of total monthly energy use was less accurate than that of the annual value. The average monthly difference varied between 4.9% and 24.0%. The maximum monthly difference varied between 13.0% and 55.2%.
5. The predicted average monthly electricity use was within 8.7% and 29.6% of the monitored data; for the average monthly gas/oil use the difference was between 9.9% and 35.0%. Hence, on the monthly basis the predictions are less accurate than on the yearly basis, mainly due to: (i) the differences between the actual and simulated schedules of operation, which on a short-term have an important impact in commercial buildings, but become less significant on a long-term, and (ii) the anomalies in monitoring the energy use, such as errors in monitoring and reading, or the estimation and compensation procedure.

This paper presents a comparative evaluation of three energy analysis programs (BESA-Design, PC-BLAST and MICRO-DOE2.1D), which were used to evaluate the energy and cost savings in a large existing office building. The purpose of this study was twofold: (1) to test the programs' capabilities to predict the energy performance of an existing large building, using information normally available to an energy consultant, that is without additional and expensive monitoring, and (2) to test the programs' capabilities to evaluate the impact of several energy efficient measures.

BUILDING DESCRIPTION

The office building, built in Montreal in 1972, has a total floor area of 10,410 m^2 spread over a seven floor office tower, an underground garage and a ground floor (with a bank, a restaurant and office spaces). There is a central Variable Air Volume system, which provides cooling in the summer and ventilation all year to the office spaces from 7:30 am to 11:00 pm, from Monday to Friday. The supply fan has a capacity of 38,000 L/s and a motor of 93 kW, and the return fan has 35,000 L/s and 56 kW. The cooling setpoint temperature is 23-24°C. Direct expansion cooling coils are connected to four condensing units, each equipped with two compressors with a refrigeration capacity of about 90 kW. The supply air temperature is controlled in terms of the outdoor air temperature; it has a minimum value of 14°C when outside temperature is 9°C or higher, and a maximum value of 16°C when outside temperature is -20°C or lower. The proportion of outdoor air varies between 5 and 100%, and is controlled by two parameters in the following order of priority: (1) the supply air temperature, and (2) the concentration of CO_2 in the return air duct. In the winter, the CO_2 level of 1000-1200 ppm is sometimes exceeded since the supply air temperature has the highest priority in the control of outdoor air rate. The system is also equipped with a dry-bulb temperature economizer system which closes the dampers to a minimum position when the outdoor temperature is too high. The heating for most of the building is provided by electric baseboard heaters with a total capacity of about 118 W/m^2 of floor area. The heating setpoint temperature is about 20-21°C. However, since there is no central control system, the occupants can modify this value. The restaurant is equipped with a constant volume rooftop unit with a refrigeration capacity of about 27 kW, which operates continuously. The unit provides cooling only and is equipped with an enthalpy economizer, which varies the proportion of fresh air from 10 to 100%. The bank is equipped with a constant volume rooftop unit, which provides heating in the winter and operates only during the business hours. The refrigeration capacity is about 55 kW. The proportion of outdoor air is kept constant at 15%. The garage is heated by two unit heaters to 18-19°C in the winter. There are two exhaust fans in the garage which work in series and are activated by a sensor of carbon monoxide. Electricity is the only source of energy in this building.

APPROACH

There are three main approaches to the validation of these energy analysis programs, which use hundreds of variables and complex calculations:

1. Verification and validation of the mathematical models, which aid for the understanding of simulation results and limits ("micro" approach).
2. Verification and validation of the simulation results by comparison with the energy performance of an existing building ("macro" approach). The difficulties in the development of input file and the errors occurring during the transfer of data can be evaluated.
3. Verification and validation of mathematical models, followed by the comparison between the simulation results and the monitored energy performance ("global" approach).

In this study the "macro" approach was used, and the evaluation was performed using the simulation results, the information presented in the user's manuals, and the utility bills of an existing large building.

DEVELOPMENT OF INPUT FILES

Problems were noticed during the development of input files since no measured values of some parameters were available or the computer programs were unable to simulate particular operating conditions of HVAC systems. Some of these problems are presented below:

1. The coefficient of performance of chillers was evaluated using the rated values published in the manufacturer's catalogue. However, for an old roof top unit, there was no manufacturer's data available; therefore, data for a similar unit was used, and the rated coefficient of performance was reduced, using a professional judgement to take into account the operating and maintenance conditions.
2. The proportion of heat generated by the interior lighting system, which is transferred to the plenum, was evaluated at 53%, using data published by CIBSE 1986.
3. The number of thermal zones used to define the entire building was different from one program to another: 19 for BESA (maximum of 25), 24 for MICRO-DOE2 (maximum of 64) and 17 for BLAST (maximum of 20). Different approaches are used by these programs to simulate the impact of a plenum on the space thermal loads.
4. The control of outdoor air rate in terms of CO_2 concentration in the indoor air and the control of exhaust fans in terms of CO concentration cannot be simulated directly by the three programs.

Other problems were due to the interpretation of available information such as thermal mass of furniture and partitions, schedule of domestic hot water, infiltration of outside air or thermal properties of glazing system. Finally, the last group of problems were generated by trivial errors concerning schedules of lighting, fans, thermostats or cooling coils, orientation of exterior walls and dimensions of tilted windows.

CALIBRATION OF MODELS

The calibration of base models was performed by comparing the simulation results (annual and monthly energy consumption and peak electric demand) with the utility bills (called monitored data), and then modifying the input value of some parameters. The calibration was defined as acceptable if the differences were less than 5% on the annual basis and 10-15% on the monthly basis. Figures 1 and 2 show a comparison between the utility bills and the simulation results of users A and B, with the BESA-Design program. The annual energy consumption was evaluated to be between 3.5 and 6.5% of the utility bills, and the annual peak demand between 4.2 and 7.3%. In general, the monthly consumption and peak demand follow the shape of utility bills, and the differences are less than the imposed criterion, except for February, with a difference of 16.2%. The weather data, monitored at the Dorval airport by the Environment Canada, were available under the TDF14 format for the DOE and BLAST programs. The developer of BESA-Design program provided the appropriate weather file, using the same source.

The initial input file (user A) for the MICRO-DOE2 program led to the underestimation of the energy performance of the building compared with the utility bills: 15.9% for the annual energy consumption, between 4 and 27% for the monthly consumption and between 1 and 24% for the monthly peak electric demand. Therefore, several other base models were developed, starting from the initial model, to comply with the requested criteria. There are two groups of base models: model NOUV1, where an additional electric load of 60 kW was input, and model NOUV2, where the thermal properties of the glazing system were modified (shading coefficient from 0.16 to 0.38, and thermal resistance from 0.45 to 0.32 $m^2 \cdot °C/W$) and the minimum supply air rate for the interior zones was changed from 20 to 80% of the maximum value. Moreover, four additional models were developed, starting from the model NOUV2: NOUV2-1, where the switchover temperature of the dry-bulb economizer system was increased from 20 to 22.2°C; NOUV2-2, where the switchover temperature was not defined, and therefore the program simulates a reduction of outside air rate when the outdoor temperature is higher than the return air temperature; NOUV2-3, where the efficiency of electric motors installed on the outside condensing units was reduced by 50%. All these models predict the annual energy consumption between 2.8 and 4.5% of the utility bills, and the maximum peak electric demand between 2.3 and 7.3%. Figures 3 and 4 show a comparison between the monthly energy performance as predicted by user A and the utility bills. The computer model developed by the user B predicts the annual energy consumption to be about 7% of the utility bills. All monthly differences for energy consumption and demand are within 14% of the utility bills, except the peak demand for January with a difference of 23.6%.

The initial input file (user A) for the PC-BLAST program, called LV-BLAS, led to the underestimation of the energy performance of the building compared with the utility bills: 25.7% for the annual energy consumption and 22% for the annual peak electric demand. However, the shape of monthly variation follows closely the utility bills (Figure 5 and 6). Several other base models were developed starting from this initial file, using the same approach as for the MICRO-DOE2 program: LV-BLAS2, where an additional electric load of 60 kW was input; LV-BLAS3, where the minimum supply air rate for the interior zones was changed from 20 to 80% of the maximum value; LV-BLAS4, where the switchover temperature of the dry-bulb economizer system was increased from 20 to 22.2°C; LV-BLAS5, where the switchover temperature was increased from 20 to 22.2°C and an additional electric load of 60 kW was input; and LV-BLAS6, where the switchover temperature was increased from 20 to 22.2°C and an additional electric load of 90 kW was input. The models LV-BLAS2 to LV-BLAS5 underestimate the annual energy consumption by 10 to 23%, compared with the utility bills, and the annual peak electric demand by 16 to 30%. However, the monthly variation of energy consumption and cost follow closely the utility bills. On the other hand, the model LV-BLAS6 gives an annual difference of 4.2% for energy consumption and 18% for the annual peak electric demand, and the monthly variation of energy consumption follows very well the utility bills. However, the peak electric demand is predicted to be almost constant throughout the year (about 500 kW), while the utility bills show a monthly variation between 450 and 620 kW. The computer model developed by the user C predicts the annual energy consumption to be about 3.7% of the utility bills. Monthly differences are within 15%, with one exception for energy consumption (17.9% in April) and two for peak demand (18.5% in February and 18.7% in March).

ENERGY EFFICIENT MEASURES

Selection of the energy efficient measures was limited due to a special request made by the building manager, that is they will not involve major investment or upgrading of any HVAC equipment. The following nine individual measures were selected: (1) insulation of the floor between the garage and the ground floor; (2) insulation of the floor between the garage and the ground floor, while decreasing the garage temperature; (3) night setback of indoor temperature to 16°C in the winter, using programmable thermostats; (4) increase of the cooling set point temperature to 25-26°C; (5) decrease of the lighting power density on the first floor from 25.8 to 22 W/m^2; (6) decrease of the lighting power density from 25.8 to 11.8 W/m^2, and use of task lighting of 1.4 W/m^2; (7) turn off lights in the washrooms, stairwells and garage during the unoccupied periods; (8) installation of timers and motion detectors to ensure the general lighting is off during the unoccupied periods; (9) installation of power management devices to turn off the office equipment when it is not in use. Four group measures were also selected, as a combination of the above individual measures: (I) measures 4 and 5; (II) measures 3,7,8 and 9; (III) measures 3,4,5,7,8 and 9; (IV) measures 4,5,7,8 and 9. The base models were then modified to simulate these energy efficient measures. The annual cost savings were predicted by three users, using a total of three models for BESA-Design program, six models for MICRO-DOE2 and eight models for PC-BLAST (Table 1). One can notice the following: (i) the range of energy savings, due to a particular measure, predicted by the person A using several models with the PC-BLAST (e.g., for measure 4, the savings are between 4932 and 5075 $) is smaller than in the case of using the MICRO-DOE2 (e.g., for measure 4, the savings are between 1193 and 3594 $); (ii) the ratio between the largest and the smallest savings, which were evaluated using the same program, is between 1:1 and 3:1 (only in two cases the ratio is about 6:1); (iii) large differences are noticed when the results obtained by the same person using different programs are compared (e.g., for measure 3, the estimates obtained by the user A varies between savings of 3090 to 4354 $ for MICRO-DOE2, 10391 to 10411 $ for PC-BLAST, and an increase of energy cost of 10838 $ for BESA-Design); (iv) in some cases, one person predicted cost savings and another person cost increases, when both used the same program (e.g., for measure II, the user A with the MICRO-DOE2 program estimated energy savings between 839 to 1754 $, while the user B estimated an increase of energy cost of 3504 $); in other cases, one program predicted savings and another program predicted a increase, when both were used by the same person (e.g., for measure II, the user B with the BESA-Design predicted energy savings of 5924 $, and increases of 3504 $ with the MICRO-DOE2).

Since there is not a predominant trend in the table of results, one can expect either underestimates or overestimates of the possible savings, depending on the computer program or the user. If the simulation results are used by an ESCO company, which guarantees the energy savings of a proposed measure, then the accuracy of these predictions is essential. If the results are used to prioritize and select one or several energy conservation measures, then the annual energy savings are only one term of the equation. The second term, which sometimes has an equal weight if not greater, is the initial cost of each measure (Table 1). Regardless of the predicted savings, the measures 1 and 2 are not selected since the simple payback period is close to 300 years, while measures 4, 5, 6, 7 and I are selected, since they do not involve any initial investment. The initial cost of measure 8 is expected to be recovered in less than two years (user A, program MICRO-DOE2) or never (user A, program PC-BLAST). Measures III and IV are selected, since the payback period is less than 3 years under the most pessimistic predictions. It is also important to note that although much time and effort can be spent on developing an input file which accurately predicts the cost savings, there is nonetheless a large uncertainty associated with the prediction of initial cost, especially in the case of an existing building.

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."

COMPUTING TIME

The computing time of the three energy analysis programs was compared, using a 486/50 MHz coprocessor. The program BESA-Design takes 36 s per thermal zone or a total of 690 s: 60 s for transfer functions, thermal loads and equipment size for design conditions; 550 s for LOADS module; and 80 s for SYSTEMS and PLANT modules. The program MICRO-DOE2 takes 18 s per thermal zone or a total of 431 s: 30 s for verification of input file and development of files *.BDL, *.STD and *.CTL; 249 s for LOADS module; 130 s for SYSTEMS module; 129 s for PLANT module; and 3 s for economic calculations. The program PC-BLAST takes 55 s per thermal zone or a total of 930 s: 90 s for verification of input file; 550 s for LOADS module; 200 s for SYSTEMS module; and 90 s for PLANT module. The time required to use the REPWRT program to obtain the peak monthly demand from the hourly data is not included.

CONCLUSIONS

What can be done to improve the estimates of the energy savings in a large commercial building ? What is a reasonable effort (time, budget) for calibrating a base model of a large existing commercial building with the utility bills ? Small differences between the simulation results and the utility bills are usually seen as a proof of an adequate simulation, or in other words that reasonable efforts were made by the consultant to accurately simulate an existing building. The program's user can relatively easily calibrate a model with the utility bills by modifying some parameters with unknown values, and giving a reasonable professional justification. However, in some cases the impact of the selected parameter is very important. The results of this study suggest that there is a serious need for a detailed methodology for the verification of quality of the input file and the calibration with the utility bills.

ACKNOWLEDGEMENTS

The authors wish to thank Hydro-Québec for the financial support for this study.

REFERENCES

Alereza, T. and L. Hovander, "Validation of an hourly microcomputer building energy analysis program," ASHRAE Transactions, Vol. 91, pp.725-734, 1985.

ASHRAE Handbook HVAC Applications. Chapter 36 "Computer Applications," pp.36.-36.5, 1991.

BESA-Design, User's Guide, Scanada Consultants Limited, Toronto, 1993.

BLAST User Reference, Vol. 1 and 2, BLAST Support Office, Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, 1991.

CIBSE Guide. Volume A. Design Data, pp.A7-5. The Chartered Institution of Building Services Engineers, London (U.K.), 1986.

Clearly, C. and V. Wong, "Conservation opportunities in commercial buildings: utilizing end-use load data to simulate and measure conservations savings," ACEEE Summer Study on Energy Efficiency in Buildings, pp.10.85-10.95, 1988.

Corson G. C., "Evaluation of software project. A comparative evaluation of commercial building energy simulation software." Prepared for Bonneville Power Administration. Contract No. DE-AC79-89BP96543, 1990.

Diamond, S.C. and B.D. Hun, "Comparison of DOE-2 computer program simulations to metered data for seven commercial buildings," ASHRAE Transactions, Vol. 87, pp.1222-1231, 1981.

Diamond, R., J. Harris, O. deBuen, B. Nordman and B. Cody, "Evaluating actual performance of new commercial buildings: the energy edge demonstration program," ACEEE Summer Study on Energy Efficiency in Buildings, pp.3.77-3.89, 1990.

Grenville, K.Y. and E.G. Phillips, "Comparison of BLAST program predictions with the energy consumptions of two buildings," ASHRAE Transactions, Vol. 87, pp.1200-1206, 1981.

Haberl, J.S. and D. Claridge, "Retrofit energy studies of a recreation centre," ASHRAE Transactions, Vol. 91, pp.1421-1433, 1985.

Heidell, J.A. and Z.T. Taylor, "Comparison of empirically measured end-use metered data with DOE-2.1 simulations," First International Building Energy Simulation Conference, pp.290-295, Seattle, 1985.

Herron, D., L. Windingland and D. Hittle, "Comparison of Building Loads Analysis and System Thermodynamics (BLAST) computer program simulations and measured energy use for Army buildings," U.S. Army Corps of Engineers, Report CERI-IR-E-161, 1980.

Jamieson, D. and S.B. Harding, "Computer simulation/end-use metering or can we count on energy savings estimates in designing demand-side programs ?" Building Simulation'89 Conference, Vancouver, 1989.

Jamieson, D. and R.L. Qualman, "Computer simulation/end-use metering or can we count on energy savings estimates in designing demand-side programs ?" ACEEE Summer Study on Energy Efficiency in Buildings, pp.10.105-10.114, 1990.

Kaplan, M.B., J. McFerran, J. Jansen and R. Pratt, "Reconciliation of a DOE-2.1C model with monitored end-use data for a small office building," ASHRAE Transactions, Vol. 96, pp.981-993, 1990.

MICRO-DOE2.1D. User's Guide. ACROSOFT International, Inc. Golden, CO. 1990.

Vaughn, K.M., "Comparison of simulated and historical energy usage in 43 existing buildings," ASHRAE Transactions, Vol.91, pp.294-305. 1984.

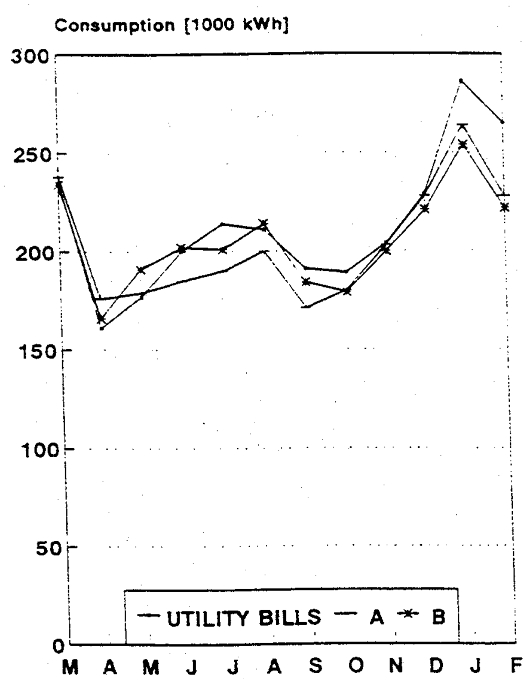

Figure 1. Monthly variation of energy consumption. Comparison between the utility bills and the results of simulations of two users with BESA-Design.

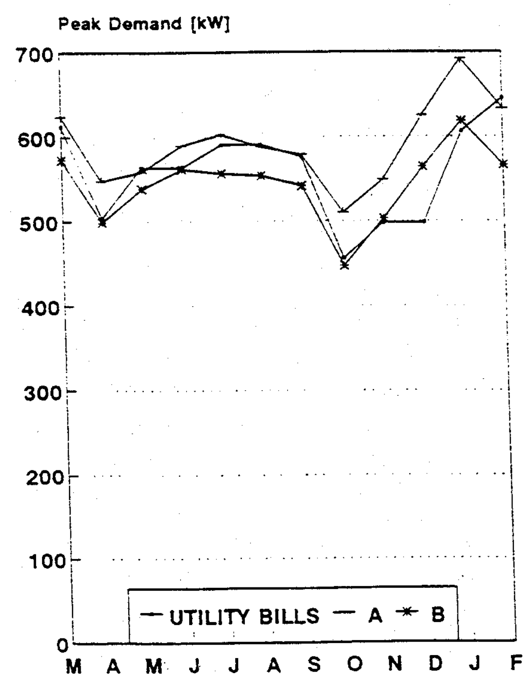

Figure 2. Monthly variation of peak demand. Comparison between the utility bills and the results of simulations of two users with BESA-Design.

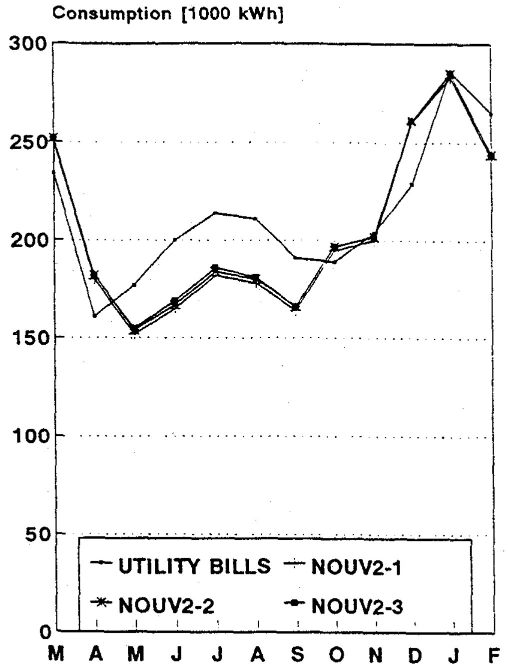

Figure 3. Monthly variation of energy consumption. Comparison between the utility bills and the results of simulations using MICRO-DOE2, files NOUV2-1, NOUV2-2 and NOUV2-3 (user A).

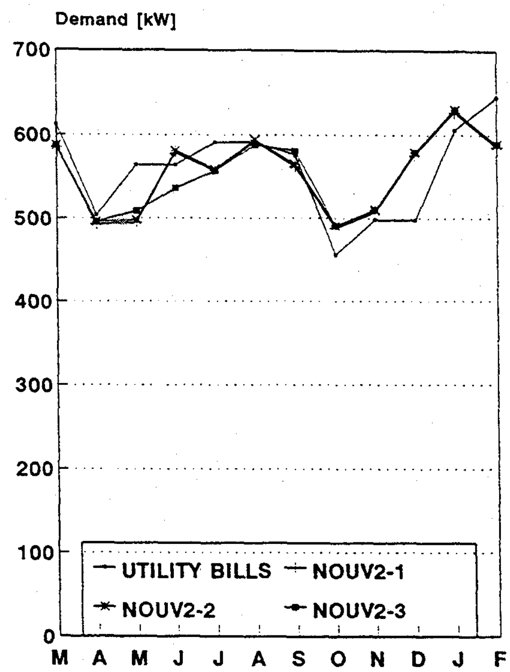

Figure 4. Monthly variation of peak demand. Comparison between the utility bills and the results of simulations using MICRO-DOE2, files NOUV2-1, NOUV2-2 and NOUV2-3 (user A).

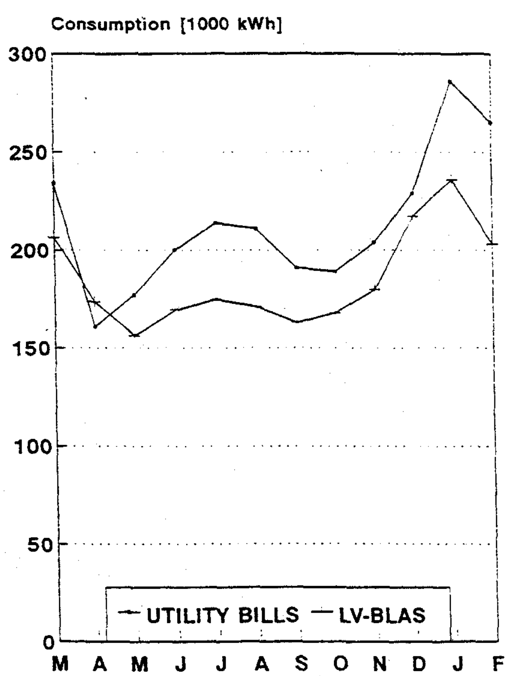

Figure 5. Monthly variation of energy consumption. Comparison between the utility bills and the results of simulation using PC-BLAST, file LV-BLAS2 (user A).

Figure 6. Monthly variation of peak demand. Comparison between the utility bills and the results of simulations using PC-BLAST, file LV-BLAS2 (user A).

Table 1. Comparison of annual cost savings (CAN$) predicted by three users (A,B,C) with three computer programs

		BESA - Design	MICRO - DOE2	PC - BLAST	Initial cost
Individual Measures					
1	A	964	-283 to 319	20	341212
	B/C	1025	-1668	-16 to 0	
2	A	704	848 to 912	101 to 142	341212
	B/C	363	807	475	
3	A	-10838	3090 to 4353	10391 to 10411	164$/unit
	B/C	-3171	-6866	3170 to 3803	
4	A	7884	1193 to 3594	4932 to 5075	-
	B/C	5175	2973	-317 to 3486	
5	A	624	2411 to 2823	3255 to 3275	-
	B/C	1852	1747	1109 to 1585	
6	A	5611	5127 to 5689	6894 to 6914	-
	B/C	6898	3688	4120 to 5705	
7	A	6043	260 to 280	61 to 101	-
	B/C	1127	106	159 to 317	
8	A	5213	2745 to 3592	-1780 to -1840	5250
	B/C	6104	1280	-1110 to -793	
9	A	4619	2400 to 3279	566 to 1011	5500
	B/C	2628	525	-475 to 0	
Group Measures					
I	A	7871	3532 to 5821	7823 to 7965	-
	B/C	7064	5385	793 to 4754	
II	A	9795	839 to 1754	18640 to 19550	10750
	B/C	5924	-3504	5547 to 7448	
III	A	16135	4345 to 6273	21268 to 26161	10750
	B/C	9450	3421	5071 to 10143	
IV	A	16699	8703 to 11062	9400 to 9725	10750
	B/C	9498	8030	-	