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Evaluation of Energy Performance of Large Commercial Buildings

Zhaonan Mei

A Thesis

in

The Centre for Building Studies

Presented in Partial Fulfilment of the Requirements for the Degree of Master of Applied Science at Concordia University
Montreal, Quebec, Canada

April 1994

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ABSTRACT

Evaluation of Energy Performance of Large Commercial Buildings

Zhaonan Mei

Although the energy consumption decreased in the last decade in Montreal, there is still a large potential for improving the energy performance of office buildings through better design and operation. The average normalized energy consumption is 455.3 $kWh/m^2/yr$, which exceeds by far the performance of the most efficient buildings which is about 200 $kWh/m^2/yr$.

The first objective of this research is to develop a new energy audit method, which is based on the analysis of utility bills, walk-through inspection and some short term measurements. Utility bills represent the only source of reliable historical information about the performance of a building, which is available to an energy consultant at the beginning of a project. The building manager can compare the energy performance of the building with some target values or with the performance of similar buildings. Furthermore, one can discover the reason of inefficient use of energy , and evaluate the need for further and more detailed analysis.

The second objective of this research is to evaluate the impact of some parameters regarding building operation and construction on energy consumption of an existing building. In order to do this, the DOE-2.1D micro-computer program was used to develop a model of a large existing office building in Montreal, which was then calibrated by

comparing the computer predictions and the utility bills. Then, the impact of this particularly higher rate of ventilation on the energy performance of the office building was evaluated.

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NOMENCLATURE

a - non weather-dependent daily energy consumption (kWh/m²/day)

A_f - floor area (m²)

b - slope of the weather-dependent energy consumption (kWh/m²/day/°C)

B_L - base-load energy consumption (kWh/m²/day)

C - weather-dependent energy consumption calculated as an average over a 19-year period (kWh)

C_i - weather-dependent energy consumption (kWh)

COP - coefficient of performance of chillers

c_p - specific heat of air (kJ/kg/°C)

E_C - daily energy consumption for chillers (kWh)

E_E - daily energy consumption for office equipment (kWh)

E_i - daily average energy consumption for the interval i (kWh)

E_L - daily energy consumption for lighting (kWh)

ELF - electric load factor

E_m - total energy consumption from utility bills (kWh)

E_{min} - lowest energy consumption (kWh)

E_P - daily energy consumption for preheating (kwh)

E_T - daily energy consumption for cooling towers (kWh)

F_1 - oversize correction factor for chillers (fraction)

F_2 - ratio of input power to capacity of cooling towers (fraction)

G_O - supply air flow (m^3/s)

NOMENCLATURE

LPD	-	load density of lighting or office equipment (W/m^2)
$\dot{m}$	-	mass flow of air (kg/s)
M_I	-	operating schedule multiplier (fraction)
NAC	-	normalized annual energy consumption (kWh/m^2)
N_{HVAC}	-	number of daily operating hours of HVAC systems (hour)
N_m	-	total number of days covered by utility bills (day)
NOP	-	number of operating hours per day (hour)
N_T	-	total number of hours when $T_{DB} < T_{REF}$ for gas-heated or $T_{DB} > T_{REF}$ for electricity-cooled buildings for the period of bills, calculated as an average over 19-year period (hour)
$N_{T,19}$	-	number of hours when $T_{DB} < T_{REF}$ for gas-heated or $T_{DB} > T_{REF}$ for electricity-cooled buildings for the period of bills (hour)
OLF	-	occupancy load factor (fraction)
P_C	-	cooling capacity of cooling towers (kW)
P_R	-	refrigeration capacity of operating chillers (kW)
R^2	-	correlation coefficient (fraction)
T_M	-	mixing temperature (°C)
T_P	-	preheating temperature (°C)
T_O	-	outdoor temperature (°C)
α_O	-	outdoor air rate (fraction)
ρ_O	-	density of air (kg/m^3)
ε	-	correction coefficient

CHAPTER 1

INTRODUCTION

1.1 Introduction

Before 1973, buildings in the western countries were designed, constructed and operated with little regard to the conservation of energy. Since the oil crisis, buildings in North America have been designed and constructed generally with energy efficiency in mind, but sometimes are still operated inefficiently. Although the building energy consumption in Montreal area decreased in the last decade, there is still a large potential for improving the energy performance of office buildings through better design and operation. A study of energy performance of 68 office buildings in Montreal [1,2] based on the analysis of utility bills indicated that the average energy consumption of office buildings in Montreal in 1988 was 455.3 kWh/m²/yr (Table 1). By comparing this value with that of the most energy efficient buildings in the same study, which is about 200 kWh/m²/yr, one can see a large potential for energy savings in the existing office buildings in Montreal.

Table 1.1 Energy performance of office buildings in Montreal in 1988

	Consumption (kWh/m²/yr)	Cost ($/m²/yr)
Average	455.3	17.9
Median	406.5	17.1
Mode	318.9	13.6
Standard deviation	166.0	8.4
Minimum	251.4	6.6
Maximum	938.3	60.5

To evaluate the potential for energy savings, an energy consultant must perform an energy audit of the building under analysis, that is a review of how the energy is used in a building and the evaluation of opportunities for increasing the efficiency of utilization. There are three main categories of energy audits:

- simple audit, where the utility bills are analyzed, the energy performance is evaluated and then compared with target values;
- walk-through audit, which implies a preliminary visual inspection of the building, to determine the major problems regarding the building construction, as well as to determine the maintenance and operation potential for energy savings; finally, it is completed with a simple audit;
- detailed audit, which in addition to a walk-through audit, involves extensive measurements on site and detailed calculations, usually using computer programs.

There are different computer programs for use in a building energy audit. Some of them can only evaluate the energy performance of an existing building, using the utility bills. Other programs can be used for detailed simulation of energy flows in a building. The use of the computer programs can increase the quality of building energy audit, and finally can lead to a higher efficiency of our built environment.

This thesis presents in chapter 2 to 3 a survey of available softwares used for building energy audits, and then the development of a new computer program for building energy audit. Chapter 4 presents the use of detailed computer program (MICRO-DOE2) to develop a model of a large existing office building in Montreal. The computer model is used as an "experimental set-up" to analyze the relationship between energy consumption and some parameters regarding building operation and construction.

1.2 Objective

The first objective of this research is to develop a new energy audit method, which is based on the analysis of utility bills, walk-through inspection and some short term measurements. Utility bills represent the only source of reliable historical information about the performance of a building, which is available to an energy consultant at the beginning of a project. The building manager can compare the energy performance of the building with some target values or with the performance of similar buildings. Furthermore, one can discover the reason of inefficient use of energy , and evaluate the need for further and more detailed analysis.

The second objective of this research is to use a detailed energy analysis program for a detailed energy audit of a large existing office building in Montreal, and then to evaluate the impact of some parameters regarding building operation and construction on energy consumption of an existing building.

CHAPTER 2

NEW COMPUTER PROGRAM FOR ENERGY AUDIT

2.1 Literature Survey of Energy Audit Methods and Softwares

The main methods used for the building energy audit can be classified in three groups:

a. Comparison of annual total energy and energy intensity

This method is a simple and straightforward way to quantify the energy performance of buildings by using the total annual energy consumption and energy intensity data, and comparing them with the performance of other buildings with similar features or with some target values. Some studies used the total annual energy use before and after the building retrofit to evaluate the energy savings, while other studies used the energy intensity to compare energy use in several buildings or in a same building but in different years [3].

Some target values of energy performance are required, and they can be developed using the average energy use of different types of existing buildings or some recommended values. Some databases of building energy performance have been developed using parameters such as location, type of HVAC system, glazing-to-wall ratio or lighting power intensity [4-6].

This method can quickly reveal if the building under analysis is energy efficient, but it does not provide additional information about how the energy is used. Hence, this method is mostly used along with other methods.

b. Linear regression models

This method [7] assumes that the total energy use is composed of two components: weather-dependent and non-weather-dependent (Fig.2.1), The relationship between daily energy use and daily average outdoor conditions, expressed as outdoor temperature or heating/cooling degree days, is then developed. This method is appropriate for buildings with important energy use for cooling or heating.

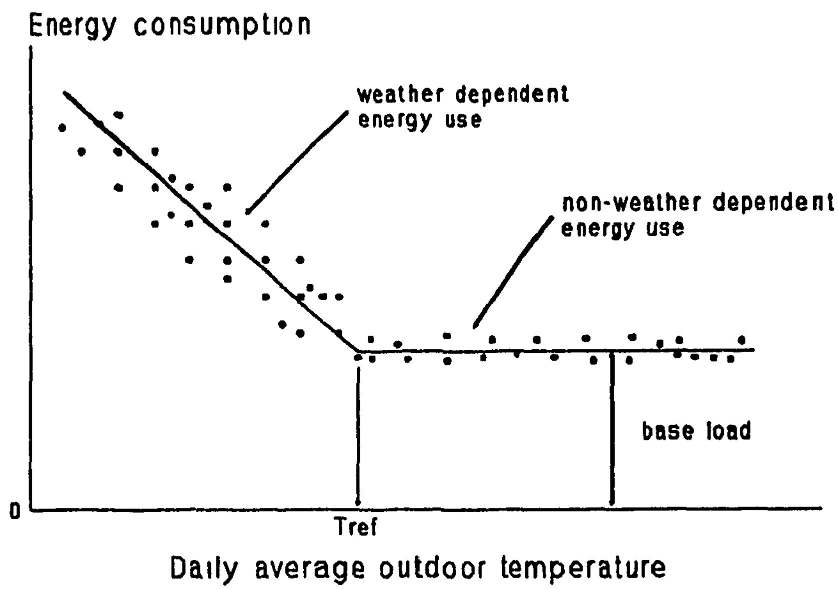

Figure 2.1 Building energy signature

In buildings where heating/cooling is not a dominant energy end-use, some difficulties are expected. In addition, this method can not be used to disaggregate the whole building energy consumption into each end-use for detailed analysis. Extensions of this method may be needed.

c. **Building energy simulation**

The detailed simulation programs [8] are used to simulate the energy flows occurring in a building using a detailed description of building and HVAC systems. Generally this method is costly and time consuming. The users must collect detailed information about building, HVAC system and operation, and must have good background in the area such as heat transfer, mechanical systems and thermal comfort. The preparation of input data requires a great amount of professional judgement. Hence, it should be used carefully by weighing the costs of energy audits against potential energy savings in the buildings.

Several softwares, which are available on the market, can be used for a building energy audit, and mainly to verify the utility bills, to develop indices of energy performance for comparison purpose, or to evaluate the impact of modifying some conditions of contract with the utility companies. The level of user-friendliness regarding the development of input files and the modification or selection of data varies from one software to another. The quality of reports varies also. Some of the available softwares are presented in this chapter.

a. **PRInceton Scorekeeping Method (PRISM) [7]**

PRISM is a weather-normalization method, which was initially created for calculating changes in energy consumption in a group of heated houses without cooling, and subsequently was developed for evaluating changes in electrical consumption in houses with cooling systems and using another fuel for heating. The options correspond to the heating-only (HO) or cooling-only (CO) models in the PRISM program. Later, analysis of the reliability of estimates from the PRISM was extended to individual houses. Presently, work is in progress for developing a module for houses using electricity for heating and cooling.

The PRISM method assumes a linear relationship between energy consumption and heating or cooling degree days:

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

where E_i is the daily average energy consumption for the interval i, calculated by dividing the total amount indicated on the utility bill by the total floor area and by the number of days of that interval; a is the base level or non-weather-dependent daily energy consumption; b is the slope of the weather-dependent energy consumption and corresponds to the ratio between heat loss rate and the efficiency of the HVAC system; $H_i(T_{REF})$ is the number of degree-days computed for the reference temperature T_{REF} within the interval i.

Least-squares linear regression is used to estimate the parameters a and b, and Newton's method is used to estimate T_{REF} for which the linear relationship between E_i and $H_i(T_{REF})$ leads to the highest correlation coefficient R^2. Finally, the normalized annual energy consumption (*NAC*) is obtained by using the parameters a and b, together with the long-term annual average of heating or cooling degree-days $H_o(T_{REF})$

$$NAC = 365a + b \cdot H_o(T_{REF}) \quad [\text{kWh/m}^2]$$

The users can obtain useful information about how energy is consumed in the building. For example, the parameter ***a*** indicates base level (e.g. non-weather-dependent daily consumption such as domestic hot water, lighting or appliances), ***b*** indicates the ratio between the heat loss rate of building and the efficiency of heating system. Since this method eliminates the yearly variations in weather conditions, the normalized annual energy consumption (*NAC*) can be used to compare the energy performance of different buildings or of the same building before and after retrofit. The PRISM program is available on IBM or compatible micro-computers.

b. Load Planner [9]

Load Planner program analyzes utility bills and disaggregates the total energy use into major end-uses such as lights, TV or domestic hot water. The program evaluates the individual contribution to the seasonal heating and cooling energy cost, as well as to the annual energy consumption and cost. The annual electricity usage (kWh) and average daily usage (kWh/day) can also be graphically displayed.

Load Planner estimates the shapes of building end-use load by using its built-in analyzer, which is based on ASHRAE hourly end-use profiles.

The program can handle facilities of all sizes and model all major types of HVAC systems. It also can be used in conjunction with other load survey tools such as XenCAP. This program is only available on main-frame computer systems.

c. Breakout [10]

Breakout program is a tool used to evaluate the energy bills of residential customers and determine the appliance-level energy usage. The program can "break out" the bill into major end-uses through analysis of weather, billing history and household characteristics. The program can also produce reports in both graphics and tabular formats, when it runs with Lotus 1-2-3.

d. TEAM [11]

TEAM program has been developed as a database to store and analyze the fuel consumption of a large building stock. The program provides a tool of energy management through monitoring and targeting the fuel usage. The program consists of three modules: (i) database of energy use, (ii) cost analysis, and (iii) statistical analysis.

Historical degree day data is supplied and can be updated monthly by the user to provide data adjustment for weather fluctuations. A temperature recorder can be used to monitor outside air conditions. A software is used to communicate with the recorder and calculate the local degree hours, and then the results can be used to adjust the local degree days and eliminate the periods when the building was not heated.

Graphs or tables can be selected by the user to present the results such as energy versus degree days, energy or cost versus time, monthly energy or cost versus time, unit cost of fuel versus time.

e. FASER [12]

FASER program performs energy accounting of up to 20 building types, including the comparison of actual energy use versus allocated budget, the forecasting of energy use, and the ranking of buildings in terms of energy performance using eight different indices. It evaluates also the correlation between energy consumption and weather conditions, and if thus correlation exists, it calculates (i) the non-weather-dependent energy use, and (ii) the energy consumption per degree-day. This program requires an IBM or compatible micro-computer.

f. Woods' program [13]

This program was developed to aid home owners to improve the energy efficiency of their homes. The program displays graphically the linear relationship between the monthly energy use, which is obtained from the utility bills, and the monthly average outdoor temperature.

By plotting energy use or cost against average monthly temperature, the program can identify a home's base load, as well as the additional amount of energy used when heating or cooling is required. These values are compared with some recommend target values. If the base load is higher than the average base load of homes with similar size, the home owners should focus on interior appliances or domestic hot water to lower their utility bills. The length of the base line indicates the impact of occupant's behaviour. A longer base line shows that the home owner takes better advantage of natural heating and cooling techniques before resorting to mechanical heating or cooling. In addition to plotting a home's base load line, the program tracks the amount of energy use per degree of outside temperature when the home is being heated or cooled. The program presents the relationship between energy use and outdoor temperature as sloped lines on the chart.

The program requires an IBM or compatible micro-computer.

g. Verifac and Verifac-II [14]

These programs aid building managers or energy consultants to develop and maintain databases of energy performance of large number of commercial buildings, detect errors in utility bills, compare the present energy consumption with that of past years, and predict the energy performance for next year, taking into account the increase of electricity rates. They simulate the impact of some modifications (e.g., reduction of electricity consumption or subscribed electric demand, improvement of power factor) on the energy cost. These programs require an IBM or compatible computer.

2.2 Conclusions

Utility bills contain helpful information for defining the energy performance of a building, provided that an appropriate procedure is used to analyze the available data. The building manager can compare the energy performance of the building with some target values or with the performance of similar buildings. Furthermore, one can discover the reasons of inefficient use of energy, and evaluate the need for further and more detailed analysis.

In the cases when the weather conditions affect the energy use significantly, it is meaningless to compare the energy performance of a building for two different years under the different weather conditions, unless the variation is taken into account. Some conventional methods just divide the total energy consumption by the total degree days to calculate an index of energy performance. Although this is a simple and fast way, it makes an incorrect assumption that energy use is entirely dependent of weather conditions.

From this literature survey, it is noticed that most computer programs were developed for accounting purposes, and in this regard they are useful tools for building manager. However, other useful information can be extracted from the utility bills, which can complete the energy audit. Therefore, a new program was developed, which integrates aspects such as weather normalization and disaggregation of energy use among the major end-uses, and performs a fast evaluation using mainly the information from the utility bills. This program will be presented in the next section.

2.3 NEW Computer Program for Building Energy Audit

2.3.1 Objective

The objective of this research is to develop a new computer program which uses information from utility bills, short term monitoring, walk-through inspection and database of energy performance, as well as weather data, to perform the following tasks:

- evaluate energy performance of existing large commercial buildings;
- disaggregate the total energy consumption among the major end-uses;
- verify utility bills;
- predict the modification of electricity cost as a result of the modification of electric demand, consumption and subscribed demand.

A software called NEW [15], which can be used on the IBM and compatible micro-computers, was developed. A user's guide is presented in Appendix A.

2.3.2 Main blocks of the NEW program

Figure 2.2 shows the main flowchart of the program. The explanation of the main blocks is shown as follows.

a. Main menu

The main screen menu of the program is shown in Fig. 2.3.

Figure 2.3 Main screen menu

1. Review and verify utility bills
2. Results of analysis
3. Comments
4. Exit

Select your choice and press ENTER to continue

There are four items in the main menu, which can be selected by users. Item 1 regards the input file, which was developed from the utility bills, and which contains in addition a general description of building. Item 2 regards the results of last evaluation. Item 3 provides to the user some comments regarding the results of evaluation. The detailed explanation of each item is given below.

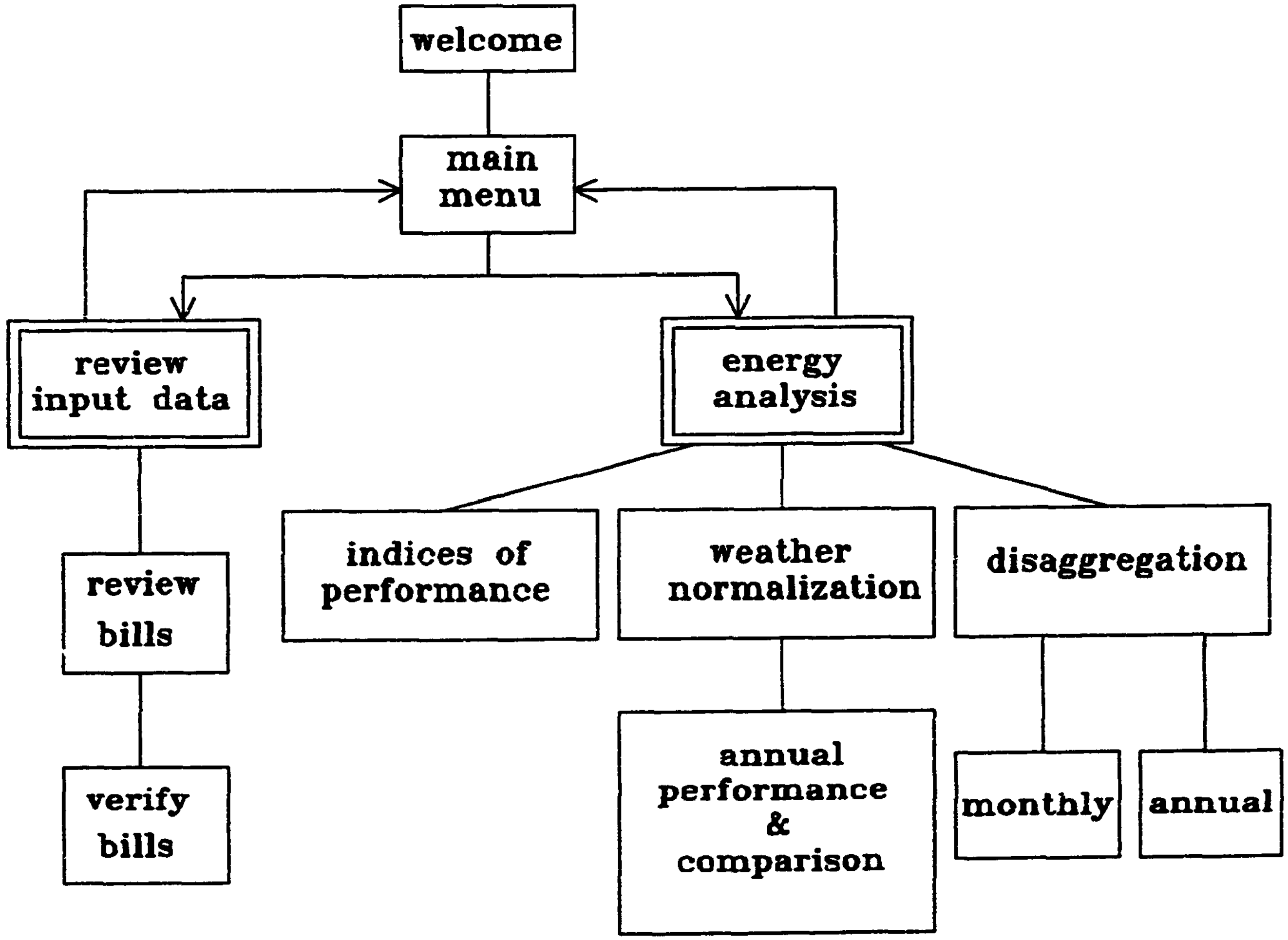

Figure 2.2 Main flowchart of the NEW software

a.1 Review and verify utility bills

Verification of utility bills is carried out according to the electric rates of Hydro-Quebec, which are built into the program. It calculates the cost of electricity consumption and demand, taking into account factors such as subscribed demand, penalties for exceeding the subscribed demand, or credits. The comparison between the utility bills and the calculated costs is presented in a tabular form. The screen menu of this section is shown in Fig. 2.4. To present the results of this program, some information from a large existing office building in Montreal was used.

Figure 2.4 Screen menu for review, verification of utility bills & selection of a new subscribed demand

1. General input data
2. Verification of electricity bill
3. Verification of gas bill
4. Verification of oil bill
5. Verification of steam bill
6. Print
7. Return to the main menu

Select your choice and press ENTER to continue

Figure 2.5 shows an example of general input data of a building. Another example shown in Table 2.1-1 shows an example of verification of the utility bills.

Figure 2.5 General input data for description of a building

```
                ********************
                *   GENERAL DATA   *
                ********************

Net floor area of zone 1:          63103.0 m2

Net floor area of zone 2:               .0 m2

Total gross floor area  :          63610.0 m2

Location:                          Montreal

Year of evaluation:                1991

Year of construction:              1857

Occupancy hours on weekdays:       12 hrs

Occupancy hours on Saturdays:       0 hrs

Occupancy hours on holidays:        0 hrs

Target energy consumption:        250.0 kWh/m2/yr
```

All information shown in Table 2.1-1 was taken directly from utility bills. Table 2.1-2 and Table 2.1-3 show the comparison between utility bills and calculated costs for electric demand and consumption respectively. Table 2.1-4 shows the differences between the total electricity costs from utility bills and those calculated.

In some buildings, the demand charges are a significant portion of the total electricity bill. The program provides an opportunity to evaluate the potential savings by modifying the subscribed electric demand. This option enables the building manager or energy consultant to select the most appropriate subscribed electric demand, by taking into

Table 2.1-1 Verification of utility bills

Period (M/D/Y)	No. days	Demand (kW)	Subscribed demand (kW)	Cons. (kWh)	*Demand Cost ($)	*Cons. Cost ($)	Total Cost ($)
1/11/91							
2/ 8/91	28	1680.0	1275.0	776000.0	9493.61	25191.33	40081.93
3/11/91	31	1600.0	1275.0	788000.0	10010.27	25845.12	41434.49
4/10/91	30	1600.0	1275.0	760000.0	9687.36	24945.60	40021.85
5/ 8/91	28	1600.0	1275.0	704000.0	9902.21	22763.11	37747.97
6/12/91	35	1872.0	1275.0	1020000.0	17628.81	31386.09	56641.62
7/11/91	29	1944.0	1275.0	896000.0	15168.53	27411.36	49205.32
8/14/91	34	1944.0	1275.0	1080000.0	17783.79	32869.49	58534.93
9/12/91	29	1872.0	1275.0	908000.0	14606.73	27564.47	48733.03
10/ 9/91	27	1728.0	1275.0	780000.0	12553.26	23773.01	41978.64
11/12/91	34	1656.0	1275.0	972000.0	15149.15	29513.47	51612.12
12/ 5/91	23	1520.0	1275.0	612000.0	9406.34	18619.41	32386.55
1/14/92	40	1520.0	1275.0	1012000.0	16358.85	31083.36	54824.21
Total:	368	20536.0	15300.0	10308000.0	157748.90	320965.80	553202.70
Average:	30	1711.3	1275.0	859000.0	13145.74	26747.15	46100.22

* Taxes are not included.

Table 2.1-2 Verification of utility bills

Period (M/D/Y)	No. days	Demand (kW)	Subscribed demand (kW)	Demand cost (from bills) ($)	Demand cost (calculated) ($)	Difference ($)
1/11/91						
2/ 8/91	28	1680.0	1275.0	10970.82	10970.82	.00
3/11/91	31	1600.0	1275.0	11567.87	11567.87	.00
4/10/91	30	1600.0	1275.0	11194.71	11194.71	.00
5/ 8/91	28	1600.0	1275.0	11442.99	11442.99	.00
6/12/91	35	1872.0	1275.0	20371.85	20371.85	.00
7/11/91	29	1944.0	1275.0	17528.75	17528.75	.00
8/14/91	34	1944.0	1275.0	20550.95	20550.95	.00
9/12/91	29	1872.0	1275.0	16879.54	16879.54	.00
0/ 9/91	27	1728.0	1275.0	14506.55	14506.55	.00
1/12/91	34	1656.0	1275.0	17506.36	17506.36	.00
2/ 5/91	23	1520.0	1275.0	10869.97	10869.96	.00
1/14/92	40	1520.0	1275.0	18904.29	18904.28	.00
Total:	368	20536.0	15300.0	182294.60	182294.60	
Average:	30	1711.3	1275.0	15191.22	15191.22	

Table 2.1-3 Verification of utility bills

Period (M/D/Y)	No. days	Consumption (kWh)	Cons. cost (from bills) ($)	Cons. cost (calculated) ($)	Difference ($)
1/11/91					
2/ 8/91	28	776000.0	29111.10	29111.10	.00
3/11/91	31	788000.0	29866.62	29866.62	.00
4/10/91	30	760000.0	28827.13	28827.13	.00
5/ 8/91	28	704000.0	26305.05	26304.97	.08
6/12/91	35	1020000.0	36269.77	36269.76	.01
7/11/91	29	896000.0	31676.57	31676.57	.00
8/14/91	34	1080000.0	37983.98	37983.97	.01
9/12/91	29	908000.0	31853.50	31853.50	.00
10/ 9/91	27	780000.0	27472.09	27472.10	-.01
11/12/91	34	972000.0	34105.77	34105.77	-.01
12/ 5/91	23	612000.0	21516.59	21516.59	.00
1/14/92	40	1012000.0	35919.93	35919.93	.00
Total:	368	10308000.0	370908.10	370908.00	
Average:	30	859000.0	30909.01	30909.00	

Table 2.1-4 Verification of utility bills

Period (M/D/Y)	No. days	Total cost (from bills) ($)	Total cost (calculated) ($)	Difference ($)
1/11/91				
2/ 8/91	28	40081.93	40081.91	.02
3/11/91	31	41434.49	41434.49	.00
4/10/91	30	40021.85	40021.85	.00
5/ 8/91	28	37747.97	37747.96	.01
6/12/91	35	56641.62	56641.61	.01
7/11/91	29	49205.32	49205.31	.01
8/14/91	34	58534.93	58534.92	.01
9/12/91	29	48733.03	48733.04	.00
10/ 9/91	27	41978.64	41978.65	-.01
11/12/91	34	51612.12	51612.13	-.01
12/ 5/91	23	32386.55	32386.55	.00
1/14/92	40	54824.21	54824.21	.00
Total:	368	553202.70	553202.60	
Average:	30	46100.22	46100.22	

account the monthly peak electric demand and the penalties for exceeding the subscribed demand. Two examples are shown below.

a.1.1 Electrical demand exceeds the subscribed demand

The subscribed demand is assumed to be reduced from 1,275 kW to 1,000 kW (Table 2.2-1). In this case, the average electrical demand is 70% higher than subscribed demand. According to Hydro Quebec, the maximum electrical demand in winter cannot exceed 33% of the subscribed demand. If this limit is exceeded, the client must face penalties. One can see the difference in Table 2.2-2 and Table 2.2-4. The total electrical cost increased from $553,202.70 to $579,724.10 (4.8%, see Table 2.2-4).

a.1.2 Electrical demand is lower than the subscribed demand

If the subscribed demand exceeds electrical demand, the owner of the building has to pay higher bills, since the cost of electricity is calculated by using the higher value among the electrical demand and the subscribed demand. Here the subscribed demand is assumed to be increased from 1,275 kW to 2,000 which is about 300 kW higher than the average electrical demand (Table 2.3-1). If it is true, the demand cost will increase from $182,294.60 to $211,902.20 (Table 2.3-2) by 16.2%, the consumption cost increase from $370,908.10 to $380,496.50 (Table 2.3-3) by 2.6%, and the total electrical cost increase from $553,202.70 to $592,398.70 (Table 2.3-4) by 7.1%, even though the electrical demand and consumption are not changed at all.

Table 2.2-1 Verification of Utility Bills

Period (M/D/Y)	No. days	Demand (kW)	Subscribed demand (kW)	Cons. (kWh)	*Demand Cost ($)	*Cons. Cost ($)	Total Cost ($)
1/11/91							
2/ 8/91	28	1680.0	1000.0	776000.0	9493.61	25191.33	40081.93
3/11/91	31	1600.0	1000.0	788000.0	10010.27	25845.12	41434.49
4/10/91	30	1600.0	1000.0	760000.0	9687.36	24945.60	40021.85
5/ 8/91	28	1600.0	1000.0	704000.0	9902.21	22763.11	37747.97
6/12/91	35	1872.0	1000.0	1020000.0	17628.81	31386.09	56641.62
7/11/91	29	1944.0	1000.0	896000.0	15168.53	27411.36	49205.32
8/14/91	34	1944.0	1000.0	1080000.0	17783.79	32869.49	58534.93
9/12/91	29	1872.0	1000.0	908000.0	14606.73	27564.47	48733.03
10/ 9/91	27	1728.0	1000.0	780000.0	12553.26	23773.01	41978.64
11/12/91	34	1656.0	1000.0	972000.0	15149.15	29513.47	51612.12
12/ 5/91	23	1520.0	1000.0	612000.0	9406.34	18619.41	32386.55
1/14/92	40	1520.0	1000.0	1012000.0	16358.85	31083.36	54824.21
Total:	368	20536.0	12000.0	10308000.0	157748.90	320965.80	553202.70
Average:	30	1711.3	1000.0	859000.0	13145.74	26747.15	46100.22

* Taxes are not included.

Table 2.2-2 Verification of Utility Bills

Period (M/D/Y)	No. days	Demand (kW)	Subscribed demand (kW)	Demand cost (from bills) ($)	Demand cost (calculated) ($)	Difference ($)
1/11/91						
2/ 8/91	28	1680.0	1000.0	10970.82	18143.67	-7172.86
3/11/91	31	1600.0	1000.0	11567.87	18574.97	-7007.10
4/10/91	30	1600.0	1000.0	11194.71	11194.71	.00
5/ 8/91	28	1600.0	1000.0	11442.99	11442.99	.00
6/12/91	35	1872.0	1000.0	20371.85	20371.85	.00
7/11/91	29	1944.0	1000.0	17528.75	17528.75	.00
8/14/91	34	1944.0	1000.0	20550.95	20550.95	.00
9/12/91	29	1872.0	1000.0	16879.54	16879.54	.00
10/ 9/91	27	1728.0	1000.0	14506.55	14506.55	.00
11/12/91	34	1656.0	1000.0	17506.36	17506.36	.00
12/ 5/91	23	1520.0	1000.0	10869.97	15375.60	-4505.64
1/14/92	40	1520.0	1000.0	18904.29	26740.18	-7835.89
Total:	368	20536.0	12000.0	182294.60	208816.10	
Average:	30	1711.3	1000.0	15191.22	17401.34	

Table 2.2-3 Verification of Utility Bills

Period (M/D/Y)	No. days	Consumption (kWh)	Cons. cost (from bills) ($)	Cons. cost (calculated) ($)	Difference ($)
1/11/91					
2/ 8/91	28	776000.0	29111.10	29111.10	.00
3/11/91	31	788000.0	29866.62	29866.62	.00
4/10/91	30	760000.0	28827.13	28827.13	.00
5/ 8/91	28	704000.0	26305.05	26304.97	.08
6/12/91	35	1020000.0	36269.77	36269.76	.01
7/11/91	29	896000.0	31676.57	31676.57	.00
8/14/91	34	1080000.0	37983.98	37983.97	.01
9/12/91	29	908000.0	31853.50	31853.50	.00
10/ 9/91	27	780000.0	27472.09	27472.10	-.01
11/12/91	34	972000.0	34105.77	34105.77	-.01
12/ 5/91	23	612000.0	21516.59	21516.59	.00
1/14/92	40	1012000.0	35919.93	35919.93	.00
Total:	368	10308000.0	370908.10	370908.00	
Average:	30	859000.0	30909.01	30909.00	

Table 2.2-4 Verification of Utility Bills

Period (M/D/Y)	No. days	Total cost (from bills) ($)	Total cost (calculated) ($)	Difference ($)
1/11/91				
2/ 8/91	28	40081.93	47254.77	-7172.84
3/11/9	31	41434.49	48441.59	-7007.10
4/10/91	30	40021.85	40021.85	.00
5/ 8/91	28	37747.97	37747.96	.01
6/12/91	35	56641.62	56641.61	.01
7/11/91	29	49205.32	49205.31	.01
8/14/91	34	58534.93	58534.92	.01
9/12/91	29	48733.03	48733.04	.00
10/ 9/91	27	41978.64	41978.65	-.01
11/12/91	34	51612.12	51612.13	-.01
12/ 5/91	23	32386.55	36892.20	-4505.64
1/14/92	40	54824.21	62660.11	-7835.89
Total:	368	553202.70	579724.10	
Average:	30	46100.22	48310.34	

Table 2.3-1 Verification of Utility Bills

Period (M/D/Y)	No. days	Demand (kW)	Subscribed demand (kW)	Cons (kWh)	*Demand Cost ($)	*Cons. Cost ($)	Total Cost ($)
1/11/91							
2/ 8/91	28	1680.0	2000.0	776000.0	9493.61	25191.33	40081.93
3/11/91	31	1600.0	2000.0	788000.0	10010.27	25845.12	41434.49
4/10/91	30	1600.0	2000.0	760000.0	9687.36	24945.60	40021.85
5/ 8/91	28	1600.0	2000.0	704000.0	9902.21	22763.11	37747.97
6/12/91	35	1872.0	2000.0	1020000.0	17628.81	31386.09	56641.62
7/11/91	29	1944.0	2000.0	896000.0	15168.53	27411.36	49205.32
8/14/91	34	1944.0	2000.0	1080000.0	17783.79	32869.49	58534.93
9/12/91	29	1872.0	2000.0	908000.0	14606.73	27564.47	48733.03
10/ 9/91	27	1728.0	2000.0	780000.0	12553.26	23773.01	41978.64
11/12/91	34	1656.0	2000.0	972000.0	15149.15	29513.47	51612.12
12/ 5/91	23	1520.0	2000.0	612000.0	9406.34	18619.41	32386.55
1/14/92	40	1520.0	2000.0	1012000.0	16358.85	31083.36	54824.21
Total:	368	20536.0	24000.0	10308000.0	157748.90	320965.80	553202.70
Average:	30	1711.3	2000.0	859000.0	13145.74	26747.15	46100.22

* Taxes are not included.

Table 2.3-2 Verification of Utility Bills

Period (M/D/Y)	No. days	Demand (kW)	Subscribed demand (kW)	Demand cost (from bills) ($)	Demand cost (calculated) ($)	Difference ($)
1/11/91						
2/ 8/91	28	1680.0	2000.0	10970.82	13060.50	-2089.68
3/11/91	31	1600.0	2000.0	11567.87	14459.84	-2891.97
4/10/91	30	1600.0	2000.0	11194.71	13993.39	-2798.68
5/ 8/91	28	1600.0	2000.0	11442.99	14303.74	-2860.75
6/12/91	35	1872.0	2000.0	20371.85	21764.80	-1392.95
7/11/91	29	1944.0	2000.0	17528.75	18033.69	-504.94
8/14/91	34	1944.0	2000.0	20550.95	21142.95	-592.00
9/12/91	29	1872.0	2000.0	16879.54	18033.69	-1154.15
10/ 9/91	27	1728.0	2000.0	14506.55	16789.99	-2283.44
11/12/91	34	1656.0	2000.0	17506.36	21142.95	-3636.59
12/ 5/91	23	1520.0	2000.0	10869.97	14302.58	-3432.62
1/14/92	40	1520.0	2000.0	18904.29	24874.06	-5969.77
Total:	368	20536.0	24000.0	182294.60	211902.20	
Average:	30	1711.3	2000.0	15191.22	17658.51	

Table 2.3-3 Verification of Utility Bills

Period (M/D/Y)	No. days	Consumption (kWh)	Cons. cost (from bills) ($)	Cons. cost (calculated) ($)	Difference ($)
1/11/91					
2/ 8/91	28	776000.0	29111.10	30076.11	-965.01
3/11/91	31	788000.0	29866.62	31202.12	-1335.50
4/10/91	30	760000.0	28827.13	30119.56	-1292.42
5/ 8/91	28	704000.0	26305.05	27422.48	-1117.43
6/12/91	35	1020000.0	36269.77	36628.01	-358.25
7/11/91	29	896000.0	31676.57	31806.43	-129.87
8/14/91	34	1080000.0	37983.98	38136.23	-152.25
9/12/91	29	908000.0	31853.50	32150.34	-296.84
10/ 9/91	27	780000.0	27472.09	28059.38	-587.29
11/12/91	34	972000.0	34105.77	35041.07	-935.31
12/ 5/91	23	612000.0	21516.59	22399.43	-882.84
1/14/92	40	1012000.0	35919.93	37455.30	-1535.38
Total:	368	10308000.0	370908.10	380496.50	
Average:	30	859000.0	30909.01	31708.04	

Table 2.3-4 Verification of Utility Bills

Period (M/D/Y)	No. days	Total cost (from bills) ($)	Total cost (calculated) ($)	Difference ($)
1/11/91				
2/ 8/91	28	40081.93	43136.61	-3054.68
3/11/91	31	41434.49	45661.96	-4227.47
4/10/91	30	40021.85	44112.95	-4091.10
5/ 8/91	28	37747.97	41726.22	-3978.25
6/12/91	35	56641.62	58392.81	-1751.19
7/11/91	29	49205.32	49840.13	-634.80
8/14/91	34	58534.93	59279.18	-744.25
9/12/91	29	48733.03	50184.03	-1451.00
10/ 9/91	27	41978.64	44849.37	-2870.73
11/12/91	34	51612.12	56184.02	-4571.90
12/ 5/91	23	32386.55	36702.02	-4315.46
1/14/92	40	54824.21	62329.36	-7505.15
Total:	368	553202.70	592398.70	
Average:	30	46100.22	49366.55	

a.2 Results of analysis

Several options are available in this section, which are shown in the following screen menu (Fig. 2.6).

Figure 2.6 Screen menu for results of analysis

```
1. Energy performance of electricity
2. Energy performance of gas
3. Energy performance of oil
4. Energy performance of steam
5. Weather normalization
6. Annual energy performance
7. Disaggregation
8. Print
9. Return to the main menu

Select your choice and press ENTER to continue
```

In this section, the program performs the following tasks:

a.2.1 Development of indices of the annual energy performance for each billing period

Tables 2.4 and 2.5 present results for the selected building in Montreal, which uses electricity and steam:

- annual energy consumption; in kWh/m^2,
- annual energy cost; in $\$/m^2$,
- peak electric demand; in W/m^2,

- average cost of equivalent-kWh; in $/kWh,
- electricity consumption; in kWh/m^2 and $kWh/m^2/day$,
- energy cost; in $\$/m^2$ and $\$/m^2/day$,

(Similar tables can be obtained for oil and gas.);

Table 2.4. Energy performance of electricity

```
*************************************
* Energy Performance (Electricity) *
*************************************

Annual energy consumption       (kWh/m2/yr):  162.05
Annual energy cost              ($/m2/yr):      8.63
Annual cost of equivalent-kWh   ($/kWh):       .0532

Yearly Load Factor:                             .60
```

Period	No. days	Electric demand W/m2	Electricity use kWh/m2	kWh/m2/day	Cost $/m2	$/m2/day	$/kWh	ELF	OLF
1 11 1991									
2 8 1991	28	26.4	12.20	.44	.63	.0225	.0517	.69	.36
3 11 1991	31	25.2	12.39	.40	.65	.0210	.0526	.66	.36
4 10 1991	30	25.2	11.95	.40	.63	.0210	.0527	.66	.36
5 8 1991	28	25.2	11.07	.40	.59	.0212	.0536	.65	.36
6 12 1991	35	29.4	16.04	.46	.89	.0254	.0555	.65	.36
7 11 1991	29	30.6	14.09	.49	.77	.0267	.0549	.66	.36
8 14 1991	34	30.6	16.98	.50	.92	.0271	.0542	.68	.36
9 12 1991	29	29.4	14.27	.49	.77	.0264	.0537	.70	.36
10 9 1991	27	27.2	12.26	.45	.66	.0244	.0538	.70	.36
11 12 1991	34	26.0	15.28	.45	.81	.0239	.0531	.72	.36
12 5 1991	23	23.9	9.62	.42	.51	.0221	.0529	.73	.36
1 14 1992	40	23.9	15.91	.40	.86	.0215	.0542	.69	.36
Total:	368		162.05		8.70				
Average:		26.9	13.50	.44	.72	.0236	.0536	.68	.36

Table 2.5 Energy performance of gas

```
******************************
* Energy Performance (Steam) *
******************************

Annual energy consumption      (kWh/m2/yr):  211.35
Annual energy cost             ($/m2/yr):      8.53
Annual cost of equivalent-kWh  ($/kWh/yr):    .0403
```

Period	No. days	Energy use eq.-kWh	kWh/m2	kWh/m2/day	Cost $/m2	$/m2/day	$/kWh
12 31 1990							
1 31 1991	31	2747500.0	43.19	1.3933	1.65	.0532	.0382
2 28 1991	28	2747500.0	43.19	1.5426	1.81	.0645	.0418
3 31 1991	31	1830172.0	28.77	.9281	1.18	.0380	.0409
4 30 1991	30	957700.1	15.06	.5019	.62	.0206	.0410
5 31 1991	31	204100.0	3.21	.1035	.14	.0044	.0422
6 30 1991	30	157224.3	2.47	.0824	.10	.0035	.0425
7 31 1991	31	.0	.00	.0000	.00	.0000	.0000
8 31 1991	31	.0	.00	.0000	.00	.0000	.0000
9 30 1991	30	251200.0	3.95	.1316	.21	.0070	.0533
10 31 1991	31	872471.5	13.72	.4424	.56	.0181	.0410
11 30 1991	30	1157314.0	18.19	.6065	.73	.0243	.0400
12 31 1991	31	2518505.0	39.59	1.2772	1.54	.0496	.0388
Total:	365	13443690.0	211.35		8.53		
Average:		1120307.0	17.6	.5841	.71	.0236	.0350

- electric load factor (*ELF*) [16,17], which is defined as follows:

$$ELF = \frac{monthly\ consumption}{\#\ days \cdot 24 \cdot monthly\ demand} \quad ; \qquad (2.1)$$

If *ELF* is greater than 1.0, then either the energy consumption or the peak electric demand is not correct; this index can be used as an additional verification of utility bills;

- occupancy load factor (*OLF*) [16]:

$$OLF = \frac{occupied\ hours}{total\ hours\ in\ the\ month} \quad ; \qquad (2.2)$$

If *ELF* is greater than *OLF*, one can conclude that electricity is used outside the normal occupancy hours or the subscribed electric demand is too high;

- energy consumption of gas, oil or steam, in equivalent-kWh, calculated by using the heating value of gas (MJ/m^3), of oil (MJ/kg) or steam (MJ/lb), and the efficiency of system (70%).

a.2.2 Comparison of annual energy budget with some target values established by the building manager, as well as with similar indices from a database, for the following cases (Table 2.6):

- average office building built in Montreal in the same year;
- average of all office buildings in Montreal, based on a survey of energy performance of office buildings in 1988;
- most energy-efficient office building.

Table 2.6 Comparison of the annual energy performance

****
* Annual energy consumption comparisons *
****

Energy budget kWh/m2	Average energy consumption(kWh/m2/yr) in				
	Year of construc.	Montreal in 1988	the best EEB in Montreal(1988)	Best EEB	Target
372.0	332.1	455.2	185.8	180.0	250.0

For instance, in this case the building has a lower energy use than the average office building in Montreal in 1988. However, it consumes more energy than the similar buildings built in the same period as well as that of the most energy efficient buildings (EEB). Finally, the target value established by the building manager is not met. One can immediately conclude that there is a potential for energy savings in this building.

a.2.3 Normalization of energy consumption and cost for the number of days of each billing period

When reading period is different from 30 or 31 days, then the program corrects the values from the utility bills. Table 2.7 shows that the annual normalized electricity consumption was 160.7 kWh/m² compared with 162.05 kWh/m², which was obtained by adding all utility bills (Table 2.4). It presents also the disaggregation of energy consumption and cost among the fuel types. For instance, electricity accounts for 43.2% of total energy consumption and 50.3% of total energy cost.

Table 2.7 Normalized energy performance

```
**********************************
*   Annual Energy Performance    *
* Normalized For Number Of Days *
**********************************
```

Type of fuel	Energy use		Cost		$/kWh
	kWh/m2	%	$/m2	%	
Electricity	160.7	43.2	8.63	50.3	.0532
Gas	.0	.0	.00	.0	.0000
Oil	.0	.0	.00	.0	.0000
Steam	211.3	56.8	8.53	49.7	.0403
Total:	372.0	100.0	17.15	100.0	.0936

a.2.4 Normalization of annual energy consumption for average weather conditions

A new weather-normalization method, developed by Zmeureanu [18], was integrated into the program, which makes the energy evaluation more reliable by eliminating the effects of different weather conditions. It uses the building energy signature, defined as the linear relation between the daily average energy consumption and the daily average outdoor temperature. The new method uses long-term average temperature data calculated over 19-year period, and is then used to calculated the normalized annual energy consumption of buildings.

The new method involves the following two steps, which correspond to (i) development of the building energy signature and (ii) calculation of the normalized annual energy consumption.

Building energy signature

The building energy signature is defined as a linear relationship between the daily average energy consumption E_i expressed in equivalent kWh/m²/day and the daily average outdoor temperature T_i in °C, for each meter reading interval:

$$E_i = a + b\ T_i \tag{2.3}$$

The coefficient b is expressed in kWh/m²/day/°C, and indicates the rate of increase of the weather-dependent energy consumption. The building consumes energy above the base load only when the outdoor temperature drops below the reference temperature T_{REF} (heating) or increases above T_{REF} (cooling). Hence, the reference temperature at which the weather-dependent curve equals the base load $E = a + b\ T_{REF} = B_L$ is calculated as follows:

$$T_{REF} = (B_L - a) / b. \tag{2.4}$$

To obtain the equation which best fits a set of points *(E1,T1)*, *(E2,T2)*, ···, *(Ei,Ti)*, which correspond to all billing periods, the simple linear regression is assumed:

$$Y = C_0 + C_1 X \tag{2.5}$$

The problem is then to find the best point estimates C_0, C_1 from the population regression values a, b where the true regression line is

$$E = a + b\,T. \tag{2.6}$$

Thus for any given T, the theoretical average value of the population of E's for this given T is a linear function of T: $a + b\,T$.

By using the simple linear regression analysis, the sum of squares of the vertical deviations S which should be minimized to obtain a line of best fit to given data is as follows:

$$S=\sum_{i=1}^{n}(E_i-a-bT_i)^2 \tag{2.7}$$

$$\begin{cases} \dfrac{\partial S}{\partial a}=0 \\ \\ \dfrac{\partial S}{\partial b}=0 \end{cases} \tag{2.8}$$

The solutions are as follows.

$$\begin{cases} na+b\sum_{i=1}^{n} T_i = \sum_{i=1}^{n} E_i \\ a\sum_{i=1}^{n} T_i+b\sum_{i=1}^{n} T_i^2 = \sum_{i=1}^{n} T_iE_i \end{cases} \tag{2.9}$$

$$a = \frac{\sum_{i=1}^{n} E_i}{n} - b\frac{\sum_{i=1}^{n} T_i}{n} \tag{2.10}$$

$$b = \frac{n\sum_{i=1}^{n} T_iE_i - \sum_{i=1}^{n} T_i \sum_{i=1}^{n} E_i}{n\sum_{i=1}^{n} T_i^2 - (\sum_{i=1}^{n} T_i)^2} \tag{2.11}$$

The correlation coefficient ***R*** is often used to describe how relatively good a fit to data is provided by the linear model.

The definition of the correlation ***R*** is given as follows.

$$R = \frac{\sum_{i=1}^{n} T_iE_i-(\sum_{i=1}^{n} T_i)(\sum_{i=1}^{n} E_i)/n}{\sqrt{\sum_{i=1}^{n} T_i^2-[(\sum_{i=1}^{n} T_i)^2/n]}\sqrt{\sum_{i=1}^{n} E_i^2-[(\sum_{i=1}^{n} E_i)^2/n]}} \tag{2.12}$$

This coefficient is always a dimensionless number, and takes values between -1 and +1. The extremes are reached only if all points lie exactly on a straight line. The coefficient of determination R^2 is linearly related to T and has always a positive value.

The daily dry-bulb average temperatures measured at Dorval Atmospheric Environment Service from 1974 to 1992 are used.

A simple procedure is used to define the base load or non-weather-dependent energy consumption.

(i) Select the lowest energy consumption E_l, which usually occurs in the summer for gas-heated buildings and in the winter for electrical-cooled buildings.

(ii) All monitored energy consumption with values between E_{min} and $1.2E_{min}$ is considered to be independent of the outdoor temperature. If the energy consumption for at least two more meter reading intervals falls within the given range, the based-load electrical energy consumption B_L is calculated as the average of values within that range. Otherwise, the point over the minimum energy use must be eliminated, a new minimum energy consumption is selected, and then the process is repeated.

(iii) The monitored data (energy consumption E, and average outdoor temperature T) are then used to define the weather-dependent energy signature. By using the simple linear regression analysis, the coefficients a and b are defined, along with the correlation coefficient R^2.

Therefore, the building energy signature was developed only for the interval covered by the utility bills. However, as proved by Zmeureanu [19] based on computer simulation, this energy signature does not change in time, unless some renovations or modifications in operation take place in the building.

Normalized annual energy consumption (*NAC*)

The normalized annual energy consumption is calculated by using the energy signature of the building and the hourly dry-bulb temperature over a 19-year period:

$$NAC = 365B_L + \varepsilon\, C\, N_{T,19} / (365\, N^2_{HVAC}), \quad (2.13)$$

where

ε	=	correction coefficient
	=	$[(E_m - N_m B_L / C_1]\, N_m N^2_{HVAC} / N_T,$
E_m	=	total energy consumption from the utility bills, in kWh;
N_m	=	total number of days covered by the utility bills, in days;
B_L	=	base-load energy consumption, in kWh/m^2/day;
N_T	=	total number of hours when $T_{DB}<T_{REF}$ for gas-heated or $T_{DB}>T_{REF}$ for electrically-cooled buildings for the period of bills, in hours;
N_{HVAC}	=	number of daily operating hours of HVAC systems, in hours/day;
$N_{T,19}$	=	number of hours when $T_{DB}<T_{REF}$ for gas-heated or $T_{DB}>T_{REF}$ for electrically-cooled buildings for the period of bills, calculated as an average over a 19-year period, in hours;
C_1	=	weather-dependent energy consumption, in kWh.

The weather dependent energy consum_ .ion is

$$C_1=\begin{cases} \sum_{i=1}^{n}(a\mp bT_{DB,i}-B_L)BIN(T_{DB,i}) & \begin{array}{l} \text{if } T_{DB}<T_{REF}(heating), \\ \text{or } T_{DB}>T_{REF}(cooling), \end{array} \\ 0 & \begin{array}{l} \text{if } T_{DB}\geq T_{REF}(heating), \\ \text{or } T_{DB}\leq T_{REF}(cooling). \end{array} \end{cases} \tag{2.14}$$

The weather-dependent energy consumption calculated as an average for a 19-year period is

$$C=\begin{cases} \frac{1}{19}\sum_{j=1}^{19}\sum_{i=1}^{n}(a\mp bT_{DB,i,j}-B_L)BIN(T_{DB,i,j}) & \begin{array}{l} \text{if } T_{DB}<T_{REF}(heating), \\ \text{or } T_{DB}>T_{REF}(cooling), \end{array} \\ 0 & \begin{array}{l} \text{if } T_{DB}\geq T_{REF}(heating), \\ \text{or } T_{DB}\leq T_{REF}(cooling). \end{array} \end{cases} \tag{2.15}$$

where

$BIN(T_{DB,i})$ is the number of hours of occurrence of the dry-bulb temperature bin having T_{DB} as centre during operation of the HVAC system. Subscript i indicates the value in each bin, while j indicates the values in different years.

By replacing the correction coefficient ε, the final formula for calculating the monitored annual energy consumption is obtained.

$$NAC = 365B_L + \begin{cases} (E_m-N_mB_L)\frac{C}{C_1}\frac{N_{T_{15}}}{N_T}\frac{N_m}{365} & \begin{array}{l} \text{if } T_{DB}<T_{REF}(heating), \\ \text{or } T_{DB}>T_{REF}(cooling), \end{array} \\ 0 & \begin{array}{l} \text{if } T_{DB}\geq T_{REF}(heating), \\ \text{or } T_{DB}\leq T_{REF}(cooling). \end{array} \end{cases} \tag{2.16}$$

Following the calculation, several results are presented for each fuel type (Table-2.8):

- normalized annual energy consumption (*NAC*); in kWh/m,^{2}
- base load or non-weather-dependent energy use; in kWh/m^2/day,
- slope of weather-dependent energy use; in kWh/m^2/day/°C,
- reference temperature; in °C,
- correlation coefficient R^2 used to test the accuracy of data fitting by the resulting linear function.

It presents also the energy signature for each fuel type, in kWh/m^2/day.

Table 2.8 Weather-normalized energy consumption

Normalized Annual Energy Consumption
For Average Weather Conditions

FUEL TYPE	NAC kWh/ m2/yr	Base kWh/ m2/day	Tref C	a kWh/ m2/day	b kWh/ m2/day	R*R
Elec.	160.12	.426	2.46	.419	.0029	.805
Gas	.00	.000	.00	.000	.0000	.000
Oil	.00	.000	.00	.000	.0000	.000
Steam	204.02	.000	19.08	.942	-.0494	.970
TOTAL	364.14	.426				

Energy Signature:

Elec. = .419 + .0029*Tout
Steam = .942 - .0494*Tout

One can notice that the gas consumption is more sensitive to weather conditions than the electricity consumption. The slope (*b*) of weather-dependent curve indicates that for 1°C increase of the average outdoor temperature, the gas use is reduced by 0.0494 kWh/m^2/day, while the electricity use is increased by 0.0029 kWh/m^2/day. One also can notice that the total annual energy consumption calculated directly from utility bills is 373.40 kWh in which electricity consumption is 162.05 kWh/m^2 (Table 2.4) and steam consumption is 211.35 kWh/m^2 (Table 2.5), the same value normalized by number of days is 372.0 kWh/m^2 (Table 2.7), and the normalized energy consumption in terms of weather conditions is 364.14 kWh/m^2 (Table 2.8).

a.2.5 Disaggregation of total energy consumption among the major end-uses such as lighting, office equipment, chillers, cooling towers or preheating coils.

To perform this task, the program requires additional information: (i) some design data, or general indices which can be provided by the operation team, or (ii) short term monitoring. In this research, the disaggregation calculations were performed using design data, and then were compared with results from a computer simulation using the MICRO-DOE2 program presented in chapter 3. Tables 2.9 and 2.10 show as examples the monthly and annual distribution of energy consumption among the major end-uses.

a.3 Option of comments

This option will be completed as further development. An expert system is recommended to be integrated within this program, in order to help building owner or manager analyzing results and making decisions.

Table 2.9 Monthly distribution of electricity consumption

****
* Monthly Electricity Distribution *
****

Month	Lighting kWh	Lighting %	Equipment kWh	Equipment %	Chiller kWh	Chiller %	Preheating kWh	Preheating %	CL-Tower kWh	CL-Tower %
JAN	324452.3	31.8	118684.2	11.6	144840.0	14.2	.0	.0	26053.0	2.6
FEB	307501.9	26.1	110779.9	9.4	134895.0	11.5	.0	.0	24264.0	2.1
MAR	367148.8	32.2	129345.4	11.3	240422.5	21.1	.0	.0	32996.0	2.9
APR	352010.6	36.2	124341.5	12.8	295375.0	30.4	.0	.0	35432.0	3.6
MAY	327382.4	28.7	119347.6	10.4	284962.5	24.9	.0	.0	34183.0	3.0
JUN	352010.6	31.4	124341.5	11.1	295375.0	26.3	.0	.0	35432.0	3.2
JUL	341614.6	27.6	122901.3	9.9	293250.0	23.7	.0	.0	35117.0	2.8
AUG	352916.6	24.7	125791.7	8.8	298775.0	20.9	.0	.0	35840.0	2.5
SEP	337778.4	28.6	120787.7	10.2	287087.5	24.3	.0	.0	34438.0	2.9
OCT	327382.4	27.9	119347.6	10.2	283602.5	24.1	.0	.0	34142.0	2.9
NOV	323546.2	29.5	117234.0	10.7	142800.0	13.0	.0	.0	25686.0	2.3
DEC	338684.4	28.8	122237.9	10.4	148665.0	12.6	.0	.0	26741.0	2.3

Table 2.10 Annual distribution of electricity consumption

****
* Electricity Distribution *
****

	(kWh)	(%)
Lighting	4052429.	29.2
Equipment	1455140.	10.5
Chiller	2850050.	20.6
Preheat	0.	.0
CL-Tower/AC-COND	380384.	2.7
Others	5127101.	37.0
Total	13865100.	100.0

2.3.3 Input data

This section presents the input data required by the NEW program.

a. Input data required for evaluating the indices of energy performance

The input data includes (i) utility billing data, and (ii) general description of the building and HVAC system. Figure 2.7 and Figure 2.8 show the examples of these input files, for a building using both electricity and steam. For instance, the building is defined by the following information:

- floor area; in m^2,
- year of evaluation and construction,
- occupancy hours; in hours/day.

The user can define up to two different zones within the building. For instance, most spaces have an operation schedule of 12 hours/day, while one floor has a special tenant with continuous operation.

The following information is used from the utility bills for each billing period to analyze the electricity consumption:

- peak electric demand; in kW,
- subscribed electric demand; in kW,
- consumption; in kWh,
- cost (total demand and consumption); in $,
- credits or penalties; in $/kW.

Credits and penalties can be changed annually with the utility rates. Therefore, two values of credits or penalties are required to be input into the program. For instance, before May 1, 1991, the penalty was 9.78 $/kW in the building. After that, the penalty was changed to 15.78 $/kW. For gas/oil/steam consumption, the following information is required for each billing period:

- consumption; in m^3, l, or lb,
- cost; in $.

Figure 2.7 Input data file for indices of energy performance (steam)

first billing day

numbers of billing period

```
STM
12 31 1990  12
*  M/D/Y      LB          $    *
01 31 1991  6125000   104838.65
02 28 1991  6125000   114883.65
03 31 1991  4080000    74849.45
04 30 1991  2135000    39251.55
05 27 1991   455000     8621.10
06 30 1991   350500     6675.40
07 27 1991        0        0.00
08 24 1991        0        0.00
09 30 1991   560000    13380.65
10 31 1991  1945000    35763.80
11 30 1991  2580000    46288.05
12 31 1991  5614500    97842.55
```

Figure 2.8 Input data file for indices of energy performance (electricity)

```
                              year of evaluation
                              year of construction
1991 1857
Montreal                      location of building
                                                first billing day
                                                numbers of billing period
                                                occupancy hours on
                                                weekdays
                                                occupancy hours on
                                                Saturdays
                                                occupancy hours on
                                                holidays
                                                net floor area for zone1
                                                net floor area for zone2
                                                gross floor area
ELE
01 11 1991  12  12  0  0  63103  0  63610
*  M/D/Y    kW   S-kW   kWh        $          $-kW      $-kWh *
02 08 1991  1680  1275   776000   40081.93   9493.60   25191.33
03 11 1991  1600  1275   788000   41434.49  10010.27   25845.12
04 10 1991  1600  1275   760000   40021.85   9687.36   24945.60
05 08 1991  1600  1275   704000   37747.97   9902.21   22763.11
06 12 1991  1872  1275  1020000   56641.62  17628.81   31386.09
07 11 1991  1944  1275   896000   49205.32  15168.53   27411.36
08 14 1991  1944  1275  1080000   58534.93  17783.79   32869.49
09 12 1991  1872  1275   908000   48733.03  14606.73   27564.47
10 09 1991  1728  1275   780000   41978.64  12553.26   23773.01
11 12 1991  1656  1275   972000   51612.12  15149.15   29513.47
12 05 1991  1520  1275   612000   32386.55   9406.34   18619.41
01 14 1992  1520  1275  1012000   54824.21  16358.85   31083.36
*credits*
0.5754  0.5982
```

b. Input data required by the disaggregation procedure

In this case, in addition to the previous data, the user has to input the following design or measured data:

b.1 Lighting/office equipment

Measured data:

- daily energy consumption on working days; in kWh/day,
- daily energy consumption on Saturdays; in kWh/day,
- daily energy consumption on holidays; in kWh/day.

Design data:

- load density on working days; in W/m^2,
- operating hours on working days; in hrs/day,
- load density on Saturdays; in W/m^2,
- operating hours on Saturdays; in hrs/day,
- load density on holidays; in W/m^2,
- operating hours on holidays; hrs/day.

b.2 Chillers/cooling towers

Measured data:

- starting date of summer operation; in M/D/Y,
- daily energy consumption on working days in summer; in kWh/day,

- daily energy consumption on Saturdays in summer; in kWh/day,
- daily energy consumption on holidays in summer; in kWh/day,
- starting date of winter operation; in M/D/Y,
- daily energy consumption on working days in winter; in kWh/day,
- daily energy consumption on Saturdays in winter; in kWh/day,
- daily energy consumption on holidays in winter; in kWh/day.

Design data:

- starting date of summer operation; in M/D/Y,
- starting date of winter operation; in M/D/Y,
- size of chillers; in kW,
- coefficient of performance (*COP*) of chillers,
- operating hours on working days; in hrs/day,
- operating hours on Saturdays; in hrs/day,
- operating hours on holidays; hrs/day.

b.3 Preheating

- return air temperature from space; in °C,
- set point temperature of mixing air; in °C,
- total supply air flow; in m^3/s,
- outdoor air flow rate; in fraction of total supply,
- operating hours on working days; in hrs/day,

- operating hours on Saturdays; in hrs/day,
- operating hours on holidays; in hrs/day,

Figure 2.9 and Figure 2.10 present two examples of input files used for the disaggregation of total energy use, the first input file uses the measured data and the second file uses the design conditions.

2.3.4 Validation of the NEW program

Validation of the disaggregation procedure used by the NEW program was performed by comparing its results with those obtained from a detailed simulation of the same building, using the MICRO-DOE2 program [20], which is a PC-version of the DOE-2.1 program developed at the Lawrence Berkeley Laboratory [21]. Hourly and daily energy consumption of major end-uses was provided by the computer model, to replace the short-term monitoring, and to obtain the daily energy consumption of major end-uses. Two periods of one-week monitoring data were selected in January and May 1988 separately (Table 2.11). Since daily energy consumption of preheating is significantly affected by outdoor temperature, average daily energy consumption can not be obtained by short-term monitoring. Some other parameters, such as return air temperature T_R, mixing air temperature T_M, preheating temperature T_P, total supply air flow G_T and maximum outdoor air rate, were simulated to calculate daily, monthly and annual energy consumption.

Figure 2.9 Input file for disaggregation (measured data)

```
* Disaggregation *
LM ------------------------------------------ lighting load
                                              (measured data)
    +---------------------------------------- daily consumption on
    |                                         weekdays
    |         +------------------------------ daily consumption on
    |         |                               Saturdays
    |         |          +------------------- daily consumption on
                                              holidays
28192.8   14764.8   14764.8
EM ------------------------------------------ office equipment load
16512.1   10940.5   10940.5
CM ------------------------------------------ loads for chillers
                                              (measured data)
   +----------------------------------------- starting date of summer
   |                                          operation
   |      +---------------------------------- starting date of winter
 --+--  --+--                                 operation
05 01 10 10
*ZONE1*  +----------------------------------- energy consumption on
         |                                    weekdays, Saturdays
---------+---------                           and holidays in summer
11443.2  0.0   0.0
14236.8  0.0   0.0  ------------------------- daily consumption in winter
*ZONE2*
0.0      0.0   0.0
0.0      0.0   0.0
TW ------------------------------------------ load for cooling towers
*ZONE1*                                       (measured data)
1014.2   0.0   0.0  ------------------------- daily consumption in summer
255.8    0.0   0.0  ------------------------- daily consumption in winter
*ZONE2*
0.0      0.0   0.0
0.0      0.0   0.0
RH ------------------------------------------ parameters for preheating
   +----------------------------------------- return air temperature
   |
   |    +------------------------------------ mixing air temperature
   |    |
   |    |      +----------------------------- total supply air flow
   |    |      |                +------------ operating hours on weekdays,
                         -------+------------ Saturdays and holidays
22.5  21.1  558.2   0.056  17  0  0
```

Figure 2.10 Input file for disaggregation (design condition)

```
* Disaggregation *
LD ---------------------------------------- lighting load
*ZONE1*                                     (design condition)
                                            load density on working days
                                            operating hours on
                                            working days
                                            schedule multiplier
                                            operating hours on Saturdays
                                            schedule multiplier
                                            operating hours on holidays
                                            schedule multiplier
20.5  13.8   1.0   0   0.0   0  0.0
*ZONE2*
0.0  0  0.0   0  0.0   0  0.0

ED ---------------------------------------- office equipment load
*ZONE1*                                     (design condition)
2.25 13  1.0   0  0.0   0  0.0
*ZONE2*
0.0  0  0.0   0  0.0   0  0.0
CD ---------------------------------------- loads for condensers & cooling
                                            towers (design condition)
                                            starting date of summer
                                            operation
                                            starting date of winter
                                            operation
04 15 10 15
*ZONE1*
A-CL -------------------------------------- type of cooling towers:
                                                A-CL --- air-cooled
                                                W-CL --- water-cooled

                                            refrigeration power for
                                            chillers in summer
                                            coefficient of performance

                                            operating hours on weekdays,
                                            Saturdays and holidays
316.5  2.8  24  0  0
316.5  2.8  24  0  0 ---------------------- refrigeration power,
*ZONE2*                                     coefficient of performance
A-CL                                        and operating hours of
732.5  5.0  24  0  0                        chillers in winter
732.5  5.0  00  0  0
```

Table 2.11 Measured average daily consumption for major end-uses (kWh/day)

Major end-uses	Monitoring period			
	January 18th-24th		May 17th-23th	
	weekdays	holidays	weekdays	holidays
Lighting	28,192.8	14,764.8		
Office equipment	16,512.0	10,940.5		
Chillers	11,443.2	0	14,236.8	0
Cooling towers	1,014.2	0	255.8	0
Preheating	0	0	0	0

The comparison among the major end-uses between the results from the NEW program and MICRO-DOE2 program is shown in Fig. 2.11. One can notice a similar distribution of energy consumption among the major end-uses. The comparison of monthly energy consumption for each major electricity end-use as evaluated by the NEW program and the MICRO-DOE2 program is shown in Tables 2.12-2.16. The comparison shows that there are negligible differences between the results of the two programs in lighting and office equipment, 3.0% difference in chillers and 4.0% difference in cooling towers on average. For preheating, except for October and November, the differences are within 8%. Although there are large differences in October and November, it is noticed that the energy consumption data from DOE-2 in these two months only account for 1.3% of total preheating, which also can be negligible.

The calculations using designed data were also compared with the results from the computer simulation using the DOE-2. The comparison shows that the distribution patterns are similar (Figure 2.11).

Next chapter presents the use of this new software for the evaluation of energy performance of three existing large office buildings in Montreal, as well as comparisons with results from DOE-2 and PRISM programs.

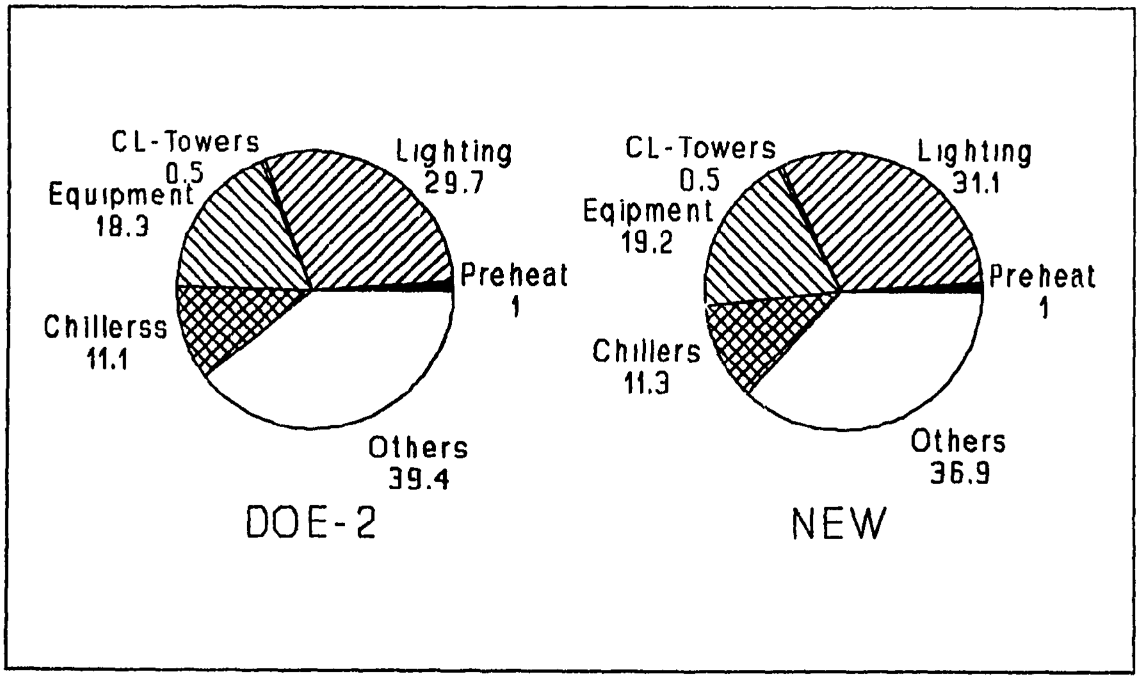

Figure 2.11 Comparison of results between NEW and MICRO-DOE2 program

Table 2.12 Comparison of monthly consumption for lighting

Month	DOE-2 (kWh)	New (kWh)	Difference (%)
Jan	726,488	726,269	-0.03
Feb	668,748	668,547	-0.03
Mar	766,785	766,553	-0.03
Apr	738,583	738,360	-0.03
May	726,488	726,269	-0.03
Jun	738,583	738,360	-0.03
Jul	739,921	739,697	-0.03
Aug	753,353	753,125	-0.03
Sep	725,151	724,932	-0.03
Oct	726,488	726,269	-0.03
Nov	711,719	711,504	-0.03
Dec	739,921	739,697	-0.03
Total	8,762,228	8,759,582	-0.03

Table 2.13 Comparison of monthly consumption for office equipment

Month	DOE-2 (kWh)	New (kWh)	Difference (%)
Jan	450.723	450,587	-0.03
Feb	412,318	412,194	-0.03
Mar	467,443	467,302	-0.03
Apr	450,926	450,790	-0.03
May	450,723	450,587	-0.03
Jun	450,926	450,790	-0.03
Jul	456,296	456,159	-0.03
Aug	461,869	461,731	-0.03
Sep	445,352	445,219	-0.03
Oct	450,723	450,587	-0.03
Nov	439,779	439,647	-0.03
Dec	456,296	456,159	-0.03
Total	5,393,374	5,391,753	-0.03

Table 2.14 Comparison of monthly cons''mption for chillers

Month	DOE-2 (kWh)	New (kWh)	Difference (%)
Jan	228,918	228,854	-0.03
Feb	217,471	217,411	-0.03
Mar	263,263	263,182	-0.03
Apr	251,840	251,740	-0.04
May	282,976	284,736	0.62
Jun	333,057	313,210	-6.96
Jul	345,296	298,973	-13.42
Aug	356,825	313,210	-12.20
Sep	300,361	298,973	-0.46
Oct	239,357	245,619	2.62
Nov	228,937	228,854	-0.04
Dec	240,363	240,297	-0.03
Total	3,288,664	3,185,057	-3.15

Table 2.15 Comparison of monthly consumption for preheating

Month	DOE-2 (kWh)	New (kWh)	Difference (%)
Jan	103,620	99,300	-4.17
Feb	71,288	65,666	-7.89
Mar	38,274	40,218	5.08
Apr	0	0	0.0
May	0	0	0.0
Jun	0	0	0.0
Jul	0	0	0.0
Aug	0	0	0.0
Sep	0	0	0.0
Oct	54	0	-100.0
Nov	3,147	544	-82.7
Dec	67,938	65,133	-4.13
Total	284,321	270,851	-4.74

Table 2.16 Comparison of monthly consumption for cooling towers

Month	DOE-2 (kWh)	New (kWh)	Difference (%)
Jan	4,931	5,116	3.75
Feb	4,665	4,860	4.18
Mar	5,735	5,883	2.58
Apr	5,619	5,628	0.16
May	21,418	20,284	-5.48
Jun	23,257	22,312	-4.06
July	20,191	21,298	5.58
Aug	24,322	22,312	-8.26
Sep	21,209	21,298	0.42
Oct	8,929	9,666	8.25
Nov	5,093	5,116	0.45
Dec	5,138	5,372	4.55
Total	150,509	149,147	-0.90

CHAPTER 3

EXAMPLES OF USE

This chapter presents examples of use of the NEW program. First the input data, and second the results of evaluation are presented. At the present development stage, all results are in tabular form. Hence, in this chapter, some figures are presented, for a better understanding of results, as well as to propose the next development to be implemented into the program. All examples are performed using information from three existing buildings in Montreal. This chapter presents also the formula used for the disaggregation procedure.

3.1 Building No.1

This office building built in 1983 has 50,544 m^2 gross floor area and 45,100 m^2 net floor area, and uses electricity and gas as energy sources. Two HVAC systems serve the building with different operating schedules. The evaluation is based on its billing data from November 20, 1987 to November 24, 1988 for electricity and from December 23, 1987 to December 23 1988 for gas.

a. Input data file

The input data file of the building No.1 is shown in Fig. 3.1.

Figure 3.1 Input data file for building No.1

```
1988  1983
Montreal         **Building #1**
ELE
11 20 1987  12  12  6  0  43154  1946  50544
*  M/D/Y     kW   S-kW    kWh          $          $-kW       $-kWh *
12 23 1987  2578  2496  1238400   54670.28    9664.41    40491.81
01 22 1988  2565  2525  1027200   47093.62    8741.52    34463.64
02 23 1988  2601  2572  1228800   53915.41    9455.15    40008.53
03 23 1988  2571  2534  1089600   48023.72    8469.90    35588.56
04 25 1988  2450  2400  1104000   50151.92    9184.56    36826.38
05 27 1988  2565  2505  1156800   53311.89    9617.23    39292.77
06 27 1988  2823  2698  1156800   55026.87   10311.65    40171.72
07 27 1988  2819  2688  1190400   55090.13    9964.88    40576.52
08 23 1988  2829  2688  1219200   53553.55    9000.21    40131.49
09 27 1988  2700  2554  1430400   64247.66   11134.93    47807.88
10 25 1988  2504  2419  1065600   47843.94    8261.29    35632.23
11 24 1988  2594  2496  1104000   50993.55    9169.53    37613.54
*credits*
0.702  0.7251

GAS
12 23 1987  13   30.1
* M/D/Y         m3      $ *
01 27 1988     47902  12321.64
02 22 1988     50094  12871.67
02 25 1988      4470   1151.82
03 23 1988     33719   8762.71
04 27 1988     10081   2703.67
05 26 1988      4689   1283.10
06 28 1988       421    133.61
07 27 1988       420    133.33
08 25 1988       420    133.33
09 26 1988         0      0.00
10 26 1988      7707   2078.54
11 23 1988     21184   5471.39
12 23 1988     34534   8896.50


*Disaggregation*
LD
*ZONE1*
19.4  17  1.0   7   0.5  24   0
*ZONE2*
19.4  24  1.0   24  1.0  24  1.0

ED
*ZONE1*
9.15   24  0.475  24  0.17  24   0.1
*ZONE2*
10.76   24  1.0   24  1.0  24  1.0
```

Figure 3.1 (continued)

```
CD
03 15 10 30
*ZONE1*
W-CL
1950  3   15   5    0
1500  5   15   5    0
*ZONE2*
A-CL
500   3   24   24   24
500   5   24   24   24
```

b. Description of input data required by the disaggregation evaluation

b.1 Daily energy consumption for lighting (E_L) is calculated as follows:

$$E_L = LPD \cdot A_F \cdot NOP \cdot M_l \text{ (kWh)}$$

where:

LPD is load density;		LPD = 19.4 W/m^2,
A_F is floor area;	zone-1:	A_F = 43,154 m^2,
	zone-2:	A_F= 1,946 m^2;

NOP is number of operating hours per day; in hours/day,

M_l is operating schedule multiplier;

	NOP	M_l
Zone-1:		
Monday-Friday	17 hrs	1.0
Saturdays	7 hrs	0.5
Holidays	24 hrs	0
Zone-2:		
Monday-Sunday	24 hrs	1.0.

b.2 Daily energy consumption for office equipment (E_E) is calculated as follows:

$$E_E = LPD \cdot A_F \cdot NOP \cdot M_I \text{ (kWh)}$$

where:

LPD is load density;	zone-1:	$LPD = 9.15$ W/m^2,
	zone-2:	$LPD = 10.76$ W/m^2;
A_F is floor area;	zone-1:	$A_F = 43{,}154$ m^2,
	zone-2:	$A_F = 1{,}946$ m^2;

NOP is the number of operating hours per day;

M_I is operating schedule multiplier;

		NOP	M_I
Zone-1:			
	Monday-Friday	10 hrs	1.0
		14 hrs	0.1
	Saturdays	4 hrs	0.5
		20 hrs	0.1
	Holidays	24 hrs	0.1
Zone-2:			
	Monday-Sunday	24 hrs	1.0.

In case two or more operating schedule multipliers occur within a same day, an average operating schedule multiplier can be calculated as follows:

- average operating schedule multiplier on weekdays for zone-2 =

  $(10 \times 1.0 + 14 \times 0.1)/24 = 0.475$,

- average operating schedule multiplier on saturdays fo. zone-2 =

  (4 x 0.5 + 20 x 0.1)/24 = 0.17.

b.3 Daily energy consumption for chillers (E_C) is calculated as follows:

$$E_C = (P_R / COP)\ NOP \cdot F_l \text{ (kWh)}$$

where:

P_R is the refrigeration capacity of operating chillers; in kW,

zone-1:	summer	1,950	kW
	winter	1,500	kW
zone-2:	summer	500	kW
	winter	500	kW;

COP is the Coefficient of Performance of chillers; the design values of *COP* are shown as follows:

zone-1:	summer	3
	winter	5
zone-2:	summer	3
	winter	5;

NOP is the number of operating hours per day;

zone-1:			*NOP*
	summer	Monday-Friday	15 hrs
		Saturdays	5 hrs
		Holidays	0 hrs

winter	Monday-Friday	15 hrs
	Saturdays	5 hrs
	Holidays	0 hrs

zone-2:

summer	Monday-Friday	24 hrs
	Saturdays	24 hrs
	Holidays	24 hrs
winter	Monday-Friday	24 hrs
	Saturdays	24 hrs
	Holidays	24 hrs;

F_1 is a correction factor; $F_1 = 0.85$.

b.4 Daily consumption for cooling towers (E_T) is calculated by the following design values:

$$ET = P_C \cdot NOP \cdot F_1 \cdot F_2 \text{ (kWh)}$$

wheic

P_C is cooling capacity; in kW,

P_C = (refrigeration capacity of chillers + input power of chillers)

$= P_R + P_R / COP$;

F_2 is a ratio of input power to cooling capacity;

air-cooled cooling tower: $F_2 = 0.03$ [21],

water-cooled cooling tower: $F_2 = 0.03$ [22].

c. Results

Tables 3.1-3.3 show the energy performance of the building. One can notice that the electricity load factors (*ELF*) are always higher than the occupancy load factors (*OLF*) in this building (Table 3.1, Fig. 3.2). According to ASHRAE [23], when the monthly *ELF* exceeds monthly *OLF*, there is a reason to believe that electricity is being consumed during unoccupied hours. This information can remind building manager or consultant to focus their attention on electricity use during unoccupied period.

Table 3.1 Energy performance of building 1 (electricity)

```
**************************************
* Energy Performance (Electricity) *
**************************************

Annual energy consumption      (kWh/m2/yr):  277.21
Annual energy cost             ($/m2/yr):     12.54
Annual cost of equivalent-kWh  ($/kWh):       .0446

Yearly Load Factor:                            .56
```

Period	No. days	Electric demand W/m2	Electricity use kWh/m2	Electricity use kWh/m2/day	Cost $/m2	Cost $/m2/day	Cost $/kWh	ELF	OLF
11 20 1987									
12 23 1987	33	51.0	24.50	.74	1.08	.0328	.0441	.61	.39
1 22 1988	30	50.7	20.32	.68	.93	.0311	.0458	.56	.39
2 23 1988	32	51.5	24.31	.76	1.07	.0333	.0439	.62	.39
3 23 1988	29	50.9	21.56	.74	.95	.0328	.0441	.61	.39
4 25 1988	33	48.5	21.84	.66	.99	.0301	.0454	.57	.39
5 27 1988	32	50.7	22.89	.72	1.05	.0330	.0461	.59	.39
6 27 1988	31	55.9	22.89	.74	1.09	.0351	.0476	.55	.39
7 27 1988	30	55.8	23.55	.79	1.09	.0363	.0463	.59	.39
8 23 1988	27	56.0	24.12	.89	1.06	.0392	.0439	.67	.39
9 27 1988	35	53.4	28.30	.81	1.27	.0363	.0449	.63	.39
10 25 1988	28	49.5	21.08	.75	.95	.0338	.0449	.63	.39
11 24 1988	30	51.3	21.84	.73	1.01	.0336	.0462	.59	.39
Total:	370		277.21		12.54				
Average:		52.1	23.10	.75	1.05	.0340	.0453	.60	.39

Table 3.2 Energy performance of building 1 (gas)

```
********************************
* Energy Performance ( Gas ) *
********************************
```

Annual energy consumption	(kWh/m2/yr):	50.96
Annual energy cost	($/m2/yr):	1.11
Annual cost of equivalent-kWh	($/kWh/yr):	.0217

Period	No. days	Energy use			Cost		
		eq.-kWh	kWh/m2	kWh/m2/day	$/m2	$/m2/day	$/kWh
12 23 1987							
1 27 1988	35	572162.8	11.32	.3234	.24	.0070	.0215
2 22 1988	26	598345.1	11.84	.4553	.25	.0098	.0215
2 25 1988	3	53391.7	1.06	.3521	.02	.0076	.0216
3 23 1988	27	402754.8	7.97	.2951	.17	.0064	.0218
4 27 1988	35	120412.0	2.38	.0681	.05	.0015	.0225
5 26 1988	29	56007.5	1.11	.0382	.03	.0009	.0229
6 28 1988	33	5028.6	.10	.0030	.00	.0001	.0266
7 27 1988	29	5016.7	.10	.0034	.00	.0001	.0266
8 25 1988	29	5016.7	.10	.0034	.00	.0001	.0266
9 26 1988	32	.0	.00	.0000	.00	.0000	.0000
10 26 1988	30	92055.8	1.82	.0607	.04	.0014	.0226
11 23 1988	28	253031.1	5.01	.1788	.11	.0039	.0216
12 23 1988	30	412489.5	8.16	.2720	.18	.0059	.0216
Total:	366	2575712.0	50.96		1.11		
Average:		198131.7	3.9	.1580	.09	.0003	.0213

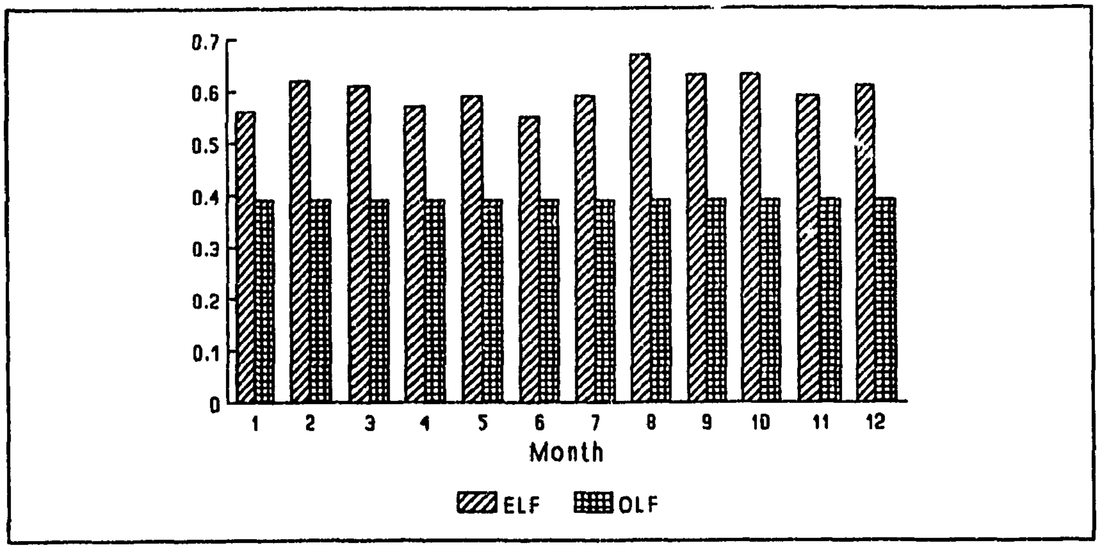

Figure 3.2 Electricity load factor & occupancy load factor of building 1.

From Table 3.3 and Fig. 3.3, one can see that the building consumes 274.3 kWh/m²/yr of electricity, which accounts for 84.3% of the total energy use and 91.8% of total energy cost; it consumes 50.9 kWh/m²/yr of gas, which accounts for 15.7% of the total energy use and 8.2% of the total energy cost.

Table 3.3 Normalized energy performance of building 1.

```
************************************
*    Annual Energy Performance     *
*  Normalized For Number Of Days   *
************************************
```

Type of fuel	Energy use kWh/m2	Energy use %	Cost $/m2	Cost %	$/kWh
Electricity	274.3	84.3	12.37	91.8	.0446
Gas	50.9	15.7	1.10	8.2	.0217
Oil	.0	.0	.00	.0	.0000
Steam	.0	.0	.00	.0	.0000
Total:	325.2	100.0	13.48	100.0	.0663

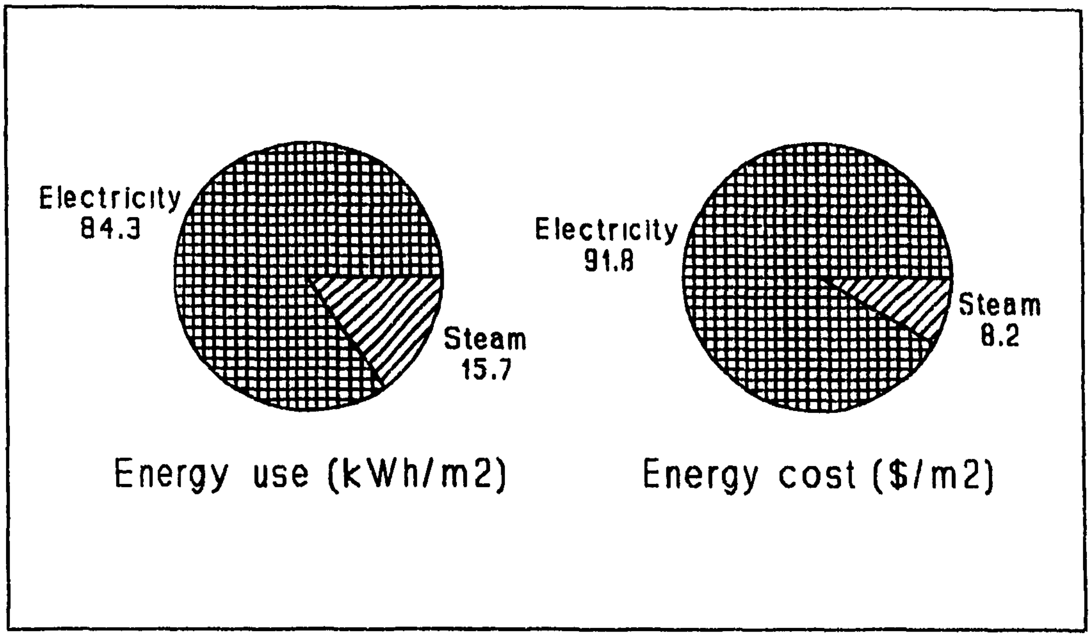

Figure 3.3 Annual energy performance of building 1.

The annual energy comparison in Table 3.4 and Fig. 3.4 shows that the building has lower energy consumption than the similar buildings built in 1983, as well as the average office buildings in Montreal. But it is still much higher than that of the most energy efficient buildings and than the target value.

Table 3.4 Annual energy comparison of building 1

* Annual Energy Consumption Comparison *

Energy budget kWh/m2	Average energy consumption (kWh/m2/yr) in				
	Year of construc. (1983)	Montreal in 1988	the best EEB in Montreal(1988)	Best EEB	Target
325.2	365.7	455.2	185.8	180.0	250.0

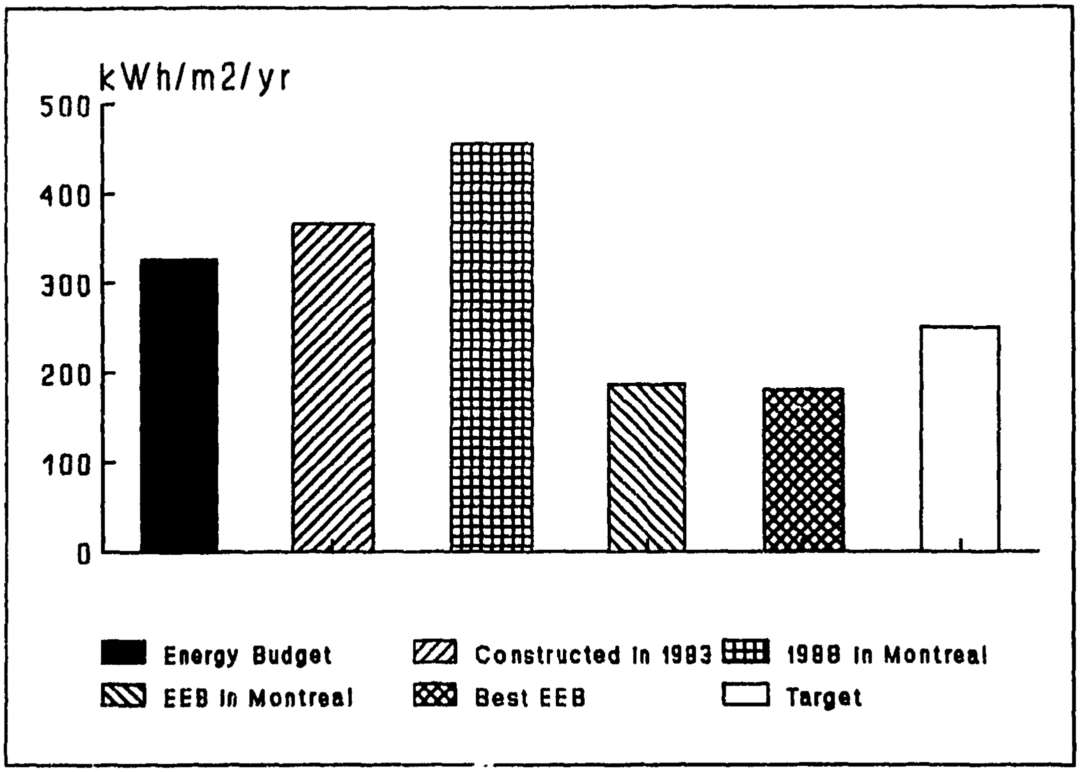

Figure 3.4 Comparison of the annual energy performance of building 1 with some target values

Table 3.5 and Fig. 3.5 show that the gas consumption is more sensitive to weather conditions than the electricity consumption, and it is only consumed in winter for heating while the electricity is mainly consumed for cooling as well as non-weather-dependent energy use. A better understanding of electricity use can be obtained from Table 3.6 and Fig.3.6, from where one can find that the non-weather-dependent energy consumption such as for lighting and office equipment is almost constant through the year. Higher energy consumption occurs in the summer due to higher cooling load.

Table 3.5 Weather-normalized energy consumption of building 1.

```
*******************************************
* Normalized Annual Energy Consumption   *
*     For Average Weather Conditions     *
*******************************************
```

FUEL TYPE	NAC kWh/ m2/yr	Base kWh/ m2/day	Tref C	a kWh/ m2/day	b kWh/ m2/day/C	R*R
Elec.	271.57	.723	-2.00	.729	.0030	.553
Gas	51.19	.000	17.82	.239	-.0134	.937
Oil	.00	.000	.00	.000	.0000	.000
Steam	.00	.000	.00	.000	.0000	.000
TOTAL	322.76	.723				

Energy Signature:

Elec. = 0.729 + 0.0030*Tout
Gas = 0.239 - 0.0134*Tout

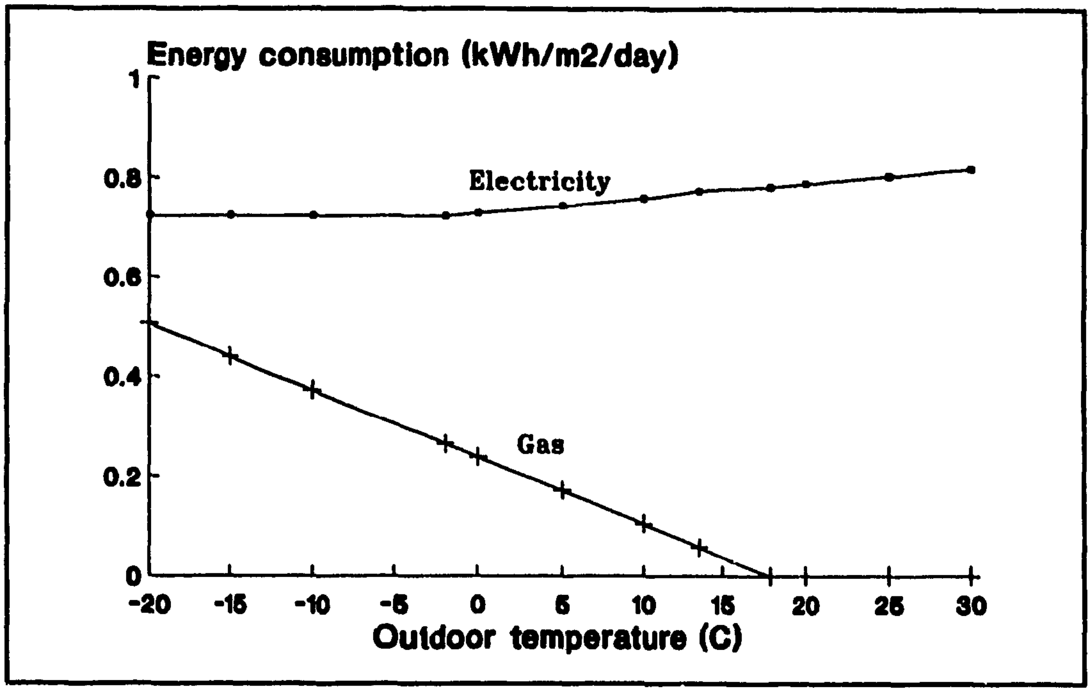

Figure 3.5 Energy signature of building 1.

Table 3.6 Monthly electricity consumption distribution of building 1.

```
*************************************
* Monthly Electricity Distribution *
*************************************
```

Month	Lighting		Equipment		Chiller		Preheating		CL-Tow r	
	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%
JAN	324452.3	31.8	118684.2	11.6	144840.0	14.2	.0	.0	26053.0	2.6
FEB	307501.9	26.1	110779.9	9.4	134895.0	11.5	.0	.0	24264.0	2.1
MAR	367148.8	32.2	129345.4	11.3	240422.5	21.1	.0	.0	32996.0	2.9
APR	352010.6	36.2	124341.5	12.8	295375.0	30.4	.0	.0	35432.0	3.6
MAY	327382.4	28.7	119347.6	10.4	284962.5	24.9	.0	.0	34183.0	3.0
JUN	352010.6	31.4	124341.5	11.1	295375.0	26.3	.0	.0	3[illegible]32.0	3.2
JUL	341614.6	27.6	122901.3	9.9	293250.0	23.7	.0	.0	35177.0	2.8
AUG	352916.6	24.7	125791.7	8.8	298775.0	20.9	.0	.0	35840.0	2.5
SEP	337778.4	28.6	120787.7	10.2	287087.5	24.3	.0	.0	34438.0	2.9
OCT	327382.4	27.9	119347.6	10.2	283602.5	24.1	.0	.0	34142.0	2.9
NOV	323546.2	29.5	117234.0	10.7	142800.0	13.0	.0	.0	25[illegible]36.0	2.3
DEC	338684.4	28.8	122237.9	10.4	148665.0	12.6	.0	.0	26741.0	2.3

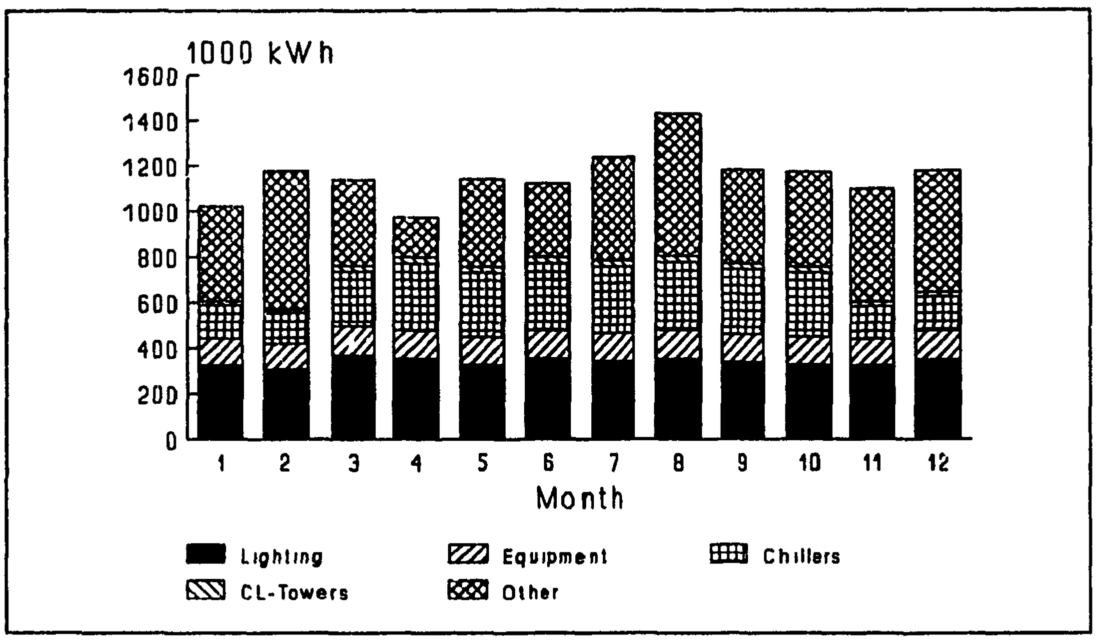

Figure 3.6 Monthly electricity distribution of building 1.

The normalized annual consumption *NAC* ($kWh/m^2/yr$), along with the base load *a* ($kWh/m^2/day$), the slope of weather-dependent energy use *b* ($kWh/m^2/day/°C$), and the correlation coefficient R^2, are compared with the results obtained from the PRISM program (Table 3.7). One can see that NAC, *a* and R^2 of the two programs are quite close, while there is a larger difference in *b*.

Table 3.7 Comparison of normalized energy use between PRISM and NEW program for building 1.

	NAC ($kWh/m^2/yr$)	*a* ($kWh/m^2/day$)	*b* ($kWh/m^2/day/°C$)	R^2
Heating				
PRISM	63.76	0.0060	0.0114	0.9424
NEW	51.19	0.0000	-0.1340	0.9370
Cooling				
PRISM	268.47	0.7290	0.0692	0.5821
NEW	271.57	0.7290	0.0030	0.5530

Table 3.8 presents the distribution of annual electricity consumption and Fig. 3.7 shows a comparison of these results of the distribution, which is compared with those obtained from MICRO-DOE2. One can notice a similar pattern between those two sets of results.

Table 3.8 Annual electricity consumption distribution of building 1.

* Electricity Distribution *

	(kWh)	(%)
Lighting	4052429.	29.2
Equipment	1455140.	10.5
Chiller	2850050.	20.6
Preheat	0.	.0
CL-Tower/AC-COND	380384.	2.7
Others	5127101.	37.0
Total	13865100.	100.0

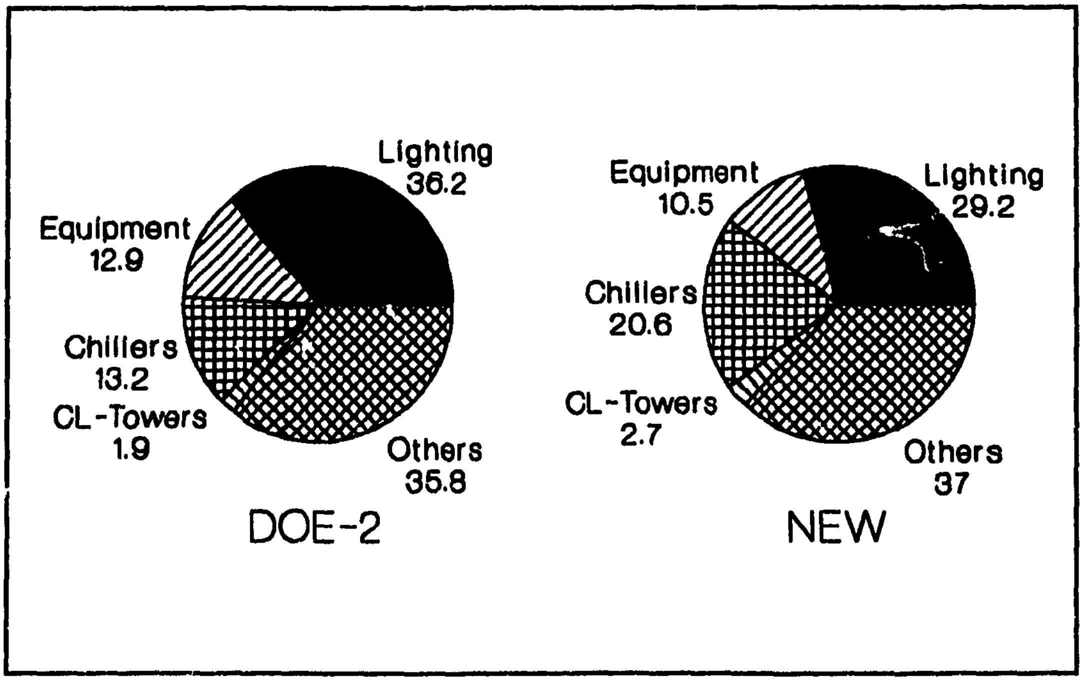

Figure 3.7 Comparison of results between NEW and DOE-2 program (building 1)

3.2 Building No.2

The 28-story large office building built in 1983, and has 97,300 m^2 gross floor area and 71,557 m^2 net floor area, and uses electricity and steam as energy sources. Two HVAC systems are used to serve the building with different operating schedules. The evaluation is based on its billing data from December 22 1987 to December 23 1988 for electricity and from December 22 1987 to December 23 1988 for steam.

a. Input data file (Fig. 3.8)

Figure 3.8 Input data file of building 2.

```
1988  1983
Montreal
ELE
12 22 1987  12   16   16    16  71557.0  0  97300
* M/D/Y      kW   S-kW   kWh        $            $-kW    s-kWh *
01 22 1988   0     0   2247976   91408.16      0        0
02 23 1988   0     0   2564481   95695.77      0        0
03 23 1988   0     0   2334903   86053.12      0        0
04 25 1988   0     0   2511484   87062.63      0        0
05 27 1988   0     0   2453642   95331.34      0        0
06 27 1988   0     0   2342028   94816.05      0        0
07 27 1988   0     0   2287154   93013.61      0        0
08 24 1988   0     0   2140972   84055.85      0        0
09 27 1988   0     0   2536413  102905.41      0        0
10 25 1988   0     0   2002874   83231.87      0        0
11 24 1988   0     0   2269352   89900.01      0        0
12 23 1988   0     0   2551484  102950.50      0        0
*credits*
0.0  0.0
```

Figure 3.8 (continued)

```
STM
12 22 1987  12   30.1
* M/D/Y       m3        $ *
01 22 1988  1886031  17747.54
02 23 1988  1708864  16080.41
03 23 1988  1450299  13647.34
04 25 1988   590960   5560.94
05 27 1988        0      0.00
06 27 1988        0      0.00
07 27 1988        0      0.00
08 24 1988        0      0.00
09 27 1988        0      0.00
10 25 1988        0      0.00
11 24 1988        0      0.00
12 23 1988  1943631  18289.57

* Disaggregation *
LD
*ZONE1*
21.5  24   0.77  24   0.45  24   0.45
*ZONE2*
0.0  0     0     0    0     0    0

ED
*ZONE1*
14.2  24   0.68  24   0.45  24   0.45
*ZONE2*
0.0  0     0     0    0     0    0

CD
05  01  10  10
*ZONE1*
W-CL
8016  5  24  0  0

3090  5  13  0  0
*ZONE2*
W-CL
0  5  0  0  0
0  5  0  0  0

PR
*ZONE1*
22.5  21.1  558  0.056  17  0  0
*ZONE2*
22.5  21.1  558  0.056  0   0  0
```

b. Description of input data required by the disaggregation evaluation

b.1 Daily energy consumption for lighting (E_L) is calculated as follows:

$$E_L = LPD \cdot A_F \cdot NOP \cdot M_I \text{ (kWh)}$$

where:

LPD is load density;	zone-1:	$LPD = 21.5$ W/m^2,
	zone-2:	$LPD = 0$ W/m^2;
A_F is floor area;	zone-1:	$A_F = 71{,}557$ m^2,
	zone-2:	$A_F = 0$ m^2;

NOP is the number of operating hours per day;

M_I is operating schedule multiplier;

	NOP	M_I
Monday-Friday	14 hrs	1.0
	10 hrs	0.45
Saturdays	24 hrs	0.45
Holidays	24 hrs	0.45,

- average operating schedule multiplier on working days =

  (14 x 1.0 + 10 x 0.45)/24 = 0.77.

b.2 Daily energy consumption for Office Equipment (E_E) is calculated as follows:

$$E_E = LPD \cdot A_F \cdot NOP \cdot M_I \text{ (kWh)}$$

where:

LPD is load density;	zone-1:	$LPD = 14.2\ W/m^2$,
	zone-2:	$LPD = 0\ W/m^2$;
A_F is floor area;	zone-1:	$A_F = 71{,}557\ m^2$,
	zone-2:	$A_F = 0\ m^2$;

NOP is the number of operating hours per day;

M_l is operating schedule multiplier;

	NOP	M_l
Monday-Friday	10 hrs	1.0
	14 hrs	0.45
Saturdays	24 hrs	0.45
Holidays	24 hrs	0.45,

- average operating schedule multiplier on working days =

  (10 x 1.0 + 14 x 0.45)/24 = 0.68.

b.3 Daily Energy Consumption for Chillers (E_C) is calculated as follows:

$$E_C = (P_R / COP)\ NOP \cdot F_l \text{ (kWh)}$$

where:

P_R is refrigeration capacity of operating chillers; in kW,

summer	8,016 kW
winter	3,090 kW;

COP is the Coefficient of Performance of chillers:

summer	5

winter	5;	

NOP is the number of operating hours per day;

		NOP
summer	Monday-Friday	24 hrs
	Saturdays	0 hrs
	Holidays	0 hrs
winter	Monday-Friday	13 hrs
	Saturdays	0 hrs
	Holidays	0 hrs;

F_1 is a correction factor; $F_1 = 0.85$.

b.4 Daily Energy Consumption for Cooling Towers (E_T) is calculated as following design values:

$$ET = P_C \cdot NOP \cdot F_1 \cdot F_2 \text{ (kWh)}$$

where

P_C is cooling capacity; in kW,

P_C = (refrigeration capacity of chillers + input power of chillers)

$= P_R + P_R / COP$;

F_2 is a ratio of input power to cooling capacity;

air-cooled cooling tower: $F_2 = 0.03$,

water-cooled cooling tower: $F_2 = 0.03$.

b.5 Daily Energy Consumption for Preheating (E_P) is calculated as follows:

$$E_P = \sum_{i=1}^{24} \begin{cases} \mathring{m}\, c_p\, M_i\, (T_P - T_{M_i}) & \text{if} \quad T_P - T_{M_i} > 0, \\ 0 & \text{if} \quad T_P - T_{M_i} \leq 0. \end{cases}$$

where

$\mathring{m}$ is mass flow of air; in kg/s,

$\mathring{m} = G_o\, \rho_o,$

G_o is supply air flow,	G_o= 558 m^3/s,
ρ_o is density of air,	ρ_o= 1 .2 kg/m^3;
c_p is specific heat of air;	c_p= 1.0005 kJ/kg/°C,
T_p is preheating temperature;	T_p= 21.1 °C,

$T_{M,i}$ is mixing temperature;

$T_{M,i} = T_{O,i}\, \alpha_o + T_R\, \alpha_o,$

$T_{O,i}$ is outdoor air temperature; in °C,

T_R is return air temperature; T_R= 22.5°C,

α_o is outdoor air rate; α_o= 0.056;

M_i is operating schedule multiplier;

	NOP	M_i
Monday-Friday	17 hrs	1.0
	7 hrs	0
Saturdays	24 hrs	0
Holidays	24 hrs	0.

c. Results

Table 3.9 and Table 3.10 present the electricity energy performance and gas energy performance of this building, and Table 3.11 presents the annual energy performance, which was normalized by number of days. In this case, the monthly electricity load factor (*ELF*) never exceeded the monthly occupancy load factor (*OLF*) (Table 3.9, Figure 3.9). Hence, the HVAC systems and the most electric appliances might be managed properly during the unoccupied periods.

Table 3.9 Energy performance of building 2 (electricity)

* Energy Performance (Electricity) *

Annual energy consumption	(kWh/m2/yr):	290.26
Annual energy cost	($/m2/yr):	11.37
Annual cost of equivalent-kWh	($/kWh):	.0390
Yearly Load Factor:		.35

Period	No. days	Electric demand W/m2	Electricity use kWh/m2	Electricity use kWh/m2/day	Cost $/m2	Cost $/m2/day	Cost $/kWh	ELF	OLF
12 22 1987									
1 22 1988	31	95.5	23.10	.75	.94	.0303	.0407	.33	.67
2 23 1988	32	95.5	26.36	.82	.98	.0307	.0373	.36	.67
3 23 1988	29	95.5	24.00	.83	.88	.0305	.0369	.36	.67
4 25 1988	33	95.5	25.81	.78	.89	.0271	.0347	.34	.67
5 27 1988	32	95.5	25.22	.79	.98	.0306	.0389	.34	.67
6 27 1988	31	95.5	24.07	.78	.97	.0314	.0405	.34	.67
7 27 1988	30	95.5	23.51	.78	.96	.0319	.0407	.34	.67
8 24 1988	28	95.5	22.00	.79	.86	.0309	.0393	.34	.67
9 27 1988	34	95.5	26.07	.77	1.06	.0311	.0406	.33	.67
10 25 1988	28	95.5	20.58	.74	.86	.0306	.0416	.32	.67
11 24 1988	30	95.5	23.32	.78	.92	.0308	.0396	.34	.67
12 23 1988	29	95.5	26.22	.90	1.06	.0365	.0403	.39	.67
Total:	367		290.26		11.37				
Average:		95.5	24.19	.79	.95	.0310	.0392	.35	.67

It is noticed that building No.1 and building No.2 have the same billing period (from November 1987 to December 1988). However, building No.2 has higher electricity energy consumption (290.26 kWh/m^2/yr) than building No.1 (277.21 kWh/m^2/yr), but has lower electricity energy cost (11.37 \$/m^2/yr) than building No.1 (12.54 \$/m^2/yr). It is probably due the different size of the two buildings. Building No.2 is a large size building, with 9,290 kW average monthly demand, so lower utility rate of Hydro of Quebec is applied.

Table 3.10 Energy Performance of Building 2. (Steam)

```
*******************************
* Energy Performance (Steam) *
*******************************

Annual energy consumption      (kWh/m2/yr):   34.94
Annual energy cost             ($/m2/yr):       .73
Annual cost of equivalent-kWh  ($/kWh/yr):    .0209
```

Period	No. days	Energy use			Cost		
		eq.-kWh	kWh/m2	kWh/m2/day	$/m2	$/m2/day	$/kWh
12 22 1987							
1 22 1988	31	846019.7	8.69	.2805	.18	.0059	.0210
2 23 1988	32	766547.6	7.88	.2462	.17	.0052	.0210
3 23 1988	29	650562.8	6.69	.2306	.14	.0048	.0210
4 25 1988	33	265087.8	2.72	.0826	.06	.0017	.0210
5 27 1988	32	.0	.00	.0000	.00	.0000	.0000
6 27 1988	31	.0	.00	.0000	.00	.0000	.0000
7 27 1988	30	.0	.00	.0000	.00	.0000	.0000
8 24 1988	28	.0	.00	.0000	.00	.0000	.0000
9 27 1988	34	.0	.00	.0000	.00	.0000	.0000
10 25 1988	28	.0	.00	.0000	.00	.0000	.0000
11 24 1988	30	.0	.00	.0000	.00	.0000	.0000
12 23 1988	29	871857.4	8.96	.3090	.19	.0065	.0210
Total:	367	3400075.0	34.94		.73		
Average:		283339.6	2.9	.0957	.06	.0002	.0087

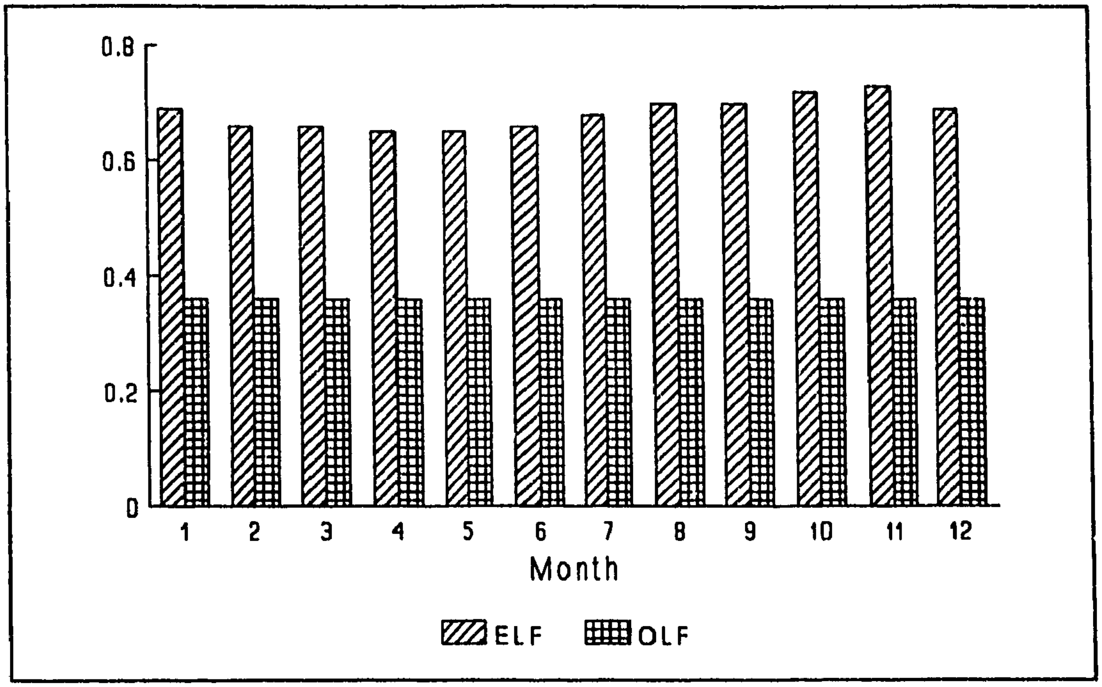

Figure 3.9 Electricity load factor & occupancy load factor of building 2.

Table 3.11 and Fig. 3.10 show the building No.2 consumes about 289.3 kWh/m²/yr of electricity, which accounts for 89.2% 2 of the total energy use and 93.9% of the energy cost; it also consumes about 34.9 kWh/m²/yr of gas, which accounts for 108.% of the total energy use and 6.1% of the total energy cost.

Table 3.11 Normalized energy performance of building 2.

```
**********************************
*   Annual Energy Performance    *
* Normalized For Number Of Days *
**********************************
```

Type of fuel	Energy use		Cost		$/kWh
	kWh/m2	%	$/m2	%	
Electricity	289.3	89.2	11.31	93.9	.0390
Gas	.0	.0	.00	.0	.0000
Oil	.0	.0	.00	.0	.0000
Steam	34.9	10.8	.73	6.1	.0209
Total:	324.3	100.0	12.04	100.0	.0598

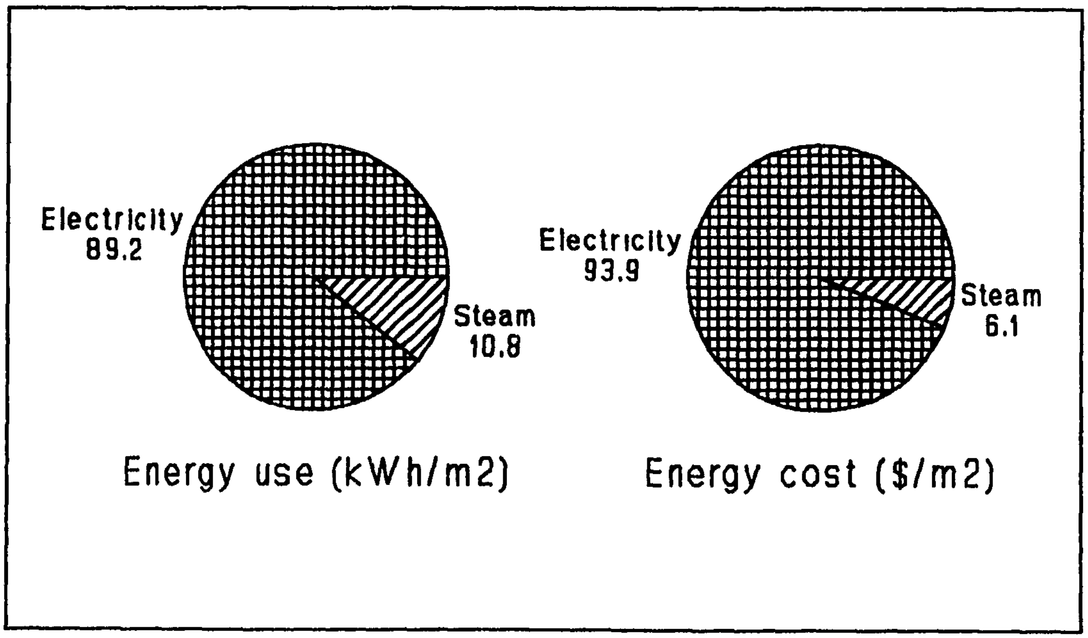

Figure 3.10 Annual energy performance of building 2

Building No.2 has lower energy consumption than the average values of the buildings built in 1983 and surveyed in 1988 in Montreal, but it has higher energy consumption than the most energy efficient buildings and the target value (Table 3.12 and Figure 3.11).

Table 3.12 Annual energy comparison of building 2.

* Annual energy consumption comparisons *

Energy budget kWh/m2	Average energy consumption(kWh/m2/yr) in				
	Year of construc. (1983)	Montreal in 1988	the best EEB in Montreal(1988)	Best EEB	Target
324.3	365.7	455.2	185.8	180.0	250.0

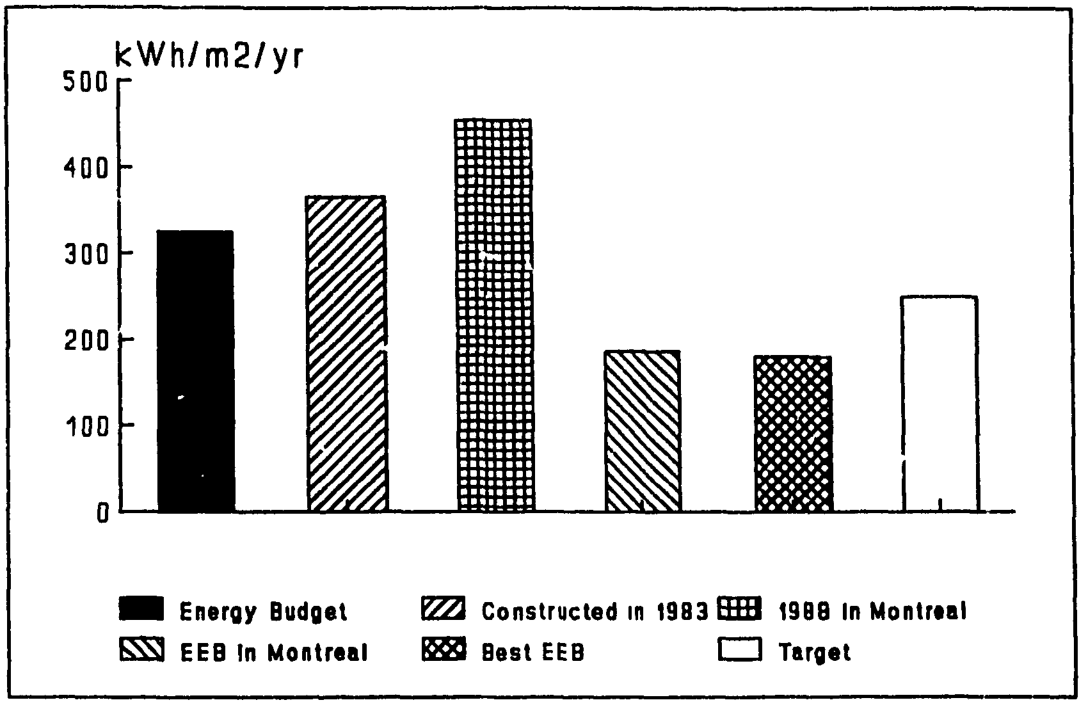

Figure 3.11 Comparison of the annual energy performance of building 2 with some target values

Table 3.13 and Fig. 3.12 present the weather-normalized energy consumption and building energy signature. One can notice that gas energy use is only consumed in the winter season and it is quite sensitive to the weather conditions. From Table 3.14 and Fig. 3.13, one can see that non-weather-dependent energy consumption, such as lighting and office equipment, is constant through out the year, while more energy is used for chillers and cooling towers in summer season. Further investigation may be needed to figure out why more electricity, which in Fig.3.13 is presented as energy used by "others", is consumed in winter season.

Table 3.13 Weather-normalized energy consumption of building 2.

```
*****************************************
* Normalized Annual Energy Consumption *
*    For Average Weather Conditions     *
*****************************************
```

FUEL TYPE	NAC kWh/ m2/yr	Base kWh/ m2/day	Tref C	a kWh/ m2/day	b kWh/ m2/day/C	R*R
Elec.	287.54	.781	13.54	.802	-.0016	.405
Gas	.00	.000	.00	.000	.0000	.000
Oil	.00	.000	.00	.000	.0000	.000
Steam	35.55	.000	16.36	.165	-.0101	.881
TOTAL	323.09	.781				

Energy Signature:
Elec. = 0.802 - 0.0016*Tout
Steam = 0.165 - 0.0101*Tout

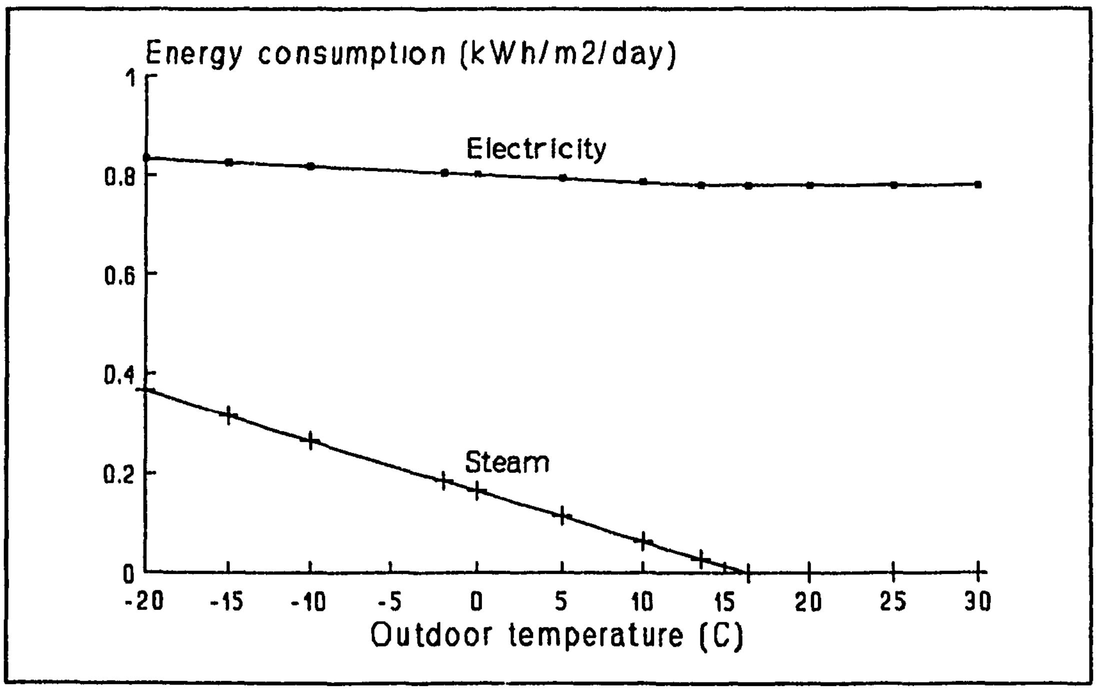

Figure 3.12 Energy signature of building 2.

Table 3.14 Monthly electricity use distribution of building 2.

```
*************************************
* Monthly Electricity Distribution *
*************************************
```

Month	Lighting		Equipment		Chiller		Preheating		CL-Tower	
	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%
JAN	751391.4	37.3	452371.9	22.5	136578.0	6.8	99300.3	4.9	24580.0	1.2
FEB	689729.3	27.6	413841.0	16.6	129749.1	5.2	65666.3	2.6	23351.0	.9
MAR	786837.8	32.1	469198.7	19.1	157064.7	6.4	40218.4	1.6	28267.0	1.2
APR	758406.8	33.6	452615.8	20.1	150235.8	6.7	.0	.0	27038.0	1.2
MAY	751391.4	31.5	452371.9	19.0	654105.5	27.4	.0	.0	117720.0	4.9
JUN	758406.8	33.6	452615.8	20.0	719516.0	31.8	.0	.0	129492.0	5.7
JUL	763206.9	32.3	457980.8	19.4	686810.8	29.0	.0	.0	123606.0	5.2
AUG	775022.4	32.7	463589.7	19.6	719516.0	30.3	.0	.0	129492.0	5.5
SEP	746591.3	33.6	447006.8	20.1	686810.8	30.9	.0	.0	123606.0	5.6
OCT	751391.4	34.0	452371.9	20.5	291836.4	13.2	.0	.0	52522.0	2.4
NOV	734775.9	31.9	441397.9	19.2	136578.0	5.9	533.9	.0	24580.0	1.1
DEC	763206.9	27.1	457980.8	16.3	143406.9	5.1	65132.5	2.3	25809.0	.9

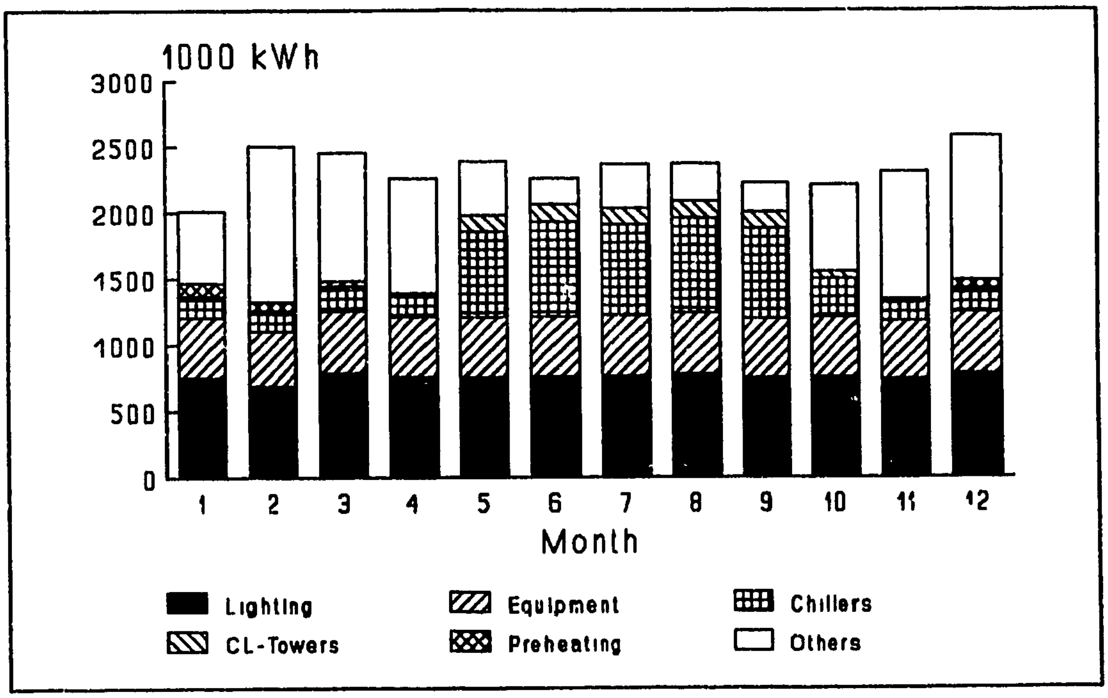

Figure 3.13 Monthly electricity use distribution of building 2.

Table 3.15 shows the comparison of normalized annual energy consumption *NAC*, and non-weather-dependent energy consumption *a*, the slope of weather-dependent energy consumption *b* as well as correlation coefficient R^2, which were evaluated by PRISM and NEW programs.

Table 3.15 Comparison of normalized energy use between PRISM and NEW program for building 2.

	NAC (kWh/m²/yr)	*a* (kWh/m²/day)	*b* (kWh/m²/day/°C)	R^2
Heating				
PRISM	45.52	0.0047	0.0044	0.9188
NEW	35.55	0.0000	-0.0101	0.4050
Cooling				
PRISM	290.08	0.8321	-0.0009	0.1730
NEW	287.54	0.8020	-0.0016	0.8810

Table 3.16 shows that the distribution of annual electricity consumption. Since the internal loads are dominant in this building, the energy use for lighting and office equipment accounts for 51.3% of the total electricity energy use, while chillers and cooling towers only consumes 19.3% of the total electricity use. Figure 3.14 shows a similar pattern of electricity energy distribution performed by using MICRO-DOE2 and NEW programs.

Table 3.16 Annual electricity use distribution of building 2.

```
****************************
* Electricity Distribution *
****************************
```

	(kWh)	(%)
Lighting	9030359.	32.1
Equipment	5413343.	19.2
Chiller	4612208.	16.4
Preheat	270851.	1.0
CL-Tower/AC-COND	830063.	3.0
Others	7995028.	28.3
Total	28151850.	100.0

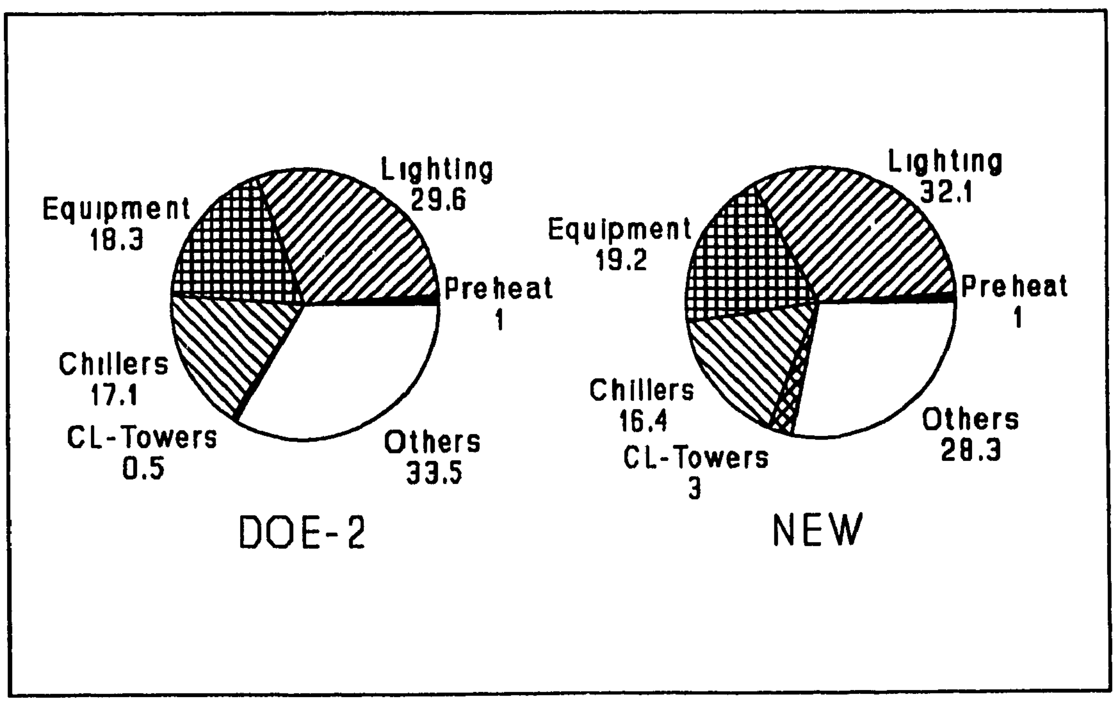

Figure 3.14 Comparison of results between NEW and DOE-2 program (building 2)

3.3 Building No.3

This commercial building built in 1857 has 63,610 m^2 gross and 63,103 m^2 net area, which uses electricity and steam as energy sources. The entire building is served by one HVAC system. The evaluation is based on its billing data from January 11, 1991 to January 14, 1992 for electricity and from January 1, 1991 to December 31, 1992 for steam.

a. Input data file

The input data file is shown in Figure 3.15.

Figure 3.15 Input data file of building 3.

```
1991 1857
Montreal
ELE
01 11 1991   12   12  0  0   63103   0  63610
*  M/D/Y     kW   S-kW    kWh        $          $-kW      $-kWh *
02 08 1991  1680  1275   776000   40081.93   9493.61   25191.33
03 11 1991  1600  1275   788000   41434.49  10010.27   25845.12
04 10 1991  1600  1275   760000   40021.85   9687.36   24945.60
05 08 1991  1600  1275   704000   37747.97   9902.21   22763.11
06 12 1991  1872  1275  1020000   56641.62  17628.81   31386.09
07 11 1991  1944  1275   896000   49205.32  15168.53   27411.36
08 14 1991  1944  1275  1080000   58534.93  17783.79   32869.49
09 12 1991  1872  1275   908000   48733.03  14606.73   27564.47
10 09 1991  1728  1275   780000   41978.64  12553.26   23773.01
11 12 1991  1656  1275   972000   51612.12  15149.15   29513.47
12 05 1991  1520  1275   612000   32386.55   9406.34   18619.41
01 14 1992  1520  1275  1012000   54824.21  16358.85   31083.36
*credits*
0.5754  0.5982
```

Figure 3.15 (continued)

```
STM
12 31 1990  12
*  M/D/Y      LB          $  *
01 31 1991  6125000  104838.65
02 28 1991  6125000  114883.65
03 31 1991  4080000   74849.45
04 30 1991  2135000   39251.55
05 31 1991   455000    8621.10
06 30 1991   350500    6675.40
07 31 1991        0       0.00
08 31 1991        0       0.00
09 30 1991   560000   13380.65
10 31 1991  1945000   35763.80
11 30 1991  2580000   46288.05
12 31 1991  5614500   97824.55
* Disaggregation *
LD
*ZONE1*
20.5  13.8   1.0   0  0.0   0  0.0
*ZONE2*
0.0  0  0.0   0  0.0   0  0.0
ED
*ZONE1*
2.25 13   1.0   0  0.0   0  0.0
*ZONE2*
0.0  0  0.0   0  0.0   0  0.0
CD
04 15 10 15
*ZONE1*
A-CL
316.5  2.8  24  0  0
316.5  2.8  24  0  0
*ZONE2*
A-CL
732.5  5.0  24  0  0
732.5    0  00  0  0
```

b. Distribution of input data required by the disaggregation evaluation

b.1 Daily energy consumption for lighting (E_L) is calculated by using the follow relation:

$$E_L = LPD \cdot A_F \cdot NOP \cdot M_l \text{ (kWh)}$$

where:

LPD is load density; zone-1: $LPD = 20.5 \text{ W/m}^2$,

zone-2: $LPD = 0 \text{ W/m}^2$;

A_F is floor area;	zone-1:	$A_F = 63{,}103\ m^2$,
	zone-2:	$A_F = 0\ m^2$;

NOP is the number of operating hours per day;

M_I is operating schedule multiplier;

	NOP	M_I
Monday-Friday	13.8 hrs	1.0
Saturdays	24 hrs	0
Holidays	24 hrs	0.

b.2 Daily energy consumption for Office Equipment (E_E) is calculated as follows:

$$E_E = LPD \cdot A_F \cdot NOP \cdot M_I \text{ (kWh)}$$

where:

LPD is load density;	zone-1:	$LPD = 2.25\ W/m^2$,
	zone-2:	$LPD = 0\ W/M^2$;
A_F is floor area;	zone-1:	$A_F = 63{,}103\ m^2$,
	zone-2:	$A_F = 0\ m^2$;

NOP is the number of operating hours per day;

M_I is operating schedule multiplier;

	NOP	M_I
Monday-Friday	13 hrs	1.0
Saturdays	24 hrs	0
Holidays	24 hrs	0.

b.3 Daily Energy Consumption for Chillers (E_C) is calculated as following design values:

$$E_C = (P_R / COP)\ NOP \cdot F_1 \text{ (kWh)}$$

where:

P_R is the refrigeration capacity of operating chillers; in kW,

zone-1	summer	361.5 kW
	winter	361.5 kW
zone-2	summer	732.5 kW
	winter	0 kW;

COP is the Coefficient of Performance of chillers;

zone-1	summer	2.8
	winter	2.8
zone-2	summer	5.0
	winter	0;

NOP is the number of operating hours per day;

			NOP
zone-1	summer	Monday-Friday	24 hrs
		Saturdays	0 hrs
		Holidays	0 hrs
	winter	Monday-Friday	24 hrs
		Saturdays	0 hrs
		Holidays	0 hrs

zone-2	summer	Monday-Friday	24 hrs
		Saturdays	0 hrs
		Holidays	0 hrs
	winter	Monday-Sunday	0 hrs
		Holidays	0 hrs;

F_1 is a correction factor; $F_1 = 0.85$.

b.4 Daily energy consumption for cooling towers (E_T) is calculated as following design values:

$$ET = P_C \cdot F_1 \cdot F_2 \text{ (kWh)}$$

where

P_C is cooling capacity; in kW,

P_C = (refrigeration capacity of chillers + input power of chillers)

$= P_R + P_R / COP$;

F_2 is a ratio of input power and cooling capacity;

water-cooled cooling tower: $F_2 = 0.03$.

c. Results

Tables 3.17-3.18 present the energy performance of the building.

Table 3.17 Energy performance of building 3. (electricity)

```
**************************************
* Energy Performance (Electricity) *
**************************************

Annual energy consumption      (kWh/m2/yr):  160.05
Annual energy cost             ($/m2/yr):      8.70
Annual cost of equivalent-kWh  ($/kWh):       .0532

Yearly Load Factor:                            .60
```

Period	No. days	Electric demand W/m2	Electricity use kWh/m2	Electricity use kWh/m2/day	Cost $/m2	Cost $/m2/day	Cost $/kWh	ELF	OLF
1 11 1991									
2 8 1991	28	26.4	12.20	.44	.63	.0225	.0517	.69	.36
3 11 1991	31	25.2	12.39	.40	.65	.0210	.0526	.66	.36
4 10 1991	30	25.2	11.95	.40	.63	.0210	.0527	.66	.36
5 8 1991	28	25.2	11.07	.40	.59	.0212	.0536	.65	.36
6 12 1991	35	29.4	16.04	.46	.89	.0254	.0555	.65	.36
7 11 1991	29	30.6	14.09	.49	.77	.0267	.0549	.66	.36
8 14 1991	34	30.6	16.98	.50	.92	.0271	.0542	.68	.36
9 12 1991	29	29.4	14.27	.49	.77	.0264	.0537	.70	.36
10 9 1991	27	27.2	12.26	.45	.66	.0244	.0538	.70	.36
11 12 1991	34	26.0	15.28	.45	.81	.0239	.0531	.72	.36
12 5 1991	23	23.9	9.62	.42	.51	.0221	.0529	.73	.36
1 14 1992	40	23.9	15.91	.40	.86	.0215	.0542	.69	.36
Total:	368		162.05		8.70				
Average:		26.9	13.50	.44	.72	.0236	.0536	.68	.36

Table 3.18 Energy performance of building 3. (Steam)

```
********************************
* Energy Performance (Steam) *
********************************

Annual energy consumption      (kWh/m2/yr):  211.35
Annual energy cost             ($/m2/yr):      8.53
Annual cost of equivalent-kWh  ($/kWh/yr):     .0403
```

Period	No. days	Energy use			Cost		
		eq.-kWh	kWh/m2	kWh/m2/day	$/m2	$/m2/day	$/kWh
12 31 1990							
1 31 1991	31	2747500.0	43.19	1.3933	1.65	.0532	.0382
2 28 1991	28	2747500.0	43.19	1.5426	1.81	.0645	.0418
3 31 1991	31	1830172.0	28.77	.9281	1.18	.0380	.0409
4 30 1991	30	957700.1	15.06	.5019	.62	.0206	.0410
5 31 1991	31	204100.0	3.21	.1035	.14	.0044	.0422
6 30 1991	30	157224.3	2.47	.0824	.10	.0035	.0425
7 31 1991	31	.0	.00	.0000	.00	.0000	.0000
8 31 1991	31	.0	.00	.0000	.00	.0000	.0000
9 30 1991	30	251200.0	3.95	.1316	.21	.0070	.0533
10 31 1991	31	872471.5	13.72	.4424	.56	.0181	.0410
11 30 1991	30	1157314.0	18.19	.6065	.73	.0243	.0400
12 31 1991	31	2518505.0	39.59	1.2772	1.54	.0496	.0388
Total:	365	13443690.0	211.35		8.53		
Average:		1120307.0	17.6	.5841	.71	.0020	.0350

The electricity load factor (*ELF*) exceeds the occupancy load factor (*OLF*) (Table 3.17, Fig. 3.16), which indicates that significant electrical energy might be used during the unoccupied period. Hence, there is a potential for energy savings that could be obtained through a better management. Unlike the other two buildings, this building consumes 211.35 kWh/m^2/yr steam that is much higher than the electricity use (162.05 kWh/m^2/yr).

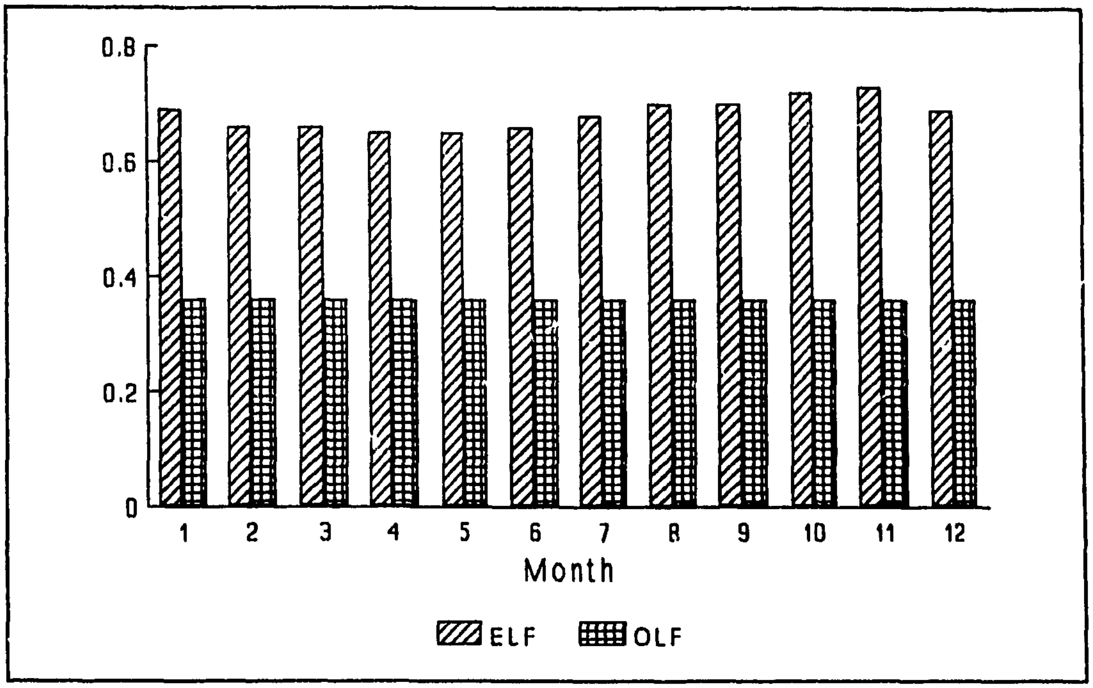

Figure 3.16 Electricity load factor & occupancy load factor of building 3.

Table 3.19 and Fig. 3.17 show the energy use that is normalized by number of days. The building consumes 160.7 kWh/m^2/yr of electricity, which accounts for 43.2% of the total energy use and 50.3% of the total energy cost, and it consumes 211.3 kWh/m^2/yr of steam, which accounts for 56.8% of the total energy use and 49.7% of the total energy cost.

Table 3.19 Normalized energy performance of building 3.

```
**********************************
*    Annual Energy Performance   *
* Normalized For Number Of Days *
**********************************
```

Type of fuel	Energy use		Cost		$/kWh
	kWh/m2	%	$/m2	%	
Electricity	160.7	43.2	8.63	50.3	.0532
Gas	.0	.0	.00	.0	.0000
Oil	.0	.0	.00	.0	.0000
Steam	211.3	56.8	8.53	49.7	.0403
Total:	372.0	100.0	17.15	100.0	.0936

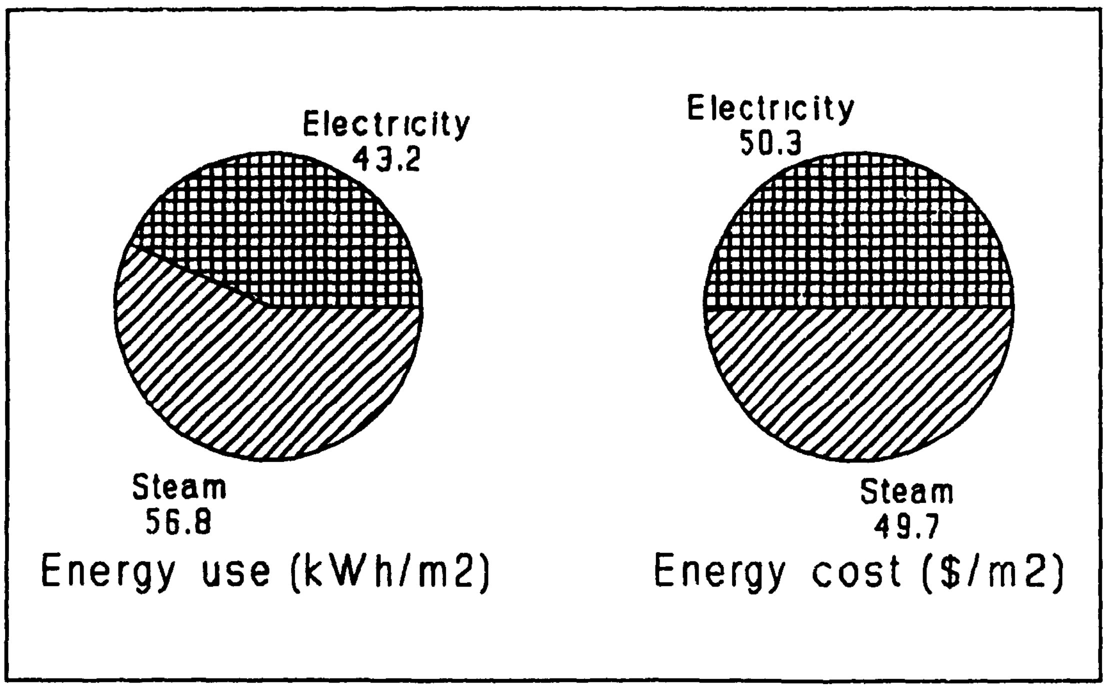

Figure 3.17. Annual energy performance of building 3.

Table 3.20 and Fig. 3.18 show that this building has lower annual energy consumption than the average values of the similar buildings built in the same period and the office buildings surveyed in 1988 in Montreal, but higher than the most energy efficient buildings as well as target value.

Table 3.20 Annual energy comparison of building 3.

* Annual energy consumption comparisons *

Energy budget kWh/m2	Average energy consumption(kWh/m2/yr) in				
	Year of construc. (1857)	Montreal in 1988	the best EEB in Montreal(1988)	Best EEB	Target
372.0	420.1	455.2	185.8	180.0	250.0

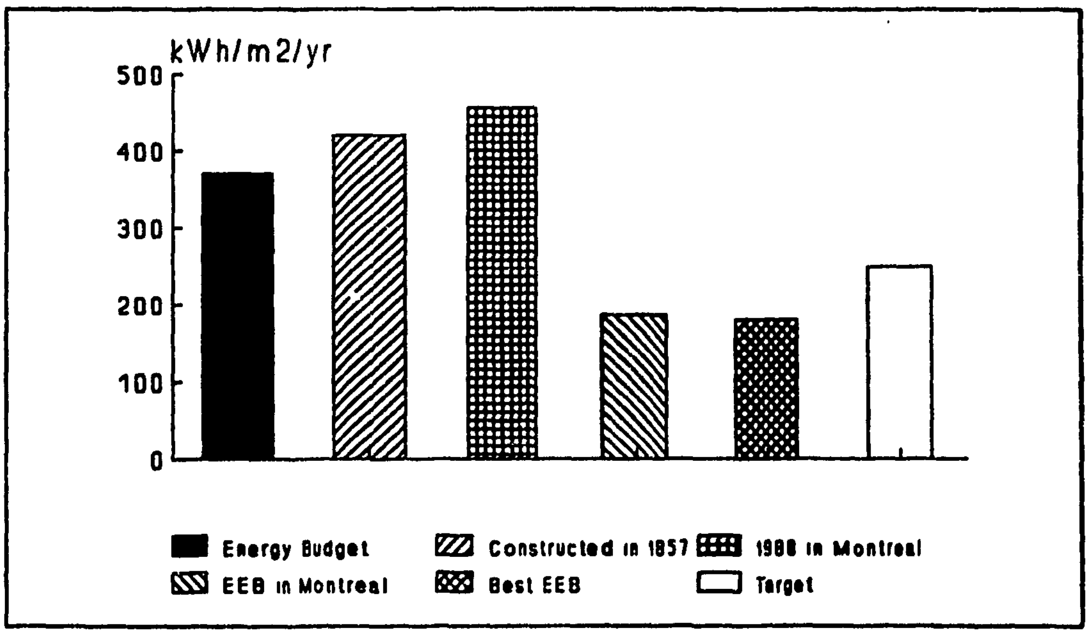

Figure 3.18 Comparison of the annual energy performance of building 3 with some target values

A good agreement of the comparison of normalized energy consumption between PRISM and NEW programs is presented in Table 3.21. Table 3.22 shows the weather normalized energy consumption and Fig. 3.19 presents the building energy signature. One can see that the electricity use tends to be constant but more energy is used during summer season. This is probably due to the use of mechanical cooling systems in the summer period (Table 3.23 and Fig. 3.20). One can notice that a great amount of steam (204.02 kWh/m ^{2}/yr, see Table 3.22) is consumed for heating, which is much higher than the heating energy consumption of the two other buildings (51.19 kWh/m ^{2}/yr, see Table 3.5; 35.55 kWh/m ^{2}/yr, see Table 3.13). Hence, more attention must be focused on the potential savings related to steam use.

Table 3.24 shows that the electricity distribution of the building, in which the lighting accounts for 43.8% of the total electricity use, office equipment accounts for 4.5% and chillers accounts for 9.4%. Fig. 3.21 shows the result of the disaggregation performed by NEW program, which is close to that performed by MICRO-DOE2.

Table 3.21 Comparison of normalized energy use between PRISM and NEW program (building 3.)

	NAC (kWh/m ^{2}/yr)	*a* (kWh/m ^{2}/day)	*b* (kWh/m ^{2}/day/°C)	R^2
Heating				
PRISM	253.19	0.0188	0.0331	0.9586
NEW	204.02	0.0000	-0.0494	0.9700
Cooling				
PRISM	159.61	0.4124	0.0041	0.8114
NEW	160.12	0.4190	0.0029	0.8050

Table 3.22 Weather-normalized energy consumption of building 3.

```
*****************************************
* Normalized Annual Energy Consumption  *
*    For Average Weather Conditions     *
*****************************************
```

FUEL TYPE	NAC kWh/ m2/yr	Base kWh/ m2/day	Tref C	a kWh/ m2/day	b kWh/ m2/day	R*R
Elec.	160.12	.426	2.46	.419	.0029	.805
Gas	.00	.000	.00	.000	.0000	.000
Oil	.00	.000	.00	.000	.0000	.000
Steam	204.02	.000	19.08	.942	-.0494	.970
TOTAL	364.14	.426				

Energy Signature:

Elec. = 0.419 + 0.0029*Tout
Steam = 0.942 - 0.0494*Tout

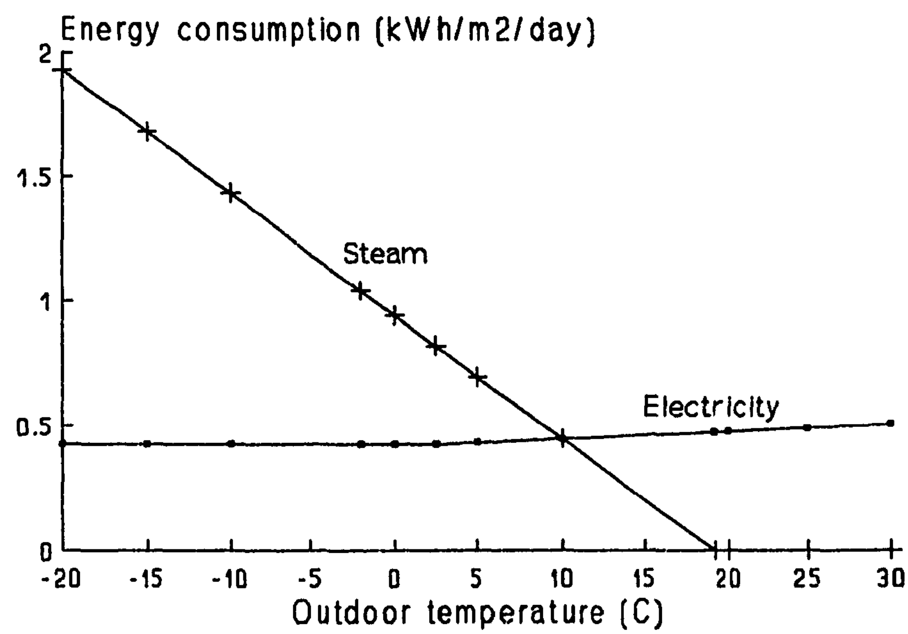

Figure 3.19 Energy signature of building 3.

Table 3.23 Monthly electricity consumption distribution of building 3.

```
**************************************
* Monthly Electricity Distribution *
**************************************
```

Month	Lighting kWh	Lighting %	Equipment kWh	Equipment %	Chiller kWh	Chiller %	Preheating kWh	Preheating %	CL-Tower kWh	CL-Tower %
JAN	357036.8	40.0	36915.2	4.1	46118.6	5.2	.0	.0	5240.0	.6
FEB	339185.0	48.3	35069.5	5.0	43812.7	6.2	.0	.0	4978.0	.7
MAR	410592.4	50.9	42452.5	5.3	53036.4	6.6	0	.0	6026.0	.7
APR	392740.5	54.7	40606.8	5.7	86593.6	12.1	.0	.0	12220.0	1.7
MAY	357036.8	40.8	36915.2	4.2	105890.6	12.1	.0	.0	16000.0	1.8
JUN	392740.5	42.3	40606.8	4.4	116479.6	12.5	.0	.0	17600.0	1.9
JUL	374888.7	39.2	38761.0	4.1	111185.1	11.6	.0	.0	16800.0	1.8
AUG	392740.5	38.2	40606.8	4.0	116479.6	11.3	.0	.0	17600.0	1.7
SEP	374888.7	43.5	38761.0	4.5	111185.1	12.9	.0	.0	16800.0	1.9
OCT	357036.8	39.5	36915.2	4.1	76004.6	8.4	.0	.0	10620.0	1.9
NOV	357036.8	43.3	36915.2	4.5	46118.6	5.6	.0	.0	5240.0	.6
DEC	374888.7	51.6	38761.0	5.3	48424.5	6.7	.0	.0	5502.0	.8

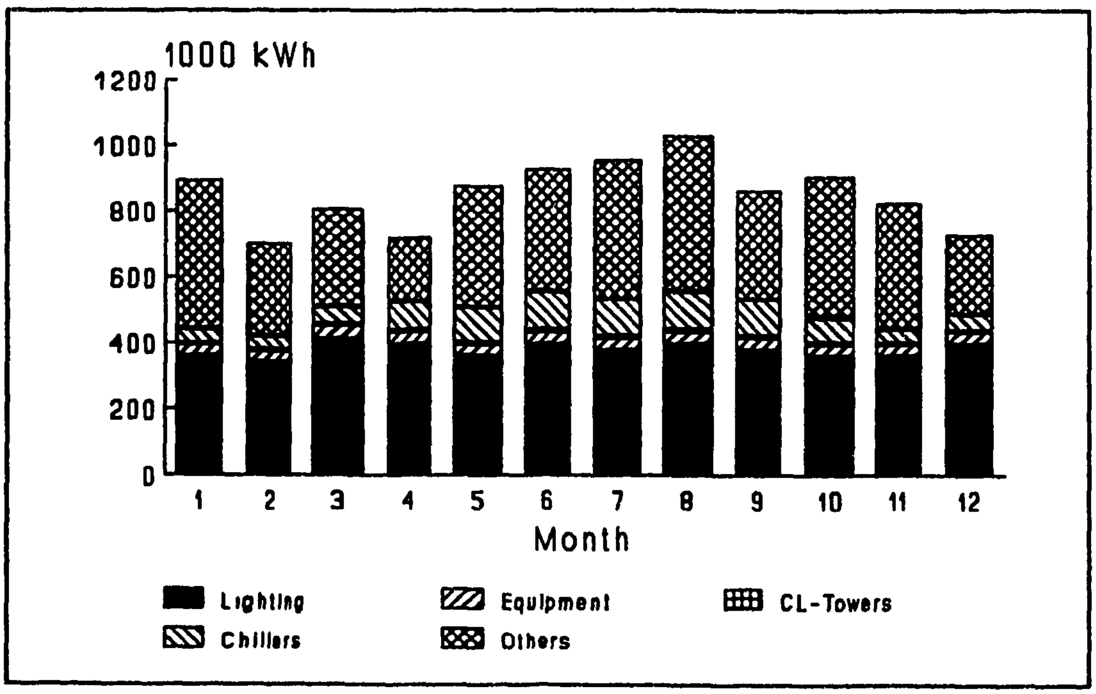

Figure 3.20 Monthly electricity distribution of building 3.

Table 3.24 Annual electricity consumption distribution of building 3.

```
******************************
* Electricity Distribution *
******************************
```

	(kWh)	(%)
Lighting	4480813.	43.8
Equipment	463286.	4.5
Chiller	961329.	9.4
Preheat	0.	.0
CL-Tower/AC-COND	134626.	1.3
Others	4181640.	40.9
Total	10221690.	100.0

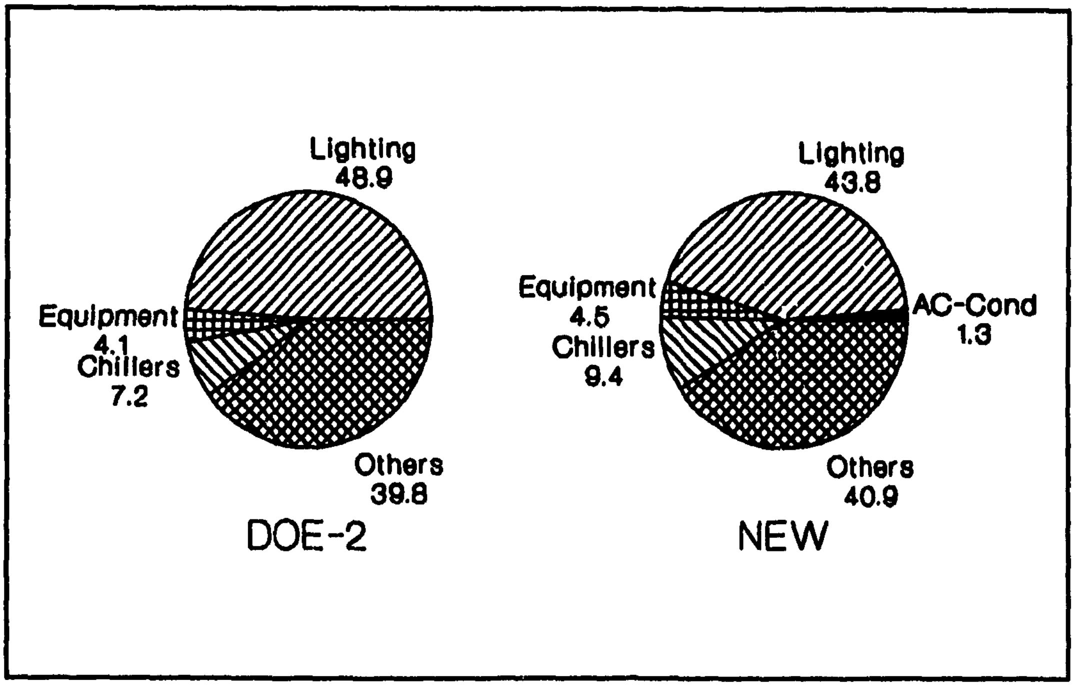

Figure 3.21 Comparison of results between NEW and DOE-2 program (building 3)

3.4 Comparison of the Energy Performance of three Existing Office Buildings

Table 3.25 presents the comparison of annual performance of the three buildings, and Figures 3.22 and 3.23 present the comparison of building signatures of these buildings. One can notice that building 1 and building 2 have similar electricity, gas (steam) and total energy use, and building 3 consumes more energy per square foot floor area than the two other buildings. The gas energy signature shows that building 2 is the least dependent on winter conditions among these three buildings. The use of heat recovery system from condensers in this building might be one of the reasons for this difference.

Table 3.25 Comparison of annual energy performance of the three buildings

	Electricity use		Gas (steam)		Total use	
	kWh/m²	\$/m²	kWh/m²	\$/m²	kWh/m²	\$/m²
Bldg. 1	277.21	12.54	50.96	1.11	328.17	13.65
Bldg. 2	290.26	11.37	34.94	0.73	325.20	12.10
Bldg. 3	162.05	8.70	211.35	8.53	373.40	17.05

After disaggregating the total electricity energy use among the major end-uses, one can perform a more detailed analysis which can not be done just based on the information from utility bills. Table 3.26 shows the comparison of the major end-uses of these buildings. One can see that the building 1 has the highest lighting consumption among the three buildings, which is 15.8% higher than that of building 2 and 30.7% than building 3. Because buildings might have different operating schedules and specific

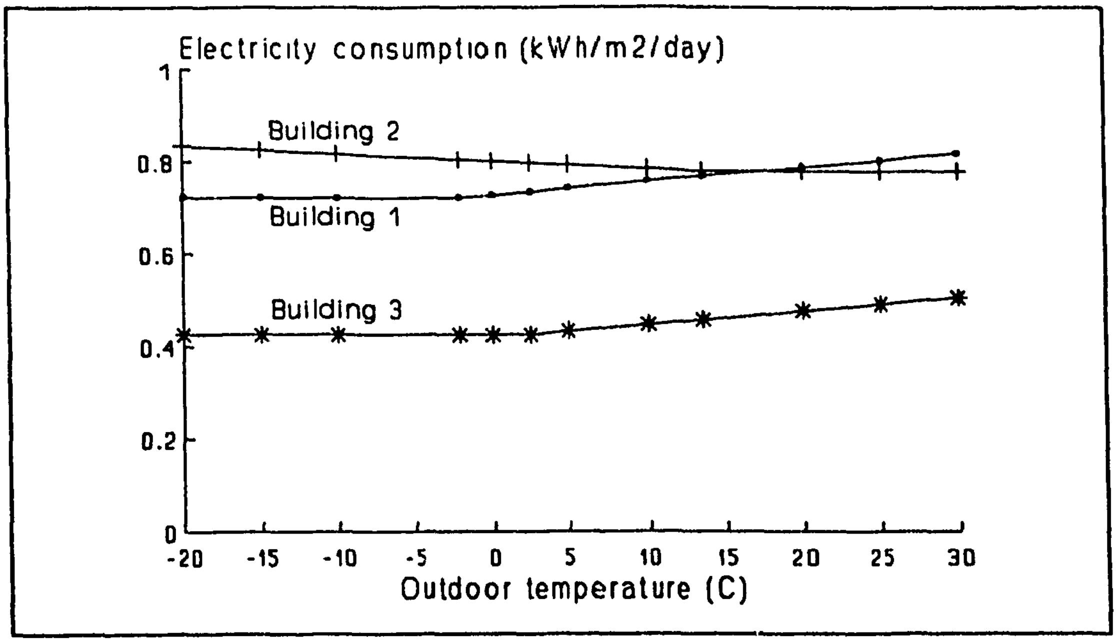

Figure 3.22 Comparison of building energy signatures (electricity)

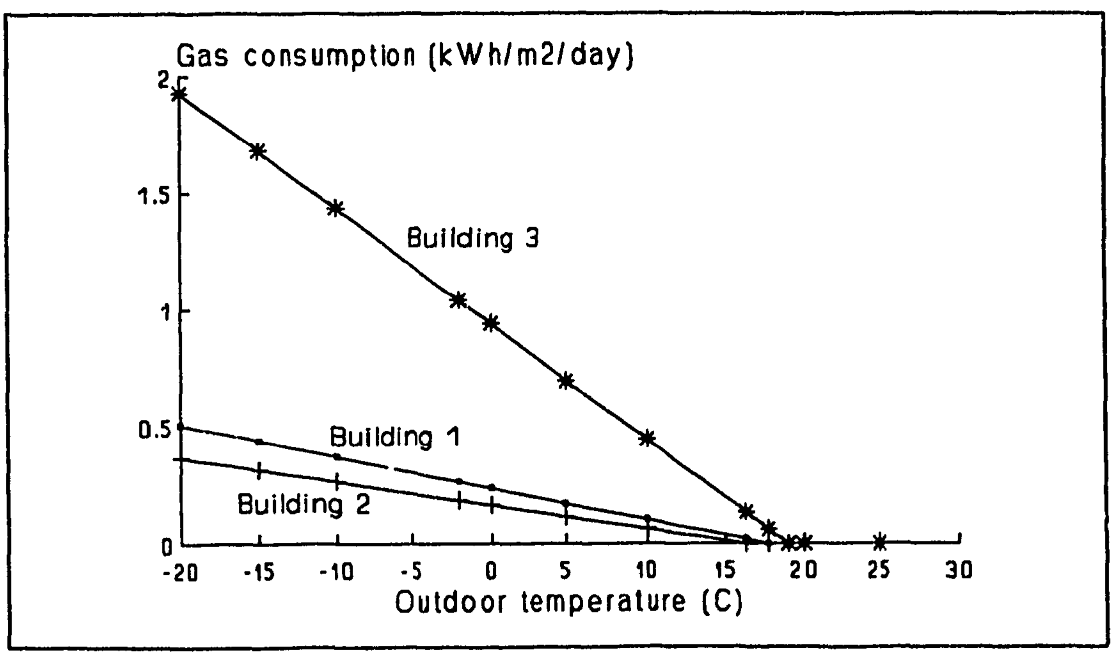

Figure 3.23 Comparison of building energy signatures (gas/steam)

Table 3.26 Comparison of the major-end-uses of the three buildings

	Lighting	Equipment	Chillers	Cl-towers
	kWh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
Bldg. 1	80.12	28.79	56.39	5.63
Bldg. 2	92.81	55.64	47.40	8.53
Bldg. 3	71.01	7.34	15.24	0.70

requirements, sometimes it is hard to compare their lighting consumption directly. On the other hand, lighting energy use is a large portion in the total energy use of large office buildings, so energy savings could be obtained through better management and operation. If the manager of building 2 can reduce the lighting consumption by 25%, he will get 5% [24] energy savings in total energy use, which costs about $52,000. It is worth mentioning that before any reduction is recommended, the specific functional and comfort needs for each individual building must be taken into account.

From Table 3.25 as well as Figures 3.22-3.23, one can notice that building 3 has significant gas consumption that is four times higher than that of building 1 and six times higher than building 2. The energy use for chillers and cooling towers is three to four times lower than that of buildings 1 and 2. Through further inquiry, building 3 was found a 147 years old building with small air conditioned area. Therefore, the lower cooling energy consumption can not indicate the energy efficiency of this building and the higher heating energy use may indicate the poor thermal characters of the envelops. To verify this extrapolation, walk-through inspection and simple measurements are recommended.

CHAPTER 4

COMPUTER SIMULATION OF THE ENERGY PERFORMANCE OF AN EXISTING LARGE OFFICE BUILDING IN MONTREAL

4.1 Introduction

In most case, the evaluation of energy performance of an existing building and the prediction of energy savings are performed using the annual and monthly values of energy consumption, which are generally obtained from the utility bills. An improvement in the quality of evaluation can be obtained by using, in addition, some hourly values, which are obtained through long-term monitoring. However, th~ monitoring is not only time consuming, but also very costly. A long-term monitoring program for a group of buildings was performed by Texas A&M University and was financially supported by the Texas LoanSTAR program [25]. Average monitoring cost of the buildings was about $\$0.64/ft^2$. If the same cost rate is applied to the office building, which is analyzed in this chapter, the monitoring cost will be about \$640,000. Moreover, in some other cases, due to the complexity of buildings the monitoring cost might exceed the value presented above. Hence, the cost of long-term monitoring becomes prohibitive in most studies for improving the energy efficiency in buildings.

The use of computer models is the alternative solution to a detailed monitoring and to the prediction of impact of new technologies or operation strategies applied to an existing building. This chapter presents the use of MICRO-DOE2 program, which is a

PC-version of the DOE-2.1 program developed at the Lawrence Berkeley Laboratory, to develop a model of a large existing office building in Montreal. The model is then calibrated by comparing the computer predictions with the utility bills. The computer model is used as an "experimental set-up" to analyze the relationships between the energy consumption and some parameters regarding building operation and construction. The main advantages of using a computer model instead of a real "experimental set-up" are the following:

- the energy audit is faster and the client can receive, after a short period, the valuation of energy performance;
- it avoids costly long-term monitoring;
- it provides weekly, daily and hourly energy consumption data for a detailed energy analysis;
- it disaggregates the total energy consumption among the major end-uses;
- it enables the user to predict the impact of different energy conservation measures applied to an existing building.

As disadvantages, one can mention:

- it requires a great amount of information to describe the building and its energy performance;
- it requires professional judgement about buildings and HVAC systems, as well as good understanding of the computer program used for the computer simulation.

4.2 Objective

The objective of this research is to use a detailed energy analysis program for a detailed energy audit of a large existing office building in Montreal, and then to evaluate the impact of several parameters on its energy performance. The main advantages offered by the use of a computer program rather than an experimental building are the following:

- save time and money;
- give to the user the access to a large number of parameters, such as weekly, daily, hourly energy consumption or indoor air temperature;
- disaggregate the total summed energy consumption among the major end-uses;
- analyze the impacts of parameters on the energy performance of the building.

4.3 Description of the Building Used in the Computer Model

A 28-story office building, located in downtown Montreal with about 100,000 m^2 of floor area, was used in this research (Fig. 4.1). The physical model of the real building contains 20 thermal zones and four plenums, to take into account: the differences in the installed power density for the office equipment, which varies from 3 to 23 W/m^2 of floor area, and the differences in schedules and density of occupancy. In this research, only the office area was considered. The lobby, the garage and the commercial underground spaces were not included in the model. The actual energy budget is about 315 $kWh/m^2/yr$ and the annual cost is 12.1 $\$/m^2/yr$. The gas consumption for heating represents about 6% of total energy consumption. Some important features of the building, which have an important impact on the energy performance, are the following:

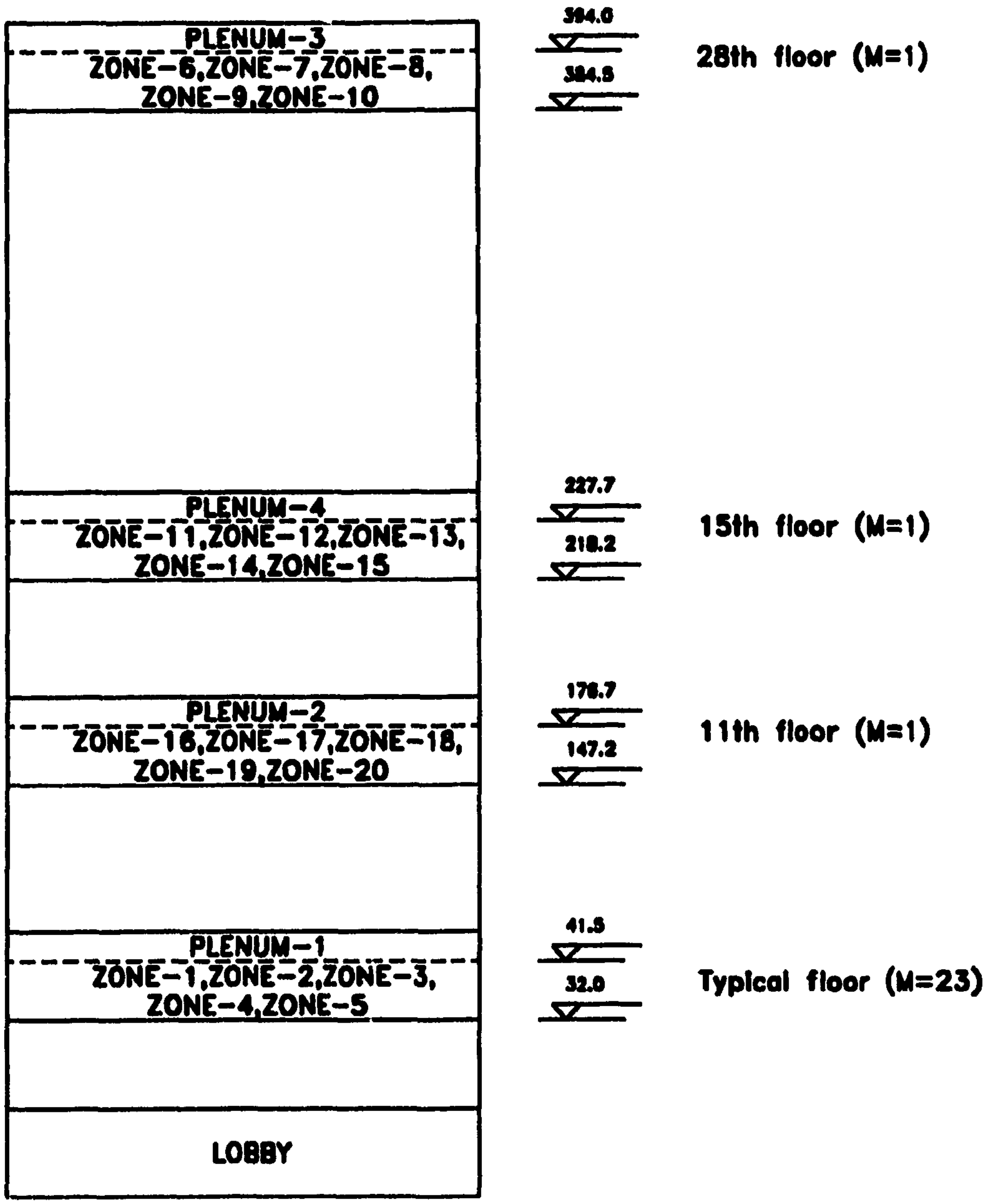

Figure 4.1 Description of the building

- power density of fluorescent lighting is 21.5 W/m^2;
- operating power density of office equipment varies from 3 to 23 W/m^2;
- on each floor, there are used two independent VAV systems;
- different schedules of operation are used in summer and in winter for the supply air temperature and for outside air flow rate in the perimeter zones;
- fixed amount of outdoor air is supplied to the building from 3:00 a.m. to 8:00 p.m.;
- total supply air flow rate is 11.4 L/s per m^2 of floor area;
- double bundle chillers of about 6,000 kW of refrigeration capacity are used during the heating season; heat recovered from these chillers covers 43% of the total heating needs;
- hermetical centrifugal chillers of about 8,000 kW of refrigeration capacity are used during the cooling season;
- heat recovered from the exhaust air is used to preheat the outside air;
- natural gas is used for heating, only during the periods of peak demand from October 10 to May 1.

The MICRO-DOE2 program uses a special language, called Building Description Language (BDL), for developing the input file. Some examples of commands used to define the HVAC systems are presented in Figures 4.2-4.5.

For instance, Figure 4.2 presents the definition of HVAC systems used for zones 1 to 5. There are two separate systems: (i) a system serving the interior zone (zone-5) and the plenum, called TYP-INT, and (ii) a system serving the perimeter zones (zone 1 to 4), called TYP-PER. The return air from the interior zone is circulated through the plenum while the air from the perimeter zones is evacuated directly through grilles and ducts. The different control strategies, including minimum supply air temperature, minimum humidity, operation schedules, are applied to the interior and perimeter zones; one control strategy is called S-INT and the other is called S-PERIM.

Figure 4.3 presents some commands used for defining the control of outside air, which is brought into the building from Monday through Friday. A fixed amount of outdoor air, of 3.8% of the total supply, is brought into the perimeter zones during the cooling season, from May 1 to October 10. During the winter, there is no fresh air provided to zones 1 to 4, the recirculated air is heated to 37 °C and then is supplied underneath the windows to compensate for the heat losses of these zones.

A fixed amount of outdoor air, of 5.6% of the total supply, is brought into the interior zone during the cooling system. There is a heat recovery system used in winter with an efficiency of 60%, which is installed on the exhaust duct from the interior zone.

Figure 4.4 presents some commands used to define the size and operation of chillers. There are two hermetical centrifugal chillers of 13.68 MBtu/h (4,000 kW) capacity each, which serve the building in summer season. Two double bundle chillers of total 20.52 MBtu/h (6,000 kW) capacity are used during heating season. One of them is used at night, and the other is used during the day time. The heat is recovered from these chillers and is used for heating and humidification.

Figure 4.2 DOE2 input file for description of HVAC systems

```
INPUT SYSTEM ..
                        .
                        .
                        .

TYPE-INT= SYSTEM
                SYSTEM-TYPE= VAVS
                ZONE-NAMES= (PLEN-1, ZONE-5)
                SYSTEM-CONTROL= S-INT
                SYSTEM-AIR= INT-AIR
                SYSTEM-FANS= S-FANINT
                SYSTEM-TERMINAL= S-T1
                HEAT-SOURCE= HOT-WATER
                PREHEAT-SOURCE= ELECTRIC
                SIZING-RATIO= 1.0
                SIZING-OPTION= COINCIDENT
                RETURN-AIR-PATH= PLENUM-ZONES
                PLENUM-NAMES= (PLEN-1) ..

TYPE-PER= SYSTEM
                SYSTEM-TYPE=VAVS
                ZONE-NAMES= (ZONE-1, ZONE-2, ZONE-3, ZONE-4)
                SYSTEM-CONTROL= S-PERIM
                SYSTEM-AIR= PERIM-AIR
                SYSTEM-FANS= S-FANPER
                SYSTEM-TERMINAL= S-T1
                HEAT-SOURCE= HOT-WATER
                SIZING-RATIO= 1.0
                SIZING-OPTION= NON-COINCIDENT
                RETURN-AIR-PATH=DIRECT ..
                            .
                            .
                            .
END
```

Figure 4.3 DOE2 input file for outside air schedule

```
    INPUT SYSTEM ..
                                .
                                .
                                .

    $ OUTSIDE AIR SCHEDULE
                  D1-AIR= DAY-SCHEDULE     (1,2)    (0.0)
                                           (3,19)   (-999.0)
                                           (20,24)  (0.0) ..

                  D2-AIR= DAY-SCHEDULE     (1,24)   (0.0) ..

                  WK1-AIR= WEEK-SCHEDULE   (MON,FRI) D1-AIR
                                           (SAT)     D2-AIR
                                           (SUN,HOL) D2-AIR ..

                  WK2-AIR= WEEK-SCHEDULE   (ALL) D2-AIR ..

                  OA-INT= SCHEDULE THRU MAY 1    WK1-AIR
                                   THRU OCT 10   WK1-AIR
                                   THRU DEC 31   WK1-AIR

                  OA-PER= SHEDULE  THRU MAY 1    WK2-AIR
                                   THRU OCT 10   WK1-AIR
                                   THRU DEC 31   WK2-AIR
                                      .
                                      .
                                      .
  INT-AIR= SYSTEM-AIR
                  MIN-OUTSIDE-AIR=0.056
                  MIN-AIR-SCH= OA-INT
                  OA-CONTROL= FIXED
                  RECOVERY-EFF= 0.60 ..

  PERIM-AIR= SYSTEM-AIR
                  MIN-OUTSIDE-AIR= 0.038
                  MIN-AIR-SCH= OA-PER
                  OA-CONTROL= FIXED ..
                                      .
                                      .
                                      .

  END ..
```

Figure 4.4 DOE2 input file for equipment description & load assignment

```
INPUT PLANT ..
                                    .
                                    .
                                    .

$ EQUIPMENT DESCRIPTION
                                    .
                                    .
                                    .

PL-2= PLANT-EQUIPMENT
                 TYPE= HERM-CENT-CHLR
                 SIZE=13.68
                 INSTALLED-NUMBER= 2
                 MAX-NUMBER-AVAIL= 2 ..

PL-3= PLANT-EQUIPMENT
                 TYPE= DBUN-CHLR
                 SIZE= 6.84
                 INSTALLED-NUMBER= 1
                 MAX-NUMBER-AVAIL= 1 ..

PL-4= PLANT-EQUIPMENT
                 TYPE= DBUN-CHLR
                 SIZE= 13.68
                 INSTALLED-NUMBER= 1
                 MAX-NUMBER-AVAIL= 1 ..

                                    .
                                    .
                                    .

$ LOAD ASSIGNMENT

NIGHT-CHLR= LOAD-ASSIGNMENT
                 TYPE= COOLING
                 LOAD-RANGE= 1000
                 PLANT-EQUIPMENT= PL-2
                 NUMBER= 0
                 PLANT-EQUIPMENT= PL-3
                 NUMBER= 0
                 PLANT-EQUIPMENT= PL-4
                 NUMBER= 0 ..

SUMMER-CHLR= LOAD-ASSIGNMENT
                 TYPE= COOLING
                 OPERATION-MODE= RUN-NEEDED
                 LOAD-RANGE= 30
                 PLANT-EQUIPMENT= PL-2
                 NUMBER= 2 ..
```

Figure 4.4 (continued)

```
SUMMER-DSCH= DAY-ASSIGN-SCH                  (1,5)       (NIGHT-CHLR)
                                             (6,18)      (SUMMER-CHLR)
                                             (19,24)     (NIGHT-CHLR) ..

      SUMMER-OFF= DAY-ASSIGN-SCH             (1,24)      (NIGHT-CHLR) ..

      SUMMER-WK= WEEK-SCHEDULE               (MON,FRI)     SUMMER-DSCH
                                             (SAT)         SUMMER-OFF
                                             (SUN)         SUMMER-OFF
                                             (HOL)         SUMMER-OFF ..

      NN-CH= LOAD-ASSIGNMENT
                      TYPE= COOLING
                      LOAD-RANGE= 8.0
                      PLANT-EQUIPMENT= PL-3
                      NUMBER= 1 ..

      DAY-CH= LOAD-ASSIGNMENT
                      TYPE= COOLING
                      LOAD-RANGE= 18.0
                      PLANT-EQUIPMENT= PL-4
                      NUMBER= 1 ..

      WINT-DSCH= DAY-ASSIGN-SCH              (1,5)        (NN-CH)
                                             (6,18)       (DAY-CH)
                                             (19,24)      (NN-CH) ..

      WINT-OFF= DAY-ASSIGN-SCH
                                             (1,24)       (NIGHT-CHLR) ..

      WINTER-WK= WEEK-SCHEDULE               (MON,FRI)    WINT-DSCH
                                             (SAT)        WINT-OFF
                                             (SUN)        WINT-OFF
                                             (HOL)        WINT-OFF ..
                                 .
                                 .
                                 .
      HEAT-RECOVERY
                      SUPPLY-1= (DBUN-CHLR)
                      DEMAND-1= (SPACE-HEAT) ..
                                 .
                                 .
                                 .
      END
```

Figure 4.5 presents some commands used to define the electrical rate of the Hydro Quebec of 1988. The electricity cost takes into account the demand and the consumption. The cost of electrical consumption is 0.0423 \$/kWh for the first 120 hours of operation at the billed demand, 0.0733 \$/kWh for the next consumption up to 2,400,000 kWh, and 0.016 \$/kWh for the balance. The cost of electrical demand is 3.3849 \$/kW. One can notice that this structure does not allow to take into account the penalties for exceeding the subscribed demand. It is assumed that the billed demand is always higher than the subscribed demand. In addition, taxes applied to the utility cost are not taken into account. The unit cost of natural gas is \$8.78 for 1,000,000 ft^3.

The computer model was calibrated using the utility bills and the weather data of 1988, and the results show differences between monitored and simulated values of 3.8% for the energy consumption and 7.5% for the energy cost. The calibration was carried out for several parameters: annual energy consumption (total, electricity, gas), annual energy cost (total, electricity, gas), and peak electrical demand.

Figures 4.6-4.7 show the comparison of monthly variation of total energy consumption and cost, and Figures 4.8-4.9 show the comparison of monthly variation of electricity consumption and cost. Slightly larger differences were obtained in the comparison of monthly values of the gas consumption and cost (Fig. 4.10-4.11). One can notice that the simulated gas consumption starts from September, but the measured consumption starts from November. The difference is due to the monitoring process, since the gas consumption is not really measured at regular intervals. Once the computer model was calibrated, it can be used as an "experimental-tool" for further investigations.

Figure 4.5 DOE2 input file for utility costs

```
INPUT ECONOMICS ..

ECONOMICS-REPORT
                    SUMMARY= (ES-D, ES-E) ..

    $ STEAM ENERGY COSTS

ENERGY-COST
                    RESOURCE= NATURAL-GAS
                    UNIT= 1000000
                    UNIFORM-COST= 8.78 ..

    $ ELECTRICITY ENERGY COSTS

ENERGY-COST
                    RESOURCE= ELECTRICITY
                    UNIT= 3412.97
                    ASSIGN-CHARGE= (BLK-1) ..


BLK-1= CHARGE-ASSIGNMENT
                    RESOURCE= ELECTRICITY
                    C-A-LINK= BLK-1
                    BLOCK-UNIT= KWH/KW
                           BLOCK-RANGE= (120)
                           BLOCK-CHARGE= (0.0423)
                    BLOCK-UNIT=ENERGY
                           BLOCK-RANGE= (2400000, 100000000)
                           BLOCK-CHARGE= (0.0233, 0.0160)
                    TYPE= DEMAND
                           UNIFORM-CHARGE= 3.3849 ..

COST-PARAMETERS
                    KWH/KW-DEM-TYPE= RECORDED
                    DEM-RATCHET-T1= MEASURED ..


END ..
```

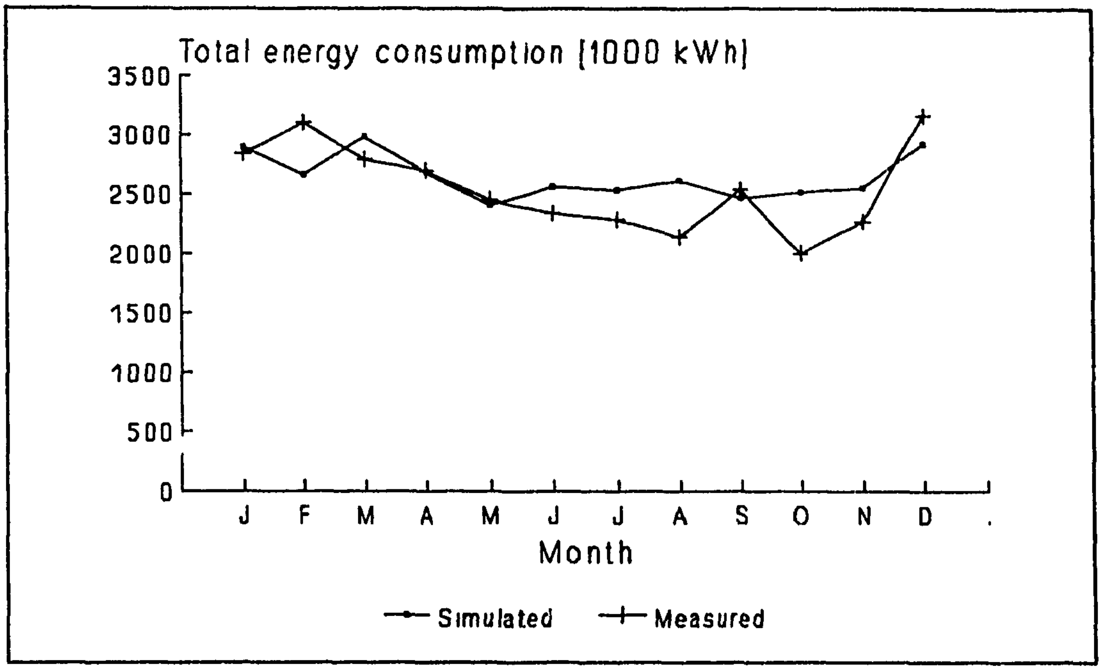

Figure 4.6 Comparison of total energy consumption

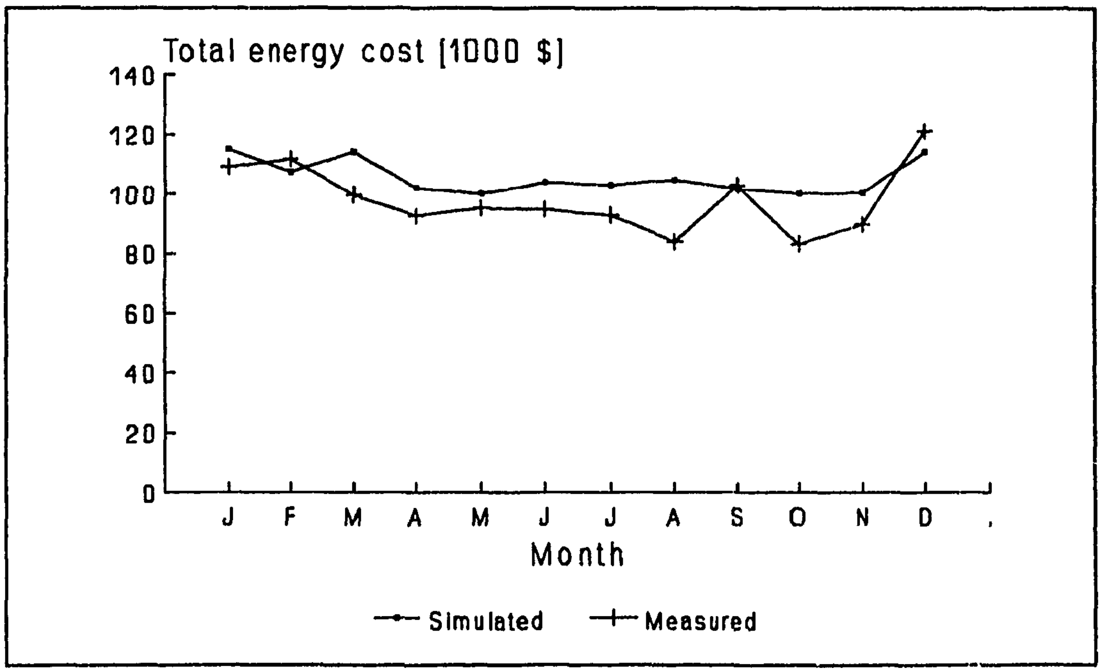

Figure 4.7 Comparison of total energy cost

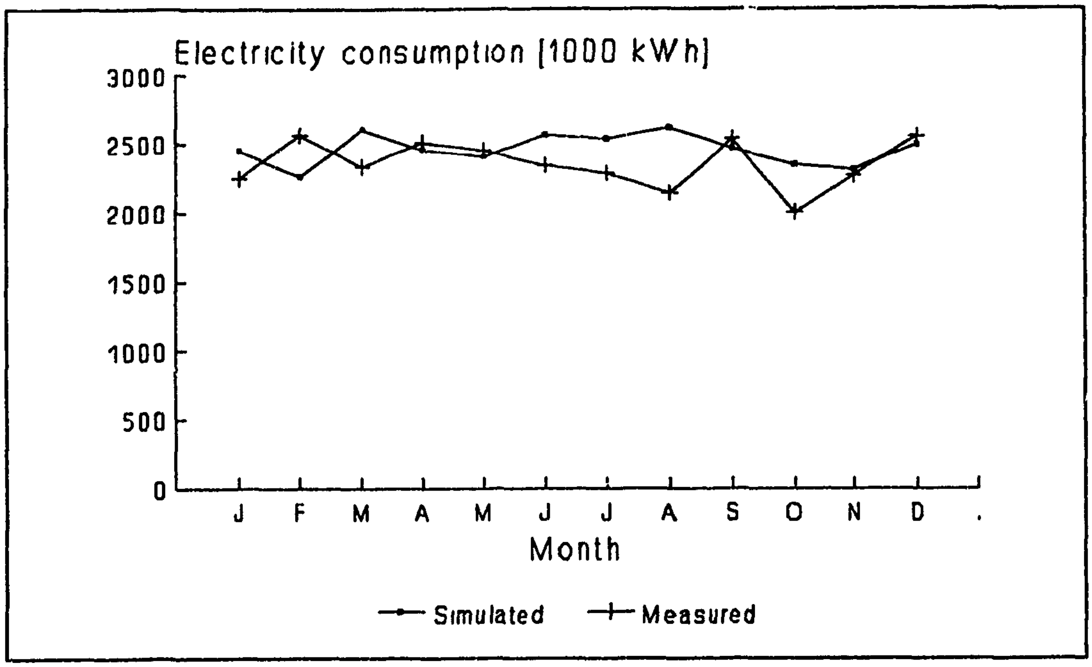

Figure 4.8 Comparison of electricity consumption

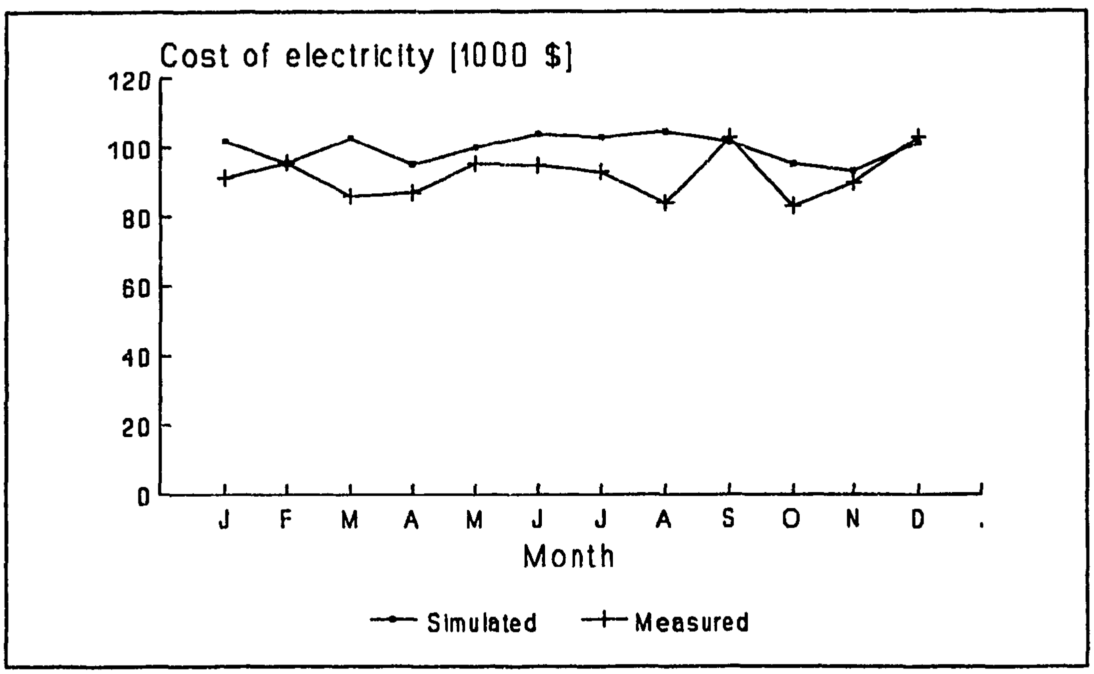

Figure 4.9 Comparison of electricity cost

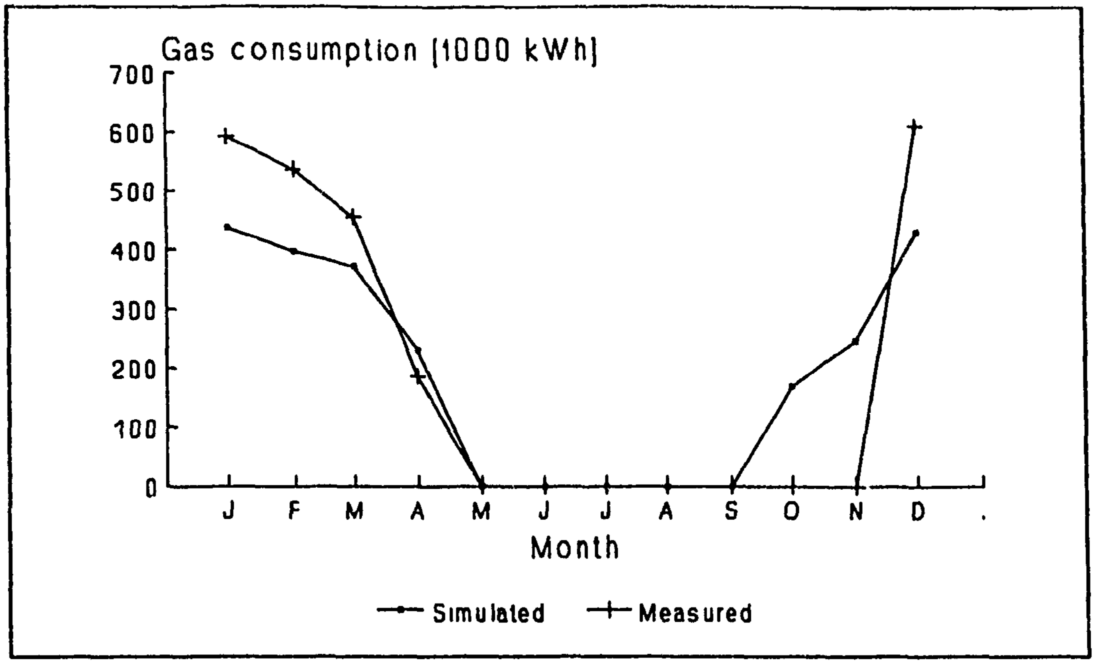

Figure 4.10 Comparison of gas consumption

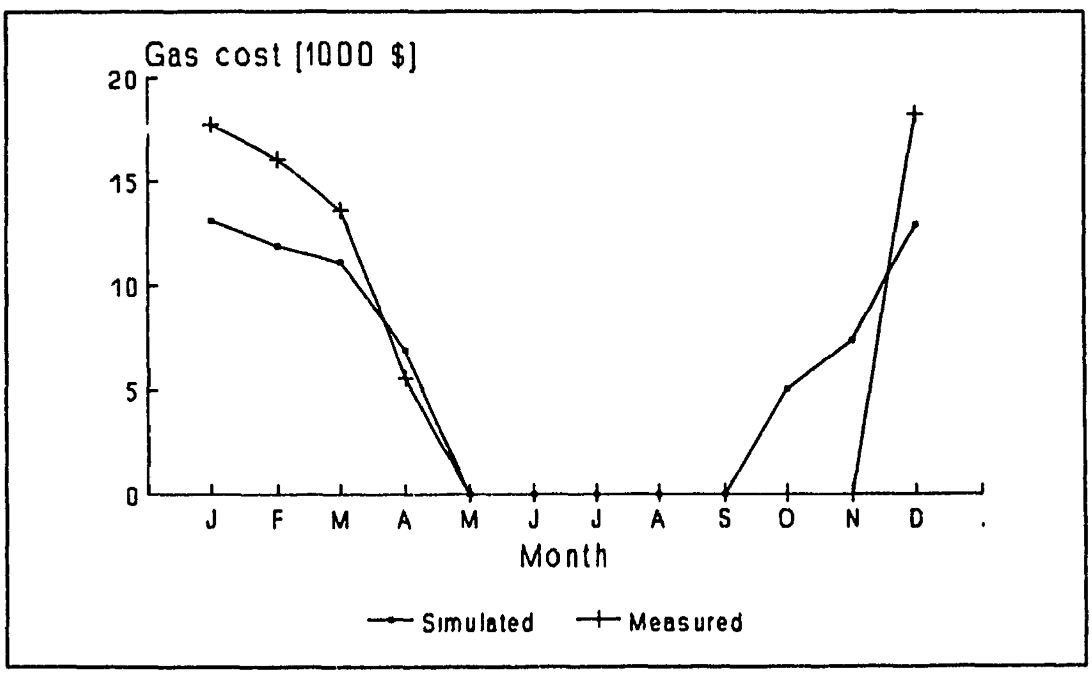

Figure 4.11 Comparison of gas cost

4.4 Applications of The Computer Model

4.4.1 Detailed energy analysis

This section presents the difference in quality of information, which can be obtained using (i) only utility bills and (ii) the computer model. Figure 4.12 shows the distribution of daily electricity consumption among the major end-uses, in terms of outdoor temperature, which is known as electrical energy signature. These values are calculated from the utility bills, as average energy use per day. The number of week-ends or holidays can affect the average value. It is also interesting to notice that the energy use for cooling is almost constant over the year. Because of the large floor area, a great amount of energy is required to cool the internal zones in winter, which is comparable with the energy used in the summer. This diagram shows that the energy consumption is mostly unaffected by the weather conditions. One of the main reasons is probably that the internal loads such as lighting and office equipment are dominant in this building.

The energy consumption for lighting and office equipment accounts for almost 50% of the total electricity energy use (Fig 4.13). The energy consumption for chillers and preheating accounts for 18.1%, while the energy consumption for total others accounts for 33.5%.

Daily and hourly data of energy consumption are useful for detailed energy analysis. One can obtain these data from the computer model instead of costly and time consuming long term monitoring. By using these data, one can define the rate of energy use on

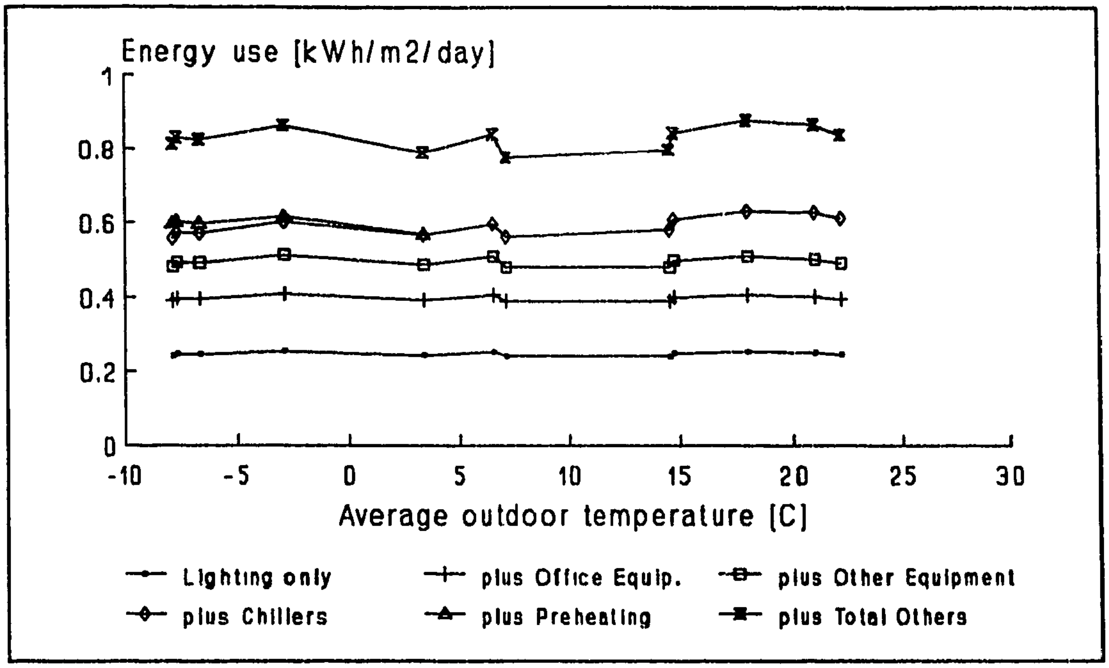

Figure 4.12 Electrical energy signature of the building

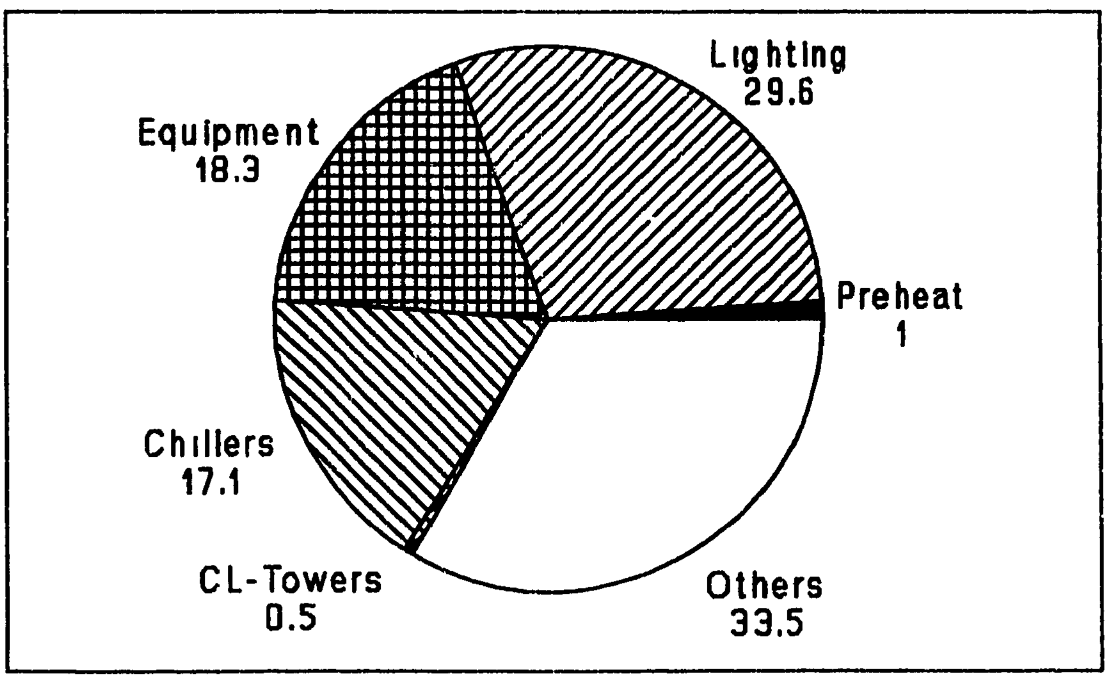

Figure 4.13 Distribution of electricity use among the major end-uses

weekdays versus weekends/holidays, the rate of energy use at night versus daytime, as well as the rate of energy use during the occupied versus unoccupied periods. There are different ways to present the daily and hourly energy consumption, and some of them presented below.

Figure 4.14 shows the average daily consumption versus outdoor temperature. It is easy to recognize the energy consumption in weekdays and weekends/holidays. The energy used in weekdays is about four times higher than that during the weekends/holidays. The base load, of about 10.5 kWh/m²/day takes place when the outdoor temperature is around 5 °C. If the outdoor temperature is lower, then more energy is used for heating; and if the outdoor temperature is greater than this range, more energy

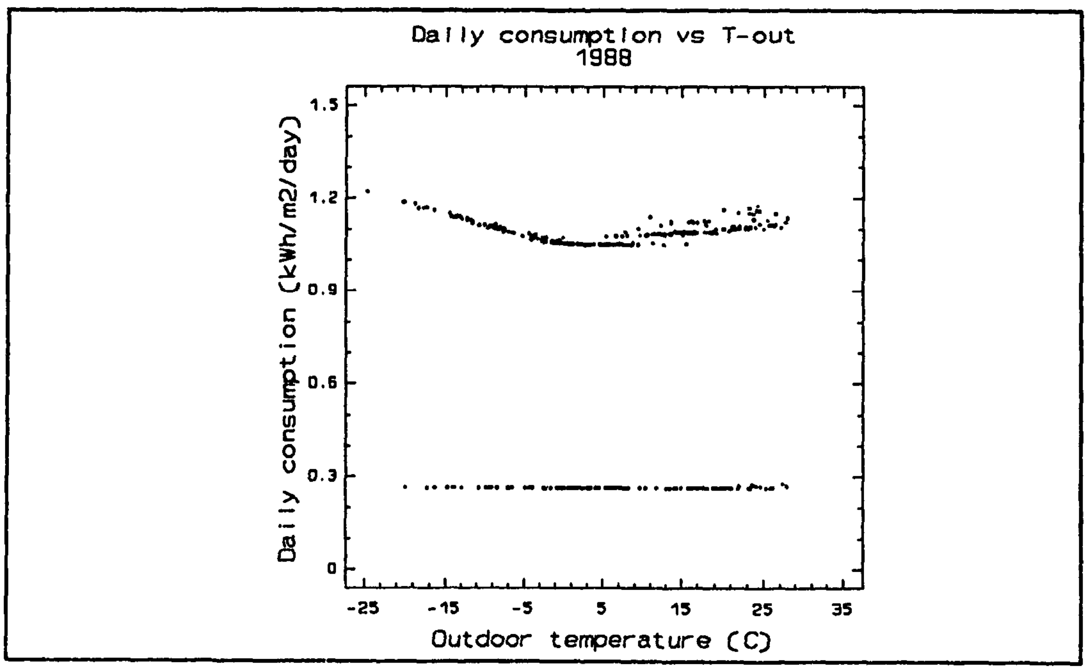

Figure 4.14 Daily consumption vs. outdoor temperature

is required for cooling. One can notice that the difference in the quality of representation between Fig. 4.12 and 4.14. The last figure was developed using information from 365 days, including weekdays and weekends/holidays, while the first figure used only 12 points, corresponding to the utility bills of twelve months. Figure 4.14 shows that the energy use during the weekdays varies from 1.0 to 1.2 $kWh/m^2/day$, and during the weekends is about 0.3/$kWh/m^2/day$. Figure 4.12 shows that on average the daily energy use is about 0.8 $kWh/m^2/day$.

The energy consumption is affected not only by the weather conditions, but also bv the operating conditions of the building and HVAC system. Along with Table 4.1, Figure 4.15 shows the distribution of energy use during a day in January. For instance, one can see that from 9:00 to 18:00 (index 6), the lighting, office equipment, occupancy and HVAC systems are all at the maximum levels. The highest energy use reaches 80 $W/m^2/h$, when the outdoor temperature is at -29 °C. From 23:00 to 2:00, the lighting is at 40% of the maximum capacity and the office equipment at 45%. The fans are turned off and the HVAC systems do not operate. During this period, because no ventilation is required and the indoor temperature is never below the night setback temperature in this case study, the energy consumption is low and constant. One can also notice that the variation of the energy consumption during one day. For instance, up to 2:00 the energy use is at the minimum level, of about 10 W/m^2 (index 1). At 3:00, the fans are turned on, and the energy use increases at about 16 W/m^2 (index 2). At 5:00, the HVAC equipment is activated to control the daily outdoor conditions, and the energy use varies in term ot outdoor temperature from 38 to 45 W/m^2 (index 3). At 7:00, all lights are

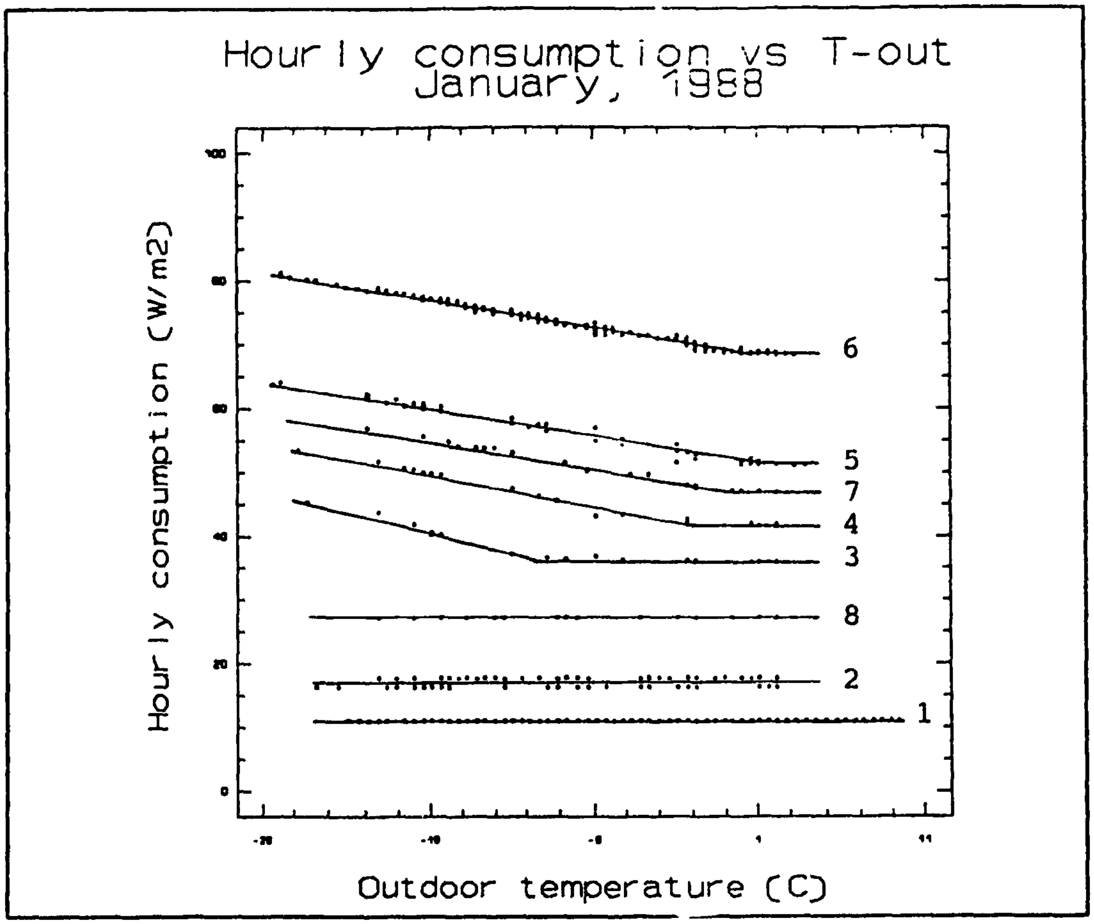

Figure 4.15 Hourly consumption in January for indices

<u>**Note:**</u>

See Table 4.1 for indices used in this figure.

Table 4.1 Distribution of energy use during a day

Hours	Index	Light	Equip.	Occup.	Fans	Thermostat
1:00 2:00	1	0.4	0.45	0	0	night
3:00 4:00	2	0.4	0.45	0	1	night
5:00	3	0.4	0.45	0	1	day
6:00	4	0.4	0.45	0.1	1	day
7:00 8:00	5	1.0	0.45	0.1	1	day
9:00 : 18:00	6	1.0	1.0	1.0	1	day
19:00	7	1.0	0.45	0	1	day
20:00	8	1.0	0.45	0	1	night
21:00 22:00	2	0.4	0.45	0	1	night
23:00 24:00	1	0.4	0.45	0	0	night

Note:

Light = Energy use for lighting
Equip. = Energy use for office equipment
Occup. = Energy use for occupancy load
Fans = Energy use for fans of HVAC system
Thermostat = HVAC system set-point temperature

turned on, and the energy use increases at 55-65 W/m^2, in term of outdoor temperature (index 5). From 9:00 till 18:00, the energy use is at the highest level (index 6). At 20:00, the HVAC systems are turned off, and the indoor conditions are no more controlled (index 8). At 21:00, the lighting systems are turned off and the energy use reclines till level of consumption of 3:00 (index 2).

Figure 4.16 shows the variation of daily consumption in this January. It is easy to distinguish betwren the energy use during weekdays and weekends/holidays.

Figure 4.17 shows the hourly energy use in January. The group of values at the top of the diagram correspond to the energy use during working hours, while the group of values at the lowest level correspond to energy use at night or on weekends/holidays. For instance, at 9:00, during the weekdays, the energy use varies from 67 to 80 W/m^2, while at 6:00 it varies from 40 to 55 W/m^2.

Based on the detailed analysis, one can notice that the hourly energy use varies mostly with the changes of internal loads that have higher effects on the energy use than the weather conditions. In the other words, the internal loads are dominant in this office building, which is a confirmation of the results obtained from the simple energy audit in the previous chapter. Since energy use varies from time to time, the hourly data offer the best quality of information for an energy audit, compared with that obtained from daily and monthly data. However, the hourly information is difficult to be obtained. Therefore, a development of a method using a short-term measurements instead of a time-consuming and costly long-term measurements to obtain hourly and daily data is highly recommended.

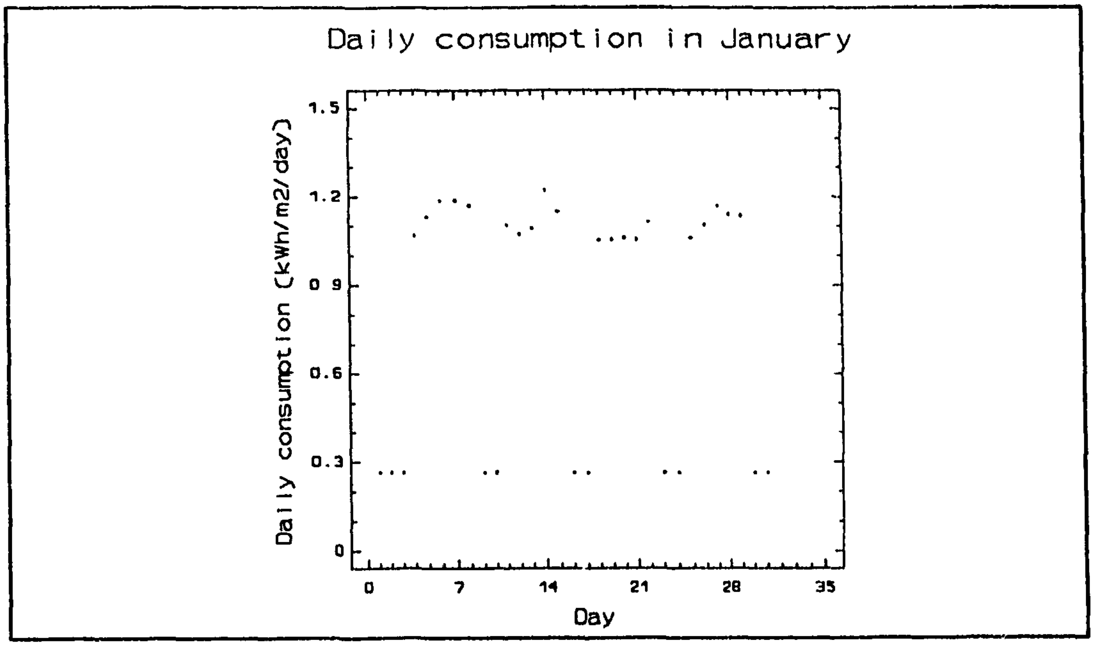

Figure 4.16 Daily consumption in January

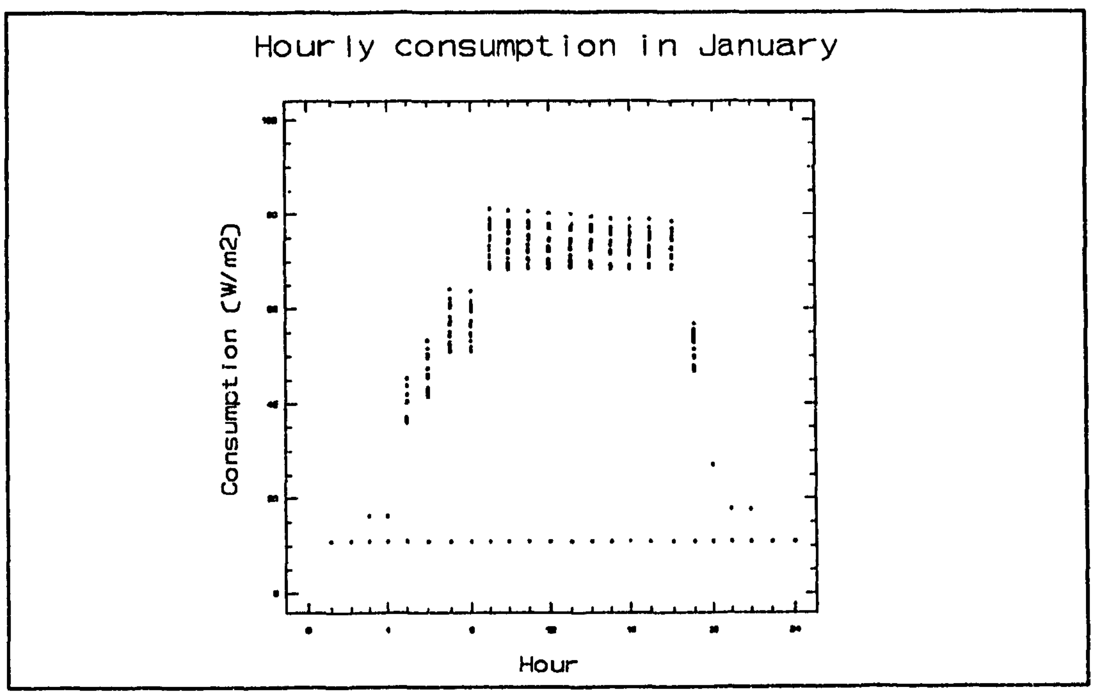

Figure 4.17 Hourly consumption in January

4.4.2 Sensitivity analysis

The purpose of sensitivity analysis applied to this existing office building is to define the impact of some parameters on the energy performance. Hence, only those energy conservation measures (ECM) with a large impact can be considered for further analysis. Other parameters with a less impact on energy consumption may be neglected, so that the costly analysis can be avoided. Two groups of parameters were selected for the sensitivity analysis: (i) related to the building envelope, and (ii) related to the internal loads. The energy performance of this building is less sensitive to the envelope than to the internal loads. For instance, if the air infiltration is decreased by 100%, then the energy cost is reduced only by 1.5% (Fig. 4.18). The largest reduction of energy cost, of about 15%, is obtained when the lighting load is reduced by 100% (Fig. 4.19).

The 100% elimination parametric procedure [26] is used to identify the impact of some parameters on the total energy consumption of this building, and then to suggest ways for improving its energy-efficiency. The variation of energy consumption is evaluated for some extreme cases, where one parameter is completely eliminated. For instance, in one extreme case it is assumed that the heat transfer through walls is negligible (U-wall=0) or another without air infiltration (Fig. 4.20). It shows also that the use of a better thermal envelope leads to small energy savings of about 0.9%. This is a confirmation of previous results, which have indicated that the further improvement of building envelope from the existing situation, has a limited impact on the total energy consumption of the internal-load dominated buildings. One can also notice that the

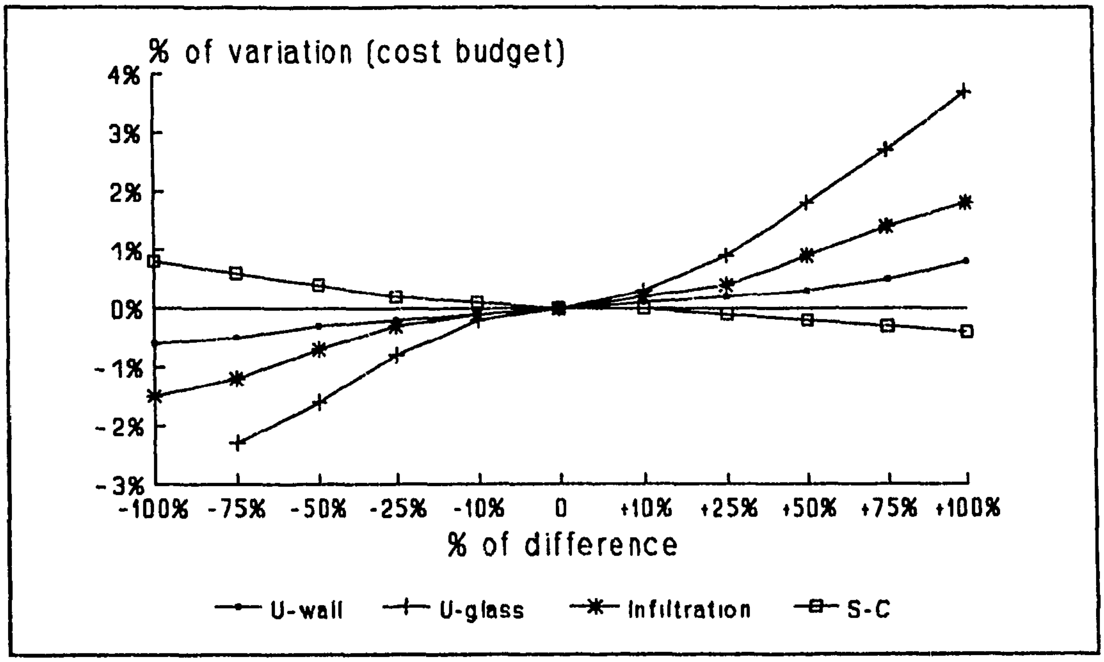

Figure 4.18 Sensitivity analysis of the building envelopes

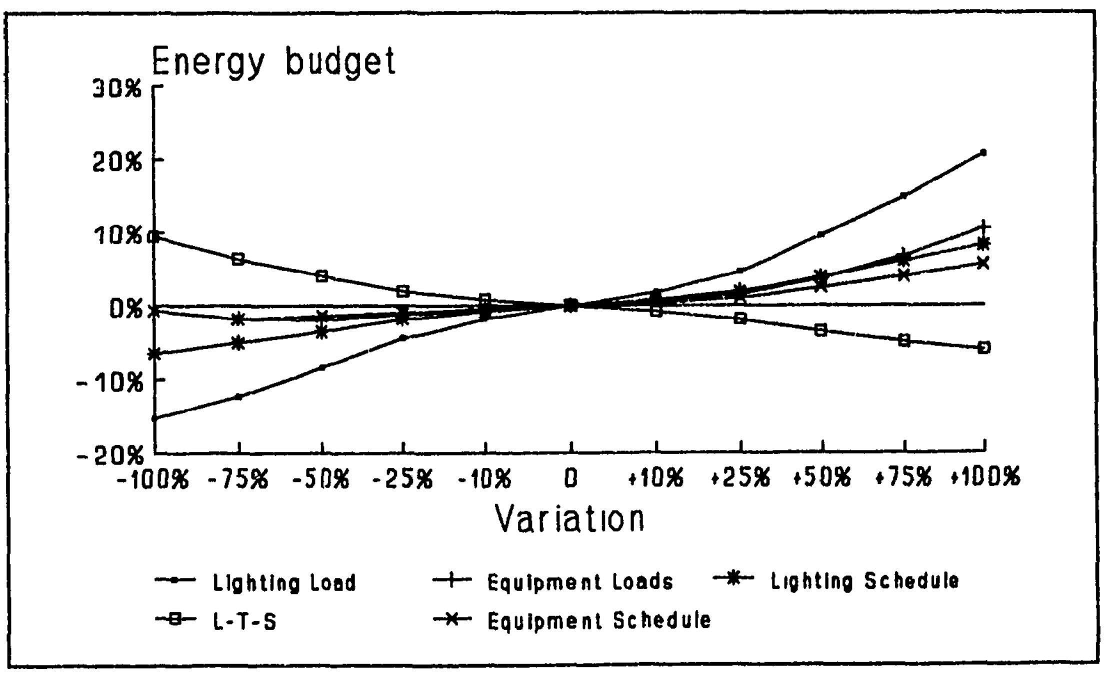

Figure 4.19 Sensitivity analysis of the internal loads

reduction of install capacity for lighting systems has an important potential for energy savings. However, the secondary effects of this measure lead to smaller energy savings. For instance, limited energy savings will be obtained from these buildings where the lighting only accounts for small part of total energy consumption, and the gas/oil, steam consumption will increase to compensate for smaller internal heat gains. So more attention may be moved on some other parameters that may have greater impact on the total energy consumption of these buildings.

A recent study [24] performed for this existing building recommended the implementation of an energy efficiency equipment, known as water-side economizer system, to improve the energy performance. The use of energy in cold winter for mechanical cooling is a paradox of these modern office buildings, where important heat gains must be mainly evacuated from the internal zones. Electricity is used to operate chillers, and then heat is eliminated into the atmosphere. A study of using the weather-side economizer system in this building has estimated the energy savings to be about 64% of electricity use for chillers in winter, or 51.7% of total electricity consumption from October to April, or 4.3% of total annual electricity use.

In addition to the two groups, due to the interest for ASHRAE Standard 62-1989 [27]. Another analysis was performed to evaluate the impact of higher ventilation rates in this office building on the energy cost (Fig. 4.21). The results indicated a more important impact than previously indicated. The more detailed evaluation is presented in the next section.

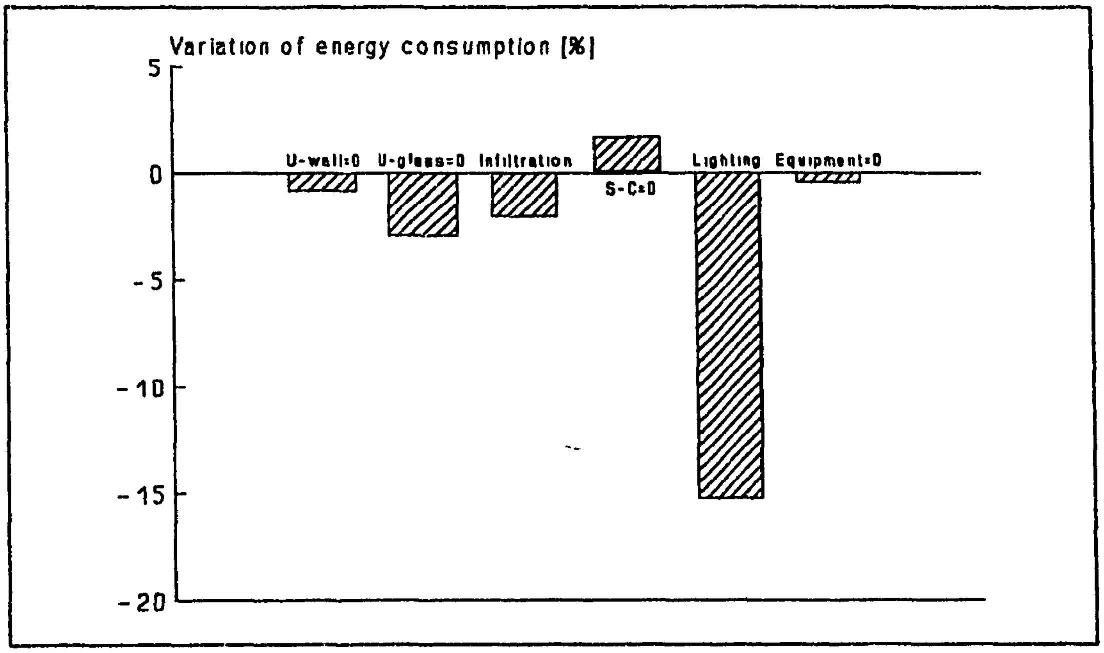

Figure 4.20 Sensitivity analysis using the 100% elimination parametric procedure

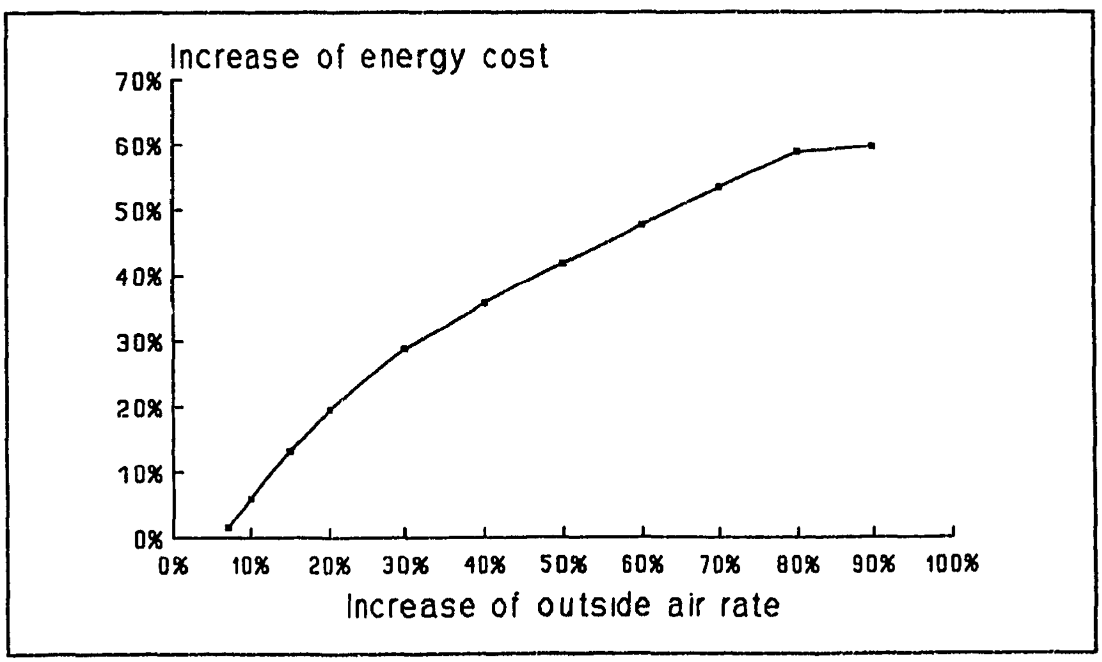

Figure 4.21 Sensitivity analysis of the increase of outside air rate

4.4.3 Evaluation of the impact of increase of the air ventilation rate on the energy performance

ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality" specifies two alternative procedures to design and operate a ventilation system for achieving acceptable indoor air quality:(i) Ventilation Rate Procedure, and (ii) Air Quality Procedure. The first procedure prescribes the minimum outdoor air ventilation rates to be delivered by HVAC systems in different commercial and residential facilities. These values were established by an interdisciplinary committee, as a compromise between indoor air quality and energy consumption. The minimum ventilation rate for office building is now 10 L/s/person, except reception areas with 8 L/s/person. It is worth mentioning that soon after its publication, the ASHRAE Standard 90.1 has been contested regarding the global approach as well as recommended values for ventilation rates. For instance, some researchers have recommended higher values for the ventilation rate in office building, up to 20 or even 50 L/s/person [28].

The simulated results [29,30] show that the increase in ventilation rate from 7.6 L/s/person (6% of total air supply) to 10.0 L/s/person (8% of total air supply) will lead to an increase of annual energy cost by 3.2% or 37,000 $. Although this building uses the heat recovered from exhaust air and condensers to preheat the outside air, the consumption of natural gas for heating increases by 11.8%, and the electrical consumption for preheating increases by 166%. The energy consumption for cooling increases only by 1.2%. Figure 4.22 shows the distribution of energy consumption among the main end-uses, for the 7.6 L/s/person case and the 10.0 L/s/person case.

It is noticed that the increase of electrical rate in 1991 has a great impact on the

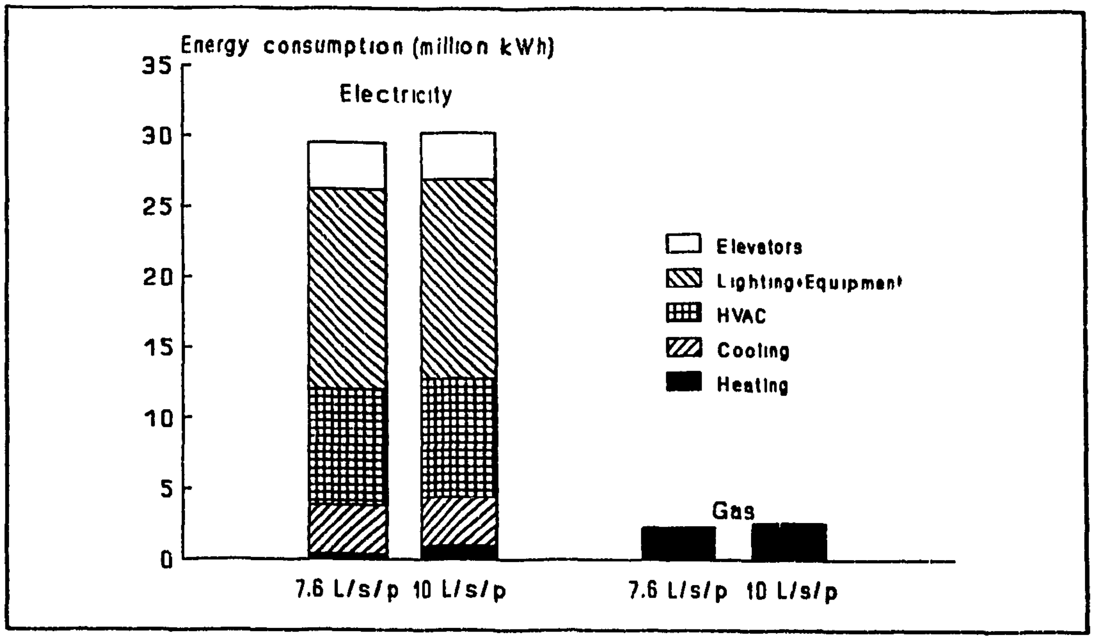

Figure 4.22 Distribution of energy consumption among the major end-uses

annual energy cost (of about 35%) than the increase due to a higher ventilation rate (Fig. 4.23). If one assumes that the electrical rate will further increase by 50% with respect to 1991, then the total energy cost for this building will increase by about 65% with respect to 1988 that is the reference year used in this work. This increase would exceed by far the increase in cost due to the ventilation rate.

In order to evaluate the impact of heat recovery systems on the increase of energy consumption, four configurations were simulated [31]: (i) with heat recovery from the exhaust air and the condensers, (ii) with heat recovery only from the exhaust air, (iii) with heat recovery only from the condensers, and (iv) without heat recovery. The amount of outdoor air is either kept constant or is controlled in terms of mixing temperature. For each configuration and control type, the ventilation rate is assumed to be increased from the actual situation (7.6 L/s/person) to 10, 20, 30, and 40 L/s/person.

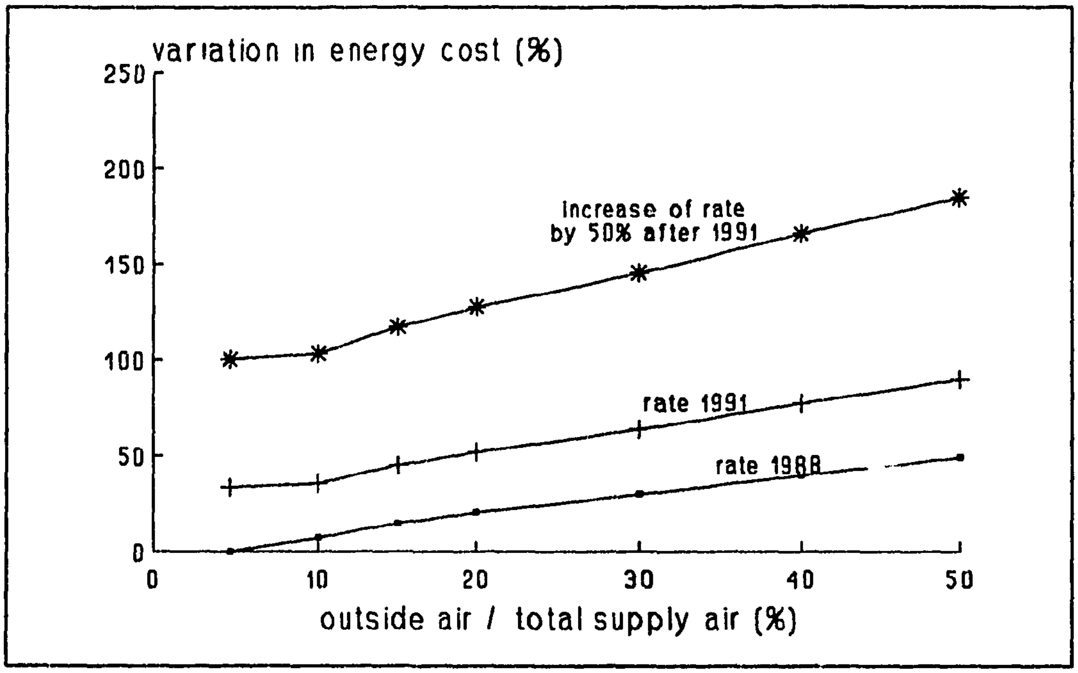

Figure 4.23 Variation of energy cost vs. ventilation rate

When the amount of outdoor air is controlled by the mixing temperature, the energy consumption is greater than in the case of a system with a fixed amount (see Fig. 4.24). However, for an existing building it is more important to evaluate the increase of energy consumption and cost with respect to the present situation. The energy use increases by 1.7-1.9% (Fig. 4.25) and the cost by 2.2-2.4% (Fig. 4.26), when the ventilation rate increases from the present situation of 7.6 L/s/person to 10 L/s/person, in a system with a fixed amount of outdoor air, for all four configurations.

When the ventilation rate is controlled by the mixing temperature, the increase of ventilation rate has a negligible impact on the energy consumption and cost. Therefore, a VAV system with a fixed amount of outdoor air is more sensitive to the increase of

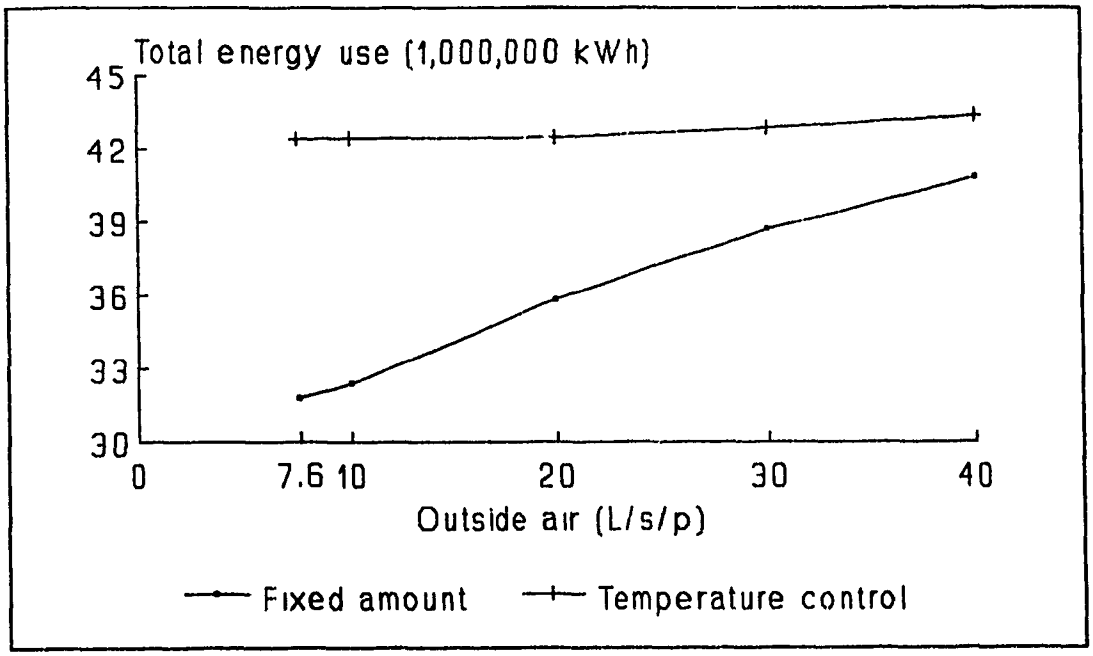

Figure 4.24 Increase of energy consumption at higher ventilation rate

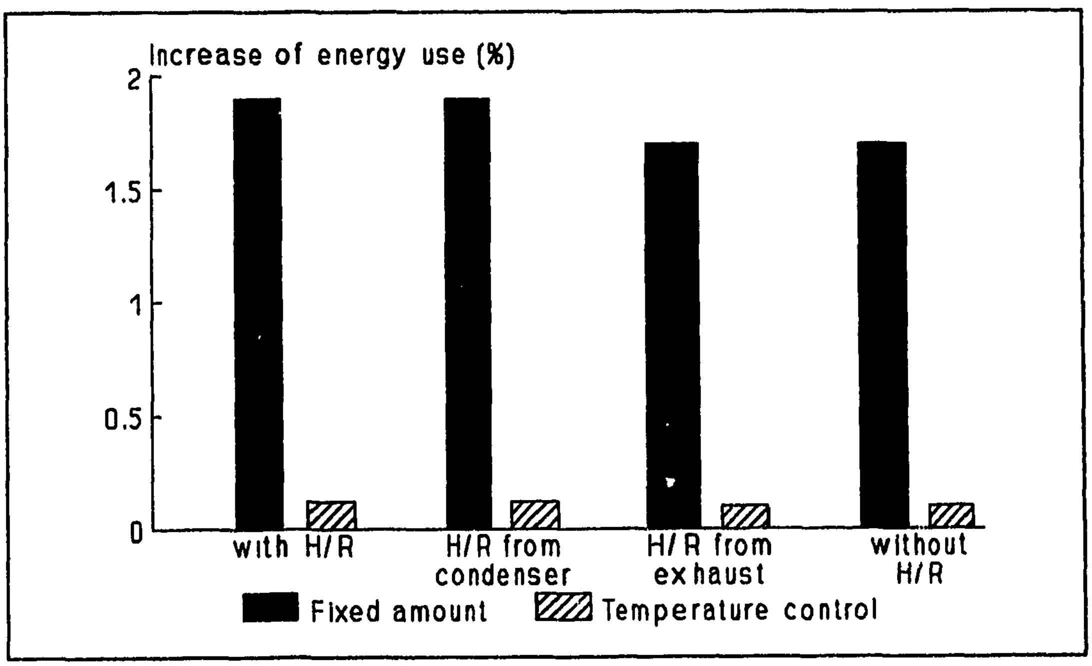

Figure 4.25 Increase of energy use due to the increase of ventilation rate from 7.6 to 10.0 L/s/person

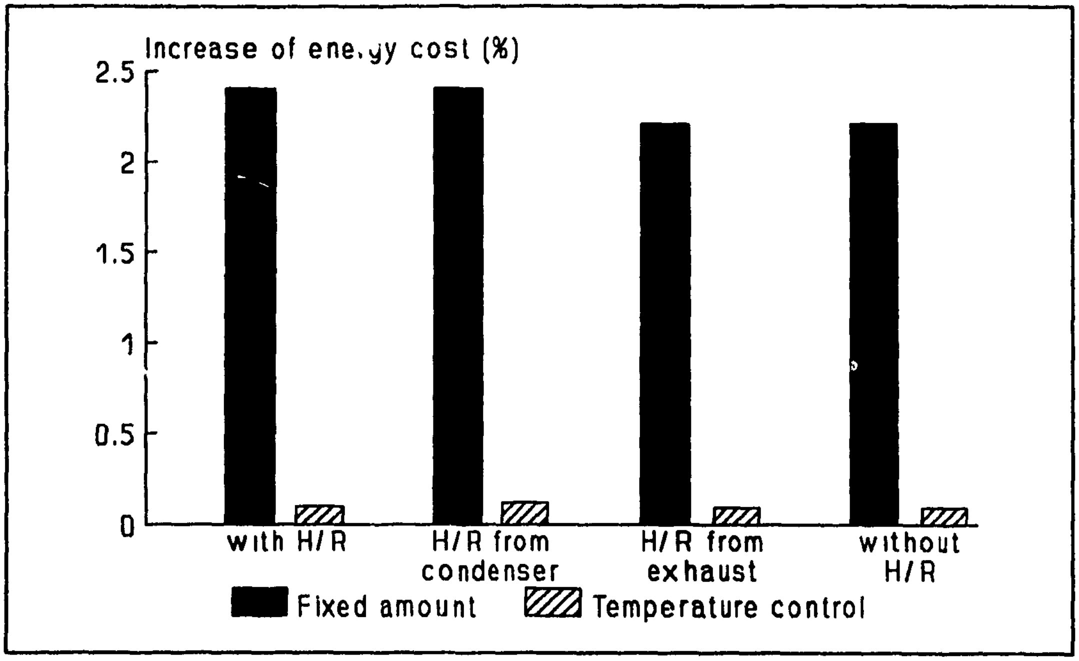

Figure 4.26 Increase of energy cost due to the increase of ventilation rate from 7.6 to 10.0 L/s/person

ventilation rate that a system controlled by the mixing temperature. The use of heat recovered from the exhaust air to preheat the outside air, and therefore to reduce the electricity used by the preheating coil, has a noticeable impact on the increase of energy use and cost, when the ventilation rate is higher than 20 L/s/person. For instance, in a system with a fixed amount of outdoor air, the largest increase of energy use (Fig. 4.27) and cost (Fig. 4.28) is obtained by using configurations without heat recovery from the exhaust air, as well as by a system with heat recovery from the exhaust air and the condensers. In the case of a system controlled by the mixing temperature, there is an important increase of the energy consumption (Fig. 4.29) and cost (Fig. 4.30) at ventilation rates greater than 20 L/s/person, when the heat recovery from the exhaust air

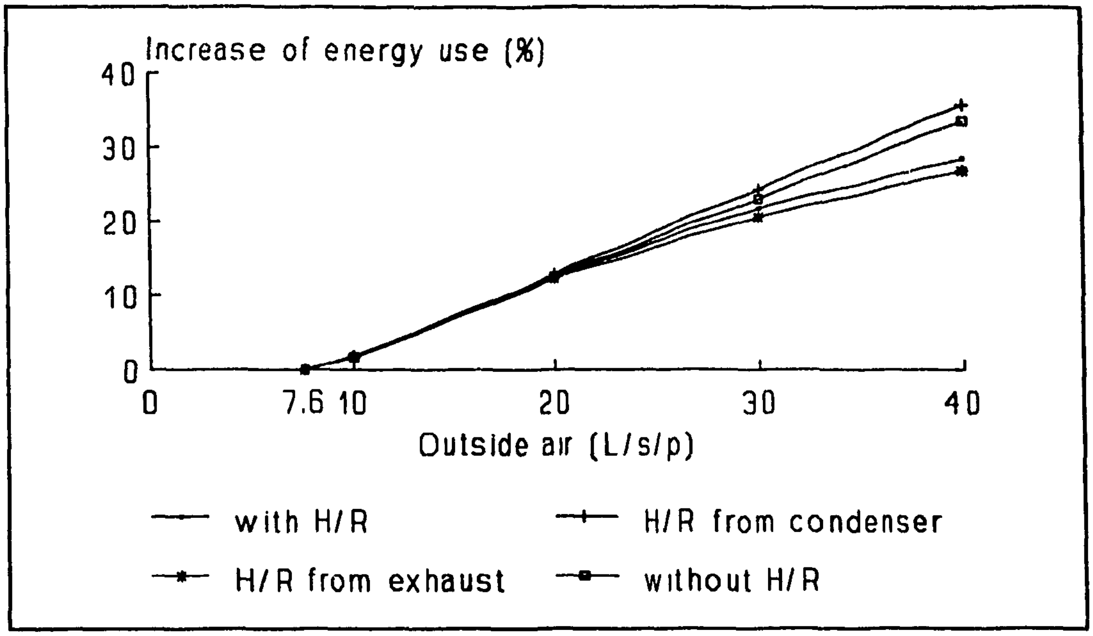

Figure 4.27 **Increase of energy use in the case of a VAV system with fixed amount of outdoor air**

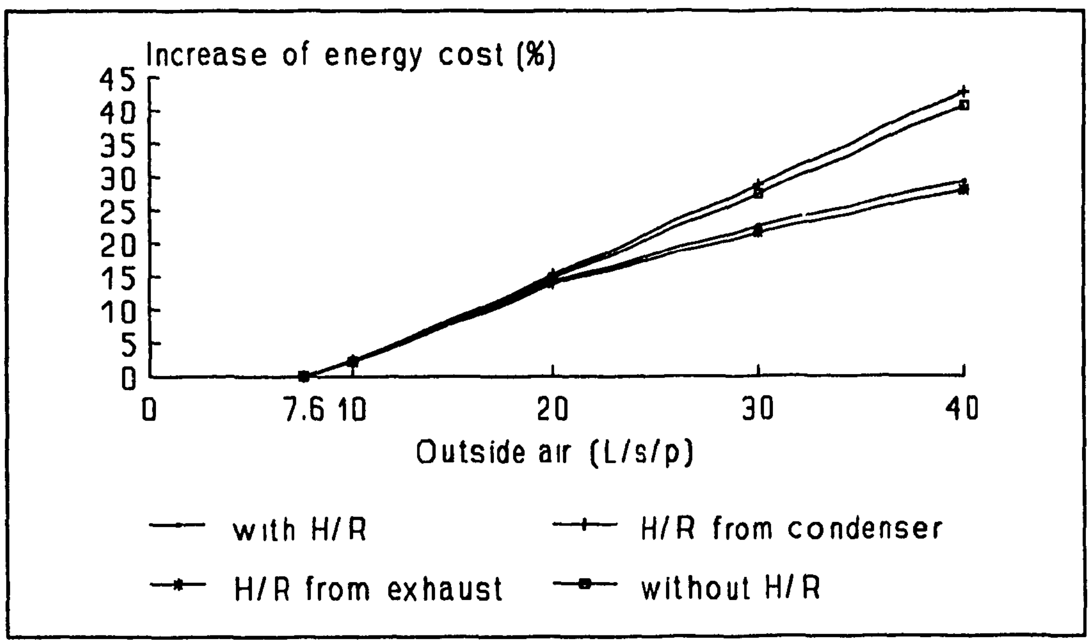

Figure 4.28 **Increase of energy cost in the case of a VAV system with fixed amount of outdoor air**

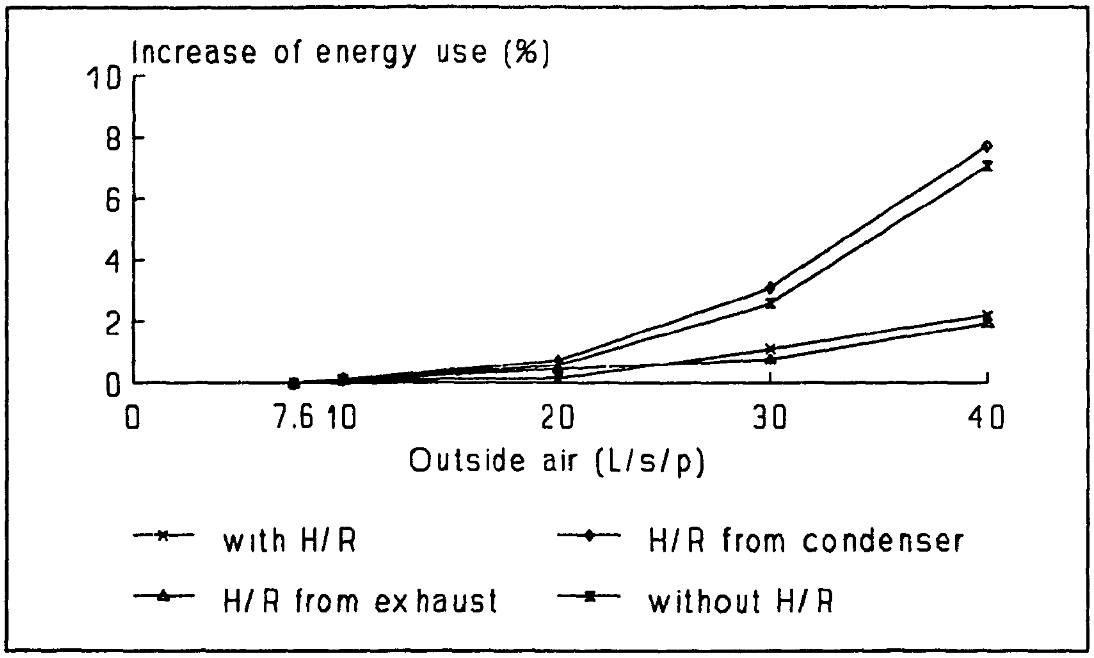

Figure 4.29 Increase of energy use in the case of a VAV system where the outdoor air controlled by mixing temperature

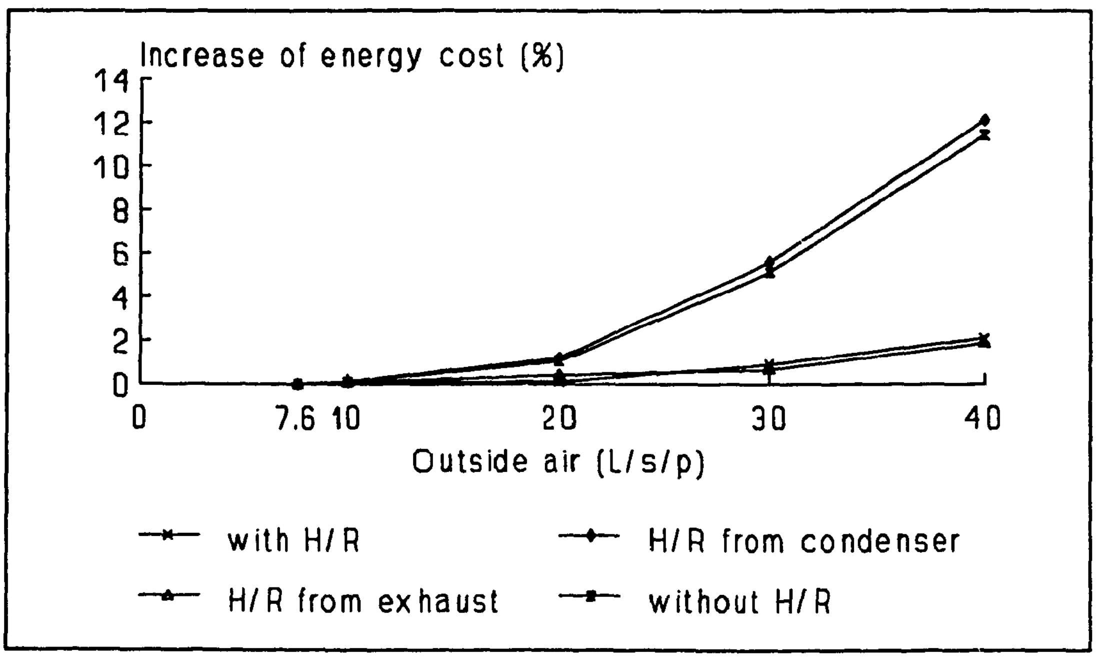

Figure 4.30 Increase of energy cost in the case of a VAV system where the outdoor air controlled by mixing temperature

is not used. On average, the energy consumption increases at a rate of about 2.3% and cost by 2.7% for each increment of 2.5 L/s/person of the ventilation rate from 7.6 L/s/person to 40.0 L/s/person, when the system uses a fixed amount of outdoor air. When the outdoor air rate is controlled by the mixing temperature and the ventilation rate is smaller than 20 L/s/person, the increase of energy consumption and cost is negligible.

Figure 4.31 and Figure 4.32 show the increase of total electricity consumption versus the ventilation rate by using different outside air control methods. One can see that the curve of energy use by using the configuration with condenser heat recovery system and the curve without heat recovery system overlap each other, and the curve with exhaust heat recovery system only and the curve with both heat recovery systems also overlap. It means that the condenser heat recovery system can not reduce the total electricity use in this building. However, one can notice that the condenser heat recovery system has greater impact on total energy consumption than the exhaust air heat recovery system (Fig. 4.33-4.34). When outside air rate is lower than 20 L/s/person, condenser heat recovery system can reduce about 9% of total energy use by using fixed amount outside air control method, and about 7% of total energy use on average, but no energy savings can be obtained by using exhaust air heat recovery system. When outside air rate is higher than 20 L/s/person, the exhaust air heat recovery system starts to affect the energy use of the building. With the increase of outside air rate, the impacts of both heat recovery systems become close.

In the case of a system with a fixed amount of outdoor air, the increase of

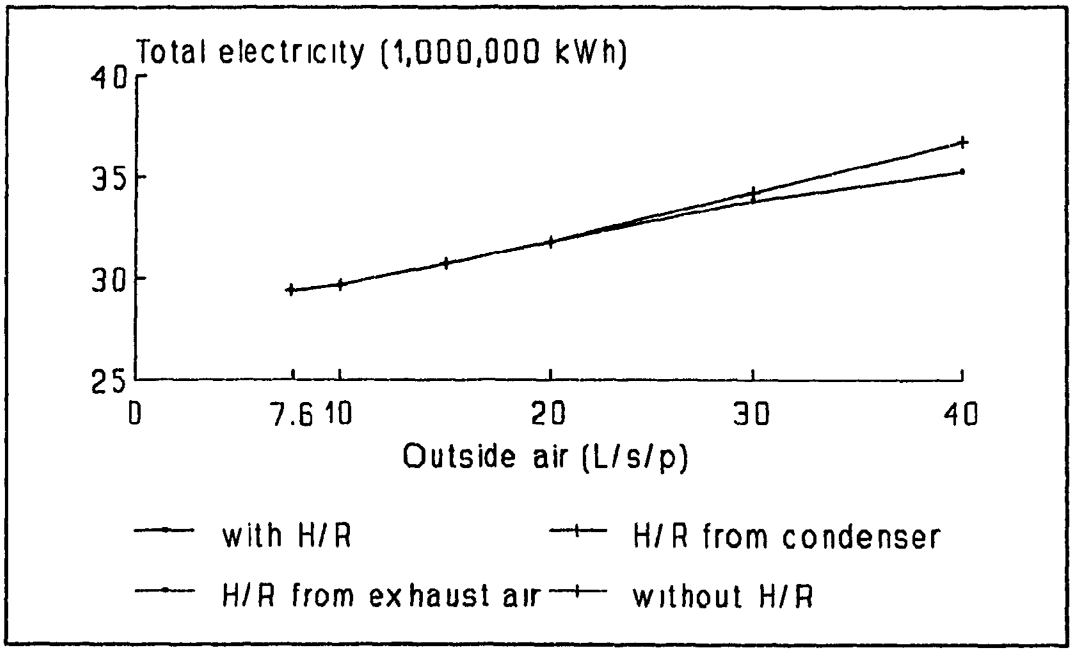

Figure 4.31 Electricity use vs. outside air rate using fixed amount OA-control method

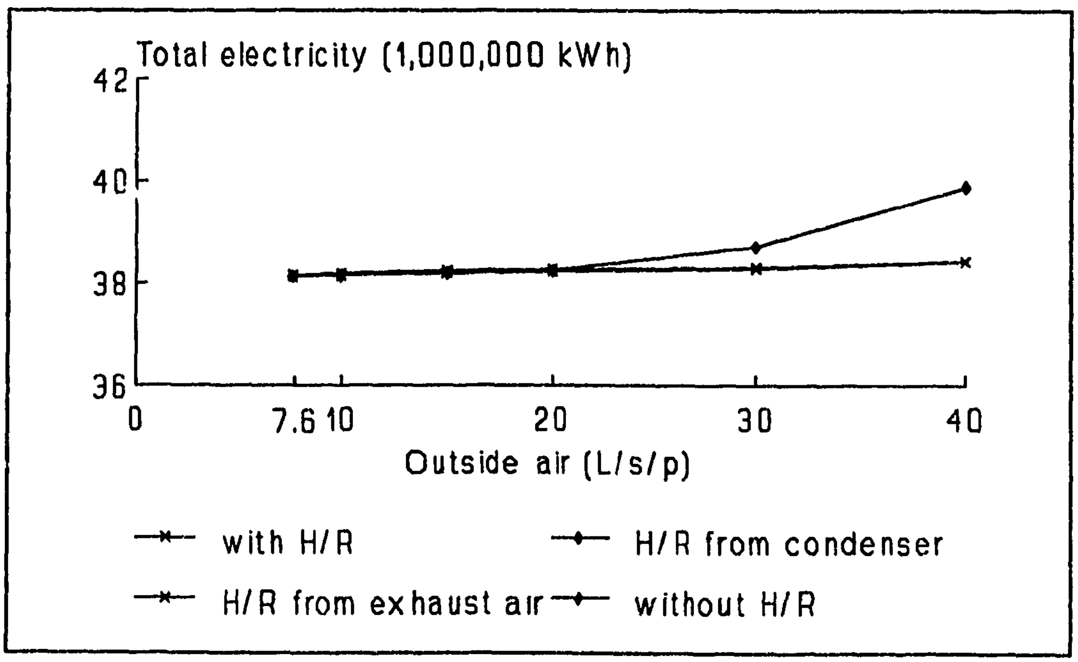

Figure 4.32 Electricity use vs. outside air rate using mixing temperature OA-control method

ventilation rate from 7.6 L/s/person to 10.0 L/s/person is expected to lead to an increase of energy consumption up to 1.9% and energy cost up to 2.4%. Since previous evaluations have considered the increase of ventilation rate from 2.5 L/s/person to 10.0 L/s/person, the results of this study are extrapolated for that condition, and the results show an increase of energy use up to 5.9% and energy cost up to 7.5%. This increase of the energy cost is higher than those obtained for Montreal by some other studies [32,33]. If the existing building operates with a fixed amount of outdoor air (7.6 L/s/person) and without heat recovery systems, then the increase of energy consumption is expected to be about 1.7% for an increase of the ventilation rate to 10 L/s/person. However, if in addition a heat recovery system from the condensers is installed, then the energy consumption will be reduced by 7.2%.

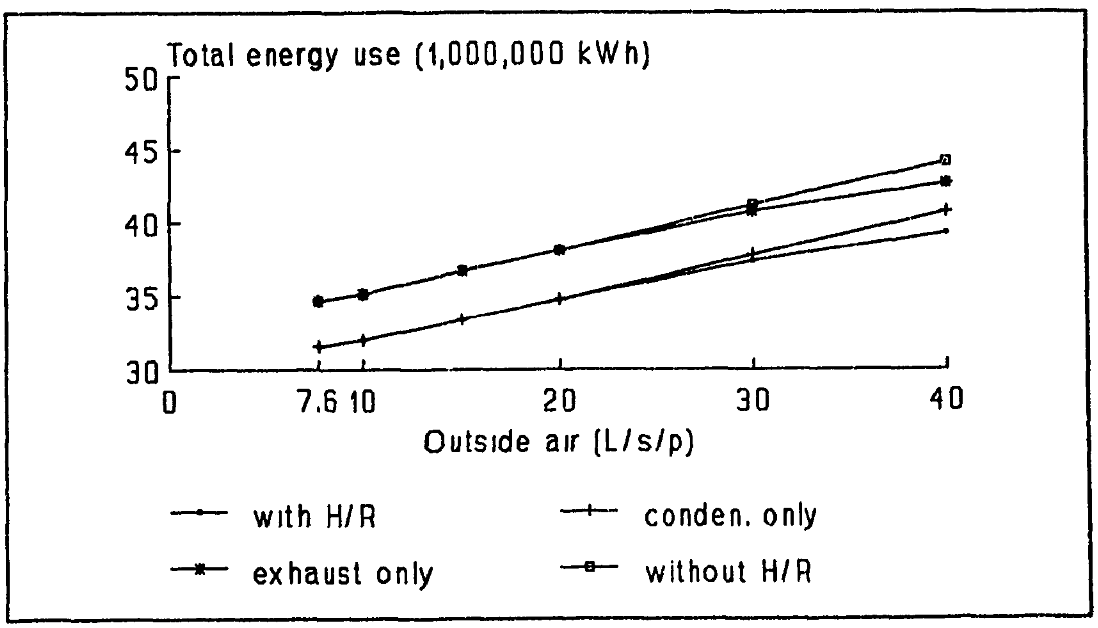

Figure 4.33 Total energy use vs. outside air rate using fixed amount OA-control method

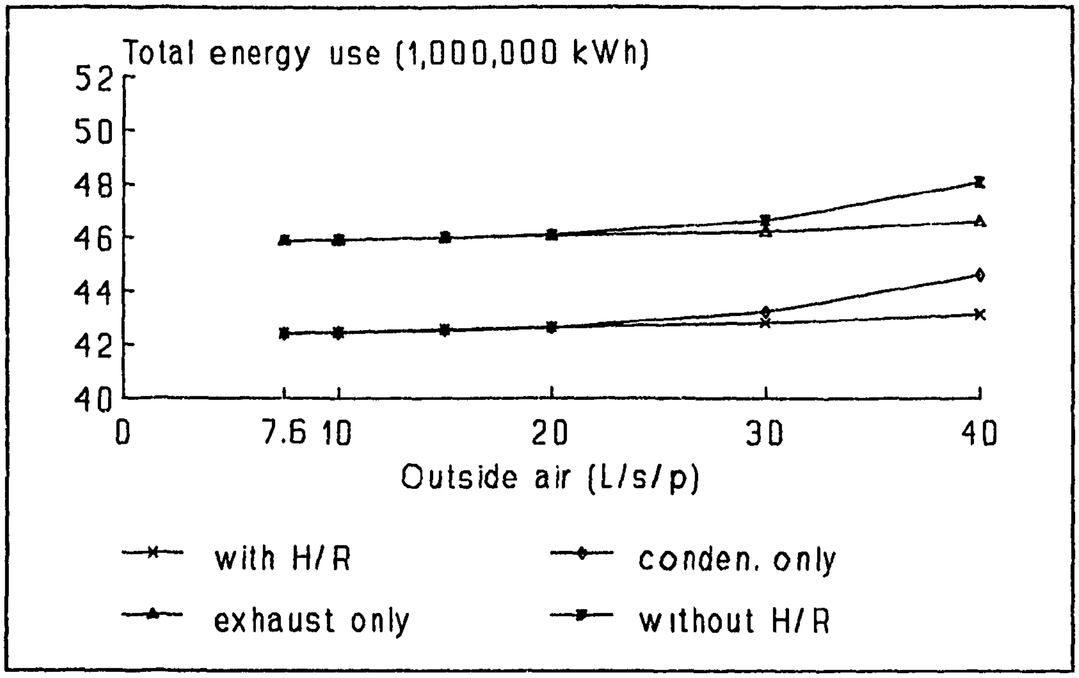

Figure 4.34 Total energy use vs. outside air rate using mixing temperature OA-control method

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Conclusions

5.1.a Simplified energy audit

Energy audit is one of the first essential steps in an energy management program. It does not in itself produce energy savings, but can indicate what is the potential for energy savings. Therefore, only cost-effective actions should be taken by comparing the costs of energy audits with the potential savings. A simple energy audit procedure is always recommended before any detailed energy audit is conducted. Only when a relatively large potential of energy saving is estimated and the solution for improving energy efficiency can not be found through a simple energy audit procedure, then a detailed energy audit has to be considered.

Utility bills contain helpful information for defining the energy performance of a building, provided that an appropriate procedure is used to analyze the available data. The building manager can compare the energy performance of the building with some target values or with the performance of similar buildings. Furthermore, one can discover the reasons of inefficient use of energy, and evaluate the need for further and more detailed analysis.

In the cases when the weather conditions affect the energy use significantly, it is meaningless to compare the energy performance of a building for two different years under the different weather conditions, unless the variation is taken into account. Some conventional methods just divide the total energy consumption by the total degree days to calculate an index of energy performance. Although this is a simple and fast way, it makes an incorrect assumption that energy use is entirely dependent on weather conditions. This new computer program uses a more detailed method for the weather normalization of energy consumption.

Disaggregation of energy consumption among the major end-uses is helpful for evaluating energy performance of a building. For instance, by comparing each end-use with the average value of similar buildings, one may discover the opportunities for potential energy savings. In addition, the pattern of distribution of total energy use can be used to indicate the dominant energy use in a building and let building manager to focus his attention on the major parts of energy use to look for larger savings.

5.1.b Detailed energy audit

Computer simulation was used for the detailed energy audit of a large existing office building. The detailed energy analysis programs such as DOE-2 are not largely used by the energy consultants, despite their large capabilities.

In most case, the evaluation of energy performance of an existing building and prediction of energy savings are performed using the annual and monthly values of energy consumption. An improvement in the quality of evaluation can be obtained by using some daily and hourly values, as presented in this thesis. Although it is easier to obtain the daily average energy consumption from the total monthly values, than the daily and hourly values, the former data lead to less accurate estimates of the energy signature and energy performance.

Results of the computer simulation indicated that in some cases, the increase of air ventilation rate, as recommended by the ASHRAE Standard 62-1989, has a much greater impact on the energy consumption of large office buildings than previously reported by other researchers. Some control strategies and utilization of heat-recovery systems can be used to reduce this impact. In addition, the computer simulation indicated that the energy performance of large modern office buildings is less sensitive to modifications of the building envelope, than to the improvement of HVAC systems and the reduction of internal heat gains.

5.2 Contributions

Main contributions and findings of this research work are summarized below.

5.2.a Simplified energy audit

- development of a new energy audit computer program, which performs a fast evaluation using information from utility bills and building managers;
- this program integrates the aspects such as a new weather normalization procedure and disaggregation of energy use among the major end-uses using data from the design conditions, which normally are not used by other programs;
- this program is better suited for a simplified energy audit for large office buildings than other existing simple energy audit programs;

- this program is much easier to be used than the detailed program DOE-2, in the preliminary energy audit of a complex commercial building;
- most large modern office buildings are internal-loads dominant; larger potentials for energy saving are expected to be obtained through a better management of internal energy uses;
- validation of this new program by comparison with the results from the PRISM and DOE-2 programs;

5.2.b Detailed energy audit

- energy use of large modern office buildings is less sensitive to weather conditions than to the improvement of HVAC systems and the reduction of internal heat gains;
- impact of the increase of air ventilation rate on the energy consumption of large office buildings varies significantly with the utilization of different control strategies and heat-recovery systems.

5.3 Recommendations for Further Research and Development Related to the New Software

(i) the improvement on the user-friendliness features of the program; presently, the program displays the results only in a tabular form; therefore, additional developments are recommended to:

- integrate graphical presentation of results,
- provide messages to explain the errors in the utility bills, and

- integrate comments on suggestions for more detailed analysis or explanations of the potential for energy savings;
- develop a method using short-term measurements instead of costly and time-consuming long-term measurements to obtain hourly and daily energy consumption data;

(ii) the integration within an existing Energy Monitoring and Control System;

(iii) the integration within an existing accounting package.

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APPENDIX A

USER'S GUIDE OF NEW PROGRAM

NEW
USER's GUIDE

A. Input Files

The energy audit program NEW is developed for building managers or consultants to evaluate the energy performance based mainly on the utility bills.

This program can be run on any IBM-compatible micro-computers with 200 kB available memory. It requires 240 kB on hard disk for installation, which is designated as follows:

```
program --------- 170 kB
input files -----  40 kB
output files ----  30 kB
```

The program is written by FORTRAN and compiled by Microsoft FORTRAN Optimizing Compiler version 5.10.

B. Description of Input Files & Output Files

B.1 Input files

B.1.1 Utility file

- **UTILITY.DAT**

This is the only file that must be prepared by users, which includes the following information:

- general information. i.g. floor area, location of the building, year of evaluation, year of construction, occupancy hours;

- input data from utility bills;
- measured or designed data for disaggregation.

B.1.2 Default files

- **RATE.DAT**
  - electricity utility rate for recent years.
- **TEMPS**
  - weather data file which contains 19 year's (1974-1992) average daily temperature.
- **CALENDAR.DAT**
  - real calendars for recent years to indicate each day in an evaluated year as a weekday, Saturday or holiday, in which different schedules may be applied.

B.2 Output files

- **SDM.DAT**
  - verify electricity utility bills;
  - change subscribed electricity demand to find potential savings.
- **ING.DAT**
  - input data for gas based on utility bills.
- **INO.DAT**
  - input data for oil based on utility bills.
- **INS.DAT**

- input data for steam based on utility bills.

- **DISIN.DAT**
  - input data for disaggregation.
- **ONE.DAT**
  - indices of electricity energy performance.
- **ONG.DAT**
  - indices of gas energy performance.
- **ONO.DAT**
  - indices of oil energy performance.
- **ONS.DAT**
  - indices of steam energy performance.
- **BKM.DAT**
  - monthly electricity energy distribution.
- **BKY.DAT**
  - annual electricity energy distribution.
- **AEP.DAT**
  - annual energy performance.
- **NOR.DAT**
  - weather normalized energy consumption;
  - building energy signature.
- **COMPARE.DAT**
  - comparison among some target values.

B.3 Preparation of input file

B.3.1 Input data for indices of energy performance

(i) Description of building

-	floor area of zone-1, in m^2	(1 to 999,999.9),
-	floor area of zone-2, in m^2	(0 to 999,999.9),
-	operating hours, in hours/day	(0 to 24.0),
-	occupancy hours, in hours/day	(0 to 24.0).

(ii) Electricity

-	monthly demand, in kW	(0 to 99,999.9),
-	monthly consumption, in kWh	(0 to 9,999,999.9),
-	monthly cost, in $	(0 to 999,999.99),
-	credits or penalties, in $/kW	(-9.9999 to 9.9999).

(iii) Gas/oil/steam

-	monthly consumption; in m^3 (l/lb)	(0 to 999,999,999.9),
-	monthly cost; in $	(0 to 999,999,999.99).

B.3.2 Input data for disaggregation

(i) Electricity/office equipment

a. Measured data:

- daily energy consumption on working days, in kWh/day (0 to 99,999.9),
- daily energy consumption on Saturdays, in kWh/day (0 to 99,999.9),
- daily energy consumption on holidays, in kWh/day (0 to 99,999.9).

b. Design data:

- load density on working days; in W/m^2 (0 to 99.9),
- operating hours on working days; in hrs/day (0 to 24.0),
- load density on Saturdays; in W/m^2 (0 to 99.9),
- operating hours on Saturdays; in hrs/day (0 to 24.0),
- load density on holidays; in W/m^2 (0 to 99.9),
- operating hours on holidays; hrs/day (0 to 24.0).

(ii) Chillers/cooling towers

a. Measured data:

- starting day of summer operating schedule; in M/D/Y (integers),
- daily energy consumption on week days in summer; in kWh/day (0 to 99,999.9),
- daily energy consumption on Saturdays in summer;

	in kWh/day,	(0 to 99,999.9)
-	daily energy consumption on holidays in summer;	
	in kWh/day	(0 to 99,999.9),
-	starting day of winter operating schedule; in M/D/Y	(integers),
-	daily energy consumption on working days in winter;	
	in kWh/day	(0 to 99,999.9),
-	daily energy consumption on Saturdays	
	in winter; in kWh/day	(0 to 99,999.9),
-	daily energy consumption on holidays in winter;	
	in kWh/day	(0 to 99,999.9).

b. Design data:

-	starting day of summer operating schedule; in M/D/Y	(integers),
-	starting day of winter operating schedule; in M/D/Y	(integers),
-	size of chillers; in kW	(0 to 99,999.9),
-	COP of the chillers;	(0 to 99.9),
-	operating hours on working days; in hrs/day	(0 to 24.0),
-	operating hours on Saturdays; in hrs/day	(0 to 24.0),
-	operating hours on holidays; hrs/day	(0 to 24.0).

(iii) Preheating

-	return temperature; in °C	(0 to 99.9),

- mixing temperature; in °C (0 to 99.9),
- total supply air flow; in m^3/s (0 to 999,999.9),
- outdoor air rate; in fraction (0 to 1.000),
- operating hours on working days; in hrs/day (0 to 24.0),
- operating hours on Saturdays; in hrs/day (0 to 24.0),
- operating hours on holidays; in hrs/day (0 to 24.0).

B.4 Example of input file

(i) Creation of input file (UTILITY.DAT)

There are two main parts in the input file: (a) general information and utility data; (b) measured or designed energy consumption for disaggregation. In part 1, general information of the building and electricity utility data are necessary. The utility data for gas, oil and steam are optional according to different cases. In part 2, measured or designed energy consumption data can be selected by users for major end-uses, such as lighting, office equipment, chillers, cooling towers and preheating. The default value for each end-use is "0". Taking into account the following notice may be helpful to create an input file.

- refer to the example shown as follows to write the file carefully;
- avoid typing errors which may result in run time error when the program is started;
- leave at least one blank between two figures.

(ii) Example of input data for indices of electricity energy performance

```
                                year of evaluation
                                year of construction
1988 1983
Montreal ---------------------- location of building
                                first billing day
                                numbers of billing period
                                occupancy hours on weekdays
                                occupancy hours on Saturdays
                                occupancy hours on holidays
                                net floor area for zone1
                                net floor area for zone2
                                gross floor area
ELE
11 20 1987  12  12  6  0  43154  1946  50544
*  M/D/Y     kW    S-kW     kWh        $          $-kW      $-kWh *
12 23 1987  2578  2496   1238400   54670.28    9664.61   40491.81
01 22 1988  2565  2525   1027200   47093.62    8741.52   34463.64
02 23 1988  2601  2572   1228800   53915.41    9455.15   40008.53
03 23 1988  2571  2534   1089600   48023.72    8469.90   35588.56
04 25 1988  2450  2400   1104000   50151.92    9184.56   36826.38
05 27 1988  2565  2505   1156800   53311.89    9617.23   39292.77
06 27 1988  2823  2698   1156800   55026.87   10311.65   40171.72
07 27 1988  2819  2688   1190400   55090.13    9964.88   40576.52
08 23 1988  2829  2688   1219200   53553.55    9000.21   40131.49
09 27 1988  2700  2554   1430400   64247.66   11134.93   47807.88
10 25 1988  2504  2419   1065600   47843.94    8261.29   35632.23
11 24 1988  2594  2499   1104000   50993.55    9169.53   37613.54
*credits*
0.702  0.7251
```

(iii) Example of input data for indices of gas energy performance

first billing day

numbers of billing period

heating value

```
GAS
12 23 1987  13    30.1
* M/D/Y          m3        $ *
01 27 1988     47902   12321.64
02 22 1988     50094   12871.67
02 25 1988      4470    1151.82
03 23 1988     33719    8762.71
04 27 1988     10081    2703.67
05 26 1988      4689    1283.10
06 28 1988       421     133.61
07 27 1988       420     133.33
08 25 1988       420     133.33
09 26 1988         0       0.00
10 26 1988      7707    2078.54
11 23 1988     21184    5471.39
12 23 1988     34534    8896.50
```

(iv) Example of input data for disaggregation (measured data)

```
* Disaggregation *

LM  ------------------------------  lighting load
                                     (measured data)
  |---------------------------------  daily consumption on
  |                                  weekdays
  |          |----------------------  daily consumption on
  |          |                       Saturdays
  |          |          |-----------  daily consumption on
  |          |          |            holidays
28192.8   14764.8   14764.8

EM  ------------------------------  office equipment load
16512.1   10940.5   10940.5

CM  ------------------------------  loads for chillers
                                     (measured data)
  |---------------------------------  the day that summer
  |                                  operating schedule started
  |      |--------------------------  the day that winter
  |      |                           operating schedule started
05 01 10 10

*ZONE1*  |--------------------------  energy consumption on
         |                           weekdays, Saturdays
_________|_______                    and holidays in summer
11443.2  0.0   0.0
14236.8  0.0   0.0  ----------------  daily consumption in winter
*ZONE2*
0.0      0.0   0.0
0.0      0.0   0.0

TW  ------------------------------  load for cooling towers

*ZONE1*                              (measured data)
1014.2   0.0   0.0  ----------------  daily consumption in summer
255.8    0.0   0.0  ----------------  daily consumption in winter
*ZONE2*
0.0      0.0   0.0
0.0      0.0   0.0

RH  ------------------------------  parameters for preheating
  |---------------------------------  return air temperature
  |
  |    |----------------------------  mixing air temperature
  |    |
  |    |      |---------------------  total supply air flow
  |    |      |            |--------  operating hours on weekdays,
  |    |      |      ______|________  Saturdays and holidays
22.5  21.1  558.2   0.056  17  0  0
```

(v) Example of input data for disaggregation (design condition)

```
* Disaggregation *
LD ————————————————————————— lighting load
*ZONE1*                       (design condition)
  ——————————————————————————— load density on working days
  ——————————————————————————— operating hours on
                              working days
  ——————————————————————————— schedule multiplier
  ——————————————————————————— operating hours on Saturdays
  ——————————————————————————— schedule multiplier
  ——————————————————————————— operating hours on holidays
  ——————————————————————————— schedule multiplier

19.4  17.0   1.0   7   0.5  24  0.0
*ZONE2*
19.4  24.0   1.0   24  1.0  24  1.0

ED ————————————————————————— office equipment load
*ZONE1*                       (design condition)
9.15 24   0.475  24   0.17  24  0.1
*ZONE2*
10.76  24  1.0  24  1.0  24  1.0

CD ————————————————————————— loads for condensers & cooling
                              towers (design condition)
  ——————————————————————————— the day that summer
                              operating schedule started
  ——————————————————————————— the day that winter
                              operating schedule started
03 15 10 30
*ZONE1*
W-CL ——————————————————————— type of cooling towers:
                              A-CL —— air-cooled
                              W-CL —— water-cooled

  ——————————————————————————— refrigeration power for
                              chillers in summer
  ——————————————————————————— coefficient of performance
  ——————————————————————————— operating hours on weekdays,
                              Saturdays and holidays
1950    3   15  5   0
1500    5   15  5   0 ———————— refrigeration power,
*ZONE2*                       coefficient of performance
A-CL                          and operating hours of
500     3   24  24  24        chillers in winter
500     5   24  24  24
```

B.5 Calculations of the input data

(i) Daily energy consumption for lighting (E_L)

$$E_L = LPD \cdot A_F \cdot NOP \cdot M_l \text{ (kWh)}$$

where:

LPD is load density; zone-1: $LPD = 19.4$ W/m²,

zone-2: $LPD = 19.4$ W/m;²

A_F is floor area; zone-1: $A_F = 43{,}154$ m²,

zone-2: $A_F = 1{,}946$ m²;

NOP is number of operating hours per day; in hours/day,

M_l is operating schedule multiplier;

Zone-1:	NOP	M_l
Monday-Friday	17 hrs	1.0
Saturdays	7 hrs	0.5
Holidays	24 hrs	0
Zone-2:		
Monday-Sunday	24 hrs	1.0.

(ii) Daily energy consumption for office equipment (E_E)

$$E_E = LPD \cdot A_F \cdot NOP \cdot M_l \text{ (kWh)}$$

where:

LPD is load density; zone-1: $LPD = 9.15$ W/m², zone-2: $LPD = 10.76$ W/m^2;

A_F is floor area; zone-1: $A_F = 43{,}154$ m^2,

zone-2: $A_F = 1{,}946$ m^2;

NOP is number of operating hours per day; in hours/day,

M_l is operating schedule multiplier;

	NOP	M_l
Zone-1:		
Monday-Friday	10 hrs	1.0
	14 hrs	0.1
Saturdays	4 hrs	0.5
	20 hrs	0.1
Holidays	24 hrs	0.1
Zone-2:		
Monday-Sunday	24 hrs	1.0.

In case two or more operating schedule multipliers occur within a same day, an average operating schedule multiplier can be calculated as follows:

Average operating schedule multiplier on week days for zone-1:

$(10 \times 1.0 + 14 \times 0.1)/24 = 0.475$,

Average operating schedule multiplier on Saturdays for zone-1:

$(4 \times 0.5 + 20 \times 0.1)/24 = 0.17$.

(iii) Daily energy consumption for chillers (E_C)

$$E_C = (P_R / COP) \cdot NOP \cdot F_I \text{ (kWh)}$$

where:

P_R is refrigeration capacity of operating chillers; in kW,

		P_R
zone-1:	summer	1,950 kW
	winter	1,500 kW
zone-2:	summer	500 kW
	winter	500 kW;

COP is Coefficient of Performance of chillers:

		COP
zone-1:	summer	3
	winter	5
zone-2:	summer	3
	winter	5;

NOP is operating hours per day; in hours/day,

zone-1:			*NOP*
	summer	Monday-Friday	15 hrs
		Saturdays	5 hrs
		holidays	0 hrs
	winter	Monday-Friday	15 hrs
		Saturdays	5 hrs

holidays 0 hrs

zone-2:

summer	Monday-Friday	24 hrs
	Saturdays	24 hrs
	holidays	24 hrs
winter	Monday-Friday	24 hrs
	Saturdays	24 hrs
	holidays	24 hrs;

F_1 is over size correction factor; $F_1 = 0.85$.

(iv) Daily consumption for cooling towers (E_T)

$$ET = P_C \cdot NOP \cdot F_1 \cdot F_2 \text{ (kWh)}$$

where

P_C is cooling capacity; in kW,

P_C = (refrigeration capacity of chillers + input power of chillers)

$= P_R + P_R / COP$

F_2 is ratio of input power and cooling capacity;

air-cooled cooling tower: $F_2 = 0.03$,

water-cooled cooling tower: $F_2 = 0.03$.

C. Run The Program

After create the input file, please check out all the default files and output files to insure that no any files are missing. Then the program is ready to run. To start the program, follow the instruction below.

> NEW <Enter>

"Welcome" will be displayed in the screen. Press the **<Enter>** again. The main menu will be shown on the screen (Fig.1).

Figure 1 Main Screen Menu

```
          1. Review and verification of utility bills
          2. Results of analysis
          3. Comments
          4. Exit

Select your choice and press ENTER to continue
```

There are three items in the main menu, which can be selected by users. The item 1 is mainly concerning the input data from utility bills and general description of a building; while the item 2 is concerning the output data of energy analysis. Item 3 is concerning some comments on the results of energy analysis, which is not available for the time being.

(i) Review and verification of utility bills

Verification of utility bills is according to the electric rates of Hydro-Quebec, which are built in the program. It calculates the cost of electricity consumption and demand, taking into account factors such as subscribed demand, penalties for exceeding the subscribed demand, or credits. The comparison between utility bills and calculated costs is presented in a tabular form. The screen menu of this section is shown in Fig.2.

Figure 2 Screen menu for reviewing & verifying utility bills

```
                 1. General input data
                 2. Verification of electricity bill
                 3. Verification of gas bill
                 4. Verification of oil bill
                 5. Verification of steam bill
                 6. Print
                 7. Return to the main menu
Select your choice and press ENTER to continue
```

(ii) Results of analysis

Several options are available in this section, which are shown in the following screen menu (Fig.3).

Figure 3 screen menu for results of analysis

```
                 1. Energy Performance for Electricity
                 2. Energy Performance for Gas
                 3. Energy Performance for Oil
                 4. Energy Performance for Steam
                 5. Weather Normalization
                 6. Annual Energy Performance
                 7. Disaggregation
                 8. Print
                 9. Return to the main menu

Select your choice and press ENTER to continue
```

D. Examples of Output Files

This chapter presents the output file produced by the NEW program, which is corresponding to the input file presented in chapter B of this guide.

Figure 4 General input data for description of a building (GENERAL.DAT)

```
                    ********************
                    *   GENERAL DATA   *
                    ********************
Floor area:                                45100.0 m2

Location:                                  Montreal

Year of evaluation:                        1988

Year of construction:                      1983

Operating hours on weekdays:               15 hrs

Operating hours on Saturdays:              6  hrs

Operating hours on holidays:               0  hrs

Occupancy hours on weekdays:               12 hrs

Occupancy hours on Saturdays:               6 hrs

Occupancy hours on holidays:                0 hrs

Target energy consumption:                250.0 kWh/m2/yr
```

Table 1-1 Verification of utility bills (SDM.DAT)

Period (M/D/Y)	No. days	Demand (kW)	Subscribed demand (kW)	Cons. (kWh)	*Demand Cost ($)	*Cons. Cost ($)	Total Cost ($)
11/20/87							
12/23/87	33	2578.0	2496.0	1238400.0	9664.41	40491.81	54670.28
1/22/88	30	2565.0	2525.0	1027200.0	8741.52	34463.64	47093.62
2/23/88	32	2601.0	2572.0	1228800.0	9455.15	40008.53	53915.41
3/23/88	29	2571.0	2534.0	1089600.0	8469.90	35588.56	48023.72
4/25/88	33	2450.0	2400.0	1104000.0	9184.56	36826.38	50151.92
5/27/88	32	2565.0	2505.0	1156800.0	9617.23	39292.77	53311.89
6/27/88	31	2823.0	2698.0	1156800.0	10311.65	40171.72	55026.87
7/27/88	30	2819.0	2688.0	1190400.0	9964.88	40576.52	55090.13
8/23/88	27	2829.0	2688.0	1219200.0	9000.21	40131.49	53553.55
9/27/88	35	2700.0	2554.0	1430400.0	11134.93	47807.88	64247.66
10/25/88	28	2504.0	2419.0	1065600.0	8261.29	35632.23	47843.94
11/24/88	30	2594.0	2496.0	1104000.0	9169.53	37613.54	50993.55
Total:	370	31599.0	30575.0	14011200.0	112975.30	468605.10	633922.60
Average:	30	2633.3	2547.9	1167600.0	9414.61	39050.42	52826.88

* Taxes are not included.

Table 1-2 Verification of utility bills

Period (M/D/Y)	No. days	Demand (kW)	Subscribed demand (kW)	Demand cost (from bills) ($)	Demand cost (calculated) ($)	Difference ($)
11/20/87						
12/23/87	33	2578.0	2496.0	10534.21	10534.20	.00
1/22/88	30	2565.0	2525.0	9528.26	9528.26	.00
2/23/88	32	2601.0	2572.0	10306.11	10306.12	-.01
3/23/88	29	2571.0	2534.0	9232.19	9232.19	.00
4/25/88	33	2450.0	2400.0	10011.17	10011.17	.00
5/27/88	32	2565.0	2505.0	10482.78	10482.79	-.01
6/27/88	31	2823.0	2698.0	11239.70	11239.71	-.01
7/27/88	30	2819.0	2688.0	10861.72	10861.72	.00
8/23/88	27	2829.0	2688.0	9810.23	9810.23	.00
9/27/88	35	2700.0	2554.0	12137.07	12137.08	-.01
10/25/88	28	2504.0	2419.0	9004.81	9004.81	-.01
11/24/88	30	2594.0	2496.0	9994.79	9994.79	.00
Total:	370	31599.0	30575.0	123143.00	123143.10	
Average:	30	2633.3	2547.9	10261.92	10261.92	

Table 1-3 Verification of utility bills

Period (M/D/Y)	No. days	Consumption (kWh)	Cons. cost (from bills) ($)	Cons. cost (calculated) ($)	Difference ($)
11/20/87					
12/23/87	33	1238400.0	44136.07	44136.08	-.01
1/22/88	30	1027200.0	37565.37	37565.37	.00
2/23/88	32	1228800.0	43609.30	43609.29	.01
3/23/88	29	1089600.0	38791.53	38791.53	.00
4/25/88	33	1104000.0	40140.75	40140.75	.00
5/27/88	32	1156800.0	42829.12	42829.12	.00
6/27/88	31	1156800.0	43787.18	43787.18	.00
7/27/88	30	1190400.0	44228.41	44228.41	.00
8/23/88	27	1219200.0	43743.32	43743.32	.00
9/27/88	35	1430400.0	52110.59	52110.59	.00
10/25/88	28	1065600.0	38839.13	38839.13	.00
11/24/88	30	1104000.0	40998.76	40998.77	-.01
Total:	370	14011200.0	510779.50	510779.60	
Average:	30	1167600.0	42564.96	42564.96	

Table 1-4 Verification of utility bills

Period (M/D/Y)	No. days	Total cost (from bills) ($)	Total cost (calculated) ($)	Difference ($)
11/20/87				
12/23/87	33	54670.28	54670.29	.00
1/22/88	30	47093.62	47093.63	-.01
2/23/88	32	53915.41	53915.41	.00
3/23/88	29	48023.72	48023.73	-.01
4/25/88	33	50151.92	50151.93	.00
5/27/88	32	53311.89	53311.91	-.02
6/27/88	31	55026.87	55026.88	-.01
7/27/88	30	55090.13	55090.13	.00
8/23/88	27	53553.55	53553.55	.00
9/27/88	35	64247.66	64247.67	-.01
10/25/88	28	47843.94	47843.95	.00
11/24/88	30	50993.55	50993.55	.00
Total:	370	633922.60	633922.60	
Average:	30	52826.88	52826.89	

Table 2 Energy performance of electricity (OUE.DAT)

```
*************************************
* Energy Performance (Electricity) *
*************************************
```

Annual energy consumption	(kWh/m2/yr):	277.21
Annual energy cost	($/m2/yr):	12.54
Annual cost of equivalent-kWh	($/kWh):	.0446
Yearly Load Factor:		.56

Period	No. days	Electric demand W/m2	Electricity use kWh/m2	kWh/m2/day	Cost $/m2	$/m2/day	$/kWh	ELF	OLF
11 20 1987									
12 23 1987	33	51.0	24.50	.74	1.08	.0328	.0441	.61	.39
1 22 1988	30	50.7	20.32	.68	.93	.0311	.0458	.56	.39
2 23 1988	32	51.5	24.31	.76	1.07	.0333	.0439	.62	.39
3 23 1988	29	50.9	21.56	.74	.95	.0328	.0441	.61	.39
4 25 1988	33	48.5	21.84	.66	.99	.0301	.0454	.57	.39
5 27 1988	32	50.7	22.89	.72	1.05	.0330	.0461	.59	.39
6 27 1988	31	55.9	22.89	.74	1.09	.0351	.0476	.55	.39
7 27 1988	30	55.8	23.55	.79	1.09	.0363	.0463	.59	.39
8 23 1988	27	56.0	24.12	.89	1.06	.0392	.0439	.67	.39
9 27 1988	35	53.4	28.30	.81	1.27	.0363	.0449	.63	.39
10 25 1988	28	49.5	21.08	.75	.95	.0338	.0449	.63	.39
11 24 1988	30	51.3	21.84	.73	1.01	.0336	.0462	.59	.39
Total:	370		277.21		12.54				
Average:		52.1	23.10	.75	1.05	.0340	.0453	.60	.39

Table 3 Energy performance of gas (OUG.DAT)

```
******************************
* Energy Performance ( Gas ) *
******************************
```

Annual energy consumption	(kWh/m2/yr):	50.96
Annual energy cost	($/m2/yr):	1.11
Annual cost of equivalent-kWh	($/kWh/yr):	.0217

Period	No. days	Energy use			Cost		
		eq.-kWh	kWh/m2	kWh/m2/day	$/m2	$/m2/day	$/kWh
12 23 1987							
1 27 1988	35	572162.8	11.32	.3234	.24	.0070	.0215
2 22 1988	26	598345.1	11.84	.4553	.25	.0098	.0215
2 25 1988	3	53391.7	1.06	.3521	.02	.0076	.0216
3 23 1988	27	402754.8	7.97	.2951	.17	.0064	.0218
4 27 1988	35	120412.0	2.38	.0681	.05	.0015	.0225
5 26 1988	29	56007.5	1.11	.0382	.03	.0009	.0229
6 28 1988	33	5028.6	.10	.0030	.00	.0001	.0266
7 27 1988	29	5016.7	.10	.0034	.00	.0001	.0266
8 25 1988	29	5016.7	.10	.0034	.00	.0001	.0266
9 26 1988	32	.0	.00	.0000	.00	.0000	.0000
10 26 1988	30	92055.8	1.82	.0607	.04	.0014	.0226
11 23 1988	28	253031.1	5.01	.1788	.11	.0039	.0216
12 23 1988	30	412489.5	8.16	.2720	.18	.0059	.0216
Total:	366	2575712.0	50.96		1.11		
Average:		198131.7	3.9	.1580	.09	.0003	.0213

Table 4 Normalized annual energy performance (AEP.DAT)

```
***********************************
*    Annual Energy Performance    *
*  Normalized For Number Of Days  *
***********************************
```

Type of fuel	Energy use		Cost		$/kWh
	kWh/m2	%	$/m2	%	
Electricity	274.3	84.3	12.37	91.8	.0446
Gas	50.9	15.7	1.10	8.2	.0217
Oil	.0	.0	.00	.0	.0000
Steam	.0	.0	.00	.0	.0000
Total:	325.2	100.0	13.48	100.0	.0663

Table 5 Annual energy comparison (COMPARE.DAT)

```
*****************************************
* Annual Energy Consumption Comparison *
*****************************************
```

Energy budget kWh/m2	Average energy consumption(kWh/m2/yr) in				
	Year of construc. (1983)	Montreal in 1988	the best EEB in Montreal(1988)	Best EEB	Target
325.2	365.7	455.2	185.8	180.0	250.0

Table 6 Weather normalized energy consumption (NOR.DAT)

```
*****************************************
* Normalized Annual Energy Consumption *
*    For Average Weather Conditions    *
*****************************************
```

FUEL TYPE	NAC kWh/ m2/yr	Base kWh/ m2/day	Tref C	a kWh/ m2/day	b kWh/ m2/day/C	R*R
Elec.	271.57	.723	-2.00	.729	.0030	.553
Gas	51.19	.000	17.82	.239	-.0134	.937
Oil	.00	.000	.00	.000	.0000	.000
Steam	.00	.000	.00	.000	.0000	.000
TOTAL	322.76	.723				

Energy Signature:

Elec. = 0.729 + 0.0030*Tout
Gas = 0.239 - 0.0134*Tout

Table 7 Annual electricity consumption distribution (BKY.DAT)

****
* Electricity Distribution *
****

	(kWh)	(%)
Lighting	4052429.	29.2
Equipment	1455140.	10.5
Chiller	2850050.	20.6
Preheat	0.	.0
CL-Tower/AC-COND	380384.	2.7
Others	5127101.	37.0
Total	13865100.	100.0

Table 8 Monthly electricity consumption distribution (BKM.DAT)

****
* Monthly Electricity Distribution *
****

Month	Lighting		Equipment		Chiller		Preheating		CL-Tower	
	kWh	%	kWh	%	kWh	%	kWh	%	kWh	%
JAN	324452.3	31.8	118684.2	11.6	144840.0	14.2	.0	.0	26053.0	2.6
FEB	307501.9	26.1	110779.9	9.4	134895.0	11.5	.0	.0	24264.0	2.1
MAR	367148.8	32.2	129345.4	11.3	240422.5	21.1	.0	.0	32996.0	2.9
APR	352010.6	36.2	124341.5	12.8	295375.0	30.4	.0	.0	35432.0	3.6
MAY	327382.4	28.7	119347.6	10.4	284962.5	24.9	.0	.0	34183.0	3.0
JUN	352010.6	31.4	124341.5	11.1	295375.0	26.3	.0	.0	35432.0	3.2
JUL	341614.6	27.6	122901.3	9.9	293250.0	23.7	.0	.0	35177.0	2.8
AUG	352916.6	24.7	125791.7	8.8	298775.0	20.9	.0	.0	35840.0	2.5
SEP	337778.4	28.6	120787.7	10.2	287087.5	24.3	.0	.0	34438.0	2.9
OCT	327382.4	27.9	119347.6	10.2	283602.5	24.1	.0	.0	34142.0	2.9
NOV	323546.2	29.5	117234.0	10.7	142800.0	13.0	.0	.0	25686.0	2.3
DEC	338684.4	28.8	122237.9	10.4	148665.0	12.6	.0	.0	26741.0	2.3