THE UNIVERSITY OF CALGARY

An Evaluation of the Potential for Improved Energy Efficiency at a Daylit High School

by

Anca Diana Galasiu

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF MECHANICAL ENGINEERING

CALGARY, ALBERTA

September 1996

THE UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "An Evaluation of the Potential for Improved Energy Efficiency at a Daylit High School" submitted by Anca Diana Galasiu in partial fulfillment of the requirements for the degree of Master of Science.

Supervisor, Dr. James A. Love
Department of Mechanical Engineering

J. A. C. Kentfield

Dr. John A. C. Kentfield
Department of Mechanical Engineering

Prof. Tang G. Lee
Faculty of Environmental Design

Sept. 6, 1996.

Date

ABSTRACT

In this study, the field performance of an existing daylit building was investigated. The DOE-2.1E building energy simulation program was used to model the energy performance characteristics of the building using site-measured meteorological data. Comparisons between calculated and field-monitored energy use were performed for a one-year period. Using the computer model as a base case, the effects of alternative daylighting strategies on the total energy consumption were investigated and parametric studies were conducted to determine the interdependance of three environmental control elements: electric lighting, glazing and ventilation. The results show that significant energy savings can be achieved by reducing the electric energy required for illumination. However, an energy efficient design cannot be accomplished by considering lighting issues only. In this study, ventilation was shown to be the major end use of electric energy (33 percent) while heating and cooling of spaces accounted for less than 10 percent each.

ACKNOWLEDGMENTS

I would like to express my sincere thanks to, and respect for, my supervisor Dr. James A. Love for his advice and guidance in this research work and in the preparation of this thesis. I would also like to acknowledge the patience and encouragement extended to me by my husband Ciprian and daughter Andreea throughout this research.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

In Canada, much of the energy used for the heating, cooling, ventilation and lighting of buildings is obtained from non-renewable resources. By constructing buildings that are more energy-efficient, we can help to conserve these valuable resources and reduce emissions correspondingly. Energy management has gained in importance since the 1970's, stimulated by the escalation of energy costs and concern for the protection of the environment. More than 90 percent of the electrical energy used in Alberta is produced through the combustion of coal [1]. The combustion of fossil fuels has adverse environmental impacts, such as the production of acid gases and the increase of atmospheric concentrations of carbon dioxide. With people becoming more conscious of this, more attention has been given to finding ways to prevent wasted lighting energy.

There are several reasons for exploiting daylight as a source of renewable energy, although it is a technology that has been largely neglected since the 1950's. During the last 15 years, interest in daylighting has increased as a result of a belief that electric lighting represents a major energy end use, accounting for about half of the energy used in buildings [2]. This would suggest that reducing the need for electric light will significantly lower the energy requirements of buildings. If appropriate attention is given to lighting controls, daylight could contribute to good building energy efficiency. In a correctly designed daylighting system, the electric light will be turned off or dimmed whenever sufficient daylight is present. The significance of daylighting as an energy conservation measure has also been recognized by major industry organizations such as The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) [3] and the Illuminating Engineering Society of North America (IESNA) [4]. A simulation study funded by Natural Resources Canada (then Energy Mines and Resources Canada) showed that use of daylight-linked fluorescent dimming systems should provide significant energy savings and be cost effective in Canada [5]. In other countries, monitoring of demonstration buildings designed to exploit daylight has revealed lighting electricity use reductions of about 50 percent compared with conventional designs [6-8].

Another important benefit of a daylit building is the reduction of cooling requirements. Much of the research done up to this point on daylighting recognized the fact that heating, cooling and lighting energy consumption in buildings are inter-related. In order to produce light, the lighting systems must also produce heat. Light, whether it is daylight or electrical light, adds heat to a building. This energy is usually extracted from buildings through cooling processes. Daylight also adds heat to a building but, because daylight adds less heat per lumen (SI unit of luminous flux) entering a space than most electric lighting systems, less heat is produced for the same amount of light. On one hand, this translates into energy savings from reduced electricity consumption for cooling. On the other hand, turning off the electric lights would mean some increase in the heating needs of a building. However, even this being the case, a decrease of the total energy cost of a building can still be expected because in a typical HVAC system, the cooling plant is often more expensive per unit of input energy than the heating plant. The results of a study done in the USA to determine the effect of lighting on the thermal behaviour of buildings showed that an increase in the lighting energy creates a larger increase in the cooling load than the corresponding decrease in heating load [9].

Another consideration that could justify considering daylight as a light source is the quality of daylight as an illuminant. Daylight is a full-spectrum light, which most closely matches the human visual response and is also considered the best source of light for good colour rendering. Several studies have been conducted that showed the fact that less daylight is needed to perform a task than would be to perform the same task under electric light [10] and that people prefer daylight over electric lighting sources [10-12]. Moreover, windows provide building occupants with a view of the outdoor environment, which has a significant influence on the occupants' well-being. People prefer work spaces with windows [13] and, while this is primarily due to a desire for an exterior view, these windows can also serve as light sources.

As noted above, to reduce energy use through daylighting, electric lighting must be reduced as permitted by daylight levels. Realizing energy savings from daylighting is critically dependent on the electric lighting control strategy. There are two basic types of lighting controls: manual and automatic. Because the performance characteristics of their operation in the field are still not well known, both approaches require further study. For instance, a study of a daylit library [8] showed that users generally did not switch on electric lights until interior illumination from daylight was well below the level at which automatic control systems would be programmed to switch them on. However, once switched on, the lights were seldom switched off until the facility was closed. Experience with automatic controls shows that a number of difficulties can occur due to lack of knowledge regarding sensor design, placement and control algorithms, especially as they relate to human preferences and behaviour, and the use of glare control devices such as blinds [14].

The hypothesis of this study is that daylighting, when used in conjunction with automatic controls, has the potential to provide large (greater than 30 percent) reductions in lighting energy use.

The hypothesis was tested through a series of experiments and computer simulations performed on an existing high school located in northeast Calgary. The Lester B. Pearson High School was designed to admit daylight to a much larger portion of the building than is normally the case, has clear (high visible transmittance) glazing and manual lighting controls.

1.1 Objectives of the study

The study was designed to provide information on:

- the energy end uses in buildings, so that the contribution of daylighting to energy requirements can be identified more accurately.
- the potential for substituting daylight for electric light.

1.2 Arrangement of the thesis

The reminder of this thesis is subdivided into four distinct chapters. Chapter 2 presents an overview of the available literature on daylighting concepts and key issues. It also provides information about the use of daylighting in buildings. Information on research conducted in recent years on daylighting, in Canada and overseas, is also included. Chapter 3 describes the methodology and procedures used in the present research. This chapter also describes the investigation of the performance of Lester B. Pearson High School as a case study in which daylighting was incorporated extensively in the design. The results of the study are presented in Chapter 4. Chapter 5 concludes the thesis with a summary of the work accomplished and presents conclusions and recommendations for future research.

CHAPTER 2
LITERATURE REVIEW

This literature review refers to relevant papers and articles on daylighting that have appeared in engineering, architectural and lighting design journals, books and conference proceedings since 1980. This material was the main source of inspiration in generating the hypothesis and the methodology for the thesis, serving to provide a prime source of information in analyzing daylighting concepts and systems.

The chapter will cover the following topics:

2.1 Daylighting concepts and key issues
2.2 Research on daylighting conducted outside Canada
2.3 Prior research conducted in Canada on daylighting
2.4 Conclusions drawn from the literature survey

2.1 Daylighting concepts and key issues

The design and analysis of any daylighting system is a very complex task which requires a profound understanding of all the factors that affect this type of design. This chapter will discuss some of the key factors and issues which must be considered and taken into account in the process of designing daylit spaces.

2.1.1 Physiological impacts of daylighting on human beings

A daylighting system includes everything needed to make daylighting perform as an environmental system in a building: daylight apertures, glazing, shading and electric lighting controls. The objective of a daylighting system is to provide a reasonable amount of light where it is needed in the building to ensure good *visual performance* and *visual comfort.* Visual performance is the quantitative assessment of the speed and accuracy with which a person performs a visual task. Visual comfort can be described by two concepts: *glare* and *luminous contrast.* Glare is usually described as the sensation produced by brightness within the visual field that is sufficiently greater than the brightness to which the eyes are adapted to cause annoyance, discomfort or loss of visual performance and visibility. Luminous contrast means the relationship between the luminance (brightness) of an object and its immediate background. In general, visual comfort or discomfort can be described in terms of *disability glare* and *discomfort glare.* Disability glare is the extent to which a source of light interferes with a person's ability to perform a task. It results from a reduction in contrast between an object and its immediate surroundings. Even though eyes experiencing disability glare are temporarily disabled (unable to perform a visual task), they are not injured. Discomfort glare, on the other side, is the sensation of irritation or pain caused by excessive brightness in the field of view [10].

Discomfort glare and disability glare are extremely important considerations in the design and analysis of daylighting systems. Problems with daylight glare most often occur in lighting designs that allow direct sunlight into a room. Because of its intensity, direct sunlight is the most critical glare source. However, glare can also be caused by the extreme brightness of an overcast sky. For example, overcast or partly cloudy skies (where clouds and haze reflect light and provide high sky luminances) may sometimes provide higher daylight levels or glare within a building than clear skies. The direct sunlight is decreased in this case and the sky component is increased.

2.1.2 Background on daylight availability and climate considerations

The performance of any daylighting system depends on the duration and frequency of illumination from the sky over the year at the location of the building. Daylight availability refers to the amount of light received from both the sun and the sky for a specific location, time-of-year, time-of-day and sky condition, and is usually defined as the amount of lumens (luminous flux) per square metre existent at the exterior of a building on either a horizontal or vertical surface. Luminous flux is the amount of radiation from a source evaluated in terms of its effect on the standard (average) human eye. When the luminous flux reaches a surface, the resulting flux-density (luminous flux per unit of surface area) is called illuminance. Illuminance is one of the key photometric quantities used to analyze the performance characteristics of daylighting systems.

The amount of cloud cover and other atmospheric conditions, such as humidity and/or particles in the air, strongly affect the amount of available daylight. A sky nearly or completely without clouds is considered to be a clear sky. An overcast sky is a sky with a complete cloud cover. A partly cloudy sky is a sky between these two extremes. Such a sky is difficult to describe, because of the wide variety of conditions that match this description. For this reason most studies on daylighting are carried out for either clear or overcast skies. The different lighting patterns produced by clear and overcast sky conditions are the reason why they are considered separately when studying daylighting concepts. The other variables, humidity and particles in the air, also influence the amount and distribution of daylight that reaches the earth. If present in high quantities, they may decrease the daylight illuminance levels. If present in small quantities they may increase these levels because of the additional scattering of direct sunlight that may occur in such cases [15].

The daylight reaching a point in a space can be divided into components representing light from different sources such as the sky, the ground, exterior reflecting surfaces and interreflections around the room. Each of these components is more or less important depending upon the sky condition and surrounding environment. Concrete, for example, with a reflectance of 40 percent [15] reflects more light than gravel with a reflectance of 13 percent [15]. The reflectance of a winter snowcover (64 to 74 percent [15]) may be higher than the reflectance of the same ground, uncovered during the summer. Surrounding surfaces, such as trees and buildings, may also increase or decrease reflected light. For this reason it is not always apparent which sky condition provides the maximum illuminance or glare. Clear skies do not always produce maximum interior daylight levels [15].

2.1.3 Daylighting delivery systems and building spatial considerations

Forty percent of the total solar energy received at the earth's surface is known to be visible radiation [16]. The rest is invisible ultraviolet radiation (about 10 percent) and infrared radiation (about 50 percent). The orientation of daylighting apertures and their degree of transmittance (defined as the ratio of the total transmitted light to the total incident light) have a great influence on the amount of natural light that reaches the indoors. The higher the transmittance, the more visible light passes through the glass into the space. The presence of shading devices, dirt on the exterior and the interior of the glazing and the framing around the glazing reduce the amount of daylight transmitted.

Absorptance (the ratio of the flux absorbed by an element to the flux incident) and reflectance (the ratio of the flux reflected by an element to the flux incident) characteristics of glazing elements are also important factors when dealing with daylighting. For example, heat-absorbing glass and heat-reflecting glass are usually characterized by low transmittance and correspondingly high absorptance or high reflectance of solar radiation, while clear glass is more efficient in obtaining good daylight penetration at the expense of higher solar gains admitted into the space.

Daylighting designs are based upon the geometric relationship between the space being daylit and the size, shapes, locations and transmittance of the fenestration system that provides natural illumination. Through the manipulation of these factors the penetration, distribution, quantity and quality of daylight penetrating a space can be changed. The most common daylighting techniques are sidelighting and top (roof) lighting. While sidelighting concepts use the walls of the building as the location of daylighting apertures, toplighting concepts are those in which daylight penetrates a space from apertures located in the roof.

The function of a space, the quantity of natural light needed in the space and the climate at the building site establish which concept is most appropriate for a given lighting requirement. For example, direct penetration of sunlight through the roof of a building may be undesirable in an office space, but acceptable in a public space such as a lobby. Because of their location in the roof of a building, top-lighting systems provide significant opportunities for solar gains which may result in increased cooling loads. In very cold climates, they may also be a source of high heat losses since hot air rises to the top of spaces. Toplighting can produce an even daylight distribution over much of a space and a better integration with the electric lighting (both illuminating the space from the ceiling), but has the disadvantage of being limited to single-story or low-rise buildings.

Sidelighting also has advantages and disadvantages. The biggest advantage is that, along with natural illumination, windows give occupants the opportunity to view the outside environment. A disadvantage would be that sidelighting systems can only effectively illuminate the perimeter of a building. In analyzing sidelighting concepts, the most commonly used rule of thumb is that usable daylight from windows penetrates a space for a distance of 2.5 times the height of the window head measured from the floor [17]. This suggests that the top part of a window contributes the most in admitting daylight furthest into a space (the higher the window, the higher and more uniform the illumination). Sidelighting provides light that sweeps across horizontal workplanes with the maximum illuminance level occurring at the window and decreasing as the distance from the window increases. The presence of obstructions, such as office partitions, reduces the areas that can be effectively illuminated with daylight.

After entering the building, daylight interacts with the interior spaces. The choice of colours, textures, building materials and furnishing affects the diffusion of daylight throughout the space. One way to reduce glare is to increase interior reflectance. For example, walls and ceiling planes with high reflectances produce a higher background illuminance, which decreases the contrast between the aperture and the room's surfaces. On the other hand, reducing the interior reflectance increases the contrast and glare may occur.

2.1.4 Daylighting - electric lighting interaction

The integration of daylighting with the electric lighting is another very important issue when dealing with daylighting designs. If energy conservation and energy cost savings are the main reason for using daylighting, the most critical step in the process of designing daylit buildings might be the integration of daylighting with the electric lighting system. Daylight will provide interior lighting if daylighting apertures are part of the building's envelope, but no energy will be saved if the electric lighting is not dimmed or turned off. That is why the design of the appropriate control system to link the operation of the electric lighting to the available daylight is so important.

An electric lighting system control consists of lighting control zones and a control strategy for each zone. The control zones are used to group luminaires in a room while the control strategy represents the specific technique chosen to switch or dim the luminaires in each zone. In most cases, control zones are chosen based on location of daylight apertures (e.g., spaces receiving equal quantities of daylight would be wired on the same electric circuits, while spaces lacking windows or positioned further away from windows would be controlled separately by a different control zone). Choosing the right control strategy for a room can be equally critical. Three types of automated control strategies are usually used in daylighting designs: on/off switching, step switching and continuous dimming. In many applications, automated control is considered to be "the only way to ensure that the electric lighting is turned off when it is not needed" [10].

2.2 Research on daylighting conducted outside Canada

Over the years, various methods and techniques have been used by lighting researchers to identify daylighting strategies that could reduce energy consumption in buildings. As we will see in the following overview, both computer modeling and experimental testing (in full-scale facilities and scale models) have been used by lighting researchers to establish the effects of daylighting on HVAC sizing and the effects of several daylighting techniques on energy savings in daylit buildings.

2.2.1 Analysis of the effect of lighting control strategies on the thermal behaviour of buildings using computer simulations combined with experimental techniques

Case studies were conducted by the US Department of Energy on twenty commercial buildings throughout the United States to obtain information on the energy impacts of new building technologies and the occupants' reactions to these technologies. The experimental buildings, designed to incorporate advanced conservation techniques, were monitored after construction to determine their performance in the field. Two levels of performance analysis were conducted. The basic level of evaluation carried out for all twenty buildings was to determine how well the buildings perform from the energy and functional points of view. Metered energy data and occupant responses to questionnaires regarding the buildings' comfort and functionality were used to evaluate the energy, functional and economic performance of the buildings.

An advanced level of evaluation was carried out for two of the experimental buildings to determine relationships among the daylighting conservation features used and their effects on the occupants [8]. One of these buildings is a 1200 square metre public library located in a small rural community of 7000 people. The dominant daylighting technique used consists of several roof apertures which illuminate the core area of about 520 square metres. In order to prevent glare and damage to library materials, the sunlight that enters the building through the vertical glazing of the south-facing apertures is reflected by the ceiling and by a set of baffles to ensure that no sunlight enters the space directly [Figure 2.1]. The lack of partitions in this section of the library permits an even distribution of sunlight across the entire area. Electric lighting is controlled manually by the library staff. The library is open to the public about 12 hours a day and usually no more than 5-12 persons are in the building at one time.

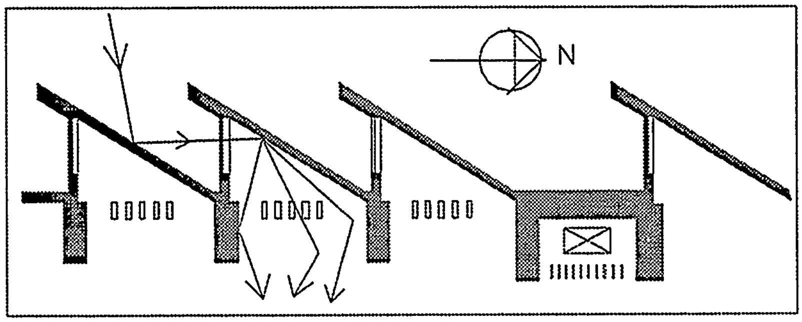


Figure 2.1 Roof apertures at Mt. Airy Public Library
(Concept of Andersson, B., M. Adegran, T. Webster, W. Place, R. Kammerud, and P. Albrand. 1987. "Effects of daylighting options on the energy performance of two existing passive commercial buildings", Building and Environment, Vol. 22, No. 1:3-12) [8].

The second building analyzed in detail is a 420 square metre addition to a community church located in a small university city. The new wing (mainly consisting of classrooms, meeting rooms and a nursery) has a very irregular occupancy, being heavily occupied only on Sunday mornings for church school and the nursery. Sunlight, which enters the spaces through large tilted roof apertures (18 percent of the floor area), is spread over the ceiling by light shelves situated just inside the windows [Figure 2.2]. To maximize the effect of solar heating in winter, the apertures angle the light in such a way that it strikes the north-facing walls of the building. These walls were built as an extensive thermal mass for thermal storage purposes. The roof aperture design (with less shallow overhangs, tilted glazing and lack of baffles) allows for higher solar gains than it did for the other building described above and the quality of light is lower in this case because of the higher potential for glare associated with unobstructed direct sunlight. Electric lighting in the building is manually controlled by the occupants of each room.

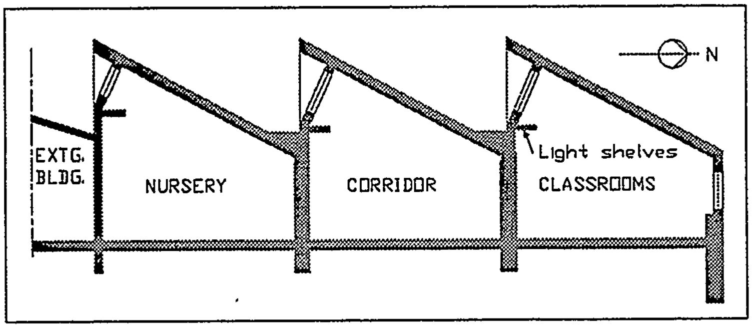


Figure 2.2 Section through the Community United Methodist Church solar wing

(Concept of Andersson, B., M. Adegran, T. Webster, W. Place, R. Kammerud, and P. Albrand. 1987. "Effects of daylighting options on the energy performance of two existing passive commercial buildings", Building and Environment, Vol. 22, No. 1:3-12) [8].

Both buildings provided quantitative information on the energy savings due to lighting conservation measures and the impact of daylighting on the HVAC sizing and the occupants' behaviour. The Building Loads Analysis and System Thermodynamics (BLAST) computer program was used to simulate the energy use. Both manual control of electric lighting and alternative automatic control strategies (such as automatic control based on sensor information about illumination and occupancy in the space) were simulated.

To ensure that the simulation represented reality, a combination of physical and computer modeling was used to study the buildings. For both buildings, the performance of the electric lighting system as affected by the manual controls was monitored to establish patterns of lighting control. Information on the daylight illuminance distribution (obtained with the help of thirty photocells placed in a physical model built for each building) was used to develop a relationship between daylight illumination levels in the space and the response of the occupants in using electric lighting. The measurements were made for a short period (5 months for the library and 3 months for the church) and extrapolated to a full year to allow for annual computer simulations. Hourly lighting schedules were generated and used as input to the simulation. Lighting, heating and cooling performance throughout the year was calculated and the results were compared with results obtained from simulations of alternative control strategies. No comparison between measured and simulated data was done for the mechanical systems.

Two automatic lighting control systems were simulated: on/off switching and continuous dimming. For both types of controls, lighting schedules were generated based on "minimum" and "average" workplane illumination. For the "average" case, the on/off control was set to turn the lights on whenever the daylight illumination dropped below 550 lux on the workplane, while the dimming controls were supposed to adjust the power to the electric lights in response to the amount of daylighting reaching the workplane (550 lux was used as a standard for proper lighting in spaces where reading and writing activities are performed). For the "minimum" case, the level of required work plane illumination was set to 330 lux. The assumption was made that the fluorescent lights could not be dimmed below 20 percent of their capacity.

The results of the computer simulations showed that, for the two buildings examined, the energy use with manually controlled lighting was lower than energy use with automatic controls. For the library, the annual energy performance in terms of lighting was about 36 percent lower for the manually controlled lighting system (9 kWh/m^2) when compared to the dimming system (14 kWh/m^2), and 53 percent lower when compared to the on/off system (19 kWh/m^2). For the church addition the annual energy consumption for lighting was about 19 percent lower for the manually controlled lighting (21 kWh/m^2) when compared to dimming (26 kWh/m^2) and 38 percent lower when compared to on/off controls (34 kWh/m^2). This was explained to be due to the flexibility of the manual control, which allows the occupants to adjust the light levels based on their own needs for the task being performed at a particular moment, in contrast to the automatic controls, which must provide light for the most visually demanding task expected in the space during all hours of occupancy. However, as stated in the article: "This benefit may be far less significant in many buildings where spaces are more heavily occupied and identified with particular tasks." In addition, the fact that all the occupants were informed that the goal of the design was to save energy and were instructed to turn the lights off if not needed might have made an important contribution to these results. For both buildings, the simulated dimming systems were superior to the on/off switching in terms of energy consumption.

The heating and cooling loads were not substantially affected by changes to the lighting control strategy. In each case the differences were lower than 6 percent.

A noticeable finding of this study is that, in both buildings, occupants kept the lights off until interior illumination from daylight was well below the level at which automatic control systems would usually be programmed to switch them on.

Once turned on, the lights remained on for the rest of the day, despite the amount of available daylight.

2.2.2 The use of computer modeling in predicting the thermal performance of buildings

In a study conducted at Colorado State University, a 1600 square metre office building, using four energy conserving strategies, was analyzed using the BLAST computer program to simulate the building energy use [18]. The research was part of a low energy building project that had the objective of designing, building and evaluating an office building that would be "nearly energy independent." In the initial phase of the project, four conservation techniques (daylighting, night setback at 15.6°C, an economizer cycle and evaporative cooling) were modeled with the BLAST computer program to decide which conservation features were to be retained in the construction of the building. Each conservation technique was evaluated and the resulting energy savings were computed.

The base building, designed to allow the researchers to study different daylighting strategies, had nearly every room made with at least one external wall. The depth of each room never exceeded 10 metres and the southern and northern wall areas both had 22 percent glazing. The south-facing zones were provided with light shelves while the north-facing zones had skylights above the view windows [Figures 2.3 and 2.4]. The depth of the southern rooms (receiving direct sunlight) was greater than the depth of the northern rooms (exposed only to diffuse skylight) because of the light shelves on the south-facing facade that were supposed to reflect the light further back into the room. As stated by the authors: "The light shelf - skylight design for this building revealed the importance of a large amount of southern exposure for the light shelves and a large view to the sky for the northern exposure."

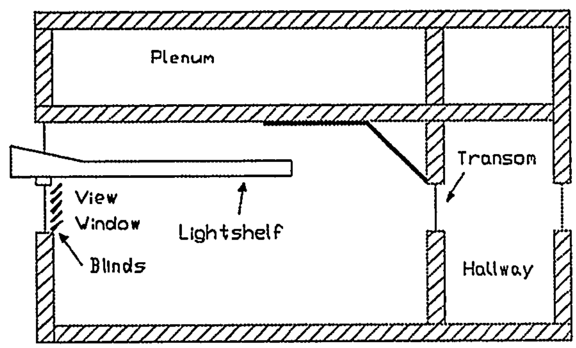


Figure 2.3 Section of south-facing rooms at an office building in Colorado

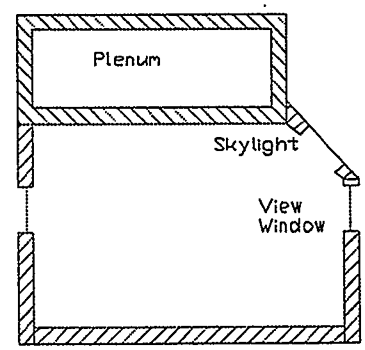


Figure 2.4 Section of north-facing rooms at an office building in Colorado

(Concept of Miller, B., J. McHugh, D. Hittle, P. Burns, and J. Brinkley. 1992. "Initial energy conserving design of a low energy office building". Sol Eng 92. ASME, New York , NY, USA. p:1155-1160) [18].

The simulation of this building indicated significant energy savings results when all four energy saving features were modeled together. The HVAC - lighting energy use was reduced by more than 73 percent compared to an overall estimated annual energy use for a similar building not including the energy conservation techniques. Taking into account the energy that would be used by office equipment, the overall simulated energy performance improved by over 50 percent.

To reduce the lighting loads, three options were evaluated: 1) daylighting in combination with dimmable fluorescent lighting, 2) high efficiency fluorescent lighting with high frequency ballasts, and 3) daylighting combined with high efficiency fluorescent lighting. Both of the first two cases reduced the lighting loads: daylighting by more than 85 percent and the efficient lighting by 33 percent. It was estimated that the annual energy use for lighting of about 57 kWh/m^2, obtained prior to simulating daylighting, could be reduced to about 8.2 kWh/m^2 through using dimmable fluorescent lighting. In both cases, the computer model showed a decrease of the cooling load (5% for high efficiency fluorescent lighting and 17% for daylighting) and an increase of the heating load (30% for fluorescent lighting and 60% for daylighting). The result of the third simulation showed, however, that the addition of high efficiency lights to daylighting was not economical due to high installation costs. As stated in the article: "With daylighting, the number of bulbs and ballasts is not reduced. Daylight only reduces the time the bulbs are on and the power required from the bulbs. If daylighting could reduce the number of bulbs and ballasts, then the chances (for this system) of being economically cost effective would rise."

2.2.3 Experimental evaluation of daylighting designs and their control strategies

Three relevant studies were conducted by a group of researchers at the Lawrence Berkeley Laboratory. These experiments indicate that effective lighting system controls can be an important factor in reducing electrical energy costs and peak demands in buildings while maintaining the light levels required at the workplane.

The objective of one of the studies was to measure the relationship between the ceiling mounted photosensor's signal and the available daylight at the workplane in a scale-model in order to analyze the ability of different controllers to supplement the daylight at the task area with "just enough electric light" to meet the design level [19].

The scale model, constructed to simulate two different room shapes (a small 4.5 x 4.5 metre office, built at 1:3 scale, with a one-to-three window-to-wall area ratio, and a very long room, of 9 metre depth, built at 1:6 scale, with the long dimension parallel to the window and a window-to-wall ratio of one-to-two) was located on the roof of a building at the Lawrence Berkeley Laboratory. To simulate the room with the long dimension parallel to the window, mirrored surfaces were placed as shown in Figure 2.6. The model could be rotated about a central pivot so that the window could be oriented towards any direction. Sixteen photocells, arranged in a regular 4 x 4 array [Figure 2.5], were used in the small office model and a linear array of 15 photocells [Figure 2.6] was installed in the long-room model to measure the illuminance distribution at the workplane. Different types of photosensors were mounted in the ceiling of the model to determine how well the photosensor's signal and location relate to the task illuminance (720 lux for the small office, and 717 lux and respectively 736 lux for the long-room model measured at the locations shown in Figures 2.5 and 2.6, at night, with the electric lights on full). The outputs of the workplane photocells and control photosensors were collected periodically for a period of about three years, for 2 to 5 days at a time. Before each test the model was rotated in a particular direction (e.g. north, east, south or west) and the data acquisition system programmed to take data scans every five minutes. The use of two types of glazing was examined (43 and 88% visible transmittance) and during some of the tests automatic shading devices (venetian blinds) were used to prevent direct sunlight from entering the space.

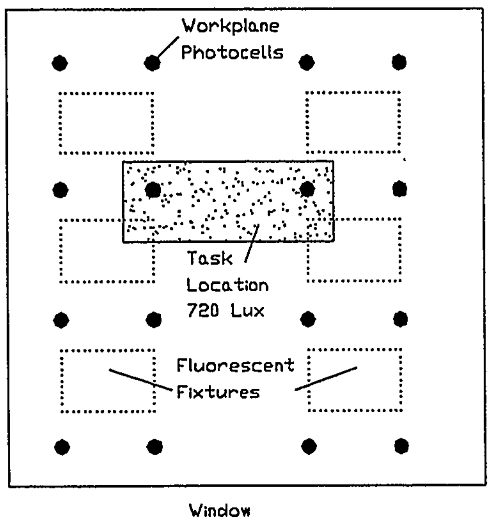


Figure 2.5 Floor plan and reflected ceiling of the small-room model

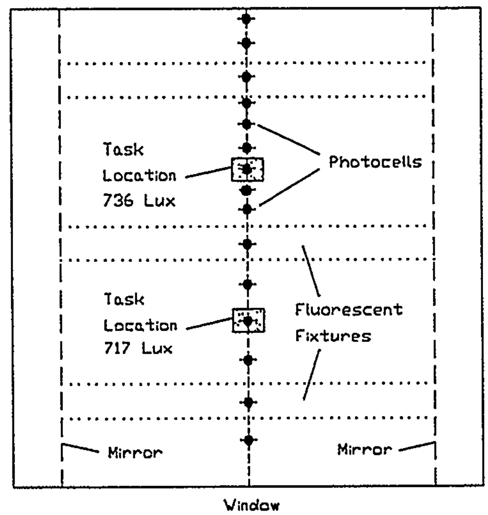


Figure 2.6 Floor plan and reflected ceiling of the long-room model

(Concept of Rubinstein, F., G. Ward, and R.Verderber. 1989. "Improving the performance of photo-electrically controlled lighting systems", Journal of the Illuminating Engineering Society , Vol. 18, No.1, p:70-94) [19].

The results of this study showed that "the ability of daylight-linked lighting systems to provide a minimum light level at the task surface is influenced by the control algorithm used, the spatial response of the ceiling mounted photosensor and the location of the photosensor relative to the task and light sources." In other words it means that, in order for the daylighting control objective to be satisfied, certain factors that constrain the application of photo-electric controls need to be addressed:

- First, the algorithm used by the controller to process the signal from the photosensor to the dimming unit has to compensate for the fact that photosensors are usually located in the ceiling rather than at the task surface.

- Second, the work plane illuminance and the output of the control photosensor must be well-correlated. As expected, partially- and fully-shielded photosensors, being protected from direct light from the window, performed better than unshielded ones when it came to best correlation with the illuminance measured at the workplane in spaces exposed to direct sunlight.

- Third, the results of the research showed that open- and closed- loop proportional control systems outperform integral-reset systems with respect to the control objectives (maintaining a target illumination on the work plane). This was explained to be due to the fact that an integral-reset system operates by maintaining a constant amount of light on its control-photosensor (reference level empirically determined by operating the electric lights at full intensity at night) while a proportional control system allows the adjustment of system sensitivity during a daytime calibration. For both, open- and closed-loop proportional control systems, a daytime calibration must be performed to adjust the system sensitivity so that the dimming of electric lights is appropriate to the specific room and daylighting conditions.

The same research group analyzed a lighting control system installed at an office building in the San Francisco Bay Area [20]. The test-site has an area of 425 square metres. Two metre high windows made of standard clear glass (88 percent estimated transmittance) are part of two walls running along the north and south sides of the demonstration site. The existing lighting system consisted of 54 fluorescent fixtures each operating 4 x 34 watt lamps. The demonstration system, which replaced the existing lighting system during the tests, was designed to exploit three control strategies: daylighting, lumen maintenance and scheduling. The system allowed the analysis of the saving potential of each lighting control strategy separately and in appropriate combinations in a real building environment. The lighting fixtures were grouped in 6 control groups running parallel to the window walls [Figure 2.7]. New high-frequency electronic ballasts were installed and the system was relamped with new 40-watt standard cool white fluorescent fixtures. Each ballast operated three fluorescent lamps and could be dimmed over a range from 100 percent to approximately 20 percent of full power. For each control group, shielded ceiling photosensors measured the illumination in the space (daylight plus electric light). The photosensors were developed to permit daylight-linked control and automatic compensation for drop in efficacy (total luminous flux emitted by a lamp divided by the total power input) caused by lamps aging. The average signal from the photosensors was transmitted to a controller that modified the light levels for all the ballasts in each of the 6 control groups.

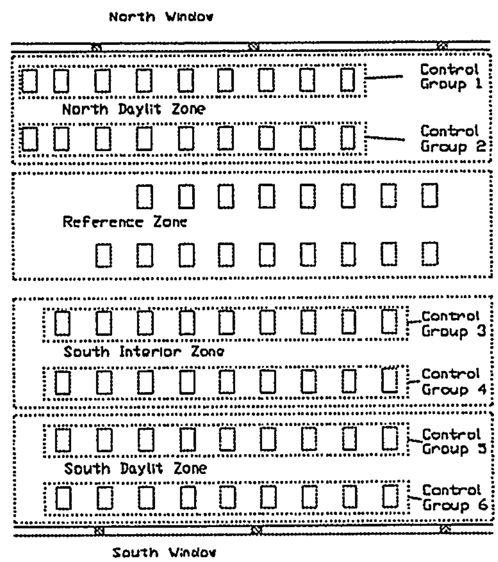


Figure 2.7 Plan view of demonstration site showing the control zones at an office building in the San Francisco Bay Area

(Concept of Rubinstein, F., M. Siminovitch, and R. Verderber. 1993. "Fifty percent energy savings with automatic lighting controls". IEEE Transactions on Industry Applications, Vol. 29, No. 4: 668-773) [20].

After nine months of operation, lighting energy was reduced in the dimming zone by 50 percent relative to previous usage. Assuming 3750 hours of operation per annum, this would mean a reduction of previous usage of about 58 kWh/m^2yr to 29 kWh/m^2yr. Significant energy savings (about 50 percent) were achieved due to reductions in lighting levels over the circulation areas and in lighting energy use outside the core operating hours. The savings due to daylighting and lumen maintenance (about 43 percent) measured in the dimming zones during core operating hours were also significant, having in view the fact that these savings occurred during peak demand hours when energy is more expensive. An important portion of these savings was attributable to the fact that, through relamping the system, power levels could be set to 75 percent of the full power obtaining the same light level of 450-575 lux as provided prior to the retrofit. This would suggest that the savings achieved during core operating hours due to daylighting were only about 18 percent.

In another study, a group of researchers analyzed a five-story office building designed to provide daylight illumination throughout its entire space [21]. Every floor, of about 3200 square metres each, had nearly all of the office space in the north- and south-facing zones. The west and east sections mostly contained service spaces, conference rooms and restrooms. Light shelves on the outer envelope that beam the sunlight inward, sloped ceilings (sloping from 4.5 metres floor-to-ceiling height at the perimeter to about 3 metres at the center of the floor plate) and a central atrium permitted daylight illumination throughout all the building's 27 metre width [Figure 2.8]. The integration of electrical and natural lighting was obtained through a dimming control system for the overhead rows of lamps installed on every floor [Figure 2.8].

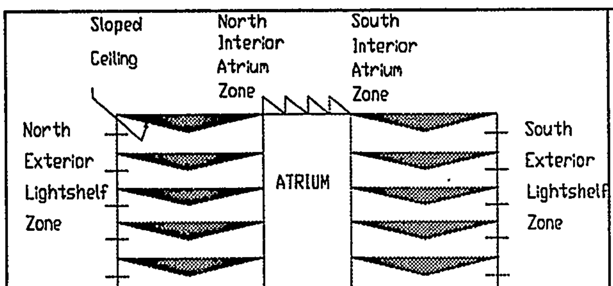


Figure 2.8 Cross section of a five - story building showing unique daylighting features

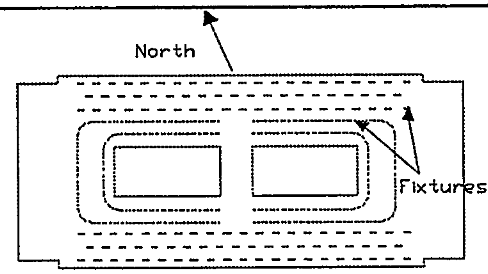


Figure 2.9 Typical floor plan of a five-story building showing ambient lighting system layout

(Concept of Verderber, R., O. Morse, and J. Jewell. "Building design: impact on the lighting control system for a daylighting strategy." IEEE Transactions on Industry Applications, Vol. Mar 1989, p: 198-202) [21].

The indirect lighting fixtures and the daylighting were expected to provide an ambient illumination level of 350 lux. The response of the electric lighting control system to the available daylight was obtained by measuring the daylight illumination level during the day without the electric lights, followed immediately by measurements of the power to each row of lamps after the electric lights were turned on. Since the power to each row of lamps at full light output was known, the percent to which each row of lamps was dimmed was determined. The results showed that daylighting provided over 70 percent of the required ambient illumination throughout the year while the electric light was required to supply the remaining of 30 percent of the ambient illumination. Assuming 3750 hours of daytime occupancy per annum, it was estimated that the annual energy use for lighting of about 39 kWh/m^2 could be reduced to about 12 kWh/m^2 through use of dimming controls. An analysis of the cost effectiveness of the system showed that the payback period for the cost of the lighting controls would be, for that particular location, less than 3 years (at 0.08 US $/kWh). This assessment did not take into account the cost due to the special design of the building and, as mentioned by the authors: "a less formidable daylit building design would limit the use of these controls to the space near the outer envelope, resulting in the same cost and savings per square foot" [21].

This last study showed that lighting control systems can be used very effectively with daylight but there is no doubt that the unique design features of the building that was analyzed, such as sloped ceilings and light shelves used to beam the daylight into the interior, proper orientation and symmetry, strongly influenced the response of the building in terms of electric energy consumption.

The performance of another dimming system was reported for an office building located near Birmingham, England [6]. The building, a four-story structure of 3000 square metres, was constructed with a continuous strip of clear double glazing (60 percent transmittance) on every floor. The windows are 2.3 metres high measured from the window sill situated at desk height (0.7 metres) to the level of the ceiling height (3 metres). Every floor has nearly all of the office space in the perimeter area. The core area contains mostly service spaces, stairs and restrooms. The design of the building includes internal and external shelves on the outer envelope, designed to act as solar shades, to reduce light levels near the window and to increase light levels at the rear of the rooms. A deep concrete window sill covered with a high reflectance material is used to enhance daylight distribution and absorb solar radiation. The electric lighting system consists of ceiling-mounted fluorescent luminaires supplemented with task lighting. The design intention was to provide 350 lux on the workplane. To ensure reduced use of electric lighting in response to daylight, a dimming control system with manual override was installed for the ceiling luminaires in the offices. Measurements carried out by the design team for a period of six months indicated an average annual electric usage for lighting of about 17 kWh/m^2 (for 50 to 60 hours use per week, equivalent to 2600 to 3100 hours per annum). This consumption included the artificially lit core area of the building. However, a short term measurement in a room in the dimming zone provided an estimate for this area of 9 kWh/m^2 annual consumption for lighting. Assuming 3750 hours of annual operation (as used to estimate consumption in the study described above) this would mean about 11 kWh/m^2. It was concluded that the lighting energy use for this building is "low and responsive to the available daylight". The fact that users never used task lighting was considered by the researchers as an indication of the sufficient level of general lighting.

2.2.4 Experimental analysis of lighting-cooling interaction

Although lighting typically accounts for 25 percent or more of a building's energy consumption [22], heating, ventilating and air-conditioning remain one of the biggest energy consumers in buildings. Reductions in the lighting load may also reduce the cooling load and, thus, the installed cooling capacity in a given building. Lighting efficiency may translate into less energy consumption for air-conditioning because less heat is produced in the building.

The interaction of lighting and HVAC systems was analyzed some years ago by a group of researchers at the National Institute of Standards and Technology in Gaithersburg, MD, USA using a full-scale test facility constructed to simulate an office building [22]. The objective of this research was to evaluate the performance of lighting and HVAC equipment as influenced by typical operating conditions and equipment configurations. Full-scale measurements of lighting and HVAC performance combined with computer simulations were used to extend the measurement results for larger facilities. The test facility, constructed to imitate an office space, allowed for testing configurations to be changed easily.

Parameters such as lighting power, cooling load, return airflow rate and room temperatures were measured and plotted. Both steady-state tests (turning the lights on or off and allowing the cooling loads to stabilize) and transient tests (the response of cooling loads due to sudden switching of the lighting system) were run.

The results showed a clear impact of the lighting system on the performance of the HVAC system, increasing the cooling load whenever the lighting system was energized and decreasing it when the lights were switched off. The impact occurred almost instantaneously after the lighting system went from one condition, lights on or off, to the other condition [Figure 2.10].

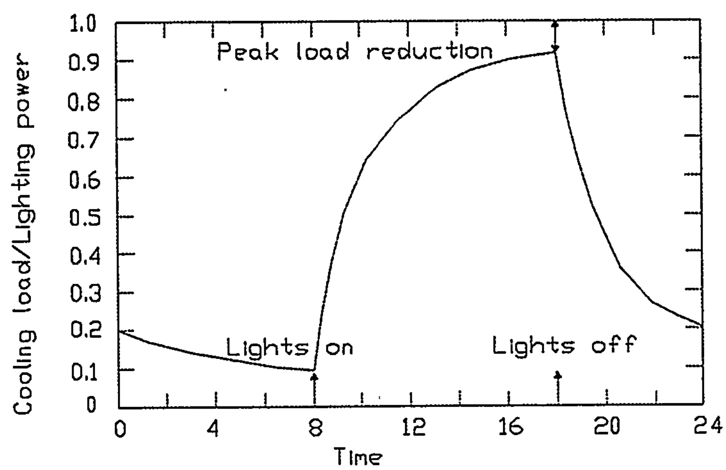


Figure 2.10 Typical profile of cooling load due to lighting for cyclic daily operation of electric lighting

(Concept of Treado, S.J., and J.W. Bean. "Experimental evaluation of lighting/HVAC interaction". Proceedings of the 1990 Annual Meeting of the ASHRAE, St. Louis, MO, USA. ASHRAE Transactions pt.2 Publ. by ASHRAE, Atlanta , GA, USA. p 773-779) [22].

2.2.5 Previous efforts to verify the accuracy of the DOE-2 computer program

Having in view the fact that the DOE-2 computer program was used in the present research as a computation tool for energy simulations, the following study was considered noteworthy to mention in the literature review.

The DOE-2 is a computer program developed at the Lawrence Berkeley Laboratory (California, USA) to provide architects and engineers with a public domain tool for energy analysis of buildings. DOE-2 computes hourly heating and cooling loads, simulates heating, ventilating and air-conditioning (HVAC) systems and energy plants and calculates the economics of projects by life-cycle costing (see Chapter 3.2 for a detailed description of the program).

At the request of the United States Department of Energy, the Los Alamos National Laboratory in the USA conducted a verification program for DOE-2. The verification project was intended to be carried out in two phases. Phase I was an analytical and full-program test phase and Phase II was to be a field-verification phase for testing individual program algorithms that has never been completed because of lack of funding [23].

From the steps involved in the verification project, only two, relevant to this thesis, will be summarized here.

A first comparative study was performed by a consortium of seven national laboratories and private contractors and consultants that participated in the project. Under the lead of the Los Alamos National Laboratory, the seven participants simulated their respective buildings using the DOE-2.0A program. Uncertainties in the program input were reduced by using historical knowledge of the buildings and their actual operation instead of assumptions. Energy consumption predictions for gas and fuel oil, electricity and total energy consumption were compared with metered data. The statistical analysis of these comparisons produced the following results: on an annual basis, the standard deviation of predicted versus measured results was 8 percent for total energy consumption, 11 percent for gas and fuel oil use and 9 percent for electrical energy use. On a monthly basis the deviations were somewhat higher: 17 percent for total energy consumption, 26 percent for gas and fuel oil use and 19 percent for electrical energy use. In addition, one of the participants in the study (The Lawrence Berkeley Laboratory) compared the annual energy-use predictions of DOE-1.4 with measured data for ten elementary schools across the United States. The maximum deviation was 10 percent for gas and fuel oil use, 9 percent for total energy consumption and 8 percent for electrical energy use.

In order to test the variations in predicted energy-use resulting from user's judgment in developing the DOE-2 program input data, some participants in the project were asked to perform DOE-2 simulation runs on four selected buildings (buildings they were not familiar with) basing their data inputs only on engineering drawings, equipment specifications and other information normally available to a contractor analyzing a building. Each contractor performed a set of three separate simulations for each building, each set representing a more precisely defined level of input data control. These user-effect simulation runs were compared with the reference runs described above to assess the sensitivity of the DOE-2 program to the program user.

The comparison of predicted monthly energy-use for the four buildings tested resulted, as stated by the authors, in the following conclusions (see previously mentioned values):

- as the input specifications became more complete and less ambiguous (when going from uncontrolled to refined input - in which many input parameters were specified) scatter in monthly total energy-consumption predictions among users of DOE-2 was successively reduced;

- in most of the cases studied, the scatter was greater for fuel energy consumption than it was for electrical energy consumption;

- when the input was uncontrolled (the simulation was based on the "as is" building data packages allowing for differences in user's judgment and interpretation of building data from drawings and specifications) considerable scatter in monthly results were obtained among the users of the DOE-2 computer program. The most significant reduction in this scatter is suggested to be obtained by having an independent observer check the input for errors and by eliminating gross ambiguities in the input.

In a second study comparisons were made between results obtained from several building energy analysis computer programs. The results of the DOE-1.4, DOE-2.0, NBSLD, BLAST and ACCESS computer programs were reported and analyzed. With few exceptions, the DOE-2 predictions agreed well with predictions of the other computer programs and the few differences which occurred were due to large variations in the user's interpretations of buildings' drawings and specifications.

2.3 Prior research done in Canada on daylit buildings

As mentioned in the introduction, very little research has been done until now in Canada to evaluate the energy savings of daylighting and very little data is available on the performance of daylighting systems. However, in the recent years, two interesting studies were conducted by researchers at two Canadian universities. These two studies will be discussed in the following summary.

2.3.1 Evaluation of daylighting systems using computer simulation

A comparative study was done at the University of Saskatchewan using the DOE-2.1B energy simulation program to determine the energy consumption levels for a 15-story, 24,600 square metre office building in four locations: Boston, MA; Denver, CO; Forth Worth, TX and Saskatoon, SK [24]. Perimeter windows, placed symmetrically on all sides of the building, were the only daylight source. The electric lighting system had a power density of 21.5 W/m^2 and provided a design illumination of 540 lux. Based on two utility rate structures, the simulation determined the life-cycle cost of the building for a 20-year period illustrating the effect of window area, glazing type and electric lighting control schemes for a daylit building as compared to a non-daylit building. The range of window area studied was 0 to 56 percent of the exterior wall area. Three types of glazing (clear, tinted and reflective) and three methods of electric lighting control (on/off, 3-step and continuous dimming) were simulated.

Simulation results indicated reductions between 5 and 11 percent in life-cycle cost for three of the locations when tinted or reflective glazing was used but did not show any savings for Boston. This was due to the fact that Boston has, among the locations studied, the lowest level of solar radiation and therefore the reduction of direct solar gain by use of reflective and tinted glazing would not be economical. It was concluded that reflective and tinted glazing reduce the life-cycle costs for locations with high solar radiation levels.

The simulation of different electric lighting control schemes showed that continuous dimming had the greatest energy saving potential for all cities. Electrical usage was reduced by 12 percent and peak demand by 9 percent compared to on/off controls. It was also reported that the optimal electrical lighting control scheme depends on the window area and therefore this result may change for very large window areas.

The study also concluded that in Saskatoon the difference in life-cycle cost between daylit and non-daylit buildings is lower than for all the other locations (this may be due to the fact that for this northern location the daylight availability during working hours is lower than for all the other locations studied). While, for all the US locations, the energy savings were relatively large for all glass-to-wall area ratios (5 to 12 percent lower life-cycle costs for daylit buildings compared to non-daylit ones), for Saskatoon, the life-cycle cost was equal for daylit and non-daylit buildings for glass-to-wall area ratios of less than 0.4. For higher values daylit buildings were superior in terms of energy savings, reaching an almost 10 percent difference at 0.56 glass-to-wall ratio.

In 1993, as a follow-up to this study, the same research group conducted an analysis of the economics of daylight for two generic types of office buildings in four different Canadian climate zones [25]. The DOE2.1C building simulation program was used to predict monthly electrical and natural gas demand and consumption levels for the buildings, which were analyzed as both daylit and nondaylit buildings, using a wide range of fenestration designs. The buildings were considered to be daylit buildings when a control scheme was used in the simulation to alter electric light levels based on the interior daylight illuminance and nondaylit buildings when such a control system was not simulated. The electric lighting control scheme simulated for the daylit building cases was continuous dimming. The control system would reduce the electric lighting power based on the interior daylight illuminance measured at a point 2.4 metres from the window and 0.76 metres above the floor. The simulations assumed perfect performance of blind control (a perfect performance of blind control is defined as one that varies the position of sun control devices in direct response to unwanted glare or window heat gain; it is presumed that users would adjust the shading devices as soon as they become disturbed by glare or heat gains, and readjust them as soon as these conditions disappear; perfect shading systems do not exist in reality and research has shown that, in cases where shading devices are controlled manually by occupants, the probability that users follow this pattern is even lower [14]). Local utility rate structures were used to determine annual energy and demand charges.

Results of this study showed that in cities such as Toronto, Edmonton and Vancouver "daylit buildings may have the least life-cycle cost" but in Montreal "daylighting is not feasible." This was explained to be due to the difference in energy rate structures, which show that Montreal has the lowest electrical rates but the highest natural gas charges while Toronto, for example, has the highest electrical energy charges and the lowest natural gas charges.

2.3.2 Evaluation of daylighting systems using experimental techniques

Prior to this thesis, studies on energy performance of buildings designed to exploit daylighting were conducted at The University of Calgary. The projects had the objective of assessing the viability of daylighting systems and the accuracy of existing daylighting design tools for northern climates, where daylight availability is short in winter and temperature conditions range from warm in summer to severe in winter.

In one of these projects [26], the effects of daylighting controls on energy utilization for lighting were studied for two office buildings employing photo-electrically controlled dimming systems. For one of the buildings the impact of daylighting on the cooling load was also reported. Illuminances, lighting power demands and energy use effects of the daylighting systems were monitored and building operators were interviewed regarding technical and human factors aspects of performance.

Monitoring of one of the buildings did not proceed beyond monitoring of lighting power demand because, during the research, it was learned that the photo-electrically controlled dimming system was so designed that all spaces (including those not receiving daylight) were wired on dimming circuits and any level of dimming would have reduced light levels in spaces lacking windows. The degree of dimming was therefore reduced by the building operator to a minimal value in order to avoid uncomfortable light levels in the spaces at the core of the building. In addition, measurements of the transmittance of glazing showed it to be only 0.48, which greatly reduced the quantities of daylight entering the perimeter spaces. It was concluded that the daylighting system in this case was poorly designed, so no further measurements were carried out.

For the second building, more intensive measurements were carried out despite the fact that the photo-electrically controlled dimming system was found to have been deactivated by the building operator in response to occupants' complaints regarding inadequate illumination and the appearance of dimmed lamps in comparison to those not in the dimming zone. For the purposes of the study, the dimming system was activated in one east-facing exterior zone on the 5th floor of the building and the measurements compared with measurements taken for an identical zone immediately above the 5th floor test zone.

Results showed that, for clear summer days, the lighting power demand was reduced by 30 to 50 percent for the 5th floor test zone when compared with the 6th floor non-dimming zone in spite of the fact that the glazing had a low transmittance coefficient (0.50). The daylighting system was found to be better designed than the one in the previous case, especially because the zones controlled by the automatic system were much smaller and located within 5 metres of the window wall.

To further analyze the effectiveness of the system, cooling rates were monitored for both 5th and 6th floor under different sky and lighting conditions. Results of the measurements indicated that internal heat sources (lights, people and equipment) had little effect on cooling rates.

Because of improper design, installation and operation, the buildings studied during this research performed well below the capability estimated to be possible (in terms of energy savings) by computer simulation programs.

2.4 Conclusions drawn from the literature survey

In order for a daylighting system to be well constructed and operated, a detailed understanding of the technology and factors that affect this type of design is needed. As stated in the literature: "At least five primary technical or design issues must be described, understood and accepted before daylighting can be fully utilized as a building-environment technology. These issues are:

- The need for a daylight- and sunlight- availability data base for analyzing lighting and energy performance characteristics of the system and building
- The need for a systematic method of describing daylighting concepts (in order to develop design intuition about the best ways to use daylight in buildings)
- The need for comprehensive methods of analysis that include all aspects of system performance (illumination, energy and visual comfort)
- The need for a method of integrating daylighting and electric lighting
- The need for a better understanding of who has responsibility for the design of daylighting systems - the architect, the engineer, the lighting designer, a daylighting consultant, or a combination of these" [10].

We can see therefore, why it is so important for the members of the building design team to have access to a reliable design tool which could give them the possibility to investigate alternative strategies to fully realize in their designs the energy savings potential of daylighting. Information on performance of representative systems would be therefore of great help to professionals in their efforts to properly use daylighting and daylighting controls.

Computer programs are the preferred method for carrying out this type of analysis because of their speed and low cost relative to experimental testing. One such program is DOE-2, widely used by architects and engineers across Canada. DOE-2 has been verified by experimental tests on actual buildings and is considered a standard in energy analysis computer packages [9].

However, predicting savings from daylight is very difficult because of the complexity of the inter-related factors that affect the performance of daylighting design. As we have seen in this chapter, earlier research has resulted in inconsistent findings:

- some building performance studies and simulations showed that large savings can be realized using daylight [8,18,20,21] while some other studies showed small or no savings [26];

- some laboratory studies indicated large lighting-cooling impacts [22], but there is little information on real installations;

- some experiments showed that buildings are not always performing in the field as in simulation models [26]; simulations usually involve many assumptions that may deviate widely from real conditions [23] and assume perfect building performance. As we have seen earlier, this may be far from what one usually calls "reality".

Obviously, these results come to emphasize once more the need for further research studies on daylighting for Canadian buildings in order to understand the conditions under which large energy savings can be realized by using daylight. Moreover, as the daylighting design and research has been concentrated up to this point on office buildings, it would be very useful to assess the potential of daylighting for other types of buildings such as the high school investigated in this thesis.

CHAPTER 3

METHODOLOGY AND PROCEDURES

Several daylit buildings have been constructed in Canada in recent years but most of them, including the one analyzed in this study, have been developed in the absence of any analysis based on prior experience with system performance in the field. Because few studies were conducted to determine how effective daylighting systems are, design solutions were adopted in many cases based on theoretical considerations rather than on an adequate proof that they would perform as expected [26].

As mentioned before, an educational facility located in Calgary was selected for study. The building, designed to exploit daylighting to replace electric lighting in parts of the building, provided a good opportunity to study the performance of daylit buildings in Canada.

The first task prior to investigating energy-conserving retrofits for the existing building was to create a computer model of the building as it exists. Due to its extensive capabilities for modeling energy use-related features of buildings in relation to weather conditions and loads (occupants, lighting, equipment), the DOE-2 building energy simulation program [27] was used to model the energy performance characteristics of the Lester B. Pearson High School. Utilizing hourly weather data, DOE-2 calculates the hour-by-hour performance and response of a building for each of the 8760 hours of a calendar year.

In order to ensure that the simulation properly represented reality, the first step of the research was to verify the accuracy of the computer model in simulating the energy used in the daylit test building by comparison of calculated and field-monitored energy use.

In the second phase of the research, the validated model was run with "typical meteorological year" weather files for two Canadian cities (Edmonton and Vancouver) in order to investigate the applicability of daylighting in different locations where weather and solar irradiance conditions differ from those in Calgary. The Edmonton and Vancouver locations were selected because first, they have different requirements than Calgary in terms of heating and cooling demand and second, because computer tapes representative of long-term weather patterns are only available for a limited number of Canadian cities. Table 3.1 presents a weather summary for these cities [28, 29].

Table 3.1 Weather summary for Calgary, Edmonton and Vancouver

Cities	Latitude (deg.)	Summer design DBT* 2.5 % (°C)	Summer design WBT** 2.5 % (°C)	Winter design DBT* 97.5 % (°C)	Heating degree days Below 18 °C	Cooling degree days Above 18 °C	Annual average direct solar rad. (MJ/m^2)
Calgary	51	29	17	-31	5321	34	8.2
Edmonton	53	28	19	-32	5782	27	7.3
Vancouver	49	26	19	-7	2924	30	6.8

* DBT - dry bulb temperature

**WBT- wet bulb temperature

In the third phase, before starting to investigate the effects of alternative daylighting strategies on the total energy consumption, parametric studies were conducted to determine the interdependent nature of three individual environmental control elements: electric lighting, glazing and ventilation. The "elimination parametrics" technique was used to clearly identify the real contribution of these three energy end uses to the total energy consumption. Elimination parametrics [2] is an energy analysis technique that provides, through sequential elimination of individual energy end uses from the simulation model, an approximation of the effect of the eliminated variable on the total energy use. For instance, eliminating all the lights from the simulation model, one can not only determine the energy needed by the building for lighting purposes, but also the impact the lights have on the cooling and heating needs of the building (the elimination of lights from the building reduces the annual cooling demand while increasing the annual heating requirements). A similar analysis can be done for glazing. By eliminating the glazing from the simulation model one can identify the influence the solar heat gains and the conduction heat losses through glazing have on the annual cooling and heating needs. Similarly, the elimination of ventilation from the computer model allowed for determination of the influence this energy end use has on the total energy consumption as well as on all the other energy end-uses.

Last, using the high school as base case, advanced daylighting strategies (e.g., use of alternative glazing and daylight-linked lighting controls) were to be examined if the previous investigation revealed a good potential for significant reductions in energy consumption.

3.1 Test-site description

The school, opened in the fall of 1991, has a gross floor area of 14,000 m^2 and a capacity of about 1500 students. Figure 3.1 shows an exterior view of the south-facing stepped facade used to introduce daylight deep into interior areas of the building.

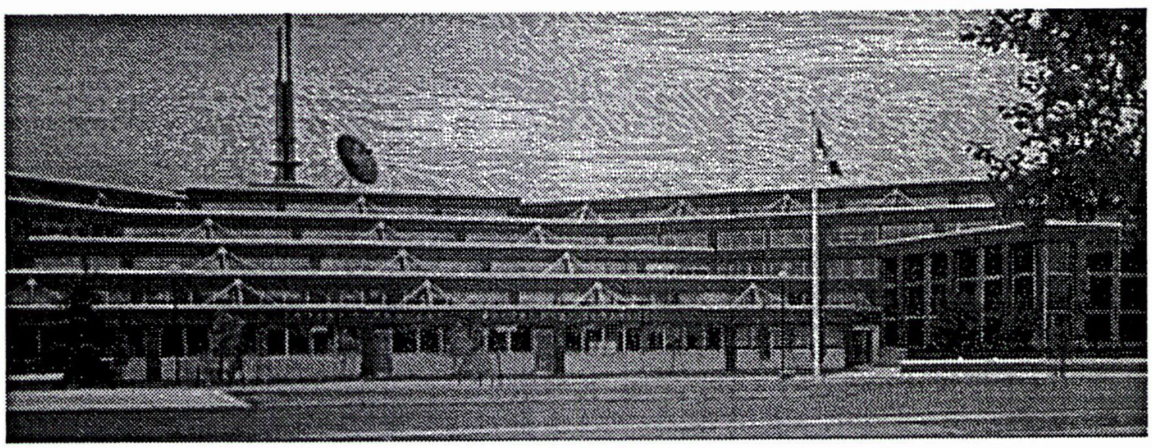


Figure 3.1 Lester B. Pearson High School - Exterior view of the south-facing facade

Plans of the main and upper floors of the building are shown in Figure 3.2 and Figure 3.3.

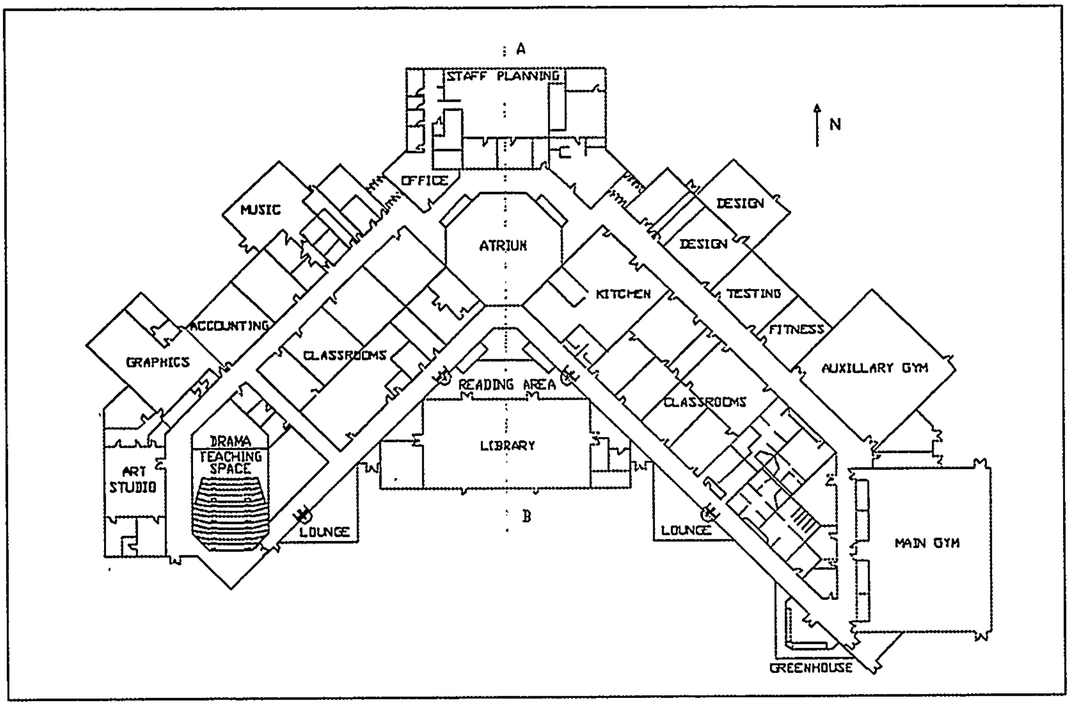


FIGURE 3.2 Lester B. Pearson High School - Main Floor Plan

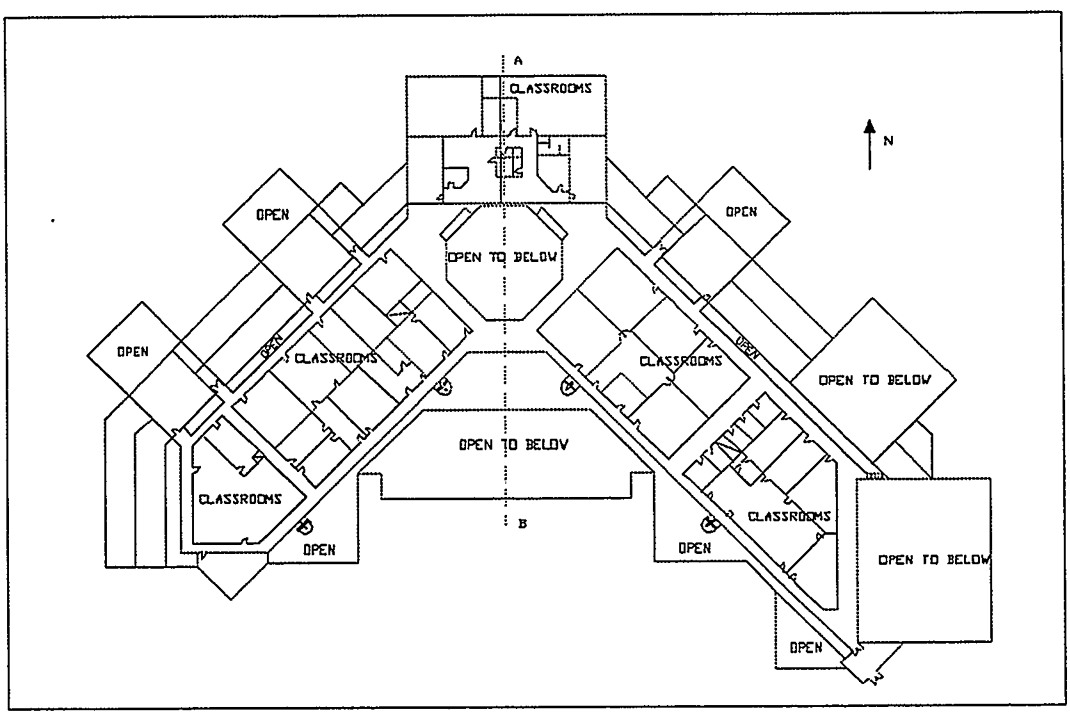


FIGURE 3.3 Lester B. Pearson High School - Upper Floor Plan

The building is served by two single duct, variable air volume (VAV) air-conditioning systems. Space mounted pneumatic thermostats modulate the VAV box volume regulating devices as required to maintain the desired space temperature. The west fan system provides supply air for cooling and ventilation to the upper and lower floor areas, west of line AB (Figures 3.2 and 3.3) while the east fan system supplies the upper and lower floor areas east of line AB. The building is also served by thermostatically controlled baseboard heating, utilized primarily to minimize heat loss at the skin of the building.

As shown in Figure 3.1, the building has large areas of south-facing glazing. The windows, made of standard clear glass with a visible transmittance of about 0.80, are placed high in the walls to admit more daylight into the spaces. The ceilings are tilted up at the perimeter of the building to allow the window heads to extend higher in the walls, improving the daylight penetration (Figure 3.4).

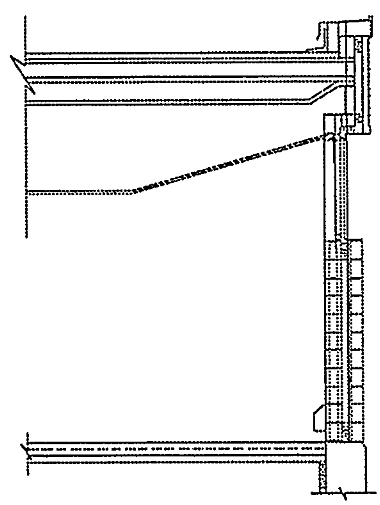


Figure 3.4 Typical wall section at Lester B. Pearson High School

The stepped section of the school and the opening to the upper floor allow more daylight into areas of the school further from the edge of the building's exterior walls. Light shelves on the outer envelope beam the light from the upper part of the sky into the building. Most windows are equipped with manually operated mesh shades that can be drawn to reduce thermal and visual discomfort from direct sunlight. Two-storey glazed south-facing reading areas have motor operated controls. The building, mainly equipped with fluorescent and high-intensity discharge (HID) lamps, has manual lighting controls.

Surface reflectances are high, most walls and ceilings having reflectances of 0.70 or more. This allows for more efficient use of both daylight and electric light, promoting uniformity of illumination and resulting in lower contrast between the apertures and the space surfaces. Light-coloured mullions around the daylight apertures reduce the contrast between the sky and the interior, reducing the glare sensation. Light-coloured floor tiles are also used in most spaces.

In spite of the unique design features of the building, which permit daylight illumination throughout most spaces, daily readings of gas and electric meters showed that it had a specific annual energy use (annual energy use per square metre) at the median for seven Calgary schools (Figure 3.5).

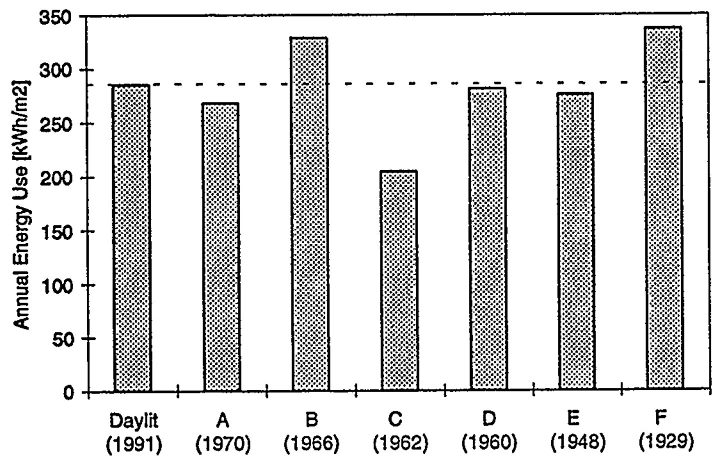


Figure 3.5 **Specific annual energy use at Lester B. Pearson High School compared with that at six high schools without special daylighting features** (The numbers in brackets represent the years when the schools were built).

The specific annual consumption of each of the above buildings according to energy type (electricity and natural gas) is presented in Figures 3.6 and 3.7.

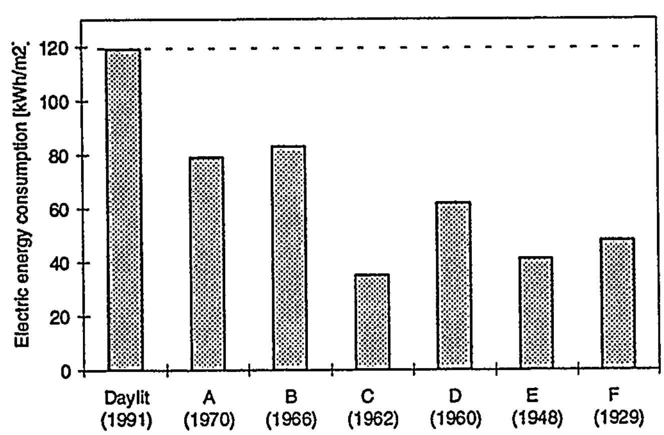


Figure 3.6 **Specific annual electricity use at Lester B. Pearson High School compared with that at six high schools without special daylighting features**

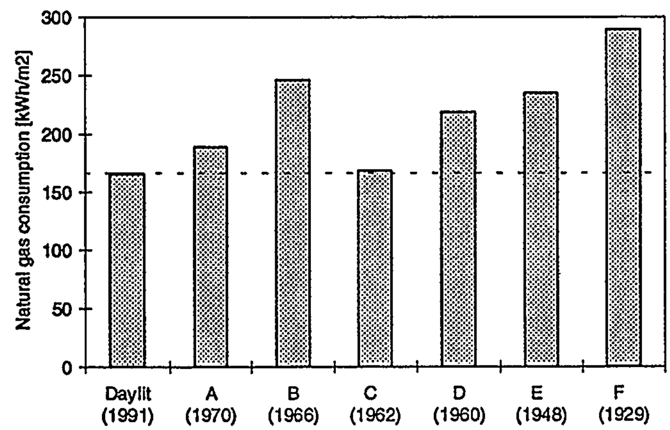


Figure 3.7 Specific annual natural gas use at Lester B. Pearson High School compared with that at six high schools without special daylighting features

As shown in the above figures, Lester B. Pearson High School had the highest use of electric energy and the lowest consumption of natural gas. The fact that the building has large areas of unshaded south-facing glazing (high solar heat gains) may account for the lower natural gas consumption for heating purposes in the winter but higher cooling loads in the summer. The higher cooling load is offset by the lower heating load resulting in a median annual energy-use.

However, there might also be other reasons for the higher electricity consumption. Observations over a number of visits indicate that, even when illumination levels are high enough that electric lighting could be switched off, this is not the practice. Electric lighting is seldom switched off (even when daylighting is adequate) and this may also be a reason for the higher electricity use.

This study was designed to provide information on the energy end uses at Lester B. Pearson High School to identify accurately the reasons why the daylit school has a higher energy use then the other Calgary schools without special daylighting features.

3.2 DOE-2 computer program description

The DOE-2 computer program, developed as a public domain tool for energy analysis of buildings, consists of four separate subprograms called LOADS, SYSTEMS, PLANT and ECONOMICS.

The LOADS program calculates the heat entering and leaving each space within a building, for each hour of a year, assuming that no HVAC equipment is operating and each space remains at a specified temperature. Heat gains and losses through the building envelope are computed as well as internal energy use for lighting and equipment. The building occupancy is taken into account by calculating the latent and sensible heat generated by occupants. The hourly heating and cooling loads calculated by the LOADS program represent the energy required to maintain a certain space temperature, taking into account all the factors that affect the energy balance of a thermal space without the effects of the ventilation air.

The SYSTEMS program simulates the operation of the secondary HVAC system (e.g., fans, coils, humidifiers) based on the hourly loads from each space as calculated by the LOADS program and a series of user-defined instructions regarding outdoor air requirements, equipment operation schedules and temperature and humidity set-points. The results (building's hourly heating and cooling requirements calculated taking into account the way the HVAC system responds to the space thermal requirements) are used as input by the PLANT program.

The PLANT program simulates the operation of the primary HVAC system (e.g., boilers, chillers, electrical generation equipment) based on the hourly loads for the building received from the SYSTEMS program and user-defined instructions that specify the plant. The program calculates the energy consumption of the primary HVAC equipment on an hourly basis and summarizes it by month and year.

The ECONOMICS program calculates life-cycle costs based on utility rate structures and equipment costs.

The calculations performed by the LOADS, SYSTEMS and PLANT programs require hourly weather data. These data are contained in weather files created using statistical criteria from long-term measurements of weather variables such as dry-bulb and wet-bulb temperature, atmospheric pressure, wind speed and direction, humidity ratio, sky condition, direct, diffuse, and global irradiance, etc. They represent typical (representative) values and therefore measured instantaneous values may differ widely from those obtained from data averaged over time. This is the reason why, in this research, real weather measurements were used instead of long-term weather data to validate the computer model.

However, in the process of investigating the applicability of daylighting in Vancouver and Edmonton as compared to Calgary, representative weather data files would have been more appropriate to use for all three locations. Due to the lack of such a file for Calgary, the simulations used representative data files (TMY-typical meteorological year) for the cities of Edmonton and Vancouver (provided by Environment Canada, Atmospheric Environment Service) and the 1994 weather data file for Calgary.

3.3 Summary of methods used to model the energy performance characteristics of the Lester B. Pearson High School

As mentioned above, the DOE-2 program requires basically two sets of information:

1) a detailed description of the building and its schedules of operation, a description of the HVAC system and its schedules and a description of the plant.

2) hour-by-hour weather information, such as dry and wet bulb temperatures, wind speed and direction, atmospheric pressure, as well as global, diffuse and direct solar radiation.

The process of creating a computer model for an existing building can sometimes be more labourious than the process of designing new buildings because the monthly energy usage is known through fuel and electric billings or, as in this case, through field monitoring. When describing the building and preparing the input for the simulation model, it was not enough to look at the architectural and mechanical drawings, but rather it was necessary to discover what was actually built and how the building is operated. Experience has shown that, for example, people's behaviour often overrides theoretical expectations of building performance. Lights might not be turned off on schedule, windows and doors might be involuntarily left open, building operators might adjust manually the design schedules and set-points, and so on. Such behaviours are not provided in official schedules and not taking them into account may make it impossible to match calculated and actual fuel and electricity used by the building. In any case, it is unreasonable to expect to match actual consumption to within less than 10 percent.

Data inputs were based mainly on engineering drawings, equipment specifications and information such as schedules of occupancy, lighting and equipment obtained from the building managers. However, the computer simulation model had to be adjusted to match the measured performance of the building. The main factors to be adjusted were the equipment loads and the lighting and equipment schedules. It was found that the amount of electrical equipment in use at any given time was much less than the sum of the nameplate ratings on all the equipment. Lighting, equipment and occupancy schedules for workdays, weekends and holidays were used in the simulation as shown in Figures 3.8 through 3.11.

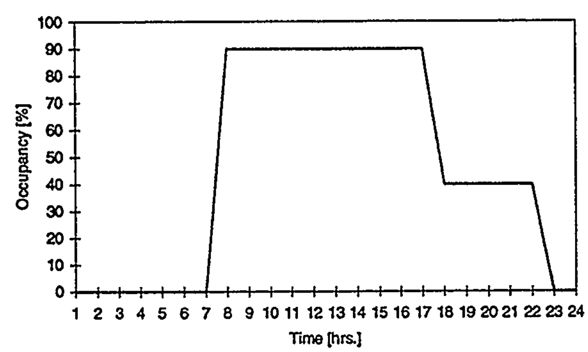


Figure 3.8 Occupancy schedule on a regular working day at Lester B. Pearson High School

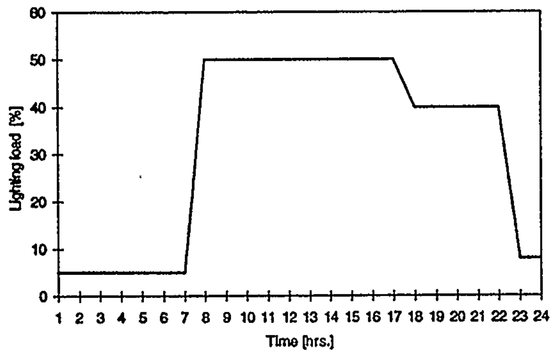


Figure 3.9 **Lighting schedule on a regular working day at Lester B. Pearson High School**

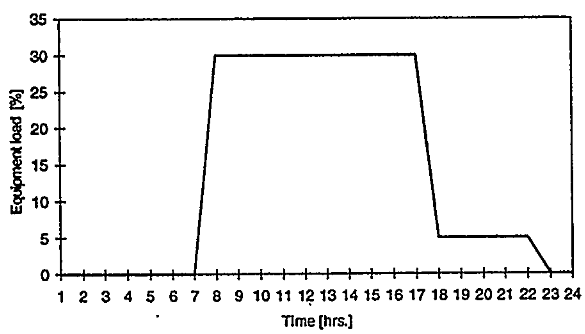


Figure 3.10 **Equipment operation schedule on a regular working day at Lester B. Pearson High School**

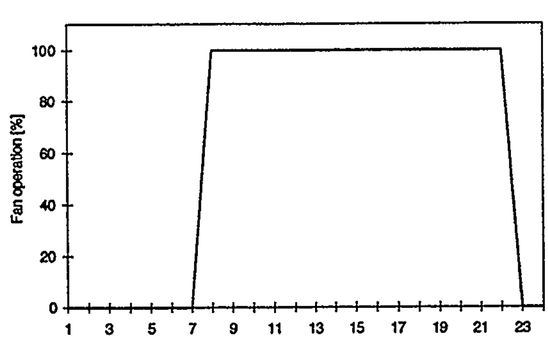


Figure 3.11 **Fans operation schedule on a regular working day at Lester B. Pearson High School**

The schedules were adjusted to match the loads as measured with the data logging system installed at the site. The lighting power density at the school is about 20 W/m^2, the occupancy level is about 10 persons/100m^2 and the equipment load is about 50 W/m^2. The heat gain from people was set to 132 W/person [28].

Related to the building geometry, the inside of the building was divided into 16 thermal zones. In the process of establishing the zones, attention was paid to the orientation of spaces and their thermal conditions in order to avoid combining spaces with different characteristics. Core spaces, perimeter spaces, gym rooms, the greenhouse and unconditioned spaces were each identified as separate thermal zones [Figures 3.12 and 3.13].

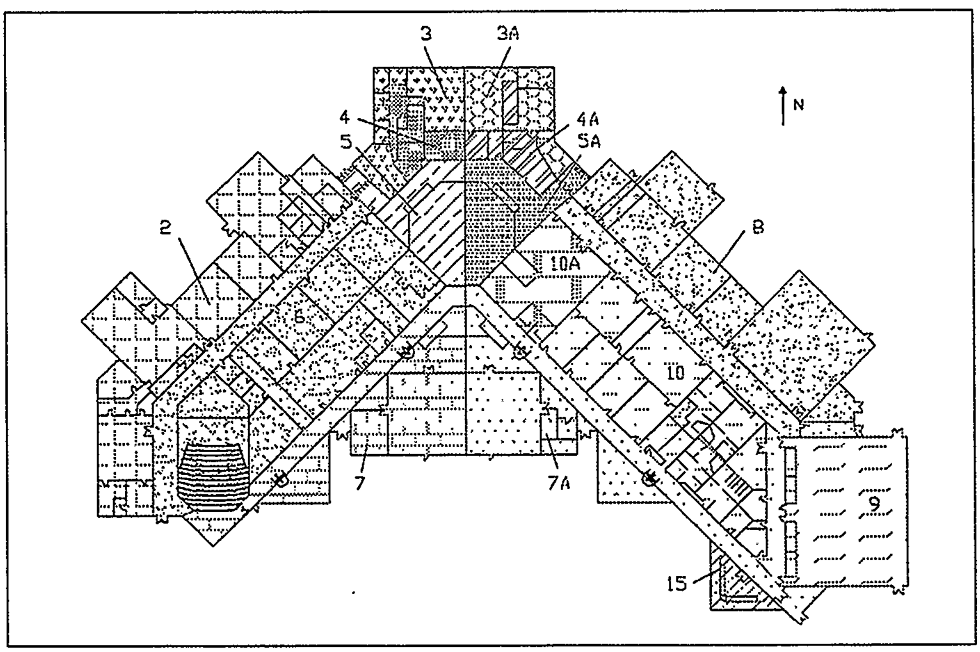


FIGURE 3.12 Lester B. Pearson - Main Floor Thermal Zones

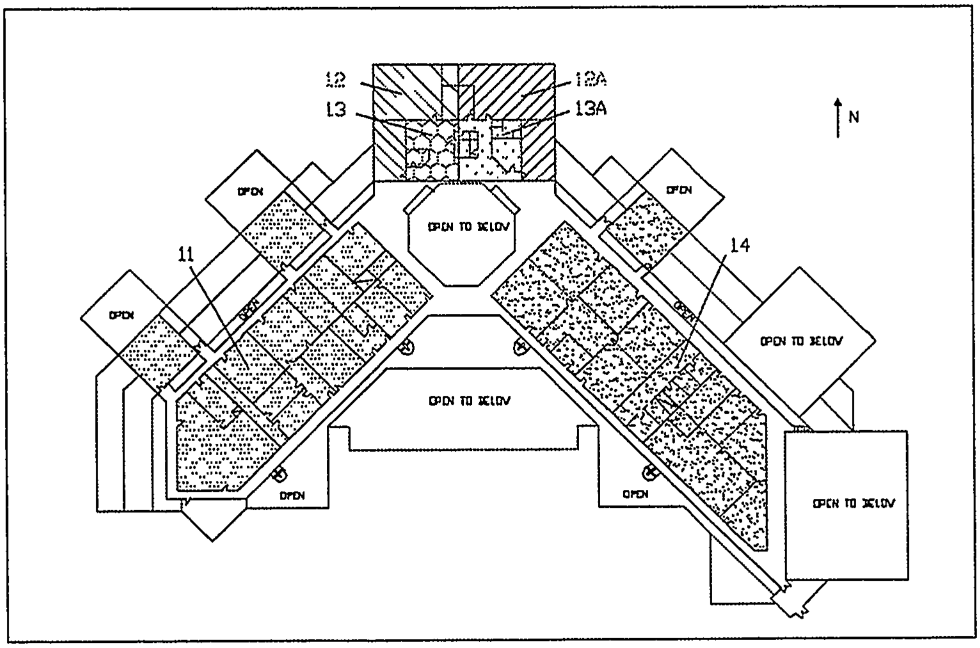


FIGURE 3.13 Lester B. Pearson - Upper Floor Thermal Zones

In order to simulate the performance of the HVAC system, a very detailed description of the building's VAV system was prepared and used as input to the computer model. Figure 3.14 presents the operation of the heating-cooling space mounted thermostats that modulate the VAV regulating devices as required to maintain the desired space temperature.

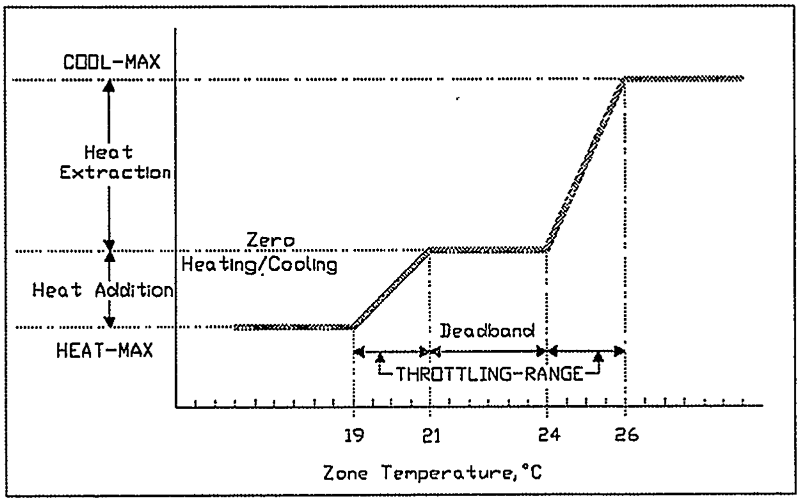


Figure 3.14 Operation of the heating-cooling space thermostats

During regular work-hours, heat is proportionally added to the zone when the indoor temperature falls under 21°C reaching maximum capacity when the zone temperature is 19°C. Likewise, heat extraction starts when the zone temperature rises above 24°C reaching maximum capacity as the zone temperature increases to 26°C. No heat is added or extracted when the zone temperature is between 21°C and 24°C.

Detailed information such as airflow quantities supplied to and exhausted from each zone, baseboard heating capacities for each zone, heating and cooling operation schedules, sizes, types and capacities of plant equipment (boilers, chillers, cooling towers, domestic hot water heaters, etc.) were also provided (see Appendix).

As mentioned before, for the purpose of validation, it was important that the weather data used by the computer program to simulate the energy performance of the building reflected the conditions at the time the monitored data was collected. Site- and time- specific meteorological data were used as an input to the simulation. Daylight availability and solar radiation data were obtained from the International Daylight Measurement Program Station at The University of Calgary. The recorded data allow the assessment of the daily and seasonal fluctuations of daylight. The parameters (such as global, direct and diffuse irradiance) needed to characterize the luminous climate of Calgary and its surroundings are measured at the station on a minute-by-minute basis. Data on air temperatures, relative humidity and wind speed and direction were obtained from the University Weather Station. Hourly averages were computed and an hour-by-hour weather data file was created for the city of Calgary for the year of 1994.

3.4 Summary of methods used to obtain measured data at the test-site

The building's energy consumption was monitored with the help of a Power Measurement 3720 ACM-Power monitor/metre and a SCADA (Supervisory Control And Data Acquisition) software package. Measurements of voltage, current, power, power factor, frequency and energy were collected, at intervals of 5 minutes, for a period of eleven months. The electrical measurements were supplemented with data obtained from daily readings of the natural gas-meter.

3.5 Validation of the computer model

The latest release of the DOE-2 energy analysis computer program (version DOE-2.1E) was used to explore the energy behaviour of the existing building and its associated HVAC system. Measured data from the building were compared with results from the DOE-2 simulation runs in order to determine how close the DOE-2 energy predictions are to the field monitored energy use.

CHAPTER 4
DATA ANALYSIS AND RESULTS

The results presented in this chapter include the analysis of the field performance of Lester B. Pearson High School as a building designed to exploit daylighting. It also presents the results obtained from parametric studies of the building's energy use.

4.1 Analysis of the field performance of Lester B. Pearson High School; Simulation results

The results described here are primarily related to the validation of the DOE-2 computer model. The energy consumption predictions for gas and electricity were compared with measured data. In order to avoid obtaining an unrealistic yearly overall energy use, which might have been close to the yearly metered data but resulted from unrealistic daily or monthly consumption, the computer model was run individually for every month of 1994 and the comparison was performed for selected days in each month. Monthly measured electrical energy and natural gas consumption, as well as daily power demands for two days of each month selected to illustrate typical 24 hour use patterns were compared with simulation results.

Figure 4.1 shows measured and simulated electrical energy use on a monthly basis for 1994 while Figure 4.2 shows measured and simulated natural gas use for the same year.

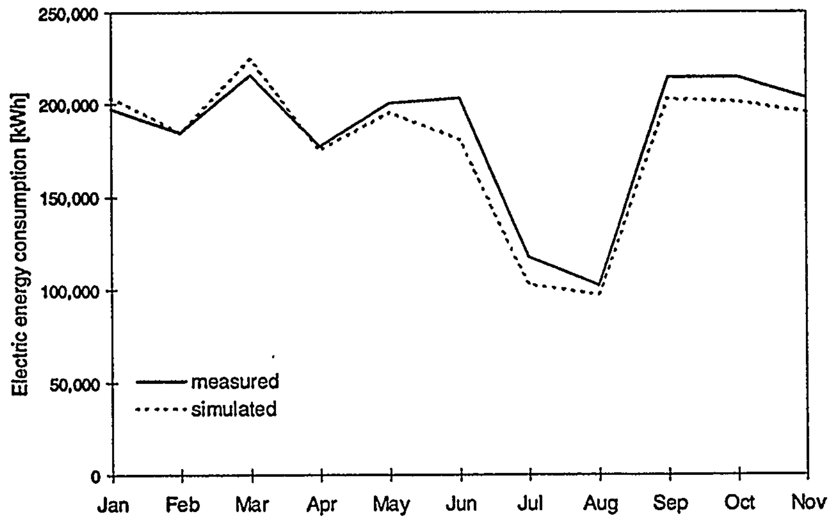


Figure 4.1 **Measured and simulated electric energy consumption for Lester B. Pearson High School, 1994**

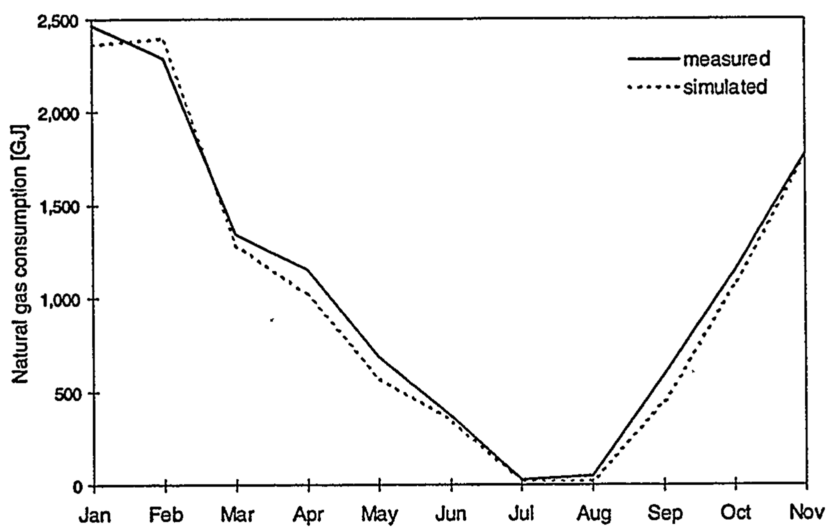
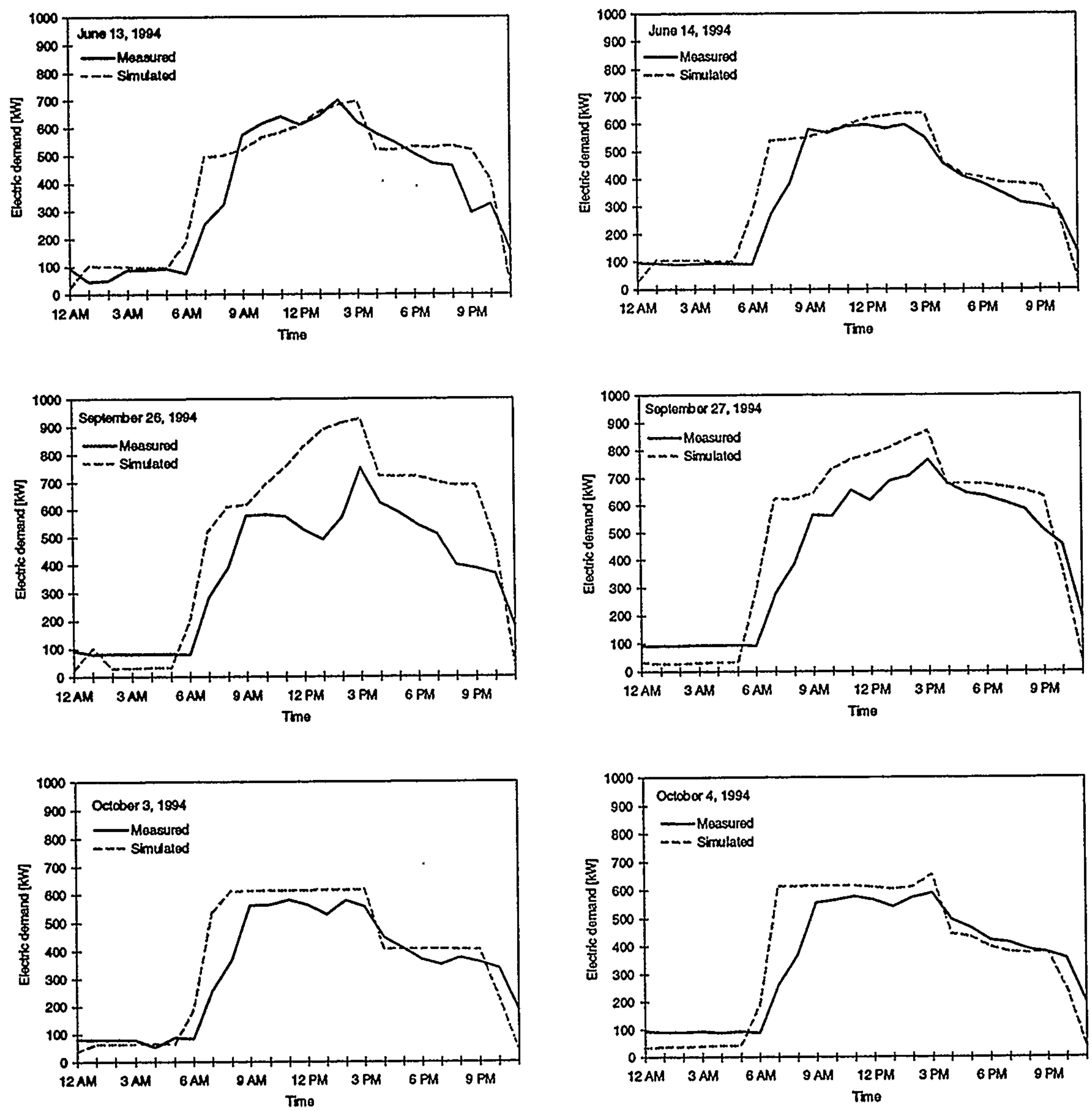


Figure 4.2 **Measured and simulated natural gas consumption for Lester B. Pearson High School, 1994**

In order to better illustrate the discrepancies between measured and calculated results, in Figure 4.3 the electricity demand was plotted for several significant days selected to illustrate typical 24 hour use patterns.



(Figure 4.3 continued on page 65)

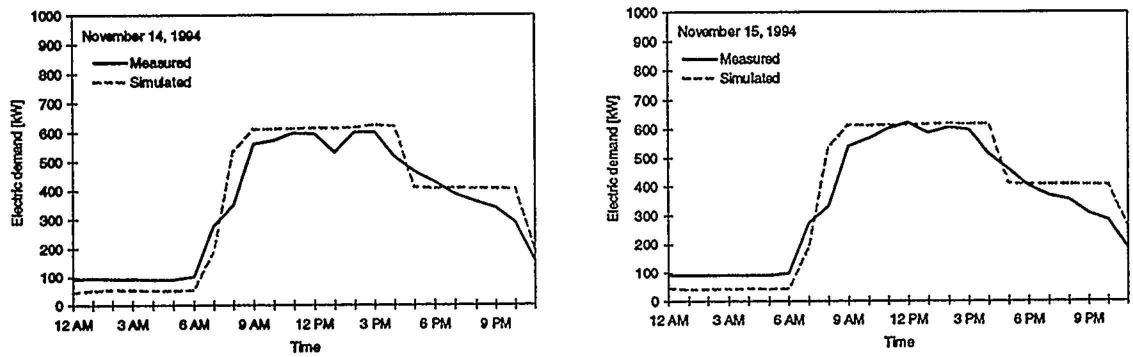


Figure 4.3 Typical 24 hour use patterns of measured and simulated electrical demand for Lester B. Pearson High School, for 8 selected days in 1994

Having in view that the comparison showed close agreement (about ±10 to 15 percent in most cases) between measured data and predicted annual, monthly and daily energy consumption it was concluded that the simulation model accurately simulates reality and it can be used to determine comparative performance of the daylit building in other Canadian regions (by using weather data for those regions) and to assess the sensitivity of the building's energy use to alternative design decisions (e.g. use of different types of glazing with different transmittance coefficients or the use of automatic lighting controls as widely as possible in the building).

Table 4.1 presents the Building Energy Performance Summary, Utility Units, (BEPU) for Lester B. Pearson High School as calculated by the DOE-2.1E computer program for the year of 1994. This report, which includes the total energy usage for the base-case building, makes it possible to review the building energy use according to energy type (electricity, natural gas, etc.) and category of use (area lighting, equipment, heating, cooling, ventilation, etc.).

Table 4.1 Simulated energy use for Lester B. Pearson High School, Calgary, 1994, validated base case

```
REPORT- BEPU  BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)
WEATHER FILE- CAL94JN WYEC2
----------------------------------------------------------------------------
```

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
SITE UNITS:	KWH	THERM **
CATEGORY OF USE		
AREA LIGHTS	442904.	0.
MISC EQUIPMT	384113.	0.
SPACE HEAT	194546.	114707.
SPACE COOL	165760.	0
HEAT REJECT	192870.	0.
PUMPS & MISC	73946.	0.
VENT FANS	713597.	0.
DOMHOT WATER	0.	2392.
TOTAL	2167737.	117099.

```
TOTAL ELECTRICITY    2167737. KWH     14.394 KWH/SQFT-YR GROSS-AREA
TOTAL NATURAL-GAS     117099. THERM    0.778 THERM/SQFT-YR GROSS-AREA

** 1 THERM = 0.1055 GJ
```

The following paragraph gives a description of each of the end uses as shown in the Building Energy Performance Summary (BEPU).

AREA LIGHTS - All electricity consumption associated with electric lighting.

MISC EQUIPMT - All electricity consumption associated with electric equipment.

SPACE HEAT - All electricity consumption associated with equipment whose primary purpose is heating.

SPACE COOL - All electricity consumption associated with cooling equipment, exclusive of condenser fans, cooling towers and pumps.

HEAT REJECT - Electrical consumption of condenser fans and cooling towers, including condenser pumps.

PUMPS & MISC - Electrical consumption of pumps and miscellaneous equipment.

VENT FANS - All electrical consumption of supply, return and exhaust fans to move air into and through the building.

DOMHOT WATER - All natural gas consumption of hot water heaters.

4.2 Analysis of the results obtained from comparative studies of the building's energy use for different Canadian locations

Table 4.2 shows the building energy performance summary for the "Lester B. Pearson" High School obtained from running the simulation model with the typical weather file for Edmonton.

Table 4.2 Simulated energy use for Lester B. Pearson High School, typical meteorological year at Edmonton

REPORT- BEPU BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)
WEATHER FILE- EDMONTON TMY

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
SITE UNITS:	KWH	THERM **
CATEGORY OF USE		
AREA LIGHTS	442904.	0.
MISC EQUIPMT	384113.	0.
SPACE HEAT	215938.	141622.
SPACE COOL	168564.	0
HEAT REJECT	183229.	0.
PUMPS & MISC	87016.	0.
VENT FANS	709775.	0.
DOMHOT WATER	0.	2392.
TOTAL	2191538.	144014.

TOTAL ELECTRICITY 2191538. KWH 14.552 KWH/SQFT-YR GROSS-AREA
TOTAL NATURAL-GAS 144014. THERM 0.956 THERM/SQFT-YR GROSS-AREA

** 1 THERM = 0.1055 GJ

The performance in Edmonton (Table 4.2) was found to be very similar to the performance in Calgary in terms of total electrical energy consumption (1 percent more for Edmonton) but differed by more than 22 percent for natural gas used for heating. The electric consumption by category of use was somewhat different for Edmonton, the space cooling electric requirements being lower by 2 percent for this location, while electric requirements for space heating were higher by 11 percent. The difference in electricity required for ventilation was insignificant (less than 1 percent).

Table 4.3 shows the building energy performance summary for the "Lester B. Pearson" High School obtained from running the simulation model with the typical weather file for Vancouver.

Table 4.3 Simulated energy use for Lester B. Pearson High School, typical meteorological year at Vancouver

```
REPORT- BEPU  BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)
WEATHER FILE- VANCOUVER TMY
```

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
SITE UNITS:	KWH	THERM **
CATEGORY OF USE		
AREA LIGHTS	442904.	0.
MISC EQUIPMT	384113.	0.
SPACE HEAT	132497.	63321.
SPACE COOL	208391.	0
HEAT REJECT	245057.	0.
PUMPS & MISC	84336.	0.
VENT FANS	741034.	0.
DOMHOT WATER	0.	2392.
TOTAL	2238331.	65714.

```
TOTAL ELECTRICITY    2238331. KWH     14.863 KWH/SQFT-YR GROSS-AREA
TOTAL NATURAL-GAS      65714. THERM    0.436 THERM/SQFT-YR GROSS-AREA

** 1 THERM = 0.1055 GJ
```

For Vancouver (Table 4.3) the distribution of the building energy use according to energy type (electricity and natural gas) and category of use (area lighting, equipment, heating, cooling, ventilation, etc.) was also different. While the total electricity use differed by only 3 percent, the natural gas consumption in Calgary was almost double the level for Vancouver. Electric requirements for space cooling were about 26 percent greater for Vancouver while space heating electric requirements differed by 32 percent, being higher for Calgary.

The following figures [Figure 4.4, Figure 4.5 and Figure 4.6] illustrate in a graphic form the similarities and differences that resulted from running the computer model for the three locations mentioned above. While Figures 4.4 and 4.5 show the building energy use according to energy type (electricity and natural gas) and category of use (area lighting, equipment, heating, cooling, ventilation, etc.), Figure 4.6 presents the total annual energy use per unit floor area.

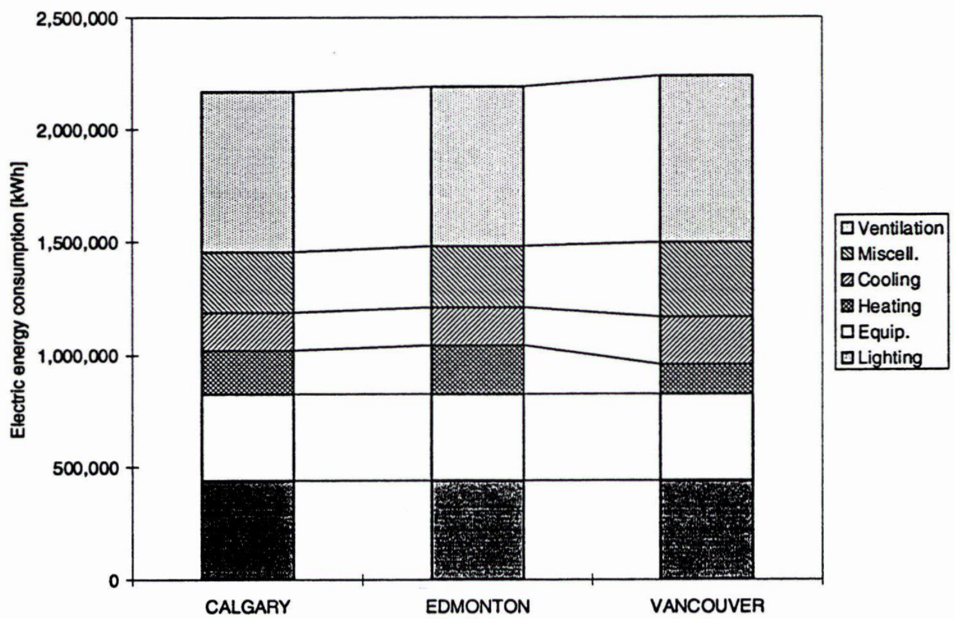


Figure 4.4 **Simulated electric energy use for Lester B. Pearson High School (1994 weather file for Calgary, typical meteorological years for Edmonton and Vancouver)**

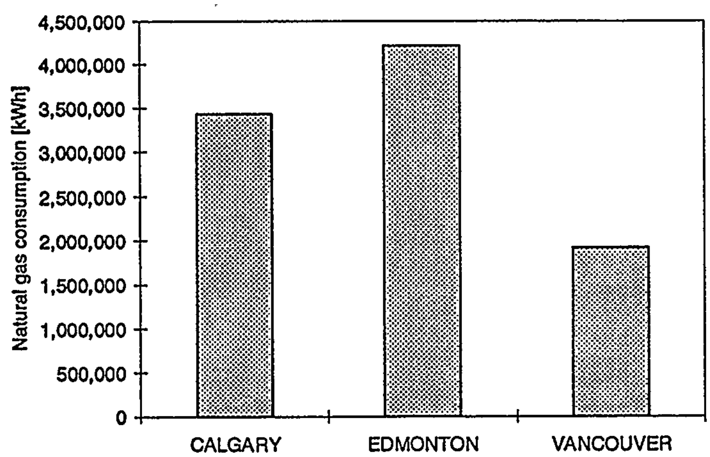


Figure 4.5 Simulated natural gas consumption for Lester B. Pearson High School (1994 weather file for Calgary, typical meteorological years for Edmonton and Vancouver)

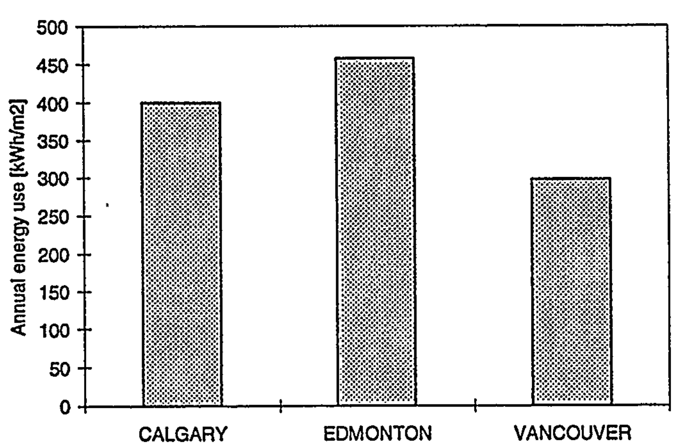


Figure 4.6 Simulated annual energy use for Lester B. Pearson High School (1994 weather file for Calgary, typical meteorological years Edmonton and Vancouver)

In all locations the dominant load was the operation of fans for ventilation, accounting for about 33 percent of total electricity use.

Lighting electricity use accounted for about 20 percent of total electricity use in all three locations. The lighting power density at the school is about 20 W/m^2. The annual energy use for lighting was found to be about 32 kWh/m^2 which is less than half the 75 kWh/m^2 that would be incurred if the "20 W/m^2 lighting power density" were operated 3750 hours per year (duration chosen to allow comparison with values reported in the literature [6,7] that assume about 14 hours of lighting use per working day and 22 working days per month). The 32 kWh/m^2 is well above the 20 kWh/m^2 reported for daylit office buildings in the literature [6,7]. Much of the load appears to be in classrooms (almost 80 percent from the total electrical load for lighting; percentage determined from running the simulation model with the lighting loads corresponding to classrooms only) which are operated only about 1400 hours a year (8:30-15:30, Monday to Friday during the regular school year). Observations and discussions with school staff indicate that electric lighting is commonly used when spaces are occupied even when daylight is adequate.

Heating and cooling loads accounted for less than 10 percent each, for all three locations. Another major end-use for this building appears to be the equipment. The school is equipped with heavy machinery and a high number of computers which account for almost 18 percent of the total electricity consumption.

4.3 Analysis of the results obtained from parametric studies of the building's energy use

Following are the results obtained from the parametric studies conducted to determine the real contribution of the electric lighting and glazing to the total energy consumption. Table 4.4 illustrates the effect the elimination of all electric lighting had on the total energy consumption.

Table 4.4 Simulated energy use for Lester B. Pearson High School, Calgary, 1994. All electric lighting eliminated from the simulation model

REPORT- BEPU BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)
WEATHER FILE- CAL94JN WYEC2

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
SITE UNITS:	KWH	THERM **
CATEGORY OF USE		
MISC EQUIPMT	384113.	0.
SPACE HEAT	199362.	122539.
SPACE COOL	146366.	0
HEAT REJECT	191317.	0.
PUMPS & MISC	69135.	0.
VENT FANS	673666.	0.
DOMHOT WATER	0.	2392.
TOTAL	1663959.	124931.

TOTAL ELECTRICITY 1663959. KWH 11.049 KWH/SQFT-YR GROSS-AREA
TOTAL NATURAL-GAS 124931. THERM 0.830 THERM/SQFT-YR GROSS-AREA

** 1 THERM = 0.1055 GJ

Compared to the base building data, eliminating all electric lighting loads would result in a 23 percent reduction in annual electricity consumption and a 7 percent increase in natural gas consumption. The electric requirements for space cooling were reduced by 12 percent while the requirements for space heating increased by only 2.5 percent. The electricity consumed by ventilation fans decreased by 6 percent.

The following table (Table 4.5) illustrates the effect the elimination of all glazed surfaces had on the total energy consumption.

Table 4.5 Simulated energy use for Lester B. Pearson High School, Calgary, 1994. All glazed areas eliminated from the simulation model

REPORT- BEPU BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)
WEATHER FILE- CAL94JN WYEC2

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
SITE UNITS:	KWH	THERM **
CATEGORY OF USE		
AREA LIGHTS	442904.	0.
MISC EQUIPMT	384113.	0.
SPACE HEAT	183108.	106873.
SPACE COOL	133963.	0.
HEAT REJECT	192880.	0.
PUMPS & MISC	71269.	0.
VENT FANS	629507.	0.
DOMHOT WATER	0.	2392.
TOTAL	2037744.	109265.

TOTAL ELECTRICITY 2037744. KWH 13.531 KWH/SQFT-YR GROSS-AREA
TOTAL NATURAL-GAS 109265. THERM 0.726 THERM/SQFT-YR GROSS-AREA
** 1 THERM = 0.1055 GJ

Compared to the base building data, eliminating all glazing loads would result in a 6 percent reduction in annual electricity consumption and an almost 7 percent reduction in natural gas consumption. As expected, the most affected were the space heating and cooling loads which showed a reduction in electricity consumption of 6 and respectively 19 percent compared to the base building. The electricity consumption for ventilation fans was also reduced by 12 percent.

The following table (Table 4.6) shows the effect the elimination of the main ventilation system had on the total energy consumption. The two ventilation systems related to the greenhouse and the boiler-room were not eliminated from the model due to their small impact on the total building energy consumption which, compared to the main ventilation system, was found to be insignificant (less than 6 percent).

Table 4.6 Simulated energy use for Lester B. Pearson High School, Calgary, 1994. Main ventilation system eliminated from the simulation model

```
REPORT- BEPU  BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)
WEATHER FILE- CAL94JN WYEC2
---------------------------------------------------------------------------
                 ENERGY TYPE:               ELECTRICITY    NATURAL-GAS
                 SITE UNITS:                   KWH           THERM **

                 CATEGORY OF USE
                 ---------------

                 AREA LIGHTS                 442904.            0.

                 MISC EQUIPMT                384113.            0.

                 SPACE HEAT                  109774.        46321.

                 SPACE COOL                   54968.            0

                 HEAT REJECT                 178136.            0.

                 PUMPS & MISC                  8036.            0.

                 VENT FANS                    79312.            0.

                 DOMHOT WATER                     0.         2392.
                                           ----------    ----------

                 TOTAL                      1257243.        48713.

TOTAL ELECTRICITY     1257243. KWH        8.348 KWH/SQFT-YR GROSS-AREA
TOTAL NATURAL-GAS       48713. THERM      0.323 THERM/SQFT-YR GROSS-AREA

** 1 THERM = 0.1055 GJ
```

Compared to the base case, this simulation shows significant reductions for both annual electricity and natural gas consumption (42 percent and respectively 58 percent).

Figure 4.7 shows the annual electricity consumption for the base building and for the base building with each of the variables eliminated. As mentioned before, each individual elimination parametric bar shows the overall impact the variable in question (electric lighting, glazing, ventilation) has on all the environmental-control systems (heating, cooling, etc.)

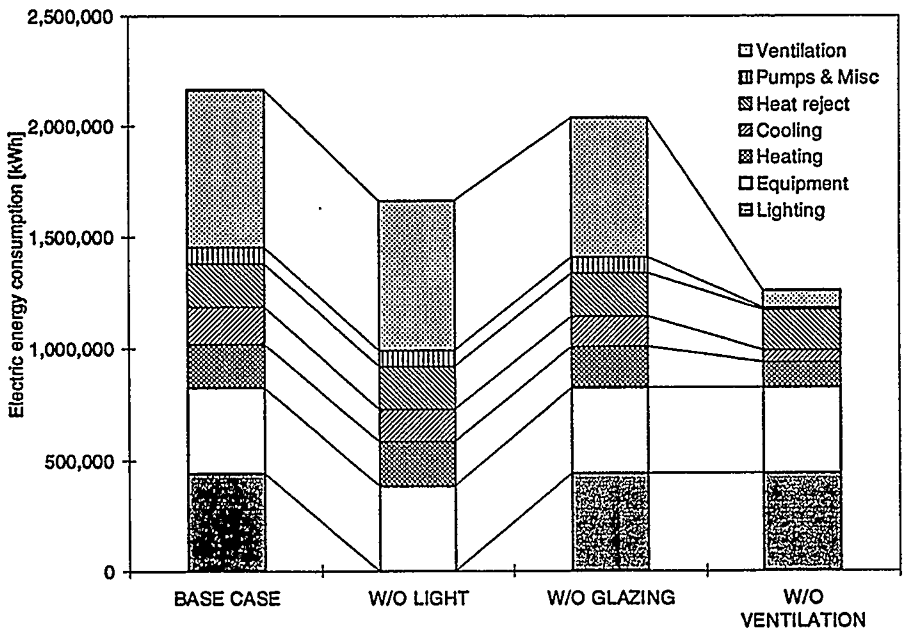


Figure 4.7 **Annual simulated electricity consumption for Lester B. Pearson High School base building, elimination parametrics**

Figure 4.8 shows the annual natural gas consumption for the base building and for the base building with each of the variables eliminated.

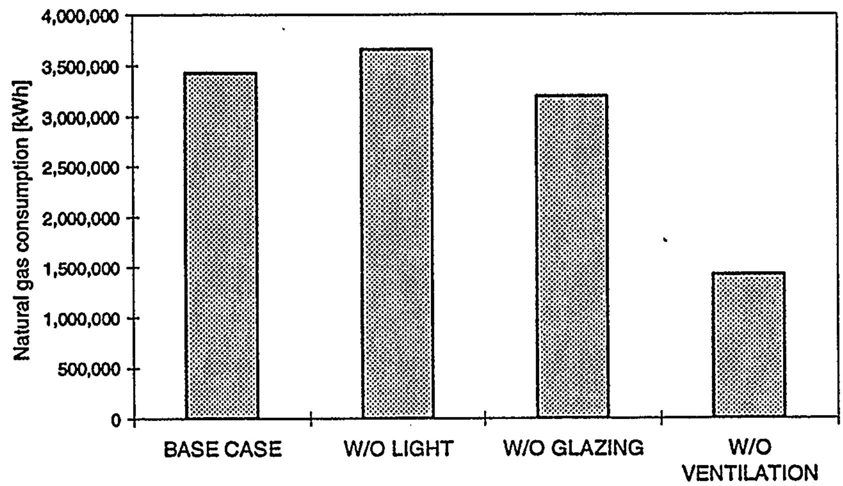


Figure 4.8 Annual simulated natural gas consumption for Lester B. Pearson High School base building, elimination parametrics

Having in view that the results obtained by using the elimination parametrics technique did not show significant reductions in annual electrical and natural gas consumption due to changes in lighting loads and heating- losses and gains through glazing, it was concluded that the major need for energy in this building is for electricity and natural gas related to the ventilation of the main spaces (cooling and heating of the outdoor air and the distribution of the building's flow rate).

Finally, in order to investigate the potential for displacement of electric lighting by daylighting, a simulation was run to determine what effect the introduction of daylight-linked lighting controls would have on the electric energy used for lighting. The effect of this retrofit on the total electricity and natural gas consumption was also analyzed. In the simulation it was assumed that no electric lighting (emergency lighting excepted) was necessary during day peak-hours in all the south-facing zones. This extreme case allowed for an analysis of the maximum energy savings that could be obtained by substituting daylight for electric light. The base case (Table 4.1) was considered in this simulation as a non-daylit building because no controls are used in reality to alter electric lighting levels based on interior daylight illuminance.

Table 4.7 and Figure 4.9 show the results of this last simulation:

Table 4.7 Simulated energy use for Lester B. Pearson High School, Calgary, 1994. Daylit building case

REPORT- BEPU BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)
WEATHER FILE- CAL94JN WYEC2

ENERGY TYPE:	ELECTRICITY	NATURAL-GAS
SITE UNITS:	KWH	THERM **
CATEGORY OF USE		
AREA LIGHTS	348508.	0.
MISC EQUIPMT	384113.	0.
SPACE HEAT	195226.	116313.
SPACE COOL	162387.	0
HEAT REJECT	192927.	0.
PUMPS & MISC	73205.	0.
VENT FANS	706165.	0.
DOMHOT WATER	0.	2392.
TOTAL	2062531.	118706.

TOTAL ELECTRICITY	2062531. KWH	13.695 KWH/SQFT-YR GROSS-AREA	
TOTAL NATURAL-GAS	118706. THERM	0.788 THERM/SQFT-YR GROSS-AREA	

** 1 THERM = 0.1055 GJ

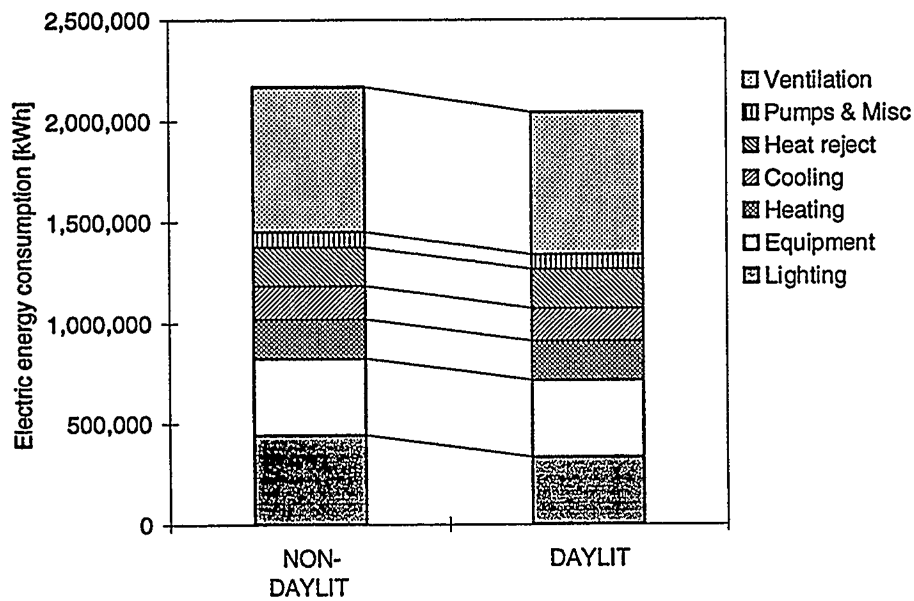


Figure 4.9 Annual simulated electricity consumption for Lester B. Pearson High School as a daylit and non-daylit building

Compared to the base building data, while the increase in natural gas consumption was insignificant (less than 2 percent), the savings achieved in the annual electrical energy through the introduction of daylight-linked controls were about 6 percent. The space cooling loads were reduced by 2.5 percent while the increase of the heating loads was negligible. The reduction in electricity used for operation of fans for ventilation was also negligible (less than 1.5 percent). The biggest savings were achieved in the electric lighting load which showed reductions of almost 25 percent.

The following table summarizes the results of the research.

Table 4.9 Summary of results

	Lighting (kWh)	Equip. (kWh)	Heating (kWh)	Cooling (kWh)	Miscell. (kWh)	Ventilation (kWh)	Total Elec. (kWh)	Gas (GJ)
Base case	442904	384113	194546	165760	266816	713597	2167736	12354
Edmonton	442904	384113	215938	168564	270245	709775	2191539	15193
Percent	0.00	0.00	11.00	1.69	1.29	0.54	1.10	22.98
Base case	442904	384113	194546	165760	266816	713597	2167737	12354
Vancouver	442904	384113	132497	208391	329393	741034	2238332	6933
Percent	0.00	0.00	31.89	25.72	23.45	3.84	3.26	43.88
Base case	442904	384113	194546	165760	266816	713597	2167737	12354
w/o Electric Lighting	0.00	384113	199362	146366	260452	673666	1663959	13180
Percent	100.00	0.00	2.48	11.70	2.39	5.60	23.24	6.69
Base case	442904	384113	194546	165760	266816	713597	2167737	12354
w/o Glazing	442904	384113	183108	133963	264149	629507	2037744	11527
Percent	0.00	0.00	5.88	19.18	1.00	11.78	6.00	6.69
Base case	442904	384113	194546	165760	266816	713597	2167737	12354
w/o Ventilation	442904	384113	109774	54968	186172	79312	1257243	5139
Percent	0.00	0.00	43.57	66.84	30.22	88.89	42.00	58.40
Base case	442904	384113	194546	165760	266816	713597	2167737	12354
Daylit building	333004	384113	195372	161650	266123	704307	2044569	12553
Percent	24.81	0.00	0.42	2.48	0.26	1.30	5.68	1.61

In the above table all the highlighted cells represent percentages of increased energy consumption, the rest representing percentages of energy savings.

CHAPTER 5
SUMMARY AND CONCLUSIONS

5.1 Summary of work completed

The objective of this study was to provide information on the performance of a selected daylit building located in Calgary, in order to assess the potential contribution of daylighting to energy conservation. The hypothesis of the study was that daylighting, when used in conjunction with automatic controls, has the potential to provide greater than 30 percent reductions in lighting energy use.

The DOE-2 building energy simulation program was used to analyze the energy use and demand levels of the building as it now exists, in order to create a base case to which energy conserving retrofits were to be compared. Simulation results were compared with site-measured data to ensure accuracy in predicting the energy requirements.

In order to investigate the applicability of daylighting designs in other parts of Canada, the validated computer model was used to determine comparative performance for Edmonton and Vancouver.

Once validated, the model was used to identify the techniques needed to improve the performance of the daylit building. Parametric studies were conducted and the overall contribution of each energy end use to the total energy use was determined. Advanced daylighting techniques such as the use of daylight-linked lighting controls and alternative glazing were investigated as possible retrofits for the existing building.

5.2 Summary of results and conclusions

Several conclusions can be drawn from the foregoing results of this study. The major conclusions are as follows:

- Significant potential exists for energy savings in buildings through the use of electric lighting controls. A maximum of 25 percent savings in lighting energy use could be achieved at Lester B. Person High School by substituting daylighting for electric lighting through the utilization of daylight-linked controls. This estimation is very close to the hypothesis of this study, which assumed that daylighting has the potential to provide greater than 30 percent reductions in lighting energy use. However, this would translate to only 6 percent savings in the total annual electric energy use.

- Cooling and heating loads were not significantly influenced by the use of daylighting. The computer simulation showed that the introduction of daylight-linked controls would decrease the cooling load by a maximum 2.5 percent, while the heating load would remain almost unchanged.

- The annual electric and natural gas consumption were not significantly influenced by the elimination of all glazing from the simulation model (boundary case). This suggests that the thermal loads, as well as the annual electric and natural gas consumption, would not significantly be affected through the use of other types of glazing with lower transmittance coefficients.

- The high energy consumption for this building was shown to be due to the high levels of ventilation rates existing in the building. While the lighting power density is about 20 W/m^2, which from simulation results translates to an annual energy use for lighting of about 32 kWh/m^2 and about 1600 hours of operation per year, the fan power density is 27 W/m^2, which translates to an annual energy use of 51 kWh/m^2 used for ventilation and almost 1900 hours of fan operation per year at rated capacity (fans are in operation for more than 4000 hours per year but since they operate at variable speed this would translate in 1900 hours of operation at maximum capacity). This is contrary to the findings of some studies that showed electric lighting to be one of the major energy consumers in office buildings, accounting for as much as 50 percent of the total electric energy use [2]. However, this does not mean that the electric lighting load is very low in this building when compared to similar buildings. It means rather that, due to the high ventilation rates, this load appears to be too small to be reduced by means of daylight-linked lighting controls since the effect of using such controls would only reduce the total electricity and natural gas consumption by less than 5 percent.

- The heating and cooling loads are also influenced by the high ventilation rates existing in the building. Outdoor air accounts for about 30 percent of the building's flow rate and the energy associated with heating and cooling this air represents a significant load in both summer and winter seasons, accounting for more than 50 percent of the building's thermal loads.

- The annual electric energy use of the building did not seem to be affected by the differences in climate for the three locations studied. The changes in annual electric energy use varied by less that 3.5 percent. This was to be expected having in view that, for all three locations, the dominant load was the electricity consumed by the ventilation fans to move the air throughout the building.

- The annual natural gas use, as well as the heating and cooling loads, were however influenced by the climate in which the building is located. The changes in natural gas consumption were between 20 and 45 percent and the heating and cooling loads changed with percentages ranging from 11 to 32 percent.

5.3 General conclusions

The incorporation of daylighting in any building design affects the energy consumption of buildings in two ways. First, because the natural illumination from daylighting can make substantial contributions to indoor illumination levels, important energy savings can be achieved by reducing the electric energy required for illumination. However, failing to provide the right type of lamps and electric lighting controls in a daylit building can lead to excessive energy use when illumination from natural light is adequate. As it was shown in this study, the occupants of Lester B. Pearson High School (which is mainly equipped with fluorescent lamps in the classrooms and HID lamps in the lounge areas, corridors and gymnasiums) seldom switch off the electric lighting. Since this mainly occurs in the common areas of the building where the HID lamps are installed, this conduct can also be due to the long warm-up time needed by these lamps, which makes the manual controls less tempting to use. Also, the fact that the lamps located on the south-facing corridors are wired on the same electric circuits with the lamps located on the north-facing corridors makes the manual controls impracticable to use even when daylight on the southern corridors is sufficient. These zones receive different quantities of daylight and should have been wired accordingly.

The presence of HID and fluorescent lamps and the fact that electric lighting represents a small portion of the total electricity use would make lighting control systems ineffective in this building. HID lamps do not operate very effectively in combination with on/off or dimming systems due to their long start-up time and the fact that usually their rate of luminous output is not equal to the rate of input energy. This last aspect also applies to fluorescent lamps. For most fluorescent and HID lamps the rate of luminous output is not equal to the rate of input energy because a certain amount of input power is needed to cause the lamps to arc initially and operate whereas for incandescent lamps the luminous output is proportional to the input power applied to the lamp (e.g. If 15 percent of the maximum input power is applied to an incandescent lamp, the luminous output would be about 15 percent of the standard operating level of light, while for most fluorescent lamps minimum lamp output occurs at 25 percent of input power).

Second, the use of large fenestration areas can lead to significant heat loses during winter months, when more heating energy may be required, or excessive heat gains during warm months when more energy may be needed for cooling. Having in view that one of the main reasons for introducing daylighting into a building is to save energy, the goal of any design should be to impact positively on both lighting and thermal systems. An energy efficient daylighting design cannot be accomplished by considering lighting issues only. Oversizing the main mechanical system (as it appears to be the case for the building studied) will also lead to excessive energy consumption. Having in view that the almost 8 air changes per hour in this building are closer to the higher limit of the ASHRAE recommendations for air circulation in office buildings rather than to the lower one (4 to 10 air changes/hour [30]), confirms the practice of sometimes oversizing the main mechanical system for the sake of air quality (instead of using cheaper means for ventilating noxious spaces through local exhausts). This is also confirmed by the fact that the outdoor air requirement for ventilation in this building is between 2 and 3 times the value recommended in the ASHRAE standards [31] for educational facilities: 8-10 l/s per person as compared to about 23 l/s per person calculated for the 1500 occupants of the Lester B. Pearson High School.

The key to achieving overall energy savings in daylit buildings would be to provide daylight as closely as possible to the recommended illuminance level for the space and to size the mechanical system accordingly. If daylight is introduced at levels exceeding the desired illuminance levels, excessive thermal gain or losses may result. Decreasing glass areas can lead to an extensive use of electric lighting systems. Undersizing the mechanical system in a daylit building can have a negative impact on the occupant's comfort. Oversizing the mechanical system can generate an excessive energy use.

In the case of Lester B. Pearson High School, the results show that the key method to significantly reduce the total energy consumption would be to decrease the outdoor air requirement for ventilation to the level recommended in the ASHRAE standard [31] and to reduce the total air flow in the building to the minimum value [30] that would satisfy the acceptable indoor air quality criterion.

5.4 Recommendations for future work

The expectation of future energy shortages and the high costs of energy have made energy conservation an imperative matter. As seen in this study, due to the multitude and complexity of the factors that affect daylighting designs, better daylit buildings can be built only after a very good understanding and knowledge about the way this type of buildings perform. Since all the factors that affect them are inter-related, the interaction among them should be addressed and analyzed in a deeper detail.

A specific example could be the tradeoff analysis between daylighting and HVAC systems in buildings. The assumption that reducing the transmittance characteristics of glazing could lead to energy savings due to lower solar gains, and therefore lower cooling loads, might be inaccurate for some buildings. The offset of electric lighting energy use by daylighting may sometimes be more critical than achieving maximum reductions in solar gains. Monitoring of real HVAC installations could help determine how, when and where daylighting can be used to its best advantage.

The climate in which the building is located has also a significant impact on the total energy use of a building. Factors such as outdoor temperature and humidity, as well as daylighting availability and percentage of cloud cover, are factors that have to be taken into account when analyzing the energy performance of buildings. Daylighting designs that appear to be energy efficient in one climate may be energy inefficient in another climate (e.g. the amount of clear and overcast days that would typically occur for a location, as well as other atmospheric conditions, such as atmospheric moisture and dust, significantly affect the amount of daylight that will be available and therefore, building designs should target accurately the climatic conditions that predominate at each site). Studies could be conducted for regions where research on daylighting has not been performed to determine the potential savings of daylighting designs for these specific locations.

Even if each building is in a way an individual case that requires detailed analysis of energy costs due to lighting, heating, cooling, availability of daylight and cost of controls, information on performance of representative systems would be of a great help to professionals in their efforts to make proper use of daylighting and daylighting controls in their designs. As very well stated by a couple of researchers "It is essential that the experience in the field - the real and final test - be recorded and communicated to others as a contribution to the body of knowledge essential for continued improvement in building" [16]. The answer to the question: "Was the predicted energy performance achieved?" should always be the final test of any daylighting design.

REFERENCES

1. Transalta Utilities. 1993. Annual Report, Calgary: Transalta Utilities, p: 40.

2. Ternoey, S., L. Bickle, C. Robbins, R. Busch, and K. McCord. 1985. The design of energy-responsive commercial buildings. New York: John Wiley & Sons, Inc.

3. ASHRAE. 1989. "Energy efficient design of new buildings except new low-rise residential buildings", ASHRAE/IES Standard 90.1-1989. Atlanta: American Society of Heating, Refrigerating and Air-conditioning Engineers.

4. IESNA Lighting Handbook - Reference & Application Volume. 1993. New York: Illuminating Engineering Society of North America.

5. Johnson, C. A., R. W. Besant, and G. J. Schoenau. 1989. "Energy-economic trade-off studies recommended to enhance the use of daylighting in large office buildings in Canada," Renewables: A Clean Energy Solution. Ottawa: Solar Energy Society of Canada, p: 25-31.

6. Heap, L. J., Palmer, J., and Hildon, A. 1988. "Redistributed daylight - A performance assessment," Proceedings of National Lighting Conference and Daylighting Colloquium, Cambridge, UK: Robinson College, p: 243-256.

7. Warren, M., S. Selkowitz, O. Morse, C. Benton, and J. E. Jewell. 1986. "Lighting system performance in an innovative daylighted structure: an instrumented study", Zdepski, M.S. and McCluney, R. (eds.), Proceedings of the 1986 International Daylighting Conference, McLean, VA (1508 Emerson Ave): 1986 International Daylighting Conference Organizing Committee, p: 215-221.

8. Andersson, B., M. Adegran, T. Webster, W. Place, R. Kammerud, and P. Albrand. 1987. "Effects of daylighting options on the energy performance of two existing passive commercial buildings", Building and Environment, Vol. 22, No. 1, p: 3-12.

9. Masek, W.S., and J.A. Tichy. 1993. "Determining the effect of lighting on the thermal behavior of buildings using a simplified computer model with DOE-2", Proceedings of the 1993 Annual Meeting of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Denver, CO, USA.

10. Robbins, C.L. 1986. "Daylighting: design and analysis", Van Nostrand Reinhold Company.

11. Markus, T.A. 1967a. The function of windows: a reappraisal. Building Science 2, p: 97-121.

12. Manning , P. 1965. Office design: A study of environment. Liverpool, England: Liverpool University Press.

13. McFadden, P. and M. Fontoynont. 1987. "Occupant response to daylighting: results from a valence school," Proceedings of the 1987 Passive Solar Conference. Boulder, CO. The American Solar Energy Society, p: 200-202.

14. Love, J.A., 1995. "Field performance of daylighting systems using photoelectric controls". Proceedings of the Third European Conference on Energy Efficient Lighting.

15. Mistrick, R.G. 1993. "Daylighting", IESNA ED-150.10, Toronto: Illuminating Engineering Society of North America.

16. Hutcheon, N.B., G.O.P. Handgord. 1983. "Building science for a cold climate", John Wiley & Sons, p: 48.

17. IESNA Lighting Handbook - Reference Volume. 1981. New York: Illuminating Engineering Society of North America.

18. Miller, B., J. McHugh, D. Hittle, P. Burns, and J. Brinkley. 1992. " Initial energy conserving design of a low energy office building". Sol Eng 92. ASME, New York , NY, USA, p:1155-1160.

19. Rubinstein, F., G. Ward, and R.Verderber. 1989. "Improving the performance of photo-electrically controlled lighting systems", Journal of the Illuminating Engineering Society , Vol. 18, No.1, p:70-94.

20. Rubinstein, F., M. Siminovitch, and R. Verderber. 1993. "Fifty percent energy savings with automatic lighting controls". IEEE Transactions on Industry Applications, Vol. 29, No. 4, p: 668-773.

21. Verderber, R., O. Morse, and J. Jewell. 1989. "Building design: impact on the lighting control system for a daylighting strategy." IEEE Transactions on Industry Applications, Vol. March, p: 198-202.

22. Treado, S.J., and J.W. Bean. 1990. "Experimental evaluation of lighting/HVAC interaction". Proceedings of the 1990 Annual Meeting of the ASHRAE, St. Louis, MO, USA. ASHRAE Transactions pt.2 Publ. by ASHRAE, Atlanta , GA, USA, p: 773-779.

23. Diamond, S. C., C. C. Charlene, and D. B. Hunn. 1986. "DOE-2 Verification Project-Phase 1".

24. Johnson, C. A., R. W. Besant, and G. J. Schoenau. 1989. "Energy-economic trade-off studies recommended to enhance the use of daylighting in large office buildings in Canada," Renewables: A Clean Energy Solution. Ottawa: Solar Energy Society of Canada, p: 25-31.

25. Johnson, C. A., and R. W. Besant. 1993. "Economic analysis of daylit and non-daylit office buildings in Canada". Proceedings of the 1993 Annual Meeting of the ASHRAE, Denver, CO, USA.

26. Love, J.A. 1994. "Field assessment of daylighting systems and design tools". Report submitted to Natural Resources Canada.

27. "DOE-2, Reference Manual (Version 2.1E)". 1994. Lawrence Berkeley Laboratory, Berkeley, CA.

28. ASHRAE Handbook. 1989. "Fundamentals", ASHRAE, Atlanta, GA.

29. National Research Council of Canada. 1990. “Supplement to the National Building Code of Canada”.

30. ASHRAE Handbook. 1995. "HVAC Applications", ASHRAE, Atlanta, GA.

31. ASHRAE Standard 62-1989. “Ventilation for Acceptable Indoor Air Quality”, ASHRAE, Atlanta, GA.

APPENDIX

Input file of the DOE-2 computer simulation model - Base case

```
INPUT LOADS ..


TITLE      LINE-1   * LESTER B. PEARSON HIGH SCHOOL *..
DIAGNOSTIC            CAUTIONS ..
ABORT                 ERRORS ..
LOADS-REPORT          SUMMARY           = (ALL-SUMMARY)
                      HOURLY-DATA-SAVE = FORMATTED ..
RUN-PERIOD            JAN 1 1994 THRU DEC 31 1994 ..
BUILDING-LOCATION     LATITUDE          = 51.07
                      LONGITUDE         = 114.13
                      ALTITUDE          = 0
                      TIME-ZONE         = 7
                      DAYLIGHT-SAVINGS = YES
                      HOLIDAY           = YES
                      AZIMUTH           = 0
                      GROSS-AREA        = 150600
                      HEAT-PEAK-PERIOD = (7,23)
                      COOL-PEAK-PERIOD = (7,23) ..

                      $ MATERIALS

W1   = LAYERS        INSIDE-FILM-RES = 0.68
                     MATERIAL = (BK01,AL21,IN02,BP03,CB31) ..

W2   = LAYERS        LIKE W1
                     MATERIAL = (BK01,AL21,IN02,BP03,CB36) ..

W3   = LAYERS        LIKE W1
                     MATERIAL = (AS01,IN02,BP03,GP01) ..

W8   = LAYERS        LIKE W1
                     MATERIAL = (AL21,IN02,BP03,GP01,GP01) ..

W12 = LAYERS         LIKE W1
                     MATERIAL = (BK01,AL21,IN02,BP03,CC26,IN35) ..

ROOF1 = LAYERS       INSIDE-FILM-RES = 0.61
                     MATERIAL = (RG01,IN37,GP02) ..

                       $ WALLS AND ROOF CONSTRUCTIONS

WALL-1   = CONS      LAYERS = W1 ..
WALL-2   = CONS      LAYERS = W2 ..
WALL-3   = CONS      LAYERS = W3 ..
WALL-8   = CONS      LAYERS = W8 ..
```

```
WALL-12 = CONS       LAYERS = W12 ..
RF-1    = CONS       LAYERS = ROOF1 ..

                       $ GLASS DESCRIPTION

G1 = GLASS-TYPE      GLASS-TYPE-CODE = 2001 ..

G2 = GLASS-TYPE      GLASS-TYPE-CODE = 2219 ..


                        $ OCCUPANCY SCHEDULE

OC1      = DAY-SCHEDULE (1,7)(0)(8,17)(0.9)(18,22)(0.4)(23,24)(0) ..
OC2      = DAY-SCHEDULE (1,10)(0)(11,17)(0.2)(18,24)(0) ..
OC3      = DAY-SCHEDULE (1,24)(0) ..
PEOPLE1 = WEEK-SCHEDULE (MON,FRI) OC1
                         (WEH) OC2 ..
PEOPLE2 = WEEK-SCHEDULE (MON,FRI) OC2
                         (WEH) OC3 ..
OCCUP    = SCHEDULE      THRU JUN 15 PEOPLE1
                         THRU AUG 31 PEOPLE2
                         THRU DEC 31 PEOPLE1 ..

                        $ LIGHTING  SCHEDULE

L1       = DAY-SCHEDULE (1,7)(0.05)(8,16)(0.5)(17,22)(0.4)(23,24)(0.08)
..
L2       = DAY-SCHEDULE (1,10)(0.01)(11,17)(0.1)(18,24)(0.01) ..
L3       = DAY-SCHEDULE (1,24)(0.01) ..
L4       = DAY-SCHEDULE (1,7)(0.05)(8,16)(0.2)(17,21)(0.1)(22,24)(0.05)
..
L5       = DAY-SCHEDULE (1,7)(0.05)(8,22)(0.15)(23,24)(0.08) ..
LIGHTS1 = WEEK-SCHEDULE (MON,FRI) L1
                         (WEH) L2 ..
LIGHTS2 = WEEK-SCHEDULE (MON,FRI) L2
                         (WEH) L3 ..
LIGHTS3 = WEEK-SCHEDULE (MON,FRI) L4
                         (WEH) L3 ..
LIGHTS4 = WEEK-SCHEDULE (MON,FRI) L5
                         (WEH) L2 ..
LT1      = SCHEDULE      THRU MAR 31 LIGHTS1
                         THRU JUN 30 LIGHTS4
                         THRU AUG 31 LIGHTS2
                         THRU SEP 15 LIGHTS3
                         THRU DEC 31 LIGHTS1 ..

                        $ EQUIPMENT SCHEDULE

ES1      = DAY-SCHEDULE (1,7)(0)(8,16)(0.3)(17,22)(0.05)(23,24)(0) ..
ES2      = DAY-SCHEDULE (1,10)(0)(11,16)(0.01)(17,24)(0) ..
ES3      = DAY-SCHEDULE (1,24)(0) ..
EQUIP1   = WEEK-SCHEDULE (MON,FRI) ES1
                         (WEH) ES2 ..
EQUIP2   = WEEK-SCHEDULE (ALL) ES3 ..
EQUIP3   = WEEK-SCHEDULE (ALL) ES2 ..
EQ1      = SCHEDULE      THRU JUN 15 EQUIP1
                         THRU AUG 31 EQUIP2
                         THRU SEP 15 EQUIP3
```

```
                              THRU DEC 31 EQUIP1 ..

                            $ INFILTRATION SCHEDULE

I1     = DAY-SCHEDULE (1,6)  (1)  (7,23)  (0.2)  (24)  (1) ..
I2     = DAY-SCHEDULE (1,7)  (1)  (8,17)  (0.2)  (18,24)  (1) ..
I3     = DAY-SCHEDULE (1,8)  (1)  (9,13)  (0.2)  (14,24)  (1) ..
I4     = DAY-SCHEDULE (1,8)  (1)  (9,15)  (0.2)  (16,24)  (1) ..
INFIL1 = WEEK-SCHEDULE (MON,FRI) I1
                       (SAT)     I2
                       (SUN)     I3
                       (HOL)     I3 ..
INFIL2 = WEEK-SCHEDULE (MON,FRI) I1
                       (WEH)     I3 ..
INFIL3 = WEEK-SCHEDULE (MON,FRI) I4
                       (WEH)     I3 ..
INF    = SCHEDULE      THRU JUN 15 INFIL1
                       THRU JUN 30 INFIL2
                       THRU AUG 31 INFIL3
                       THRU DEC 15 INFIL1
                       THRU DEC 31 INFIL2 ..

                            $ SHADING SCHEDULE

SHADE1     = DAY-SCHEDULE (1,24) (0.1) ..
SHADE2     = DAY-SCHEDULE (1,24) (0.9) ..
SHADE3     = DAY-SCHEDULE (1,24) (0.5) ..
SHA1       = WEEK-SCHEDULE (ALL) SHADE1 ..
SHA2       = WEEK-SCHEDULE (ALL) SHADE2 ..
SHA3       = WEEK-SCHEDULE (ALL) SHADE3 ..
SHADE-N    = SCHEDULE THRU DEC 31 SHA1 ..
SHADE-S    = SCHEDULE THRU DEC 31 SHA2 ..
SHADE-E/W  = SCHEDULE THRU DEC 31 SHA3 ..

                            $ SPACE DESCRIPTION

ZONE1      = SPACE-CONDITIONS   TEMPERATURE        = (73)
                                PEOPLE-SCHEDULE    = OCCUP
                                NUMBER-OF-PEOPLE   = 20
                                PEOPLE-HEAT-GAIN   = 450
                                LIGHTING-SCHEDULE  = LT1
                                LIGHTING-TYPE      = SUS-FLUOR
                                LIGHTING-KW        = 10
                                EQUIP-SCHEDULE     = EQ1
                                EQUIPMENT-KW       = 0
                                INF-SCHEDULE       = INF
                                INF-METHOD         = AIR-CHANGE
                                AIR-CHANGES/HR     = 0.2
                                ZONE-TYPE          = CONDITIONED ..

BSMT       = SPACE              SPACE-CONDITIONS   = ZONE1
                                AREA               = 4011
                                VOLUME             = 30265 ..

BSEW1      = EXTERIOR-WALL      CONSTRUCTION       = WALL-1
                                AZIMUTH            = 270
                                GND-REFLECTANCE    = 0.18
                                HEIGHT             = 9.84
```

```
                                   WIDTH              = 23 ..

BSEW2      = EXTERIOR-WALL         LIKE BSEW1
                                   AZIMUTH            = 180
                                   WIDTH              = 24.2 ..

ZONE2      = SPACE-CONDITIONS      LIKE ZONE1
                                   NUMBER-OF-PEOPLE   = 132
                                   LIGHTING-KW        = 25
                                   EQUIPMENT-KW       = 52.1
                                   AIR-CHANGES/HR     = 0.5 ..

MFZONE2    = SPACE                 SPACE-CONDITIONS   = ZONE2
                                   AREA               = 13154
                                   VOLUME             = 203103 ..

MFEW1      = EXTERIOR-WALL         CONSTRUCTION       = WALL-1
                                   AZIMUTH            = 270
                                   GND-REFLECTANCE    = 0.18
                                   HEIGHT             = 14.5
                                   WIDTH              = 88.56 ..

WIN1       = WINDOW                GLASS-TYPE         = G1
                                   SHADING-SCHEDULE   = SHADE-E/W
                                   HEIGHT             = 3.94
                                   WIDTH              = 80.5 ..

MFEW1A     = EXTERIOR-WALL         LIKE MFEW1
                                   AZIMUTH            = 180
                                   WIDTH              = 35.4 ..

WIN1A      = WINDOW                LIKE WIN1
                                   S-SCH              = SHADE-S
                                   WIDTH              = 30.8 ..

MFEW1B     = EXTERIOR-WALL         LIKE MFEW1
                                   AZIMUTH            = 315
                                   WIDTH              = 90.5 ..

WIN1B      = WINDOW                LIKE WIN1
                                   S-SCH              = SHADE-N
                                   WIDTH              = 72.5 ..

MFEW2      = EXTERIOR-WALL         CONSTRUCTION       = WALL-3
                                   AZIMUTH            = 270
                                   HEIGHT             = 5.25
                                   WIDTH              = 82.7 ..

WIN2       = WINDOW                GLASS-TYPE         = G1
                                   S-SCH              = SHADE-E/W
                                   HEIGHT             = 3.94
                                   WIDTH              = 74.5 ..

MFEW2A     = EXTERIOR-WALL         LIKE MFEW2
                                   AZIMUTH            = 180
                                   WIDTH              = 17.7 ..

WIN2A      = WINDOW                LIKE WIN2
```

```
                                      S-SCH               = SHADE-S
                                      WIDTH               = 15.4 ..

MFEW2B      = EXTERIOR-WALL           LIKE MFEW2
                                      AZIMUTH             = 315
                                      WIDTH               = 105.3 ..

WIN3A       = WINDOW                  LIKE WIN2
                                      S-SCH               = SHADE-N
                                      WIDTH               = 88.2 ..

MFEW3       = EXTERIOR-WALL           CONSTRUCTION        = WALL-2
                                      AZIMUTH             = 225
                                      GND-REFLECTANCE     = 0.18
                                      HEIGHT              = 26.25
                                      WIDTH               = 24.88 ..

MFEW3A      = EXTERIOR-WALL           LIKE MFEW3
                                      AZIMUTH             = 315
                                      WIDTH               = 94.5 ..

WIN3A1      = WINDOW                  GLASS-TYPE          = G1
                                      S-SCH               = SHADE-N
                                      HEIGHT              = 7.87
                                      WIDTH               = 18.37 ..

WIN3A2      = WINDOW                  LIKE WIN3A1
                                      HEIGHT              = 3.28
                                      WIDTH               = 13.12 ..

WIN3A3      = WINDOW                  LIKE WIN3A1
                                      HEIGHT              = 3.94
                                      WIDTH               = 36.7 ..


MFEW4       = EXTERIOR-WALL           CONSTRUCTION        = WALL-1
                                      GND-REFLECTANCE     = 0.18
                                      AZIMUTH             = 315
                                      HEIGHT              = 19.68
                                      WIDTH               = 14.76 ..

WIN4        = WINDOW                  GLASS-TYPE          = G1
                                      HEIGHT              = 3.94
                                      WIDTH               = 14.76 ..

WIN4A       = WINDOW                  LIKE WIN4
                                      HEIGHT              = 7.22
                                      WIDTH               = 4.6 ..

MFEW5       = EXTERIOR-WALL           LIKE MFEW4
                                      HEIGHT              = 11.48
                                      WIDTH               = 23.6 ..

WIN5        = WINDOW                  LIKE WIN4
                                      HEIGHT              = 9.12
                                      WIDTH               = 15.74 ..
```

```
MFEW5A     = EXTERIOR-WALL        LIKE MFEW5
                                  AZIMUTH           = 45
                                  WIDTH             = 17.7 ..

ROOF-Z2    = ROOF                 CONSTRUCTION      = RF-1
                                  TILT              = 0
                                  HEIGHT            = 98.7
                                  WIDTH             = 98.7 ..

ZONE3      = SPACE-CONDITIONS     LIKE ZONE1
                                  NUMBER-OF-PEOPLE  = 25
                                  LIGHTING-KW       = 4.5
                                  EQUIPMENT-KW      = 10.5
                                  AIR-CHANGES/HR    =  0.5 ..

MFZONE3    = SPACE                SPACE-CONDITIONS  = ZONE3
                                  AREA              = 2433.6
                                  VOLUME            = 22350 ..

MFEW6      = EXTERIOR-WALL        CONSTRUCTION      = WALL-1
                                  GND-REFLECTANCE   = 0.18
                                  AZIMUTH           = 315
                                  HEIGHT            = 11.48
                                  WIDTH             = 15.25 ..

WIN6       = WINDOW               GLASS-TYPE        = G1
                                  S-SCH             = SHADE-N
                                  HEIGHT            = 7.87
                                  WIDTH             = 14.43 ..

MFEW6A     = EXTERIOR-WALL        LIKE MFEW6
                                  AZIMUTH           = 270
                                  WIDTH             = 51 ..

WIN6A      = WINDOW               LIKE WIN6
                                  S-SCH             = SHADE-E/W
                                  HEIGHT            = 7.87
                                  WIDTH             = 42.3 ..

MFEW6B     = EXTERIOR-WALL        LIKE MFEW6
                                  AZIMUTH           = 0
                                  WIDTH             = 60.5 ..

WIN6B      = WINDOW               LIKE WIN6
                                  WIDTH             = 40.6 ..

WIN6B1     = WINDOW               LIKE WIN6
                                  HEIGHT            = 11.15
                                  WIDTH             = 10.5 ..

ROOF-Z3    = ROOF                 CONSTRUCTION      = RF-1
                                  TILT              = 0
                                  HEIGHT            = 10.9
                                  WIDTH             = 10.9 ..

ZONE3A     = SPACE-CONDITIONS     LIKE ZONE1
                                  NUMBER-OF-PEOPLE  = 25
                                  LIGHTING-KW       = 4.8
```

```
                                         EQUIPMENT-KW      = 7
                                         AIR-CHANGES/HR    = 0.5 ..

MFZONE3A   = SPACE                       LIKE MFZONE3
                                         SPACE-CONDITIONS = ZONE3A ..

MFEW7      = EXTERIOR-WALL               LIKE MFEW6
                                         AZIMUTH           = 45
                                         HEIGHT            = 17.7
                                         WIDTH             = 19.68 ..

WIN7       = WINDOW                      LIKE WIN6
                                         HEIGHT            = 7.87
                                         WIDTH             = 15.41 ..

MFEW7A     = EXTERIOR-WALL               LIKE MFEW6
                                         AZIMUTH           = 90
                                         WIDTH             = 51.1 ..

WIN7A      = WINDOW                      LIKE WIN6A
                                         WIDTH             = 31.5 ..

MFEW7B     = EXTERIOR-WALL               LIKE MFEW6B
                                         AZIMUTH           = 0
                                         WIDTH             = 61 ..

WIN7B      = WINDOW                      LIKE WIN6B
                                         WIDTH             = 40.6 ..

WIN7B1     = WINDOW                      LIKE WIN6B1 ..

ROOF-Z3A   = ROOF                        LIKE ROOF-Z3 ..

ZONE4      = SPACE-CONDITIONS            LIKE ZONE1
                                         NUMBER-OF-PEOPLE = 19
                                         LIGHTING-KW       = 2.88
                                         EQUIPMENT-KW      = 2.1
                                         AIR-CHANGES/HR    = 0 ..

MFZONE4    = SPACE                       SPACE-CONDITIONS = ZONE4
                                         AREA              = 1830
                                         VOLUME            = 16807 ..

ZONE4A     = SPACE-CONDITIONS            LIKE ZONE1
                                         NUMBER-OF-PEOPLE = 19
                                         LIGHTING-KW       = 4
                                         EQUIPMENT-KW      = 1.4
                                         AIR-CHANGES/HR    = 0 ..

MFZONE4A   = SPACE                       LIKE MFZONE4
                                         SPACE-CONDITIONS = ZONE4A ..

ZONE5      = SPACE-CONDITIONS            LIKE ZONE1
                                         NUMBER-OF-PEOPLE = 36
                                         LIGHTING-KW       = 4.5
                                         EQUIPMENT-KW      = 0
                                         AIR-CHANGES/HR    = 0.3 ..
```

```
MFZONE5     = SPACE              SPACE-CONDITIONS = ZONE5
                                 AREA             = 3570.3
                                 VOLUME           = 101882 ..

ROOF-Z5     = ROOF               CONSTRUCTION     = RF-1
                                 TILT             = 45
                                 HEIGHT           = 31.16
                                 WIDTH            = 31.16 ..

SKY-LIGHT1 = WINDOW              GLASS-TYPE       = G1
                                 HEIGHT           = 31.15
                                 WIDTH            = 31.15 ..

ZONE5A      = SPACE-CONDITIONS   LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 36
                                 LIGHTING-KW      = 4.5
                                 EQUIPMENT-KW     = 0
                                 AIR-CHANGES/HR   = 0.3 ..

MFZONE5A    = SPACE              LIKE MFZONE5
                                 SPACE-CONDITIONS = ZONE5A ..

ROOF-Z5A    = ROOF               LIKE ROOF-Z5 ..

SKY-LIGHT1A = WINDOW             LIKE SKY-LIGHT1 ..

ZONE6       = SPACE-CONDITIONS   LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 178
                                 LIGHTING-KW      = 30.4
                                 EQUIPMENT-KW     = 101.9
                                 AIR-CHANGES/HR   = 0.5 ..

MFZONE6     = SPACE              SPACE-CONDITIONS = ZONE6
                                 AREA             = 17775
                                 VOLUME           = 163658.4 ..

MFEW8       = EXTERIOR-WALL      CONSTRUCTION     = WALL-1
                                 GND-REFLECTANCE  = 0.18
                                 AZIMUTH          = 180
                                 HEIGHT           = 24.6
                                 WIDTH            = 14.76 ..

WIN8        = WINDOW             GLASS-TYPE       = G1
                                 HEIGHT           = 7.87
                                 WIDTH            = 13.12 ..

MFEW8A      = EXTERIOR-WALL      CONSTRUCTION     = WALL-3
                                 AZIMUTH          = 270
                                 HEIGHT           = 5.25
                                 WIDTH            = 78.72 ..

WIN8A       = WINDOW             GLASS-TYPE       = G1
                                 HEIGHT           = 3.94
                                 WIDTH            = 72 ..

MFEW8B      = EXTERIOR-WALL      LIKE MFEW8A
                                 AZIMUTH          = 315
                                 WIDTH            = 105 ..
```

```
WIN8B      = WINDOW              LIKE WIN8A
                                 WIDTH              = 98.5 ..

ROOF-Z6    = ROOF                CONSTRUCTION       = RF-1
                                 TILT               = 0
                                 HEIGHT             = 182
                                 WIDTH              = 14.76 ..

ZONE7      = SPACE-CONDITIONS    LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 9
                                 LIGHTING-KW        = 18.4
                                 EQUIPMENT-KW       = 0
                                 AIR-CHANGES/HR     = 0.5 ..

MFZONE7    = SPACE               SPACE-CONDITIONS = ZONE7
                                 AREA               = 837.75
                                 VOLUME             = 5307 ..

MFEW10     = EXTERIOR-WALL       CONSTRUCTION       = WALL-12
                                 GND-REFLECTANCE    = 0.24
                                 AZIMUTH            = 180
                                 HEIGHT             = 21.32
                                 WIDTH              = 50 ..

WIN10      = WINDOW              GLASS-TYPE         = G2
                                 S-SCH              = SHADE-S
                                 HEIGHT             = 21.31
                                 WIDTH              = 49 ..

MFEW10A    = EXTERIOR-WALL       LIKE MFEW10
                                 AZIMUTH            = 90 ..

WIN10A     = WINDOW              LIKE WIN10 ..

MFEW11     = EXTERIOR-WALL       CONSTRUCTION       = WALL-3
                                 AZIMUTH            = 180
                                 HEIGHT             = 5.25
                                 WIDTH              = 215.17 ..

WIN11      = WINDOW              GLASS-TYPE         = G1
                                 S-SCH              = SHADE-S
                                 HEIGHT             = 3.94
                                 WIDTH              = 198 ..

MFEW11A    = EXTERIOR-WALL       LIKE MFEW11
                                 AZIMUTH            = 135
                                 WIDTH              = 120 ..

WIN11A     = WINDOW              GLASS-TYPE         = G1
                                 HEIGHT             = 3.94
                                 WIDTH              = 111.5 ..

MFEW12     = EXTERIOR-WALL       CONSTRUCTION       = WALL-1
                                 GND-REFLECTANCE    = 0.24
                                 AZIMUTH            = 180
                                 HEIGHT             = 8.2
                                 WIDTH              = 15.75 ..
```

```
WIN12        = WINDOW             GLASS-TYPE        = G1
                                  HEIGHT            = 7.22
                                  WIDTH             = 4.6 ..

MFEW12A      = EXTERIOR-WALL      LIKE MFEW11
                                  AZIMUTH           = 225
                                  WIDTH             = 13.12 ..

MFEW12B      = EXTERIOR-WALL      LIKE MFEW11A
                                  AZIMUTH           = 135 ..

MFEW13       = EXTERIOR-WALL      CONSTRUCTION      = WALL-1
                                  AZIMUTH           = 135
                                  HEIGHT            = 11.5
                                  WIDTH             = 26.25 ..

MFEW13A      = EXTERIOR-WALL      LIKE MFEW12
                                  AZIMUTH           = 225
                                  WIDTH             = 14.76 ..

MFEW14       = EXTERIOR-WALL      CONSTRUCTION      = WALL-1
                                  GND-REFLECTANCE   = 0.24
                                  AZIMUTH           = 180
                                  HEIGHT            = 9.84
                                  WIDTH             = 75 ..

WIN14        = WINDOW             GLASS-TYPE        = G1
                                  S-SCH             = SHADE-S
                                  HEIGHT            = 5.25
                                  WIDTH             = 64.5 ..

MFEW14A      = EXTERIOR-WALL      LIKE MFEW13
                                  AZIMUTH           = 270
                                  WIDTH             = 13.77 ..

ROOF-Z7      = ROOF               CONSTRUCTION      = RF-1
                                  TILT              = 0
                                  HEIGHT            = 28
                                  WIDTH             = 28 ..

ZONE7A       = SPACE-CONDITIONS   LIKE ZONE1
                                  NUMBER-OF-PEOPLE  = 10
                                  LIGHTING-KW       = 20.3
                                  EQUIPMENT-KW      = 4.2
                                  AIR-CHANGES/HR    = 0.5 ..

MFZONE7A     = SPACE              SPACE-CONDITIONS  = ZONE7A
                                  AREA              = 981.75
                                  VOLUME            = 4900 ..

MFEW15       = EXTERIOR-WALL      LIKE MFEW10 ..

WIN15        = WINDOW             LIKE WIN10 ..

MFEW15A      = EXTERIOR-WALL      LIKE MFEW10
                                  AZIMUTH           = 270 ..
```

```
WIN15A      = WINDOW           LIKE WIN10 ..

MFEW16      = EXTERIOR-WALL    LIKE MFEW11
                               WIDTH              = 223 ..

WIN16       = WINDOW           LIKE WIN11
                               WIDTH              = 198.5 ..

MFEW16A     = EXTERIOR-WALL    LIKE MFEW16
                               AZIMUTH            = 225
                               WIDTH              = 177 ..

WIN16A      = WINDOW           LIKE WIN11A
                               WIDTH              = 164 ..

MFEW17      = EXTERIOR-WALL    LIKE MFEW14
                               WIDTH              = 75 ..

WIN17       = WINDOW           LIKE WIN14 ..

MFEW17A     = EXTERIOR-WALL    LIKE MFEW17
                               AZIMUTH            = 90
                               WIDTH              = 13.12 ..

MFEW18      = EXTERIOR-WALL    LIKE MFEW12 ..

WIN18       = WINDOW           LIKE WIN12 ..

MFEW19      = EXTERIOR-WALL    CONSTRUCTION       = WALL-12
                               GND-REFLECTANCE    = 0.24
                               AZIMUTH            = 135
                               HEIGHT             = 10.83
                               WIDTH              = 36.08 ..

WIN19       = WINDOW           GLASS-TYPE         = G1
                               HEIGHT             = 3.6
                               WIDTH              = 11.15 ..

WIN19-1     = WINDOW           GLASS-TYPE         = G1
                               HEIGHT             = 6.56
                               WIDTH              = 6.56 ..

WIN19-2     = WINDOW           GLASS-TYPE         = G1
                               HEIGHT             = 10.5
                               WIDTH              = 21 ..

MFEW19A     = EXTERIOR-WALL    LIKE MFEW19
                               AZIMUTH            = 225
                               WIDTH              = 11.48 ..

WIN19A      = WINDOW           GLASS-TYPE         = G1
                               HEIGHT             = 10.5
                               WIDTH              = 10.16 ..

MFEW20      = EXTERIOR-WALL    LIKE MFEW19
                               AZIMUTH            = 225
                               HEIGHT             = 27.2
```

```
                                    WIDTH             = 23 ..

WIN20      = WINDOW                 GLASS-TYPE        = G1
                                    WIDTH             = 23
                                    HEIGHT            = 22 ..

ROOF-Z7A   = ROOF                   CONSTRUCTION      = RF-1
                                    TILT              = 0
                                    HEIGHT            = 31
                                    WIDTH             = 31 ..

ZONE8      = SPACE-CONDITIONS       LIKE ZONE1
                                    NUMBER-OF-PEOPLE  = 152
                                    LIGHTING-KW       = 25.5
                                    EQUIPMENT-KW      = 1.4
                                    AIR-CHANGES/HR    = 0.5 ..

MFZONE8    = SPACE                  SPACE-CONDITIONS  = ZONE8
                                    AREA              = 15168
                                    VOLUME            = 309853 ..

MFEW21     = EXTERIOR-WALL          CONSTRUCTION      = WALL-1
                                    GND-REFLECTANCE   = 0.18
                                    AZIMUTH           = 45
                                    HEIGHT            = 11.48
                                    WIDTH             = 72.5 ..

WIN21-1    = WINDOW                 GLASS-TYPE        = G1
                                    HEIGHT            = 3.94
                                    WIDTH             = 14.76 ..

WIN21-2    = WINDOW                 GLASS-TYPE        = G1
                                    HEIGHT            = 7.22
                                    WIDTH             = 4.6 ..

MFEW21A    = EXTERIOR-WALL          LIKE MFEW21
                                    AZIMUTH           = 315
                                    WIDTH             = 22.6 ..

MFEW22     = EXTERIOR-WALL          CONSTRUCTION      = WALL-1
                                    GND-REFLECTANCE   = 0.18
                                    AZIMUTH           = 45
                                    HEIGHT            = 13.7
                                    WIDTH             = 70.8 ..

WIN22      = WINDOW                 GLASS-TYPE        = G1
                                    S-SCH             = SHADE-N
                                    HEIGHT            = 4
                                    WIDTH             = 65.1 ..

MFEW23     = EXTERIOR-WALL          CONSTRUCTION      = WALL-3
                                    AZIMUTH           = 45
                                    HEIGHT            = 5.25
                                    WIDTH             = 178 ..

WIN23      = WINDOW                 LIKE WIN22
                                    WIDTH             = 161 ..
```

```
MFEW24     = EXTERIOR-WALL       CONSTRUCTION     = WALL-2
                                 GND-REFLECTANCE  = 0.18
                                 AZIMUTH          = 45
                                 HEIGHT           = 27.55
                                 WIDTH            = 118 ..

WIN24-1    = WINDOW              GLASS-TYPE       = G1
                                 HEIGHT           = 3.28
                                 WIDTH            = 13 ..

WIN24-2    = WINDOW              GLASS-TYPE       = G1
                                 HEIGHT           = 16.4
                                 WIDTH            = 18.37 ..

MFEW24A    = EXTERIOR-WALL       LIKE MFEW24
                                 AZIMUTH          = 315
                                 WIDTH            = 71.5 ..

MFEW24B    = EXTERIOR-WALL       LIKE MFEW24A
                                 AZIMUTH          = 135 ..

ROOF-Z8    = ROOF                CONSTRUCTION     = RF-1
                                 TILT             = 0
                                 HEIGHT           = 117.75
                                 WIDTH            = 117.75 ..

ZONE9      = SPACE-CONDITIONS    LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 82
                                 LIGHTING-KW      = 16.64
                                 EQUIPMENT-KW     = 0
                                 AIR-CHANGES/HR   = 0.5 ..

MFZONE9    = SPACE               SPACE-CONDITIONS = ZONE9
                                 AREA             = 8155.16
                                 VOLUME           = 268779.8 ..

MFEW25     = EXTERIOR-WALL       CONSTRUCTION     = WALL-2
                                 GND-REFLECTANCE  = 0.18
                                 AZIMUTH          = 90
                                 HEIGHT           = 34.5
                                 WIDTH            = 100 ..

MFEW25A    = EXTERIOR-WALL       LIKE MFEW25
                                 AZIMUTH          = 180
                                 WIDTH            = 36.7 ..

MFEW25B    = EXTERIOR-WALL       LIKE MFEW25
                                 AZIMUTH          = 0
                                 WIDTH            = 34.4 ..

ROOF-Z9    = ROOF                CONSTRUCTION     = RF-1
                                 TILT             = 0
                                 HEIGHT           = 81.35
                                 WIDTH            = 100.04 ..

ZONE10     = SPACE-CONDITIONS    LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 137
                                 LIGHTING-KW      = 26.1
```

```
                                       EQUIPMENT-KW       = 7.7
                                       AIR-CHANGES/HR     = 0 ..

MFZONE10  = SPACE                      SPACE-CONDITIONS = ZONE10
                                       AREA             = 13670
                                       VOLUME           = 154203 ..

ZONE10A   = SPACE-CONDITIONS           LIKE ZONE1
                                       NUMBER-OF-PEOPLE = 35
                                       LIGHTING-KW      = 7.13
                                       EQUIPMENT-KW     = 200
                                       AIR-CHANGES/HR   = 0 ..

MFZONE10A = SPACE                      SPACE-CONDITIONS = ZONE10A
                                       AREA             = 3641.6
                                       VOLUME           = 41080 ..

ZONE11    = SPACE-CONDITIONS           LIKE ZONE1
                                       NUMBER-OF-PEOPLE = 251
                                       LIGHTING-KW      = 51
                                       EQUIPMENT-KW     = 57.6
                                       AIR-CHANGES/HR   = 0.5 ..

UFZONE11  = SPACE                      SPACE-CONDITIONS = ZONE11
                                       AREA             = 25092.5
                                       VOLUME           = 329319.72 ..

UFEW1     = EXTERIOR-WALL              CONSTRUCTION      = WALL-3
                                       AZIMUTH           = 180
                                       HEIGHT            = 5.25
                                       WIDTH             = 50 ..

UWIN1     = WINDOW                     GLASS-TYPE        = G1
                                       S-SCH             = SHADE-S
                                       HEIGHT            = 3.94
                                       WIDTH             = 44 ..

UFEW1A    = EXTERIOR-WALL              LIKE UFEW1
                                       AZIMUTH           = 270
                                       WIDTH             = 50 ..

UWIN1A    = WINDOW                     LIKE UWIN1
                                       S-SCH             = SHADE-E/W ..

UFEW1B    = EXTERIOR-WALL              LIKE UFEW1
                                       AZIMUTH           = 135
                                       WIDTH             = 173.18 ..

UWIN1B    = WINDOW                     LIKE UWIN1
                                       WIDTH             = 157 ..

UFEW1C    = EXTERIOR-WALL              LIKE UFEW1
                                       AZIMUTH           = 315
                                       WIDTH             = 126 ..

UWIN1C    = WINDOW                     LIKE UWIN1
                                       S-SCH             = SHADE-N
                                       WIDTH             = 109 ..
```

```
UFEW1D     = EXTERIOR-WALL      LIKE UFEW1
                                AZIMUTH          = 45
                                WIDTH            = 70.2 ..

UFEW2      = EXTERIOR-WALL      CONSTRUCTION     = WALL-3
                                AZIMUTH          = 135
                                HEIGHT           = 13.12
                                WIDTH            = 38.4 ..

UWIN2      = WINDOW             GLASS-TYPE       = G1
                                S-SCH            = SHADE-S
                                HEIGHT           = 3.94
                                WIDTH            = 35.5 ..

UFEW2A     = EXTERIOR-WALL      LIKE UFEW2
                                AZIMUTH          = 225 ..

UWIN2A     = WINDOW             LIKE UWIN2 ..

ROOF-Z11   = ROOF               CONSTRUCTION     = RF-1
                                TILT             = 0
                                HEIGHT           = 163.34
                                WIDTH            = 163.34 ..

ZONE12     = SPACE-CONDITIONS   LIKE ZONE1
                                NUMBER-OF-PEOPLE = 32
                                LIGHTING-KW      = 6.42
                                EQUIPMENT-KW     = 2.8
                                AIR-CHANGES/HR   = 0.5 ..

UFZONE12   = SPACE              SPACE-CONDITIONS = ZONE12
                                AREA             = 3177
                                VOLUME           = 32325 ..

UFEW3      = EXTERIOR-WALL      CONSTRUCTION     = WALL-1
                                AZIMUTH          = 270
                                HEIGHT           = 13.12
                                WIDTH            = 75.44 ..

UWIN3      = WINDOW             GLASS-TYPE       = G1
                                S-SCH            = SHADE-E/W
                                HEIGHT           = 3.94
                                WIDTH            = 69 ..

UFEW3A     = EXTERIOR-WALL      LIKE UFEW3
                                AZIMUTH          = 0
                                WIDTH            = 60.5 ..

UWIN3A     = WINDOW             GLASS-TYPE       = G1
                                S-SCH            = SHADE-N
                                HEIGHT           = 3.94
                                WIDTH            = 52.5 ..

ROOF-Z12   = ROOF               CONSTRUCTION     = RF-1
                                TILT             = 0
                                HEIGHT           = 40.18
                                WIDTH            = 40.18 ..
```

```
ZONE12A    = SPACE-CONDITIONS    LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 33
                                 LIGHTING-KW      = 6.42
                                 EQUIPMENT-KW     = 3.5
                                 AIR-CHANGES/HR   = 0.5 ..

UFZONE12A  = SPACE               SPACE-CONDITIONS = ZONE12A
                                 AREA             = 3259
                                 VOLUME           = 33160 ..

UFEW4      = EXTERIOR-WALL       LIKE UFEW3
                                 AZIMUTH          = 90 ..

UWIN4      = WINDOW              LIKE UWIN3 ..

UFEW4A     = EXTERIOR-WALL       LIKE UFEW3A ..

UWIN4A     = WINDOW              LIKE UWIN3A ..

ROOF-Z12A  = ROOF                LIKE ROOF-Z12 ..

ZONE13     = SPACE-CONDITIONS    LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 12
                                 LIGHTING-KW      = 1.8
                                 EQUIPMENT-KW     = 0
                                 AIR-CHANGES/HR   = 0 ..

UFZONE13   = SPACE               SPACE-CONDITIONS = ZONE13
                                 AREA             = 1193
                                 VOLUME           = 10963 ..

ZONE13A    = SPACE-CONDITIONS    LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 13
                                 LIGHTING-KW      = 1.8
                                 EQUIPMENT-KW     = 0
                                 AIR-CHANGES/HR   = 0 ..

UFZONE13A  = SPACE               SPACE-CONDITIONS = ZONE13A
                                 AREA             = 1248
                                 VOLUME           = 11469 ..

ZONE14     = SPACE-CONDITIONS    LIKE ZONE1
                                 NUMBER-OF-PEOPLE = 192
                                 LIGHTING-KW      = 55.5
                                 EQUIPMENT-KW     = 21.7
                                 AIR-CHANGES/HR   = 0.5 ..

UFZONE14   = SPACE               SPACE-CONDITIONS = ZONE14
                                 AREA             = 19181
                                 VOLUME           = 269847 ..

UFEW5      = EXTERIOR-WALL       CONSTRUCTION     = WALL-3
                                 AZIMUTH          = 225
                                 HEIGHT           = 13.12
                                 WIDTH            = 11.5 ..

UWIN5      = WINDOW              GLASS-TYPE       = G1
```

```
                                        HEIGHT           = 7.87
                                        WIDTH            = 9.84 ..

UFEW5A     = EXTERIOR-WALL              LIKE UFEW5
                                        AZIMUTH          = 135
                                        WIDTH            = 37.8 ..

UWIN5A     = WINDOW                     LIKE UWIN5
                                        WIDTH            = 32.8 ..

UFEW6      = EXTERIOR-WALL              CONSTRUCTION     = WALL-3
                                        AZIMUTH          = 225
                                        HEIGHT           = 5.25
                                        WIDTH            = 246.7 ..

UWIN6      = WINDOW                     GLASS-TYPE       = G1
                                        S-SCH            =SHADE-S
                                        HEIGHT           = 3.94
                                        WIDTH            = 221.4 ..

UFEW6A     = EXTERIOR-WALL              LIKE UFEW6
                                        AZIMUTH          = 45
                                        WIDTH            = 129.2 ..

UWIN6A     = WINDOW                     LIKE UWIN6
                                        S-SCH            = SHADE-N
                                        WIDTH            = 107 ..

UFEW6B     = EXTERIOR-WALL              LIKE UFEW6
                                        AZIMUTH          = 315
                                        WIDTH            = 70.85 ..

ROOF-Z14   = ROOF                       CONSTRUCTION     = RF-1
                                        TILT             = 0
                                        HEIGHT           = 105
                                        WIDTH            = 105 ..

ZONE15      = SPACE-CONDITIONS          LIKE ZONE1
                                        TEMPERATURE      = (72)
                                        NUMBER-OF-PEOPLE = 4
                                        LIGHTING-KW      = 4.8
                                        EQUIPMENT-KW     = 0
                                        AIR-CHANGES/HR   = 0.5 ..

GREENHOUSE = SPACE                      SPACE-CONDITIONS = ZONE15
                                        AREA             = 1370
                                        VOLUME           = 27870 ..

MFEW26      = EXTERIOR-WALL             CONSTRUCTION     = WALL-12
                                        AZIMUTH          = 180
                                        HEIGHT           = 21.32
                                        WIDTH            = 49.2 ..

WIN26       = WINDOW                    GLASS-TYPE       = G1
                                        S-SCH            = SHADE-N
                                        HEIGHT           = 21.31
                                        WIDTH            = 49.1 ..
```

```
MFEW26A      = EXTERIOR-WALL       LIKE MFEW26
                                   AZIMUTH             = 270 ..

WIN26A       = WINDOW              LIKE WIN26 ..

ROOF-Z15     = ROOF                CONSTRUCTION        = RF-1
                                   TILT                = 45
                                   HEIGHT              = 36
                                   WIDTH               = 35 ..

SKY-LIGHT2 = WINDOW                GLASS-TYPE          = G2
                                   HEIGHT              = 28
                                   WIDTH               = 28 ..

ZONE16       = SPACE-CONDITIONS    LIKE ZONE1
                                   NUMBER-OF-PEOPLE = 0
                                   LIGHTING-KW         = 1.72
                                   EQUIPMENT-KW        = 200
                                   AIR-CHANGES/HR      = 0.5 ..

MECH-ROOM    = SPACE               SPACE-CONDITIONS = ZONE16
                                   AREA                = 2418.3
                                   VOLUME              = 36106 ..

UFEW7        = EXTERIOR-WALL       CONSTRUCTION        = WALL-8
                                   AZIMUTH             = 0
                                   HEIGHT              = 14.76
                                   WIDTH               = 51.82 ..

UFEW7A       = EXTERIOR-WALL       LIKE UFEW7
                                   AZIMUTH             = 270
                                   WIDTH               = 47.56 ..

UFEW7B       = EXTERIOR-WALL       LIKE UFEW7A
                                   AZIMUTH             = 90 ..

ROOF-Z16     = ROOF                CONSTRUCTION        = RF-1
                                   HEIGHT              = 49
                                   WIDTH               = 49 ..

END ..
COMPUTE LOADS ..

INPUT SYSTEMS ..

                         $ FANS SCHEDULE

FAN-1      = DAY-SCHEDULE  (1,6)  (0)  (7,23)  (1)  (24)  (0)  ..
FAN-2      = DAY-SCHEDULE  (1,7)  (0)  (8,17)  (1)  (18,24)  (0)  ..
FAN-3      = DAY-SCHEDULE  (1,8)  (0)  (9,13)  (1)  (14,24)  (0)  ..
FAN-4      = DAY-SCHEDULE  (1,8)  (0)  (9,15)  (1)  (16,24)  (0)  ..
DAYS1      = WEEK-SCHEDULE (MON,FRI) FAN-1
                           (SAT)     FAN-2
                           (SUN)     FAN-3
                           (HOL)     FAN-3 ..
DAYS2      = WEEK-SCHEDULE (MON,FRI) FAN-1
```

```
                                  (WEH)      FAN-3 ..
DAYS3      = WEEK-SCHEDULE (MON,FRI) FAN-4
                                  (WEH)      FAN-3 ..
F-1        = SCHEDULE THRU  JUN 15 DAYS1
                      THRU  JUN 30 DAYS2
                      THRU  AUG 31 DAYS3
                      THRU  DEC 15 DAYS1
                      THRU  DEC 31 DAYS2 ..

FAN-GH     = DAY-SCHEDULE (1,24) (1) ..
DAYS4      = WEEK-SCHEDULE (ALL) FAN-GH ..
F-2        = SCHEDULE THRU DEC 31 DAYS4 ..

                        $ HEATING SCHEDULES

HEAT-1        = DAY-SCHEDULE  (1,24) (0) ..
HEAT-2        = DAY-SCHEDULE  (1,24) (1) ..
IN-SCHOOL     = WEEK-SCHEDULE (ALL) HEAT-2 ..
ON-VACATION   = WEEK-SCHEDULE (ALL) HEAT-1 ..
H-1           = SCHEDULE THRU  JUN 30 IN-SCHOOL
                         THRU  AUG 31 ON-VACATION
                         THRU  DEC 31 IN-SCHOOL ..

HEAT-1A       = DAY-SCHEDULE  (1,6) (60) (7,23) (68) (24) (60) ..
HEAT-2A       = DAY-SCHEDULE  (1,8) (60) (9,17) (68) (18,24) (60) ..
HEAT-3A       = DAY-SCHEDULE  (1,8) (60) (9,13) (68) (14,24) (60) ..
DAYHEAT       = WEEK-SCHEDULE (MON,FRI) HEAT-1A
                              (SAT)     HEAT-2A
                              (SUN)     HEAT-3A
                              (HOL)     HEAT-3A ..
H-2           = SCHEDULE THRU  DEC 31 DAYHEAT ..

                        $ COOLING SCHEDULE

COOL-1        = DAY-SCHEDULE  (1,6) (99) (7,23) (78) (24) (99) ..
COOL-2        = DAY-SCHEDULE  (1,8) (99) (9,17) (78) (18,24) (99) ..
COOL-3        = DAY-SCHEDULE  (1,8) (99) (9,13) (78) (14,24) (99) ..
COOL-4        = DAY-SCHEDULE  (1,24) (99) ..
DAYCOOL1      = WEEK-SCHEDULE (MON,FRI) COOL-1
                              (SAT)     COOL-2
                              (SUN)     COOL-3
                              (HOL)     COOL-3 ..
DAYCOOL2      = WEEK-SCHEDULE (MON,FRI) COOL-3
                              (WEH)     COOL-4 ..
C-1           = SCHEDULE THRU  JUN 30 DAYCOOL1
                         THRU  AUG 31 DAYCOOL2
                         THRU  DEC 31 DAYCOOL1 ..

                        $ ZONE SUB-COMMANDS

CONTROL       = ZONE-CONTROL        DESIGN-HEAT-T    = 68
                                    DESIGN-COOL-T    = 78
                                    HEAT-TEMP-SCH    = H-2
                                    COOL-TEMP-SCH    = C-1
                                    BASEBOARD-CTRL   = THERMOSTATIC
                                    THERMOSTAT-TYPE  = REVERSE-ACTION
                                    THROTTLING-RANGE = 4 ..
```

```
AIR1          = ZONE-AIR          ASSIGNED-CFM     = 2107.28
                                  EXHAUST-CFM      = 2298.08
                                  EXHAUST-KW       = 0.0024 ..

AIR2          = ZONE-AIR          ASSIGNED-CFM     = 14125.56
                                  EXHAUST-CFM      = 6251.88
                                  EXHAUST-KW       = 0.0003 ..

AIR3          = ZONE-AIR          ASSIGNED-CFM     = 2120
                                  EXHAUST-CFM      = 0
                                  EXHAUST-KW       = 0 ..

AIR3A         = ZONE-AIR          ASSIGNED-CFM     = 167.4
                                  EXHAUST-CFM      = 400.68
                                  EXHAUST-KW       = 0.0005 ..

AIR4          = ZONE-AIR          ASSIGNED-CFM     = 2789.9
                                  EXHAUST-CFM      = 472.76
                                  EXHAUST-KW       = 0.0003 ..

AIR4A         = ZONE-AIR          ASSIGNED-CFM     = 5380.56
                                  EXHAUST-CFM      = 1028.2
                                  EXHAUST-KW       = 0.0003 ..

AIR5          = ZONE-AIR          ASSIGNED-CFM     = 8480
                                  EXHAUST-CFM      = 0
                                  EXHAUST-KW       = 0 ..

AIR5A         = ZONE-AIR          ASSIGNED-CFM     = 8480
                                  EXHAUST-CFM      = 0
                                  EXHAUST-KW       = 0 ..

AIR6          = ZONE-AIR          ASSIGNED-CFM     = 16790.4
                                  EXHAUST-CFM      = 2194.2
                                  EXHAUST-KW       = 0.00017 ..

AIR7          = ZONE-AIR          ASSIGNED-CFM     = 18304.08
                                  EXHAUST-CFM      = 725.04
                                  EXHAUST-KW       = 0.00016 ..

AIR7A         = ZONE-AIR          ASSIGNED-CFM     = 23411.16
                                  EXHAUST-CFM      = 0
                                  EXHAUST-KW       = 0 ..

AIR8          = ZONE-AIR          ASSIGNED-CFM     = 16500
                                  EXHAUST-CFM      = 7046.88
                                  EXHAUST-KW       = 0.00036 ..

AIR9          = ZONE-AIR          ASSIGNED-CFM     = 16010.24
                                  EXHAUST-CFM      = 0
                                  EXHAUST-KW       = 0 ..

AIR10         = ZONE-AIR          ASSIGNED-CFM     = 10201.46
                                  EXHAUST-CFM      = 8490.6
                                  EXHAUST-KW       = 0.00045 ..

AIR10A        = ZONE-AIR          ASSIGNED-CFM     = 10633.48
                                  EXHAUST-CFM      = 13756.68
```

```
                                  EXHAUST-KW        = 0.00045 ..

AIR11        = ZONE-AIR           ASSIGNED-CFM      = 28800
                                  EXHAUST-CFM       = 4880.24
                                  EXHAUST-KW        = 0.00064 ..

AIR12        = ZONE-AIR           ASSIGNED-CFM      = 4112.8
                                  EXHAUST-CFM       = 0
                                  EXHAUST-KW        = 0 ..

AIR12A       = ZONE-AIR           ASSIGNED-CFM      = 3786.32
                                  EXHAUST-CFM       = 0
                                  EXHAUST-KW        = 0 ..

AIR13        = ZONE-AIR           ASSIGNED-CFM      = 920
                                  EXHAUST-CFM       = 0
                                  EXHAUST-KW        = 0 ..

AIR13A       = ZONE-AIR           ASSIGNED-CFM      = 835.3
                                  EXHAUST-CFM       = 0
                                  EXHAUST-KW        = 0 ..

AIR14        = ZONE-AIR           ASSIGNED-CFM      = 28800
                                  EXHAUST-CFM       = 460.04
                                  EXHAUST-KW        = 0.002 ..

AIR15        = ZONE-AIR           ASSIGNED-CFM      = 9010
                                  EXHAUST-CFM       = 9459.44
                                  EXHAUST-KW        = 0.0001 ..

AIR16        = ZONE-AIR           ASSIGNED-CFM      = 3806
                                  EXHAUST-CFM       = 0
                                  EXHAUST-KW        = 0 ..

BSMT         = ZONE               ZONE-CONTROL      = CONTROL
                                  ZONE-AIR          = AIR1
                                  ZONE-TYPE         = CONDITIONED
                                  MAX-HEAT-RATE     = -74197.37
                                  MAX-COOL-RATE     =  27824
                                  BASEBOARD-RATING  = -98118.7 ..

MFZONE2      = ZONE               LIKE BSMT
                                  ZONE-AIR          = AIR2
                                  MAX-HEAT-RATE     = -502919.24
                                  MAX-COOL-RATE     =  186457.4
                                  BASEBOARD-RATING  = -849940.8 ..

MFZONE3      = ZONE               LIKE BSMT
                                  ZONE-AIR          = AIR3
                                  MAX-HEAT-RATE     = -74624
                                  MAX-COOL-RATE     =  27984
                                  BASEBOARD-RATING  = -121786 ..

MFZONE3A     = ZONE               LIKE BSMT
                                  ZONE-AIR          = AIR3A
                                  MAX-HEAT-RATE     = -5895.3
                                  MAX-COOL-RATE     =  2210.7
                                  BASEBOARD-RATING  = -157269.9 ..
```

```
MFZONE4      = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR4
                             MAX-HEAT-RATE     = -136292.5
                             MAX-COOL-RATE     =  36826.7
                             BASEBOARD-RATING = -0 ..

MFZONE4A     = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR4A
                             MAX-HEAT-RATE     = -225470
                             MAX-COOL-RATE     =  71023.4
                             BASEBOARD-RATING = -0 ..

MFZONE5      = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR5
                             MAX-HEAT-RATE     = -482519.57
                             MAX-COOL-RATE     =  111936
                             BASEBOARD-RATING = -60987 ..

MFZONE5A     = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR5A
                             MAX-HEAT-RATE     = -3168983.57
                             MAX-COOL-RATE     =  119360
                             BASEBOARD-RATING = -60987 ..

MFZONE6      = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR6
                             MAX-HEAT-RATE     = -591022
                             MAX-COOL-RATE     =  221633
                             BASEBOARD-RATING = -0 ..

MFZONE7      = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR7
                             MAX-HEAT-RATE     = -644303.6
                             MAX-COOL-RATE     =  241613.8
                             BASEBOARD-RATING = -1172950.4 ..

MFZONE7A     = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR7A
                             MAX-HEAT-RATE     = -824072.8
                             MAX-COOL-RATE     =  309027.3
                             BASEBOARD-RATING = -827502.9 ..

MFZONE8      = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR8
                             MAX-HEAT-RATE     = -638375.62
                             MAX-COOL-RATE     =  217800
                             BASEBOARD-RATING = -828903.2 ..

MFZONE9      = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR9
                             MAX-HEAT-RATE     = -563560.5
                             MAX-COOL-RATE     =  211335.16
                             BASEBOARD-RATING = -463784.1 ..

MFZONE10     = ZONE          LIKE BSMT
                             ZONE-AIR          = AIR10
                             MAX-HEAT-RATE     = -359091
```

```
                                          MAX-COOL-RATE     =  134659.3
                                          BASEBOARD-RATING = -519793.4 ..

MFZONE10A    = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR10A
                                          MAX-HEAT-RATE     = -127741
                                          MAX-COOL-RATE     =  47902.8
                                          BASEBOARD-RATING = -0 ..

UFZONE11     = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR11
                                          MAX-HEAT-RATE     = -1013689.6
                                          MAX-COOL-RATE     =  380133.6
                                          BASEBOARD-RATING = -557599.7 ..

UFZONE12     = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR12
                                          MAX-HEAT-RATE     = -144770.56
                                          MAX-COOL-RATE     =  54288.96
                                          BASEBOARD-RATING = -209590.8 ..

UFZONE12A    = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR12A
                                          MAX-HEAT-RATE     = -133278.5
                                          MAX-COOL-RATE     =  49979.4
                                          BASEBOARD-RATING = -163349 ..

UFZONE13     = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR13
                                          MAX-HEAT-RATE     = -32384
                                          MAX-COOL-RATE     =  12144
                                          BASEBOARD-RATING = -0 ..

UFZONE13A    = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR13A
                                          MAX-HEAT-RATE     = -30036
                                          MAX-COOL-RATE     =  11026
                                          BASEBOARD-RATING = -0 ..

UFZONE14     = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR14
                                          MAX-HEAT-RATE     = -1551932.8
                                          MAX-COOL-RATE     =  581974.8
                                          BASEBOARD-RATING = -544177.9 ..

GREENHOUSE   = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR15
                                          MAX-HEAT-RATE     = -332972.28
                                          MAX-COOL-RATE     =  124864.6
                                          BASEBOARD-RATING = -196510.6 ..

MECH-ROOM    = ZONE                       LIKE BSMT
                                          ZONE-AIR          = AIR16
                                          MAX-HEAT-RATE     = -81366.12
                                          BASEBOARD-RATING = -0 ..

                                  $ SYSTEM SUBCOMMANDS
```

```
SC-E/W       = SYSTEM-CONTROL     MAX-SUPPLY-T       = 110
                                  MIN-SUPPLY-T       =  55
                                  HEATING-SCHEDULE = H-1
                                  COOLING-SCHEDULE = F-1
                                  COOL-CONTROL       = SCHEDULED
                                  COOL-SET-SCH       = C-1
                                  MAX-HUMIDITY       = 55
                                  MIN-HUMIDITY       = 30
                                  ECONO-LIMIT-T      = 45 ..

SC-AH1       = SYSTEM-CONTROL     MAX-SUPPLY-T       = 110
                                  MIN-SUPPLY-T       =  55
                                  HEATING-SCHEDULE = H-1
                                  MAX-HUMIDITY       =  45
                                  MIN-HUMIDITY       =  25
                                  ECONO-LIMIT-T      =  45 ..

SC-SF3       = SYSTEM-CONTROL     MAX-SUPPLY-T       = 110
                                  MIN-SUPPLY-T       =  55
                                  HEATING-SCHEDULE = H-1
                                  ECONO-LIMIT-T      =  45 ..

WEST-SF1     = SYSTEM-AIR         RATED-CFM          = 102608
                                  RETURN-CFM         =  86581
                                  MIN-OUTSIDE-AIR    = 0.13
                                  OA-CONTROL         = TEMP ..

EAST-SF2     = SYSTEM-AIR         RATED-CFM          = 111004
                                  RETURN-CFM         =  93874
                                  MIN-OUTSIDE-AIR    = 0.13
                                  OA-CONTROL         = TEMP ..

BOILER-SF3   = SYSTEM-AIR         RATED-CFM          = 3806
                                  MIN-OUTSIDE-AIR    = 0.20
                                  OA-CONTROL         = FIXED ..

AH1          = SYSTEM-AIR         RATED-CFM          = 9010
                                  MIN-OUTSIDE-AIR    = 0.15
                                  OA-CONTROL         = TEMP ..

SF-1         = SYSTEM-FANS        FAN-SCHEDULE       = F-1
                                  FAN-CONTROL        = SPEED
                                  SUPPLY-DELTA-T     = 4.13
                                  SUPPLY-KW          = 0.001
                                  MOTOR-PLACEMENT    = IN-AIRFLOW
                                  FAN-PLACEMENT      = DRAW-THROUGH
                                  RETURN-DELTA-T     = 4.13
                                  RETURN-KW          = 0.0008
                                  NIGHT-CYCLE-CTRL = STAY-OFF ..

SF-AH1       = SYSTEM-FANS        FAN-SCHEDULE       = F-2
                                  FAN-CONTROL        = CONSTANT-VOLUME
                                  SUPPLY-DELTA-T     = 2.37
                                  SUPPLY-KW          = 0.00062
                                  MOTOR-PLACEMENT    = IN-AIRFLOW
                                  FAN-PLACEMENT      = DRAW-THROUGH ..
```

```
SF-SF3        = SYSTEM-FANS          FAN-SCHEDULE      = F-2
                                     FAN-CONTROL       = CYCLING
                                     SUPPLY-DELTA-T    = 2.37
                                     SUPPLY-KW         = 0.00059
                                     MOTOR-PLACEMENT   = IN-AIRFLOW
                                     FAN-PLACEMENT     = DRAW-THROUGH ..

ST-1          = SYSTEM-TERMINAL      REHEAT-DELTA-T    =  55
                                     MIN-CFM-RATIO     = 0.5 ..

                                  $ SYSTEM DESCRIPTION

S1-WEST       = SYSTEM            SYSTEM-TYPE      = VAVS
                                  ZONE-NAMES =(BSMT,MFZONE2,MFZONE3,
                                               MFZONE4,MFZONE5,MFZONE6,
                                               MFZONE7, UFZONE11,
                                               UFZONE12,UFZONE13)
                                  SYSTEM-CONTROL   = SC-E/W
                                  SYSTEM-AIR       = WEST-SF1
                                  SYSTEM-FANS      = SF-1
                                  SYSTEM-TERMINAL  = ST-1 ..


S2-EAST        = SYSTEM           SYSTEM-TYPE      = VAVS
                                  ZONE-NAMES =(MFZONE3A,MFZONE4A,MFZONE5A,
                                              MFZONE7A, MFZONE8, MFZONE9,
                                              MFZONE10,MFZONE10A,UFZONE12A,
                                              UFZONE13A, UFZONE14)
                                  SYSTEM-CONTROL   = SC-E/W
                                  SYSTEM-AIR       = EAST-SF2
                                  SYSTEM-FANS      = SF-1
                                  SYSTEM-TERMINAL  = ST-1 ..


S3-GREENHOUSE = SYSTEM            SYSTEM-TYPE       = SZRH
                                  ZONE-NAMES        = (GREENHOUSE)
                                  SYSTEM-CONTROL    = SC-AH1
                                  SYSTEM-AIR        = AH1
                                  SYSTEM-FANS       = SF-AH1
                                  SYSTEM-TERMINAL   = ST-1 ..


S3-BOILER      = SYSTEM           SYSTEM-TYPE       = SZRH
                                  ZONE-NAMES        = (MECH-ROOM)
                                  SYSTEM-CONTROL    = SC-SF3
                                  SYSTEM-AIR        = BOILER-SF3
                                  SYSTEM-FANS       = SF-SF3 ..


PLANT-1        = PLANT-ASSIGNMENT  SYSTEM-NAMES    = (S1-WEST,S2-EAST,
                                                     S3-GREENHOUSE,S3-
BOILER) ..

END ..
COMPUTE SYSTEMS ..
```

```
INPUT PLANT ..

PLANT-REPORT               SUMMARY           = (BEPU) ..

                  $ EQUIPMENT DESCRIPTION

PE-1 = PLANT-EQUIPMENT                  TYPE               = STM-BOILER
                                        SIZE               = 1.6
                                        INSTALLED-NUMBER   = 1 ..

PE-2 = PLANT-EQUIPMENT                  TYPE               = HW-BOILER
                                        SIZE               = 7.2
                                        INSTALLED-NUMBER   = 2
                                        MAX-NUMBER-AVAIL   = 2 ..

PE-3 = PLANT-EQUIPMENT                  TYPE               = DHW-HEATER
                                        SIZE               = 0.3
                                        INSTALLED-NUMBER   = 3
                                        MAX-NUMBER-AVAIL   = 3 ..

PE-4 = PLANT-EQUIPMENT                  TYPE               = OPEN-CENT-CHLR
                                        SIZE               = 6.35
                                        INSTALLED-NUMBER   = 1 ..

PE-5 = PLANT-EQUIPMENT                  TYPE               = COOLING-TWR
                                        SIZE               = -999 ..

PLANT-PARAMETERS                        HW-BOILER-HIR      = 0.8
                                        TWR-PUMP-HEAD      = 86
                                        CCIRC-HEAD         = 95
                                        HCIRC-HEAD         = 95 ..

BOILERS  = LOAD-ASSIGNMENT              TYPE               = HEATING
                                        OPERATION-MODE     = RUN-NEEDED
                                        LOAD-RANGE         = 14
                                        PLANT-EQUIPMENT    = PE-2
                                        NUMBER             = 2 ..

CHILLERS = LOAD-ASSIGNMENT              TYPE               = COOLING
                                        OPERATION-MODE     = RUN-NEEDED
                                        LOAD-RANGE         = 6.35
                                        PLANT-EQUIPMENT    = PE-4
                                        NUMBER             = 1 ..

LOAD-MANAGEMENT                         PRED-LOAD-RANGE    = 999
                                        LOAD-ASSIGNMENT    =
(BOILERS,CHILLERS) ..
```

```
ENERGY-RESOURCE                         RESOURCE          = NATURAL-GAS ..
PLANT-1                                                   = PLANT-ASSIGNMENT
..

$                                  HOURLY-REPORT  ELECTRICAL

R-SCHED = SCHEDULE                THRU DEC 31 (ALL) (1,24) (1) ..

RB5     = REPORT-BLOCK            VARIABLE-TYPE = END-USE
                                  VARIABLE-LIST = (1,3,5,6,8,9,23,28) ..

REPORT1 = HOURLY-REPORT           REPORT-SCHEDULE = R-SCHED
                                  REPORT-BLOCK    = (RB5) ..

$                                  HOURLY-REPORT  NATURAL GAS

RB6     = REPORT-BLOCK            VARIABLE-TYPE = PLANT
                                  VARIABLE-LIST = (1,2,3,8,9,10,12) ..

REPORT2 = HOURLY-REPORT           REPORT-SCHEDULE = R-SCHED
                                  REPORT-BLOCK    = (RB6) ..

END ..
COMPUTE PLANT ..

STOP ..
```