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An Evaluation of a Solar Heating System and other Alternatives for Energy Conservation in a Church Building

by

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ABSTRACT

In this study, the energy performance of a solar heated building was investigated. The solar air heater was tested for thermal efficiency. To analyze the energy use characteristics of the investigated building, DOE-2.1E simulations were conducted using locally-measured meteorological data. The base case simulation model was calibrated by comparing the calculated energy use values with the actual utility bills. Theoretical analysis of the modified solar air heater was performed to assess the potential to improve performance.

The results show that significant energy savings can be achieved by separating a central system into a few systems sewing smaller groups of zones. Simulated results showed that total electricity use was reduced by about 17000 kWh/year and natural gas use by about 340 GJ/year.

The results show that the solar system contributes only 50 GJ/year. The existing solar collectors work with an efficiency of less than 17 percent. By changing parameters such as the depth of the air flow channel in the collectors, the flow rate of the working fluid and the shape of the solar collector, the efficiency of the solar collector could be increased to about 38 percent.

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NOMENCLATURE

ACRONYMS:

OPEC	Organization of Petroleum Exporting Countries
HVAC	Heating, Ventilation, and Air Conditioning
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
DOE	The U.S. Department of Energy
DOE-2.1E	Building Energy Simulation Program Sponsored by DOE
WYEC	Weather Year for Energy Calculations

SYMBOLS:

C2000	Program for Advanced Commercial Buildings, Natural Resources Canada
Q_u	Useful heat gain (W)
C_p	Specific heat of the fluid (J/kg°C)
T_o, T_i	Outlet and inlet temperature of the collector (°C)
T_a	Ambient temperature (°C)
A_c	Aperture collector area (m^2)
F_R	Heat removal factor
G_T	Instantaneous solar radiation (W/m^2)
$(\tau\alpha)$	Transmittance-absorptance product
U_L	Collector overall energy loss coefficient ($W/m^2\,°C$)

$\dot{m}$	Mass flow rate (kg/s)
η_i	Instantaneous efficiency
L_{st}	Standard meridian for the local time zone
L_{loc}	Longitude of the location
E	Equation of time
ρ	Density of air (kg/m^3)
V	Average velocity (m/s)
P	Absolute pressure (Pa)
R	Gas constant for the air (J/kgK)
υ	Kinematics viscosity (m^2/s)
$\bar{H}_T$	Monthly average daily radiation per unit area on the tilt surface (MJ/m^2)
$\bar{H}_o$	Extraterrestrial radiation (MJ/m^2)
$\bar{H}$	Monthly average daily radiation on the horizontal surface (MJ/m^2)
$\bar{K}_T$	Monthly average clearness index
ϕ	Latitude of the location
δ	Solar declination
ω_s	Sunset hour angle
n	Mean day of the month, number of glass covers
$\bar{H}_d$	Diffused component of solar irradiation (W/m^2)
ρ_g	Diffuse reflectance of ground
β	Sloped surface angle (degree)

$\bar{R}$	The average ratio of the total radiation on a tilted plane to that on the horizontal
$\bar{R}_b$	The ratio of the average daily beam radiation on the tilted surface to that on a horizontal surface for the month
$\bar{H}_{bT}$	Average daily beam radiation on the tilted surface (J/m^2)
R_n	The ratio of radiation on the tilted surface to that on a horizontal surface at noon for an average day of the month
$r_{T,n}$	The ratio of radiation at noon to the daily total radiation
$r_{d,n}$	The ratio of diffuse radiation at noon to the daily diffuse radiation
I_{TC}	Critical radiation level (W/m^2)
$\bar{T}_{im}$	Average inlet temperature for the month (°C)
$\bar{T}_{av}$	Average ambient temperature for the month (°C)
$\bar{X}_c$	The ratio of the critical radiation to the radiation at noon for the average day during the month in which the total radiation for the day is the same as the average for the month
$\bar{\phi}$	Utilizability coefficient
N	Number of days in the month
λ	Air thermal conductivity (W/m °C)
μ	Air dynamic viscosity (Pa s)
h_c	Convective heat transfer coefficient (W/m^2 °C)
L	Length of collector (m)
b	Thickness of air flow channel (m)

D_e	Equivalent diameter (m)
ε_p	Plate emittance
ε_g	Glass emittance
T_{mp}	Mean plate temperature (K)
h_w	Wind heat transfer coefficient (W/m^2 °C)
σ	Stefan-Boltzmann constant
$\bar{T}$	Main fluid temperature
Re	Reynolds number
A_f	Fluid flowing area (m^2)
U_t	Top heat loss coefficient (W/m^2 °C)
F'	Collector efficiency factor
h_r	Radiative heat loss coefficient (W/m^2 °C)
F"	Collector flow factor
F_R	Heat removal factor
T_{mp}	Theoretical mean plate temperature (°C)
T_{mf}	Theoretical mean fluid temperature (°C)

CHAPTER 1

INTRODUCTION

1.1 Overview

A dramatic increase in the price of energy as a result of the 1973 oil embargo and later OPEC pricing strategy together with rapidly increasing energy demand has forced people to think about energy conservation. As a result of this situation, energy conservation in the sense of energy efficiency and the use of renewable energy is vital.

It has been estimated that roughly one-third of the national annual consumption of primary energy is used for building services in the US and Canada [1]. Energy consumption and the efficiency of energy use in buildings depend on design and the conservation strategies that have been taken to save energy.

Components such as building materials, orientation, shape, percentage of glazing area, HVAC system, ventilation, and lighting density are highly dependent on the design of the building. These components play an important role in building energy use. In general, three basic systems determine the efficiency of energy use in buildings [2]:

- energized systems, such as those required for heating, cooling, lighting, ventilation, business equipment operation, etc.

- nonenergized systems, such as walls, roofs, floors, windows.

Solar heating of buildings with air as a working fluid has been used for a long time in the USA and other countries. The feasibility of solar heating is a function of several things such as initial cost, installation cost, heating fuel cost, and geographic and atmospheric conditions. Because of high installation costs, payback periods can be long, especially in places where energy prices are low. Solar heating systems might be feasible in northern climates like Calgary's if the systems (i.e., structure plus solar system) are integrated architecturally [5]. In addition, solar systems may help to improve environmental quality by reducing the use of fossil fuels.

1.2 Solar air heating system

In this study, a church with a curtain wall acting as an active flat plate solar collector and a partition wall acting as an energy storage subsystem was selected for performance evaluation. Figure 1.1 shows an exterior view of the building with south-facing collectors for active collection of solar energy.

Figure 1.1 Exterior view of the south-facing facade

- human systems, such as maintenance, operation, and energy management.

Each of these systems can be modified for significant savings of energy. However, modifications must be analyzed in terms of comfort of occupants, cost-effectiveness and pollution control.

Before designing energy strategies for commercial buildings, a clear picture of the most significant components of energy utilization should be developed based on annual energy use patterns. Methods of conservation should then be applied to get desired energy savings. For cold climate regions, heating is the largest annual energy consumption component followed by ventilation, lighting, and cooling [3]. In terms of annual energy expenditure, electricity is the major energy cost for buildings in cities like Calgary, because of the relatively low cost of natural gas.

One of the ways to improve the energy performance of buildings in cold climates is to employ solar heating systems that could reduce fossil fuel requirements for heating. Generally, the earth receives solar energy at a rate of 5.6×10^{24} J/year which is equivalent to about 30,000 times the energy used at the present time [4]. Utilization of this huge amount of renewable energy requires knowledge of the nature of solar insolation, the factors that influence its intensity and systems that utilize such energy.

In most cases, whether air or water is the working fluid, simple flat plate collectors with selective and nonselective absorber plates are used, because of their relatively low cost of construction compared with other types of collectors such as concentrating systems.

This solar heating system consists primarily of solar collector panels, a masonry wall for thermal storage, a heat exchanger for water preheating, a circulation fan, ducting, and a control system to operate the system properly. All mechanical and structural components are connected via a duct network. A detailed description of the building is given in Chapter 3.

Solar radiation on the collector surface passes to the absorber surface; consequently the absorber surface becomes heated. The absorber's surface temperature depends on the radiation level on the surface and the optical and thermal properties of the collectors. As a result of heat transfer between the absorber plate and circulated air, air leaving the collector part of the system should be hotter than at the inlet. After pre-heating domestic hot water (DHW) via the air-to-water heat exchanger, the air gives up the remaining heat gained to the thermal storage wall.

The main disadvantage of this type of system is that significant temperature swings are needed in the building to provide maximum exploitation of the solar heating. Higher temperature swings in the building could affect occupant comfort. However, the system is a good alternative to systems with active discharge storage [6].

1.3 Objective and methodology

This research had the following objectives:

- to evaluate the performance of the building-integrated solar air heating system in terms of energy gain.
- to evaluate the solar heating option relative to other energy conservation strategies.

The major steps for this study were as follows:

- obtain utility meter data (i.e., natural gas and electricity consumption) for the building for one year (1995).

- prepare an hourly 1995 weather file for Calgary; this was required for energy use simulation and for calculation of solar heat collection.

- determine the amount of annual heat collection from the solar air heater.

- prepare a DOE-2 simulation model of the investigated building and calibrate it with the metered and weather data for 1995.

- evaluate possible retrofits for the investigated building by computer simulation.

- determine performance of retrofiting the solar collector.

Beyond this chapter, Chapter 2 contains a literature review of basic factors that govern building energy use and solar air heater performance, and on the performance and validation of the DOE-2 simulation program. Chapter 3 presents features of the building, envelope constructions, operating conditions, and the HVAC/DHW equipment, and summary of Calgary weather files for 1995. Chapter 4 presents efficiency calculations for the solar air heater and the solar system's annual heat accumulation. Chapter 5 presents the calibration of the simulation model based on the building energy use data and concludes with DOE-2 simulation results. Chapter 6 contains results of computer simulation of possible retrofits of the building in terms of energy conservation and theoretical analysis of the solar system in terms of changing parameters such as air gap and flow rate from the existing design. Chapter 7 concludes the research with conclusions and some recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Many papers have been written on energy conservation in office, school, and hotel buildings, but it is very hard to find out about energy conservation in church buildings. Because of their function, religious buildings differ from the others in terms of energy requirements. Factors such as occupancy schedules, daily activity and facilities provided in the church could lead to differences from other buildings. Often, architectural design and facility use change the energy use characteristics of buildings and consequently, conservation methods.

In this literature review, papers dealing with major building components that affect building energy consumption are discussed first. Second, papers related to performance factors and economic feasibility of solar heating systems are considered. Third, research that has been done on the performance of DOE-2 and its sensitivity to user decisions are discussed.

2.2 Major building energy consumption components

There are many components that affect energy consumption in buildings. These are briefly discussed below:

2.2.1 Building envelope

An architect's ability to properly develop the functional and esthetic features of a building is very important in controlling heating and cooling requirements, as well as corresponding initial and operating costs. Geographic location, variation of outside temperature and wind and solar intensities are influential factors in building envelope design. The ultimate choice of the building configuration should be determined based on both design and energy issues [3].

Heat loss from the envelope depends on many factors, other than climate conditions, such as structure, window to wall ratio (WWR), U-value (i.e., wall, roof, floor, and window), geometrical shape, orientation, and others. Out of these characteristics, WWR is one of the most significant factors affecting energy demand. Hence, it should be determined through economic analysis for the specified geographic location [7,8].

2.2.2 Ventilation

The ventilation rate is one of the basic factors that affects annual energy use, equipment sizing and first cost of HVAC systems. For offices, the old ASHRAE Standard 62-81 recommended 2.3 l/s/person without smokers and 9.4 l/s/person with smokers [9]. ASHRAE Standard 62-89 does not distinguish the presence of smoking and simply recommends a minimum of 9.4 l/s/person [10]. This new standard for outside air rate, based on indoor air quality, remains a subject of debate. The outdoor ventilation air requirements specified by ASHRAE exceed rate to meet oxygen replacement requirements and control carbon dioxide concentrations which, for normal activities, are about 0.6 and 1.8 l/s/person respectively [11].

According to Eto and Meyer [12], the changes in the ventilation rate from the former standard would increase chiller and boiler size up to 20 and 10 percent respectively. The largest increases in boiler capacity occur in colder climates and the smallest in milder ones. The largest increases in chiller capacity are found in climates with the greatest cooling requirement. HVAC first costs increase by less than US \$ 0.35/ m^2. Annual energy use for heating would increase by up to 8 percent and annual energy use for cooling by up to 14 percent.

One way to reduce the ventilation cost or life cycle cost of HVAC system is through heat recovery devices. Waste heat recovery devices such as run-round heat exchangers, heat pipes, and rotary air-to-air regenerative heat exchangers (heat wheels) are widely used in HVAC systems.

2.2.3 Lighting

Lighting systems are designed to create safe and pleasing visual working environments. Lighting systems use a large portion of a building's energy. Lighting may represent 23 percent or more of the total energy consumption in commercial buildings and it has an impact on the energy consumption of the HVAC system [2]. The lighting system has a greater impact on the annual cooling energy used in warm climates than in cold climates.

Efficient lighting systems not only decrease electrical energy costs but also decrease the operating cost of air-conditioning in hot climates. For example, according to Shavit and Richard [13] an individual dimmable electronic ballast system could save 64, 5, and 12 percent for the lighting, fan and chiller systems respectively.

2.2.4 Infiltration

One of the major loads in commercial buildings is infiltration of outside air through cracks around doors and windows, and when exterior doors are used. According to the C2000 program [14], this is one of the major factors that reduces the energy efficiency of buildings. Energy losses from infiltration can be substantially reduced through improved sealing of the air flow paths.

2.2.5 HVAC Systems and equipment

HVAC systems differ according to the precise location of the heating and cooling coils in the air stream and according to the manner in which systems meet varying space loads in each zone. Energy conservation standards are particularly difficult to develop for HVAC systems. The factors that affect the energy performance of HVAC systems are difficult to describe. Some of the recent general recommendations for HVAC systems for heating dominated climates are [15]:

- the elimination of simultaneous heating and cooling of supply air for a single conditioned space (a major objective of efforts to improve the efficiency of HVAC systems).
- use of automatic off-hour control (time clock).
- large central systems should have options to isolate zones or small groups of zones during unoccupied periods.
- optimal insulation thickness.
- minimum leakage of air distribution system to avoid energy losses.
- use of systems with an economizer cycle.
- use of heat recovery systems.

- use of direct digital control systems for better energy management.

- use of variable speed pumping systems (can save considerable pumping energy, especially in large distribution systems).

- use of renewable energy sources if economically justified.

In studying the influence of these options on energy consumption, computer modeling of buildings can help greatly. In addition, simulation makes it possible to individually evaluate the impact of each parameter on energy use.

2.3 Technical and economic reviews of solar heating system

2.3.1 Steady-state model of solar air heater

Winter [16] concluded that, even though solar radiation, wind speed, ambient temperature and the building heating load vary continuously, steady-state models are adequate for estimating performance of conventional flat plate collectors if hourly meteorological data are used. In other words, transient effects can be ignored for calculation of the collector performance.

According to Duffie and Beckman [6], the following assumptions can be made to simplify calculation of a collector's heat transfer:

- steady-state conditions.

- uniform flow of the fluid in the collectors

- no absorption of solar energy by collector covers

- one dimensional heat flow
- temperature gradients along the collector plate may be neglected
- isotropic sky conditions
- material properties are independent of temperature

2.3.2 Performance of solar collector arrays

Duffie and Beckman [6] noted that performance of a solar collector array differs from that of an individual collector. It could drop to half the efficiency predicted for a single collector because of the following reasons:

- increases in heat and pressure losses from array connections.
- flow maldistribution among the collectors.
- large thermal capacitance or amount of heat absorbed by the body of the collectors.
- occasional mutual shading of collectors.
- air leakage from the collectors (at gaps in sealant)

2.3.3 Major factors affecting solar air heater performance

In the case of solar air heaters, flow rate and the geometric construction of the collector strongly influence the efficiency. This is expressed by the convective heat transfer coefficient (h_c). Biondi et. al. [17] reported that, assuming factors such as inlet temperature, environment parameters and materials of construction to be constant, the performance of a collector is solely determined by two factors: the specific air flow rate or mass flow rate per unit area of solar collector and the geometry of the solar air heater. Graphs produced for different values of geometric coefficient and specific flow rate show that both these parameters have equal influence on the collector performance. More detail on this subject is given in Chapter 6.

2.3.4 Effect of air leakage from solar collectors

Because of the pressure difference between collector air streams and the atmosphere, most conventional collectors experience leakage, which significantly affects performance. Two situations may occur: significant quantities of air may leak into or out of the collectors. In the former case, air leaking into the collector must be heated from the outdoor temperature to the outlet temperature of the collector, which requires more energy than heating of the recirculation air. In the latter case, less air passes through the collector. This reduces the performance of the collector, because efficiency of the collector is highly dependent on the mass flow rate in the collector. Close and Yusoff [18] reported that air leakage should be accounted for in collector efficiency measurements even if a constant leakage rate must be assumed, otherwise the leaked air will appear as an extra load on the collector.

2.3.5 Optimum tilt angle of flat-plate collector

Optimum tilt angle of a flat-plate collector is one of the factors that affects solar system performance. There is a range of tilt angles that gives near-maximum solar heat gain during a whole year of application. The optimum tilt angle for a collector is a function of the latitude and the seasonal application (i.e., for space heating or water heating). For year round application, different investigators propose varying tilt angles to obtain maximum collector performance. Mustafa's [19] study showed that changing the tilt angle by about ± 10° from its optimum angle reduces the amount of the monthly absorbed radiation by less than 3 percents.

Based on his analysis, the optimum tilt angle for Calgary, with a latitude of 51°, approximate clearness index ($\bar{K}_T$) of 0.5 and ground reflectance of 0.7 for January, February, November, and December lies between 70° - 80° for space heating.

2.3.6 Performance deterioration due to ambient conditions

Grag [20] reported that ambient dust could decrease performance of solar collectors. Energy absorbed by the collector is not only a function of the optical and thermal properties of the collector, but also a function of many factors such as ambient dirt concentration, inclination angle of the collector, exposure time without rain, and type of cover plate. He mentioned that the transmittance could be reduced by 1 percent in a moderately clean atmosphere.

2.3.7 Economic feasibility survey of solar heating systems

A survey conducted by Roger et. al. [21] in 1977-1978 addressed the economic feasibility of solar water and space heating for single-family residences and multi-family apartment buildings in four US cities: Boston, Washington, Grand Junction, and Los Angeles. In this study, economic criteria such as payback period, years to recovery of down payment, and years to net positive cash flow were used. The cost competitiveness of solar systems compared with heating systems based on electricity, fuel oil, and natural gas were analyzed, taking into account federal incentives for solar systems. The authors found that combined solar water and space heating is only marginally feasible for single-family residences. Tax incentives made solar systems competitive with electricity in all four cities, but for multi-family apartments the relationships were unclear. In addition, combined solar water and space heating systems are not economically feasible in any of the four locations when compared to natural gas even with the federal investment tax credit.

2.4 Literature review on the DOE-2 simulation program

The building energy simulation program DOE-2 was chosen to analyze the building that was investigated in the study reported here. It computes hourly heating and cooling loads. It has the capacity to simulate dynamic heating and cooling loads, amount of air supply, equipment sizing, and economic evaluation for the selected time period. Generally, it is used as a preliminary design tool to calculate energy consumption for different options in a new building. Recently, it has also been used as a simulation tool to analyze the economic impact of different retrofit options. This is one of the few computer programs recommended by ASHRAE for building energy analysis [15]. This section addresses publications on the performance, validation, and input sensitivity of DOE-2.

2.4.1 Comparison of DOE-2 with other simplified procedures

Energy calculations were carried out for a variety of house types such as ranch, split-level, two-story detached, and townhouse in ten different US locations using DOE-2. From simulation results, Kusuda [22] reported that, DOE-2 could be a good alternative to the energy analysis procedures such as the degree-day and the ASHRAE TC 4.7 bin method for building energy calculation.

For single-story residences, all the heating loads calculated using variable-base degree-day fell within 10 percent of those computed by DOE-2, while 50 percent fell within 5 percent. For two-story residences, all heating loads fell within 20 percent and cooling loads fell within 15 percent except for one of the locations studied.

Almost all points obtained with TC 4.7 fell well within 15 percent of the DOE-2 results. Both comparisons show that the DOE-2 simulation program could be used as an alternative to the simple methods .

2.4.2 DOE-2 verification

The DOE-2 Verification Project conducted by Diamond and Hunn [23] used DOE-2 to model seven existing commercial buildings. These buildings included a restaurant, a single-floor office building, a retail store, a hospital, a multifloor office building, a school, and a solar-heated and-cooled building. Each building was simulated by contractors, except the solar building and the school, which were done by Lawrence Berkeley Laboratory (LBL). Simulated results were compared to utility data for monthly and annual periods. Simulation results showed that DOE-2 is highly sensitive to the data entered by the user. Higher deviations in monthly results relative to annual results may be due to actual building parameters differing from standard schedules for occupants, lights, equipment, DHW and long term weather data. Annual results for these buildings show that the standard deviation between simulated and metered values for gas/fuel oil, electricity and total energy consumption was 11, 9, and 8 percent respectively. The absolute difference between predicted and measured monthly data ranged from 14 to 45 percent for gas/fuel oil, 13 to 37 percent for electricity, and 15 to 33 percent for total energy use. In spite of large deviations for a few individual months, statistical analysis of all months for these buildings shows "composite" (all buildings combined) standard deviations of 26, 19, and 17 percent for gas/fuel oil, electricity, and total energy consumption respectively.

2.4.3 Input sensitivity of DOE-2

To determine the effects of user judgments regarding interpretation of input data on the simulation results, Diamond et. al. [24] assigned six experienced DOE-2 users to make DOE-2 models of four commercial buildings. These buildings included the single-floor office building, multifloor office building, retail store, and restaurant. Initially, less detailed input data was given for the assigned buildings. This was supplemented in stages so that three levels of increasingly refined input data were used. These were: (1) uncontrolled input (2) refined input and (3) input constrained by the Standard Evaluation Technique (SET) defined for the Building Energy Performance Standards (BEPS) proposed by the U.S. Department of Energy (DOE). For uncontrolled input, the buildings and their operation were described as they would be to a consultant conducting an energy audit. Assumptions concerning missing information and ambiguities were left to the contractors. For the refined input level, missing data were supplied, gross ambiguities in data were eliminated, and analyst's questions regarding the buildings were answered. For the Standard Evaluation Technique, fixed parameters were used such as: weather data, standard building operating conditions, and selected fixed-data input values.

The results of the experiment were presented in terms of monthly standard deviation among multiple users for the three sets of input specification. The reduction of scatter in the monthly total energy prediction was about 40 percent when information supplied to analysts improved from uncontrolled to refined. Similarly, scattering was further reduced about 30 percent when information improved from the refined to SET input. In addition, results also show greater variations in fuel energy than in electrical energy consumption. The study indicated that scatter in results can be reduced significantly by having an independent observer check the input for errors and by eliminating gross ambiguities in the input.

CHAPTER 3

FEATURES OF THE BUILDING AND SIMULATION MODEL

3.1 Overview

The Sandstone Valley Ecumenical Centre was built in 1987. It is located at 1100 Berkshire Boulevard, N.W., Calgary, Alberta. The building lies at 51° north latitude, 114° west longitude, and 1,100 metres elevation. The three-story structure, including basement, has a floor area of approximately 3,300 m^2. A plan of each floor is given at the end of this chapter. The building is not shaded by nearby structures or trees. The building consists of two sanctuaries, a chapel, a fireside lounge, a lobby, a gymnasium/hall with commercial kitchen facilities, a recreation centre, a nursery, and administrative offices. To reduce operating costs and for social reasons, the building facilities are shared by Catholic and Lutheran congregations.

3.2 Solar heating system

3.2.1 Design and operation of solar system

The architecturally integrated active charge-passive discharge solar system, as shown in figure 3.1, consists primarily of solar collector panels, a thermal mass masonry wall, a heat exchanger for water preheating, a circulation fan, a control system, and ducting. All mechanical and structural components are connected in a closed loop.

The absorber's surface temperature depends on the radiation incident on the surface and on the optical and thermal properties of the collectors. As a result of heat transfer between the absorber plates and circulated air, air leaves the collector area with a higher temperature than at the inlet. Useful heat gain from the system is possible only when the incident radiation is sufficient to exceed losses in the collector.

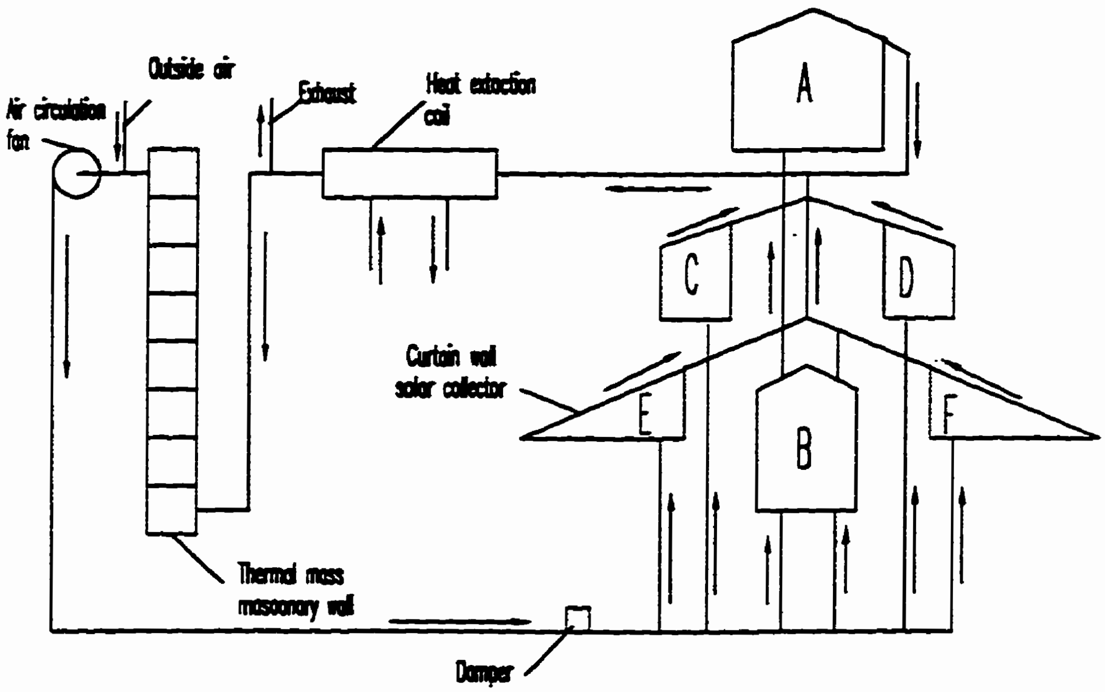

Figure 3.1 Schematic diagram of active charge-passive discharge solar heating system

Gross collectors area :

A = 28 m^2

B = 18 m^2

C = D = 14 m^2

E = F = 13.5 m^2

Heated air from the absorbers' surfaces is circulated by a fan via a duct network. The fan delivers 700 l/s at static pressure of 0.5 kPa (2 in H_2O). The calculated air flow per unit area of solar panel is given in Chapter four. After pre-heating domestic hot water via the air-to-water heat exchanger, the air gives up the remaining heat accumulated in the collectors in the thermal storage wall.

The thermal storage wall stands between the gymnasium and recreation centre. This thermal storage structural wall also functions as a primary structural support, a fire separator and a sound attenuator between the gymnasium and adjacent spaces. The area of the thermal storage is twice that of the solar collector, the ratio the designers determined to be most efficient [5]. It has an area of approximately 200 m^2.

The system was designed to deliver heat when the collectors reach 35 °C and to shut off 3 °C below this set point. Overheating protection is accomplished with motorized inlet and exhaust dampers. If the temperature of the solar heated air rises to 60 °C, these dampers open to the atmosphere such that the overheated air may be purged. Two automatic dampers located above and below the solar panels act to prevent excessive rise in temperature of the solar panels in case of power failure.

3.2.2 Curtain wall solar collector

A distinguishing feature of the building is the south-facing glass-clad wall, which is designed to act as the collector of the solar system. Wall construction is shown in figure 3.2.

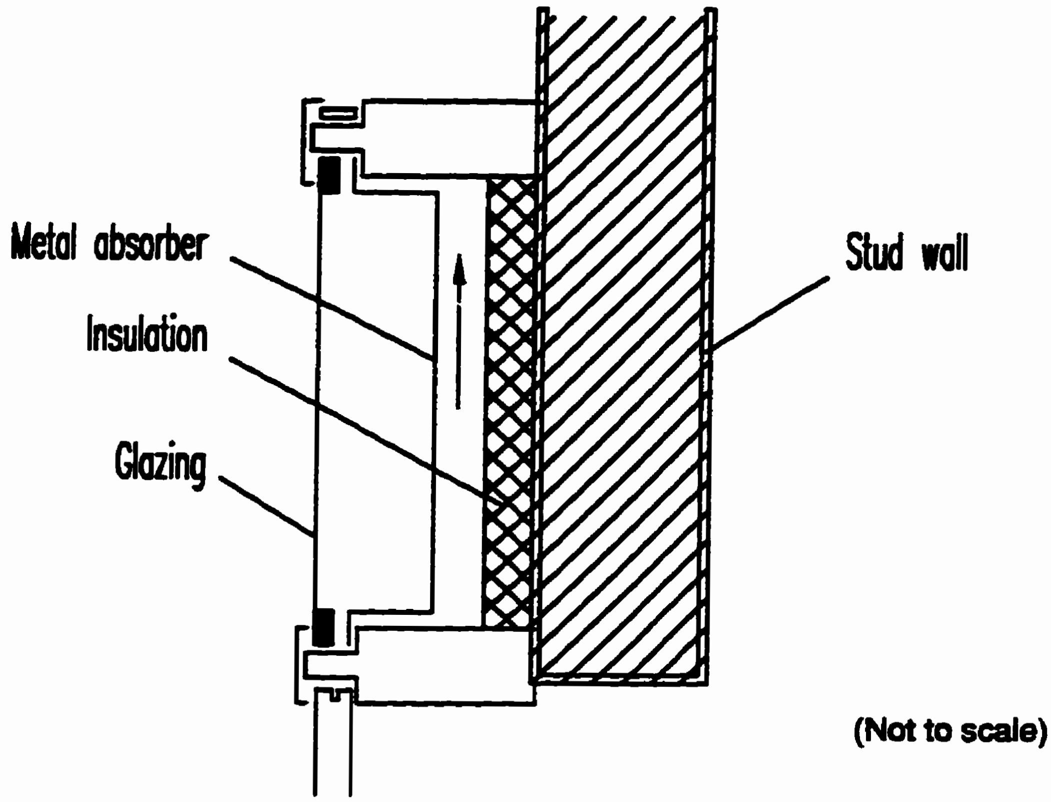

Fig. 3.2 Curtain wall solar collectors

The collectors vary in size and shape as dictated by the shape of the facade. Figure 3.1 shows collector shapes.

3.2.3 Solar panel materials

The solar collectors are glazed with a single pane of clear 6 mm tempered float glass and the absorber plates are 20 GA galvanized sheet steel painted with flat black high temperature paint.

3.3 Building envelope characteristics

Major exterior wall and roof constructions, excluding interior finishes, of the building are given in Appendix A1.

Exterior windows are fixed and clear double-glazed units except the window just below solar collector A (see figure. 3.1). This is triple-glazed with an approximate area of 7 m^2. Glazing U-values and shading coefficients were taken from the DOE-2 window library [25]. Values are shown in the Table 3.1 with DOE-2 glass-type-codes.

Exterior	Glass-type-code	Heat tranfer coeff.	Shading coeff.
Triple-glazed	3002	1.8 W/m^2 C	0.8
Double-glazed	2004	2.7 W/m^2 C	0.8
Single-glazed	1001	6.2 W/m^2 C	0.9

Table 3.1 Glazing properties

Near the middle of the building's longest axis, a skylight admits natural light. It has area of approximately 14 m^2. A heat transfer coefficient or U-value of 5.9 W/m^2K is assumed for this construction.

3.4 Space conditions

As mentioned earlier, features that significantly influence energy consumption are highly important for energy use simulation. These values were collected at the site, from architectural drawings, or based on typical conditions. A brief discussion of these parameters is presented below.

3.4.1 Outside air supply

Ventilation is very important in maintaining adequate indoor air quality. Ventilation is a process that introduces the outside air or fresh air into the occupied spaces. Its quantity has substaintial effect on building energy consumption.

In this study, the ventilation rate was assumed to follow ASHRAE standard 62-81 because the building was constructed before ASHRAE standard 62-1989. There are three air handling units.

AHU-1: Catholic and Lutheran sanctuaries, lobby, mezzanine class rooms, main vestibule, and mezzanine core zone (4.7 L/s/person or 10 cfm/person).

AHU-2: basement and main floor service zone, chapel, and play room (7.1 L/s/person or 15 cfm/person).

AHU-3: gymnasium/hall (7.1 L/s/person or 15 cfm/person).

To minimize ventilation heating load for AHU-3 a run-around heat exchanger is used to recover some heat from the exhaust air.

The quantity of outdoor air is controlled based on the outdoor air temperature by a ventilation position selector. The higher the outdoor temperature, the more outdoor air is introduced in to the spaces. This control would be set at its minimum position during winter.

3.4.2 Lighting and lighting density

Lighting systems are designed to meet architectural and visual requirements of the spaces. In most of the spaces, a combination of fluorescent and incandescent lighting was found. The simulation program allows only one type of lighting system for a space. Thus, the dominant light fixture in terms of lighting power was chosen for simulation.

In most of the spaces, a lighting power density of about 15 W/m^2 was found except in one office room (recently used as a morning class room) which has 5.5 W/m^2. These data show that the lighting system seems efficient in terms of power density.

3.4.3 Infiltration quantity

For this building, as per ASHRAE [26] recommendations, infiltration was taken to be that of a tight building envelope (200 cm^3/s m^2). According to Parker and McQuiston [27], the amount of infiltration for vestibules is 8100 cm^3/s m^2; this includes infiltration for walls, door cracks, and infiltration due to traffic.

3.4.4 Occupancy schedules

Schedules were based on several visits and information available from the building operators and the administration. However, they might not be accurate for all seasons or every year. Because of the range of facilities provided in this building, it was necessary to make different schedules for different parts of the building. The occupancy fraction was assumed to be 100 percent when occupied, but in reality it might be different. Occupancy schedules for dominant spaces are demonstrated in figures 3.3 to 3.4.

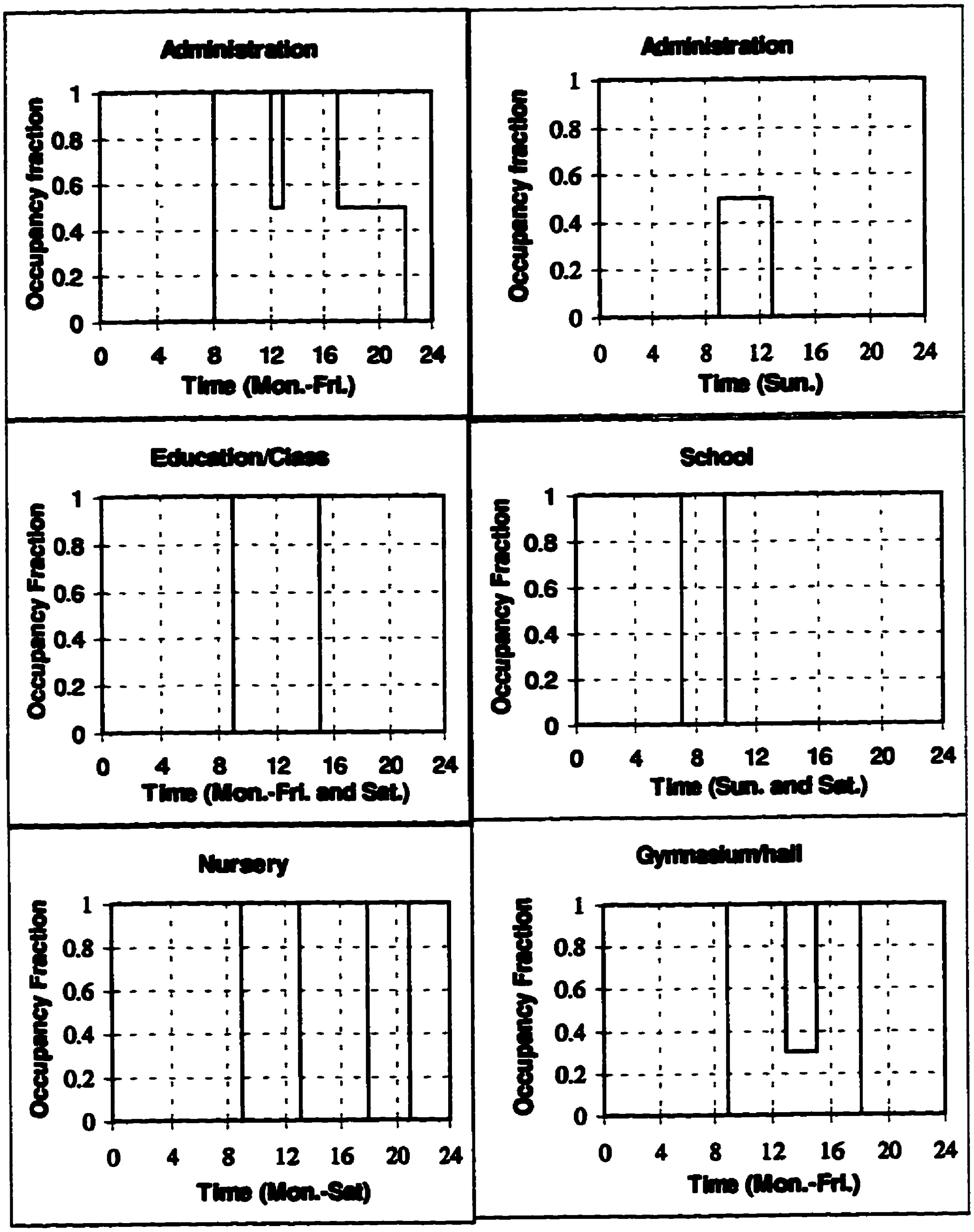

Figure 3.3 Occupancy schedules for different facilities

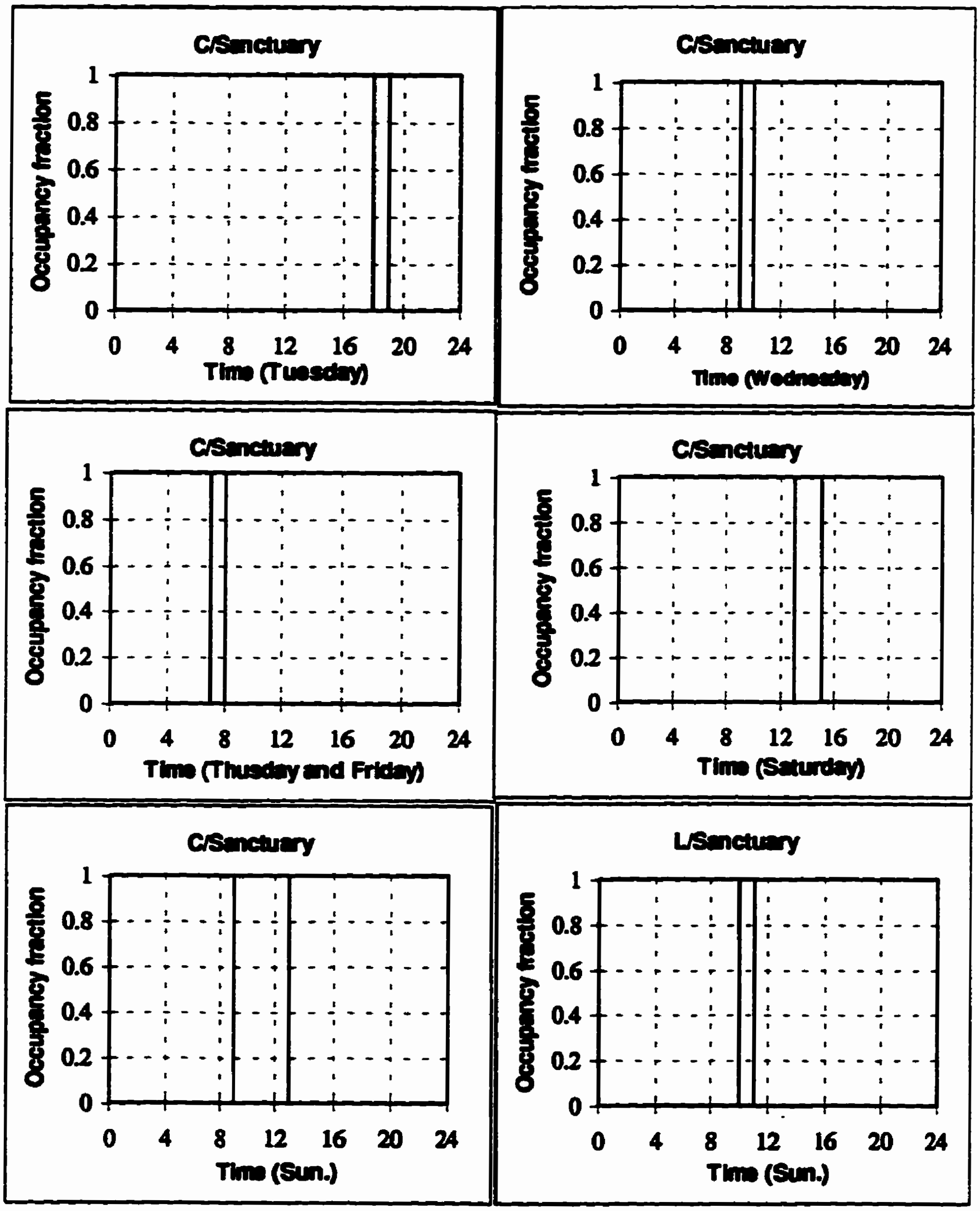

Figure 3.4 Occupancy schedules for Catholic and Lutheran sanctuaries

3.4.5 Other space conditions

Heat gain from people was selected for light working conditions and set to 120 W/person (420 Btu/hr/person) except for the gymnasium/hall at 375 W/person (960 Btu/hr/person) [28].

Based on monitoring of temperature in one of the sanctuaries for one week, the room temperature for winter was found to be 20 °C.

Ten percent of lighting was assumed to be in use in areas such as administration and mezzanine floor class rooms during unoccupied periods and at night time.

3.5 Building HVAC system and equipment

3.5.1 AHU units and exhaust fans

The building HVAC system is designed for winter heating. During the summer season, free cooling of the building is used. The building HVAC system consists of three constant-volume air systems with radiative (hot water) heating around the building perimeter. Four exhaust fans are provided for the washrooms (main floor), kitchen hood (gymnasium/hall), dryer (gymnasium/hall), and washrooms (mezzanine floor). The capacity and specifications of AHU units and exhaust fans are given in Appendix A2.

3.5.2 Space heating boiler

The plant equipment includes two natural gas-fired boilers rated at 316 kW each. These boilers have two firing stages. Natural gas flow rates in each stage and corresponding efficiencies are given in Appendix A2. Gas flow rates and efficiencies were determined on site [29].

3.5.3 Domestic Water Heater (DWH)

There are two DWH heaters rated at 95 kW each. Both these DWHs are the single stage firing type. Measured gas flow rates and efficiencies [29] are given in Appendix A2. Each DWH has a heating capacity of 1,270 l/hr.

Mansour [29] reported that hot water consumption is negligible relative to the design value. This is because facilities such as gymnasium showers and the kitchen were not used as planned. This was verified during several visits to the site.

3.6 Thermal zoning of the building

3.6.1 Overview

It is well known that the perimeter area adjacent to the exterior wall and windows is most affected by temperature differences between the outside and the inside of the envelope. Factors such as heat loss or gain through the envelope, infiltration, and solar radiation will change thermal conditions in these perimeter areas. On the other hand, thermal conditions of the core zone of any building are determined by internal heat gains. For simultaneous control of both perimeter and core zone thermal conditions during the heating season, cooling as well as heating may be required.

Because the major internal heat gain (sanctuaries) is for short periods and the building is designed only for heating, thermal zoning of the building was done according to the function of the space ignoring the fact mentioned above.

3.6.2 Thermal zoning

Zones in each floor and their associate places are as follows:

Basement: 5 zones

1- gymnasium/ hall, 2-washroom with changing rooms, cafeteria, and storage, 3- staircase, 4- recreation centre and store, 5- basement corridor.

Main floor: 6 zones

1- nursery, 2- administration, 3- chapel, 4- catholic sanctuary, 5- lutheran sanctuary, 6- lobby.

Mezzanine: 7 zones

1- office, 2- corridor, 3- core, and W/R, 4- lutheran/catholic mezzanine room, 5- mechanical (uncondition), and 7- play room.

Altogether there are three vestibules, one in the basement and two on the main floor. During several visits to the building, it was noticed that only one vestibule is commonly used. In the simulation mode, only one vestibule is used for the building energy analysis. The rest of the vestibules are treated as envelope for infiltration. In Figures 3.5 to 3.7, at the end of the chapter, floor plans show the zoning of the building.

3.7 Calgary weather file for 1995

In terms of climatic condition, Calgary's high altitude and dry and fairly clean atmosphere with 2,200 hours/year bright sunshine indicates a good potential for solar energy [29]. To increase accuracy in simulation and calculation of solar gain from the solar air heater, an hourly weather file was prepared for 1995. Data recorded at The University of Calgary, Alberta, were used. By re-formatting the recorded data, a WYEC (Weather Year for Energy

Calculations) format weather file was prepared. This WYEC format weather file consists of 8760 records, one for each hour of the year. Each record has 116 characters. Details of the WYEC format are available from the Atmospheric Environment Service of Environment Canada in Downsview, Ontario.

The DOE-2 simulation program needs an hourly weather file to simulate building energy use. Table 3.5 presents a brief monthly summary of the 1995 weather file. However, for more representative energy consumption forecasting or building energy analysis, it is better to have a file representative of long-term weather patterns.

	Monthly average daily radiation on horizontal surface	Monthly Average daily Outside temperature	Heating Degree Days
Month	MJ/m^2	T_o °C	°C
Jan.	4.9	-6.0	774
Feb.	5.6	-5.0	671
Mar.	13.4	-2.2	653
Apr.	15.9	3.1	466
May	20.7	9.5	292
Jun.	21.0	14.1	148
Jul.	19.4	15.4	107
Aug.	19.4	13.5	155
Sep.	15.3	11.8	209
Oct.	9.0	5.3	432
Nov.	4.6	-4.2	665
Dec.	3.7	-9.8	861
		Total	5433

Table 3.5 Calgary weather summary for 1995

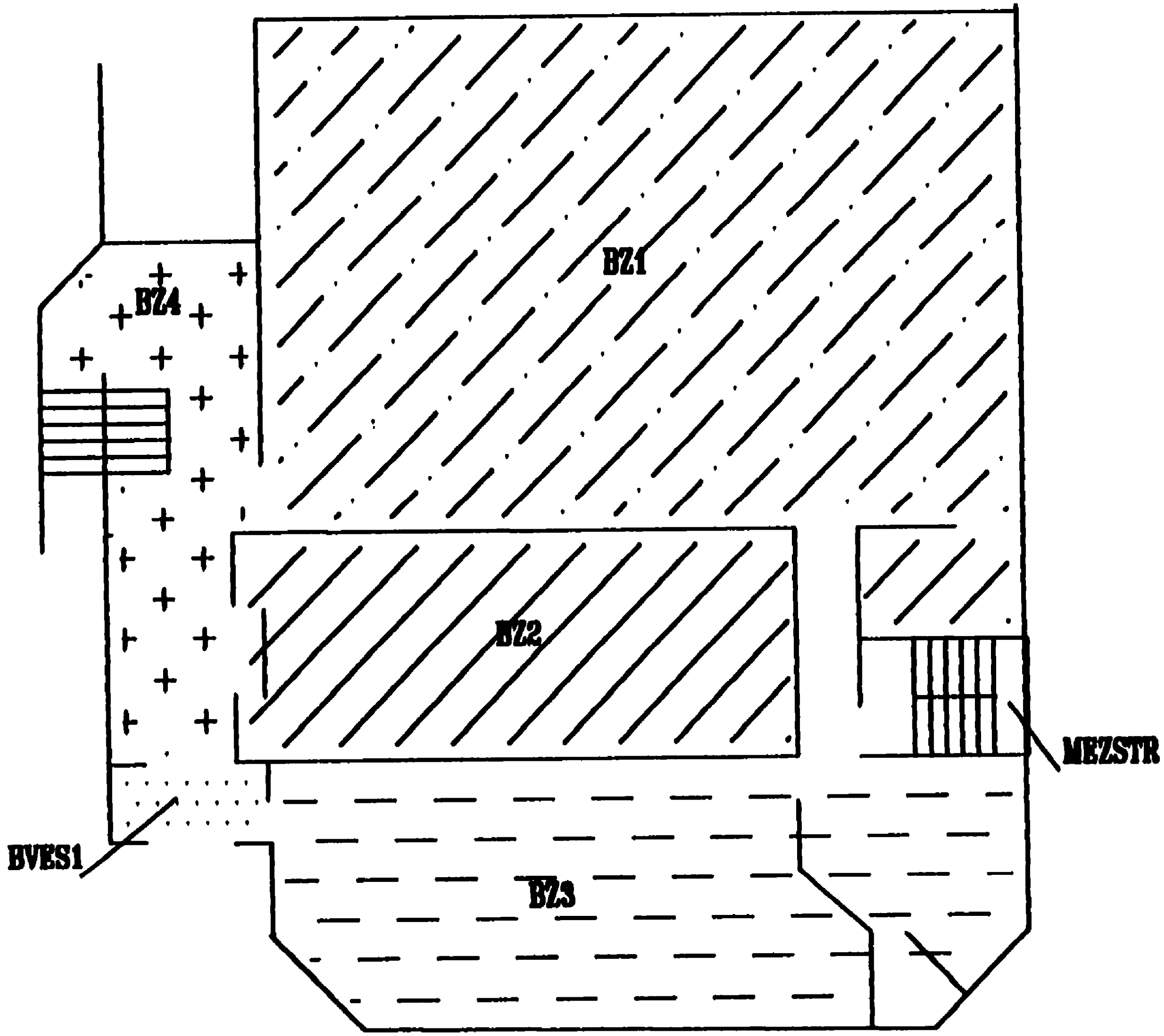

Figure 3.5 Basement floor plan

(Not to scale)

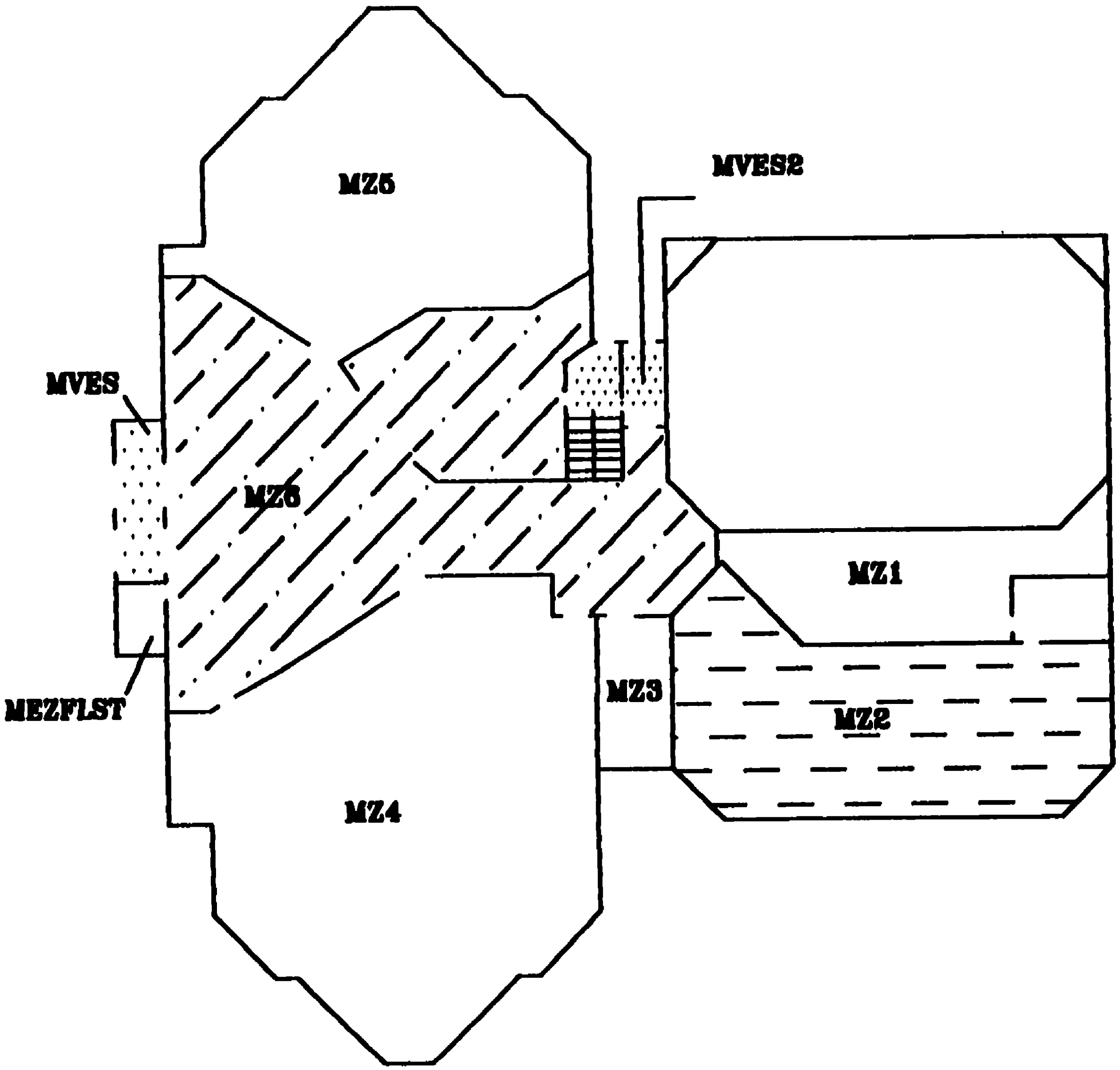

Figure 3.6 Main floor plan

(Not to scale)

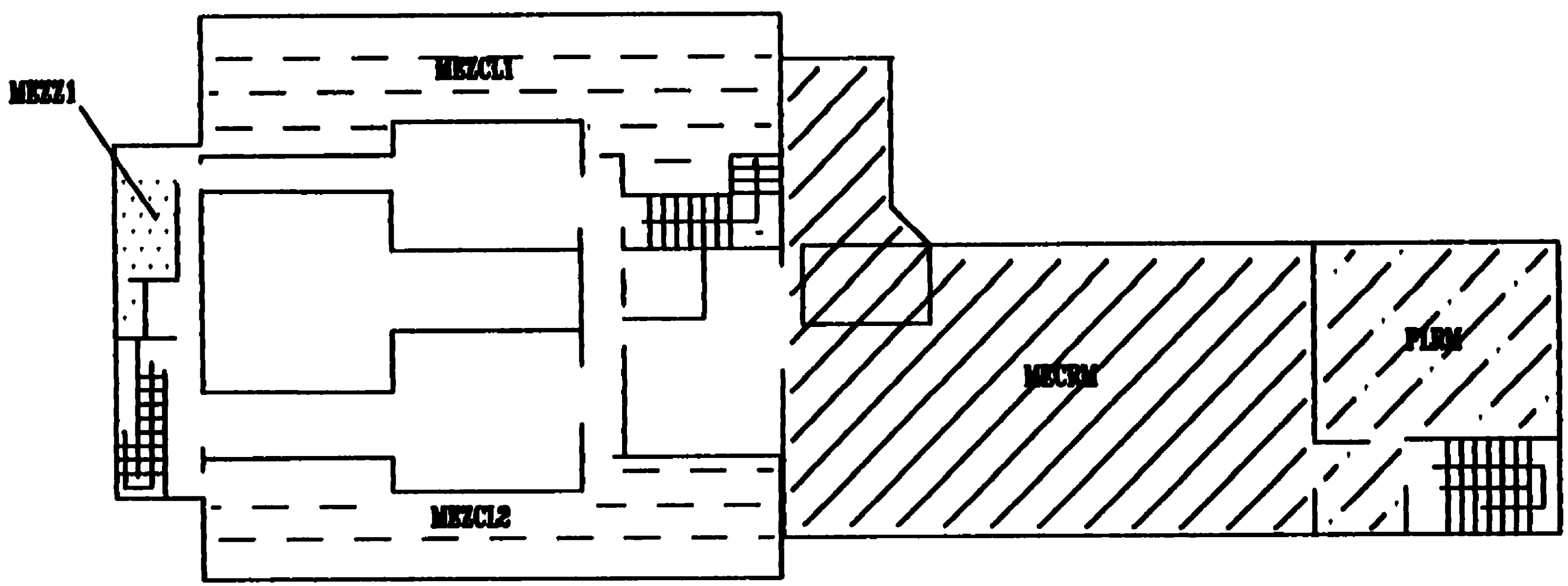

Figure 3.7 Mezzanine floor plan

(Not to scale)

CHAPTER 4

SOLAR SYSTEM PERFORMANCE

4.1 Overview

This chapter details the testing procedure and the results for the existing solar heating system. It describes how the efficiency and thermal performance factors were measured and calculated. Secondly, the useful monthly solar energy received from the solar heating system for 1995 is calculated using the daily utilizability method.

Generally, thermal performance testing of solar collectors is conducted to determine three parameters: 1) the instantaneous efficiency of the collector, 2) the effects of angle of incidence of incident radiation, and 3) the heat capacity of the collector in terms of time constant. In this study, the collector was only tested for instantaneous efficiency because the other two factors were not relevant to this study.

4.2 Solar collector testing procedure

The thermal performance of any solar system varies depending on parameters such as operating temperature, flow rates, solar insolation, orientation, tilt, time of day, wind condition, outdoor temperature, clearness index, and geometry of the solar collector. Despite the transient effect of all these variables on the thermal performance, steady-state conditions are adequate for estimating solar collector performance [16]. The testing procedure used in this project allows the determination of the fundamental characteristics of a collector. The temperature measuring points for testing of the closed-loop solar system are shown in figure 4.1.

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4.3 Determination of collector performance metrics

4.3.1 Efficiency

Assuming steady-state conditions, the useful gain by the solar collector may be expressed by

$$Q_u = \dot{m} C_P (T_o - T_i) \quad (1)$$

where $\dot{m}$ is mass flow rate (kg/s)

Q_u - useful gain (W)

C_p - specific heat of the fluid at average temperature (J/kg°C)

T_o . T_i - outlet and inlet temperature of the collector (°C)

Equation (2) gives the expression for absorption of energy by the collector and losses to the surroundings. Under steady-state conditions, collector thermal performance may also be written as [6]

$$Q_u = A_c F_R [G_T (\alpha\tau) - U_L (T_i - T_a)] \quad (2)$$

where A_c - collector area (m^2)

F_R - heat removal factor

G_T - instantaneous solar radiation (W/m^2)

$(\alpha\tau)$ - the transmittance-absorptance product

U_L - collector overall energy loss coefficient ($W/m^2{}^\circ C$)

T_i and T_a - fluid inlet and ambient temperature (°C)

Instantaneous efficiency (η_i) of the collector is then expressed as

$$\eta_i = Q_u / A_c G_T = F_R(\tau\alpha) - [F_R U_L (T_i - T_a) / G_T] \quad (3)$$

and $$\eta_i = \dot{m} C_p (T_o - T_i) / A_c G_T \quad (4)$$

Assuming constant weather conditions and little difference in angle of incidence, the performance of a solar heating system can be characterized by the intercept and slope of η_i plotted against $(T_i - T_a) / G_T$. Because collector properties such as U_L, F_R, and $(\tau\alpha)$ are not constant with respect to time, the slope could otherwise be nonlinear.

Evaluations of efficiency are made based on symmetrical pairs, pairing data sets for before and after solar noon to minimize the effect of heat capacity of the solar collectors. Data are averaged for 30 minute periods. Instantaneous efficiencies are determined from equation (4) and plotted as a function of $(T_i - T_a) / G_T$. Aperture area (i.e., total cover area less the area of cover supports) is used to determine the efficiency of the collector.

The intercept with the Y-axis, or efficiency (η_i) coordinate, represents the $F_R(\tau\alpha)_n$ value for the tested solar collector and F_RU_L is given by the slope of the graph. Mathematically F_RU_L can be calculated as

$$F_RU_L = \text{- slope (graphically)}$$

$$F_RU_L = - \ (\eta_1 - \eta_2) / [((T_{i1} - T_{a1}) / G_{T1}) - ((T_{i2} - T_{a2}) / G_{T2})] \quad (5)$$

where η_1, η_2 - obtained efficiency before and after solar noon

T_{i1}, T_{a1} - inlet and ambient temperature of collector for first pair (°C)

T_{i2} - T_{a2} - inlet and ambient temperature of collector for second pair (°C)

G_{T1}, G_{T2} - Instantaneous solar radiation (W/m^2)

Data from the collector testing are plotted as η_i vs. $(T_{av} - T_a) / G_T$, then the following formulas are used to convert the format.

$$F_R(\tau\alpha)_n = F_{av}(\tau\alpha)_n \ [1 + (A_cF_{av}U_L) / (2 \dot{m} C_p)]^{-1} \tag{6}$$

$$F_RU_L = F_{av}U_L [1 + (A_cF_{av}U_L) / (2 \dot{m} C_p)]^{-1} \tag{7}$$

where $T_{av} = (T_{i1} + T_{o1})/2$

T_{av} - average of inlet and outlet temperature (°C)

4.3.2 Calculation of values needed to determine efficiencies

4.3.2.1 Solar time

Most sun-angle relationships are based on solar time, which does not coincide with local time. To convert local time into solar time, two correction factors were used [6]:

- for the difference in longitude between the local longitude and the meridian on which the local time is based.
- the equation of time, which takes into account the effect of the rotation of the earth on the observer's meridian

$$\text{Solar time} - \text{Standard time} = 4\ (L_{st} - L_{loc}) + E$$

where L_{st} - standard meridian for the local time zone

L_{loc} - longitude of the location

E - equation of time in minute and expressed as

$$E = 229.2\ (0.000075 + 0.001868 \cos B - 0.032077 \sin B - 0.014615 \cos 2B - 0.04089 \sin 2B)$$

and $B = (n - 1)\ 360 / 365$ n = day of the year $1 \le n \le 365$

The standard meridian (L_{st}) for Calgary's time zone is 105°W (Mountain) and the longitude (L_{loc}) is 114°W.

4.3.2.2 Calculation of mass flow rate

The mass flow rate in a round duct is given by

$$\dot{m} = A \rho V$$

where A is area (m^2)

ρ is density at given pressure and temperature (kg/m^3)

V is average velocity (m/s)

4.3.2.2.1 Calculation of fluid density

According to the ideal-state gas law for air, the density of air is given by

$$\rho = P / RT$$

where ρ is the density of the air at given pressure and temperature

P is absolute pressure (Pa)

T is absolute temperature (°C)

R gas constant for the air (J/kgK)

In this formula, the density of the air (ρ) is taken as independent of the velocity and gauge pressure. The gauge pressure developed by the fluid flow is negligible compared to the barometric pressure.

The flow is considered to be incompressible, because of the very low Mach number [30]. The Mach number is the ratio of the velocity fluid in the pipe to the velocity of sound.

4.3.2.2.2 Calculation of average velocity

A hot wire anemometer was used to measure velocity in the ducts. After measuring the velocity at the center of the round duct, the logarithmic-law of velocity distribution was applied to calculate average velocity in the duct [31].

$$V = Q / A = \frac{1}{\pi R^2} \int_0^R u 2\pi r dr \quad \text{(m/s)}$$

where $u = u^* \left[\left(\frac{1}{k} \right) \ln \left(\frac{y u^*}{\upsilon} \right) + B \right]$ (m/s)

Where u^* is the friction velocity (m/s)

k, B - are constant and for turbulent flow values are 0.41 and 5 respectively

y - is the distance from the outer surface to the center (m)

ν - is the kinematic viscosity (m^2/s)

The friction velocity is given by

$$\frac{u_0}{u^*} = \frac{1}{0.41} + \ln \frac{R}{\upsilon} + 5$$

where u_0 is velocity at the center of the round duct.

4.4 Measurements to determine collector characteristics

System monitoring began in September 1996. Data were collected for September and October. Out of this data, only a few days data were chosen for further analysis, because only data for clear days could be used.

ASHRAE Standard 93-77 [32] was followed in selecting weather conditions for determining the solar air heater performance. The standard proposes that the testing should be done for clear days to minimize the effect of diffuse radiation on the solar collector. In terms of radiation, the standard specifies that tests should be conducted for periods during which the 15-minute integrated average solar radiation is at least 630 W/m^2.

In this study, south-facing vertical irradiation, wind speed, outside temperature, and barometric pressure were recorded at The University of Calgary. The data are recorded every minute.

4.4.1 Measuring instruments

4.4.1.1 Temperature measuring instruments

Electronic instruments (thermistor type) were used to read the temperature of the working fluid in the duct network of the solar system. Electronic microloggers (StowAway-XT) were programmed with Logbook software to measure temperature every minute. This instrument can store approximately 8000 values for approximately 5.5 days (for one minute measurement intervals). These data can be uploaded from the instrument to the computer using Logbook software. The maximum total error of these instruments ranges from 0.3 to 0.5 °C of full scale.

4.4.1.2 Velocity measuring instrument

The centre velocity of the inlet and outlet of the solar collector was measured with a Wallac Thermo-Anemometer, model No. GGA 23s. The centre velocities in outlet and inlet ducts were measured three or four times in every recording period (the solar system circulation fan has a constant speed, so very little change in velocity should occur). This instrument was calibrated in 1986 and the calibration certificate shows the maximum instrument error to range from ± .33 % to ± 2 % (low range) or to ± 2.33 % (high range) of full scale. A few years ago, the anemometer was checked in the wind tunnel at the Department of Mechanical Engineering of the University of Calgary.

4.5 Assumptions for analysis

Because of limited access to the solar system duct network, efficiency and values such as $F_R(\tau\alpha)_n$, F_RU_L, were based on measurements for solar panels B, C, and D (see figure 3.1). These panels represent approximately 46 percent of the total collector area.

The overall collector efficiency is probably less than the one based on panels B, C, and D, because solar panels E and F (see figure 3.1) are triangular. This configuration reduces the contact period of the working fluid with the absorber plate. In other words, these configurations result in a shorter flow path for the working fluid than the rectangular panels. In this study, this effect could not be calculated, because the ducts to these panels were inaccessible.

4.6 Solar system test results

To eliminate errors due to the thermal constant of the solar collector, only radiation values higher than or equal to 600 W/m^2 were used for calculation of efficiency. The data show that the efficiency appears to rise in the afternoon even though the irradiation is very low, because of the thermal constant of the solar collector.

Tables 4.1a and 4.1b contain test results for October 3, 8, 9, 18, and 20, 1996. Thirty minute average values of the parameters and their corresponding efficiency values are shown in these tables.

Note that for the existing flow rate, the efficiency is strongly dependent on the ambient temperature and irradiation value, but varies little with wind speed.

Graphs of η_i vs. $(T_{av} - T_a) / G_T$ and η_i vs. $(T_i - T_a) / G_T$ are presented in figures 4.2 and 4.3 respectively. Each graph represents individual $F_R(\tau\alpha)_n$, and F_RU_L for a given testing day. Comparing these graphs, F_RU_L, and $F_R(\tau\alpha)_n$ remain almost constant in different weather conditions.The F_RU_L value of Oct. 20 is an exception. Calculation of monthly utilizable solar energy for 1995 was based on average values of $F_R(\tau\alpha)_n$ and F_RU_L obtained from the testing.

October 3	T_o	T_i	T_{av}	T_a	G_T	$\dot{m}$	Q_u	η		Wind speed
time	°C	°C	°C	°C	w/m2	kg/s	MJ/h		$(T_{av} - T_a)/G_T$	m/s
9:21	30.8	21.3	26.0	11.8	611	0.21	7.1	7.4	0.0234	2.3
10:51	36.4	21.5	29.0	14.1	725	0.20	10.9	9.5	0.0205	2.2
11:21	40.0	21.8	30.9	16.2	779	0.20	13.3	10.8	0.0189	2.1
11:51	42.8	22.0	32.4	17.8	827	0.20	14.9	11.4	0.0176	3.2
12:21	44.8	22.2	33.5	18.6	853	0.20	16.1	12.0	0.0175	3.4
12:51	47.7	22.7	35.2	19.5	862	0.20	17.6	13.0	0.0182	3.8
13:21	47.7	22.9	35.3	20.1	783	0.20	17.5	14.3	0.0194	3.4
13:51	47.1	23.1	35.1	20.3	665	0.20	17.0	16.7	0.0223	3.3
14:21	46.5	22.5	34.5	19.2	864	0.20	17.0	12.6	0.0178	3.9
October 9										
9:53	32.3	22.5	27.4	6.7	592	0.21	7.3	7.8	0.0349	0.6
10:23	36.8	22.6	29.7	8.7	679	0.20	10.4	9.8	0.0310	0.4
10:53	40.8	22.8	31.8	10.7	751	0.20	13.0	11.0	0.0281	0.2
11:23	43.6	22.9	33.3	12.8	807	0.20	14.9	11.7	0.0253	0.2
11:53	46.4	23.1	34.7	14.3	848	0.20	16.6	12.5	0.0240	0.4
12:23	48.9	23.3	36.1	15.3	874	0.20	18.1	13.2	0.0238	0.5
12:53	50.8	23.4	37.1	15.8	875	0.20	19.3	14.0	0.0244	0.6
13:23	51.7	23.5	37.6	16.1	864	0.20	19.8	14.6	0.0248	0.6
13:53	51.6	23.7	37.7	16.8	834	0.20	19.6	14.9	0.0251	0.5
14:23	50.9	23.9	37.4	17.2	784	0.20	19.0	15.4	0.0257	0.5
14:53	49.8	24.1	36.9	17.9	718	0.20	18.1	16.0	0.0265	0.5

Table 4.1a. Solar analysis data

October 18	T_o	T_i	T_a	G_T	$\dot{m}$	Q_u	η		Wind speed
time	°C	°C	°C	w/m2	kg/s	MJ/h		$(T_i - T_a)/G_T$	m/s
9:51	27.7	20.8	5.0	632	0.20	5.1	5.0	0.0231	2.0
10:21	33.9	21.4	6.6	686	0.20	9.0	8.4	0.0189	2.1
10:51	38.5	21.6	7.8	787	0.20	12.1	9.7	0.0163	2.8
11:21	41.8	21.8	9.0	850	0.20	14.1	10.5	0.0141	4.3
11:51	44.1	21.9	10.0	902	0.20	15.5	10.9	0.0128	5.1
12:21	45.3	22.1	9.9	927	0.20	16.1	11.1	0.0132	5.7
12:51	44.2	22.3	9.7	928	0.20	15.3	10.5	0.0136	5.4
13:21	45.7	22.5	9.9	926	0.20	16.1	11.1	0.0140	5.7
13:51	42.4	22.7	10.3	901	0.20	13.9	9.8	0.0145	6.0
14:21	38.3	22.8	9.9	858	0.20	11.0	8.2	0.0162	6.4
14:51	32.5	22.8	9.9	793	0.20	7.0	5.6	0.0163	5.6
October 20									
9:51	18.5	2.0	-2.2	95	0.21	0.0	0.0	0.0619	12.0
10:21	19.4	2.1	-1.6	377	0.21	0.0	0.0	0.0293	9.0
10:51	20.1	2.8	-0.5	774	0.21	0.0	0.0	0.0249	7.0
11:21	23.9	4.3	0.7	845	0.21	2.5	1.8	0.0222	5.0
11:51	38.2	5.1	2.0	902	0.20	11.7	8.2	0.0215	3.0
12:21	43.3	5.7	4.2	922	0.20	14.8	10.2	0.0192	5.0
12:51	47.0	5.4	4.3	930	0.20	17.0	11.6	0.0197	6.0
13:21	44.9	5.7	4.6	923	0.20	15.4	10.6	0.0204	7.0
13:51	41.9	6.0	4.4	890	0.20	13.3	9.5	0.0222	7.0
14:21	47.5	6.4	4.6	836	0.20	16.7	12.7	0.0246	9.0
14:51	48.2	5.6	5.5	763	0.20	17.0	14.2	0.0237	11.0

Table 4.1b. Solar data analysis

Figure 4.2 shows graphs of η_i vs. $(T_{av} - T_a) / G_T$ based on average fluid temperature. $F_R(\tau\alpha)_n$ and F_RU_L had values of 0.24 and 6.03 W/m^2 for Oct. 3 and 0.22 and 4.96 W/m^2 for Oct. 9.

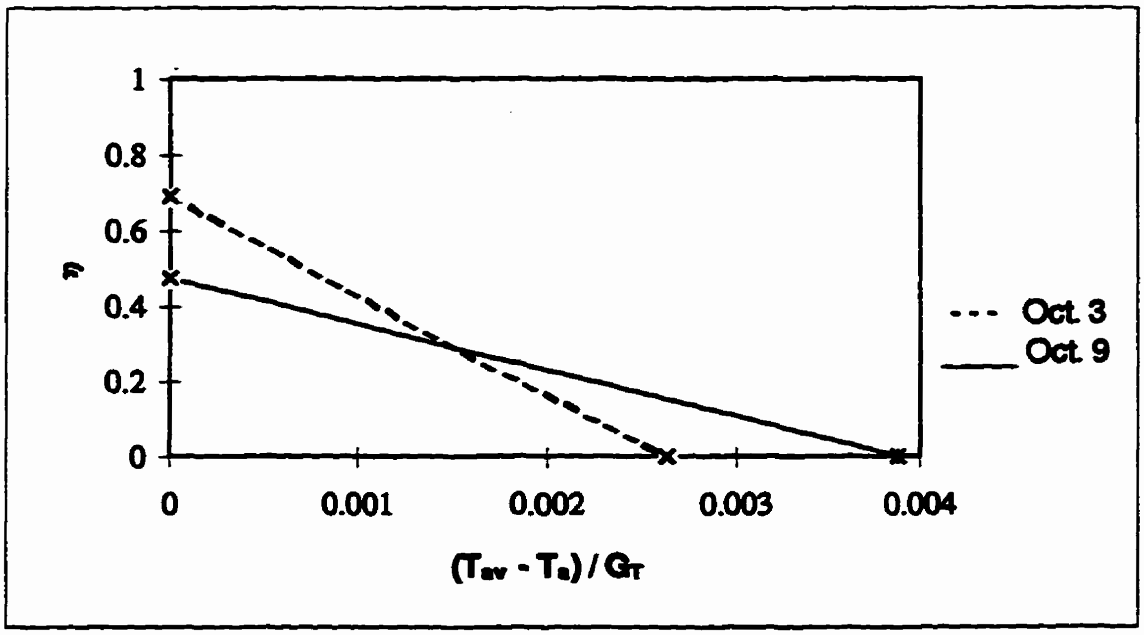

Figure 4.2 Characteristic efficiency curves for the air heating flat-plate collector plotted as function of T_{av}.

Figure 4.3 shows graphs of η_i vs. $(T_i - T_a) / G_T$ based on inlet fluid and ambient temperature. $F_R(\tau\alpha)_n$ and F_RU_L had values of 0.2 and 5.43 W/m^2 for Oct. 18 and 0.4 and 14.90 W/m^2 for Oct. 20. The value of F_RU_L for Oct. 20 is not included in the average value.

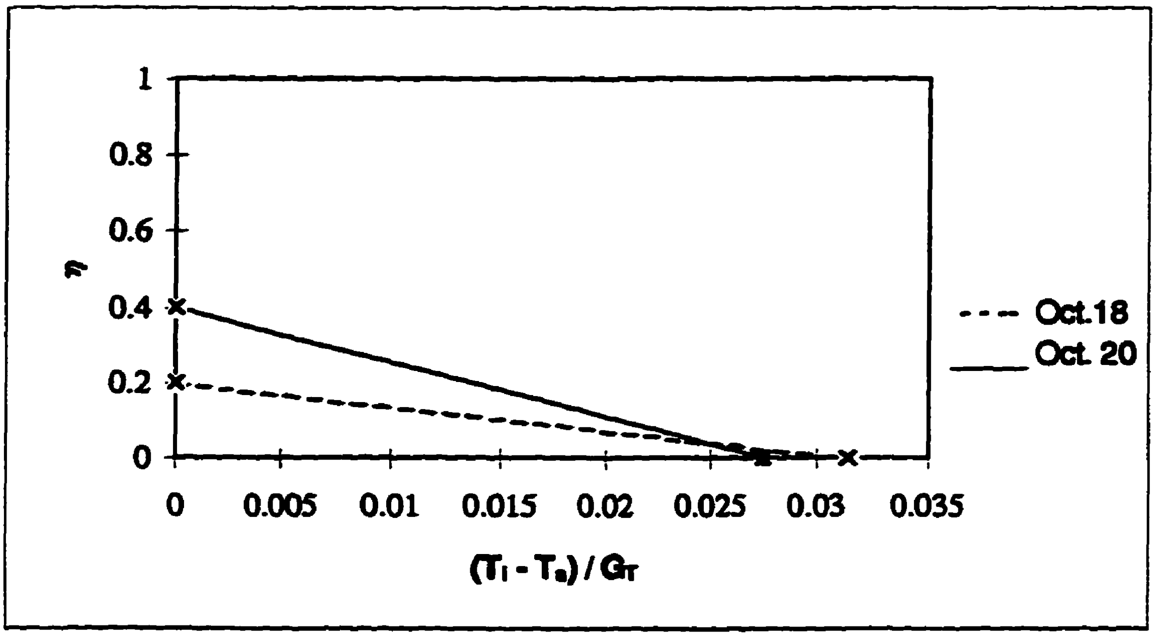

Figure 4.3 Characteristic efficiency curves for the air heating flat-plate collector plotted as function of T_i.

The average values of $F_R(\tau\alpha)_n$ and F_RU_L were 0.26 and 5.4 W/m^2 respectively. For solar energy utilizibility calculations, $F_R(\tau\alpha)_n$ and F_RU_L were taken as average values obtained from the experiment on the existing solar air heater.

4.7 Calculation of monthly useful solar energy

In this study, monthly average daily solar radiation was used to estimate the heat delivered by the solar air heater. To determine flate-plate collector utilizability, a method proposed by Klein [33] was used. This method is called the daily $\bar{\phi}$-chart method. The utilizable solar energy is defined as the fraction of incident solar radiation converted to useful heat.

The calculation steps are:

- determine $\bar{H}_T$, the monthly average daily radiation per unit area on the collector surface.
- determine R_n, the ratio of the radiation on the tilted surface to that on the horizontal surface at solar noon on the average day of the month.
- calculate utilizability coefficient $\bar{\phi}$ and monthly total energy collection by the solar heater.

4.7.1 Monthly radiation on the tilted surface

4.7.1.1 Monthly average daily extraterrestrial radiation

Monthly average daily extraterrestrial radiation ($\bar{H}_0$, MJ/m^2) for each month of the year is:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
8.5	13.8	22.0	31.1	38.3	41.5	39.9	33.8	25.0	16.1	9.7	7.1

Table 4.2 Average daily extraterrestrial radiation

4.7.1.2 Monthly average daily radiation on the horizontal surface

Monthly average daily radiation on the horizontal surface ($\bar{H}$, MJ/m^2) for 1995 meteorological data was:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.9	5.6	13.4	15.9	20.7	21.0	19.4	19.5	15.3	9.0	4.6	3.7

Table 4.3 Daily radiation on horizontal surface

4.7.1.3 Monthly average clearness index

The monthly average clearness index $\bar{K}_T$ ($\bar{H}$ / $\bar{H}_0$) for Calgary was:

Jan	Feb	Ma	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
.58	.41	.61	.51	.54	.51	.49	.58	.61	.56	.47	.52

Table 4.4 Clearness index

4.7.1.4 Calculation of sunset hour angles

Calculation of the sunset hour angle (ω_S) is given by expression:

$$\cos \omega_S = - \tan \phi \times \tan \delta$$

where ϕ - latitude of the location (51°for Calgary)

δ - solar declination

δ changes with mean day of the month and it is given by expression:

$$\delta = 23.45 \sin (360 \times (284+n) / 365)$$

where n - mean day of the month.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
n	17	47	75	105	135	162	198	228	258	288	318	344
δ	-20.9	-13.0	-2.4	9.4	18.8	23.1	21.2	13.5	2.2	-9.6	-18.9	-23.0
ω_S	61.8	73.4	87.0	78.2	65.2	58.2	61.4	72.8	87.3	77.9	65.0	58.4

Table 4.5 Monthly values of n, δ, ω_S

4.7.1.5 Diffused component

Calculation of the beam and diffuse components of the monthly radiation for the mean day of the month is given by

for $\omega_S \leq 81.4°$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\bar{H}_d / \bar{H} = 1.391 - 3.56 \bar{K}_T + 4.189 \bar{K}_T^2 - 2.137 \bar{K}_T^3$$

for $\omega_S > 81.4°$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\bar{H}_d / \bar{H} = 1.311 - 3.022\ \bar{K}_T + 3.427\ \bar{K}_T^2 - 1.821\ \bar{K}_T^3$$

where $\bar{H}_d$ - diffused component of solar irradiation (J/m^2)

4.7.1.6 Average radiation on the tilted surface

Monthly mean solar radiation on the tilted surface for isotropic sky can be calculated from the expression:

$$\bar{H}_T = \bar{H}\,(1 - H_d / H)\ \bar{R}_b + \bar{H}_d\left[\frac{(1+\cos\beta)}{2}\right] + \bar{H}\,\rho_g\left[\frac{(1-\cos\beta)}{2}\right]$$

where $\frac{(1+\cos\beta)}{2}$ - view factor to the sky $F_{C\text{-}S}$

$\frac{(1-\cos\beta)}{2}$ - view factor to the ground $F_{C\text{-}G}$

ρ_g - diffuse reflectance of ground

β - sloped surface angle (degree)

4.7.1.7 Value $\bar{R}$

The average ratio of the total radiation on a tilted plane to that on the horizontal is given by

$$\bar{R} = \bar{H}_T / \bar{H} = (1 - \bar{H}_d / \bar{H})\ \bar{R}_b + (\bar{H}_d / \bar{H})\left[\frac{(1+\cos\beta)}{2}\right] + \rho_g\left[\frac{(1-\cos\beta)}{2}\right]$$

where $\bar{H}_d / \bar{H}$ is a function of $\bar{K}_T$

4.7.1.8 Value $\bar{R}_b$

The ratio of the average daily beam radiation on the tilted surface to that on a horizontal surface for the month is $\bar{R}_b$ and it is given by

$$\bar{R}_b = \bar{H}_{bT} / \bar{H}_b$$

or $$\bar{R}_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega'_s + (\pi/180)\omega'_s \sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + (\pi/180)\omega_s\sin\phi\sin\delta}$$

where ω'_s - sunset hour angle for the tilted surface of the mean day of the month

$$\omega'_s = \min [\cos^{-1}(-\tan\phi \tan\delta)$$
$$\cos^{-1}(-\tan(\phi-\beta)\tan\delta)]$$

where min means the smaller of the two items in the brackets

$\bar{H}_{bT}$ - average daily beam radiation on tilted surface (J/m²)

$\bar{H}_b$ - average daily beam radiation on horizontal surface (J/m²)

Table 4.6 presents results of the calculations.

Month	$\bar{H}$, MJ/m²	$\bar{H}_d/\bar{H}$	1- $\bar{H}_d/\bar{H}$	ρ_g	$\bar{R}_b$	$\bar{R}$	$\bar{H}_T$ MJ/m²
Jan.	4.9	0.32	0.68	0.7	4.0	3.2	16
Feb.	5.6	0.49	0.51	0.7	2.5	1.9	10
Mar.	13.4	0.29	0.71	0.4	1.4	1.3	18
Apr.	15.9	0.38	0.62	0.4	0.8	0.9	14
May	20.7	0.35	0.65	0.2	0.5	0.6	12
Jun.	21.0	0.39	0.61	0.2	0.4	0.5	11
Jul.	19.4	0.40	0.60	0.2	0.5	0.6	12
Aug.	19.5	0.32	0.68	0.2	0.7	0.7	14
Sep.	15.3	0.29	0.71	0.2	1.1	1.0	16
Oct.	9.0	0.34	0.66	0.2	2.1	1.7	15
Nov.	4.6	0.42	0.58	0.4	3.5	2.4	11
Dec.	3.7	0.34	0.63	0.7	4.7	3.5	13

Table 4.6 Irradiation on the tilted surface of the solar collector based on 1995 weather data for Calgary

4.7.2 Useful solar energy calculation

4.7.2.1 Calculation of R_n

The ratio of radiation on the tilted surface to that on a horizontal surface at noon for an average day of the month (R_n) is calculated based on the individual components of solar radiation (i.e., beam, diffuse, and ground-reflected). Mathematically it is expressed as:

$$R_n = [(1 - (r_{d,n} / r_{T,n})(H_d / H)) R_{bn}] + [(r_{d,n} / r_{T,n})(H_d / H) ((1+\cos\beta)/2)] + \rho_g [(1 - \cos\beta)/2]$$

where $r_{t,n}$ is the ratio of radiation at noon to the daily total radiation

$$r_{t,n} = r_{d,n} [1.07 + 0.025 \sin(\omega_S - 60)]$$

$r_{d,n}$ is the ratio of diffuse radiation at noon to the daily diffuse radiation

$$r_{d,n} = \pi / 24 [(1-\cos\omega_S) / (\sin \omega_S - (\pi/180)\, \omega_S \cos\omega_S)]$$

$R_{b,n}$ - the ratio of beam radiation on the tilted surface to that on a horizontal surface at noon. For surfaces facing directly towards the equator:

$$R_{b,n} = (\cos (\phi-\beta) \cos \delta + \sin (\phi-\beta) \sin \delta)/(\cos \phi \cos \delta + \sin \phi \sin \delta)$$

4.7.2.2 Critical radiation level

The critical radiation level is defined as the irradiance at which the heat lost due to convection, conduction and radiation from the solar collector is equal to the heat produced by the collector. In other words, only radiation above this intensity (radiation level at tilted surface) will produce useful energy for space or water heating. The critical radiation level is defined as:

$$I_{TC} = \frac{F_R U_L(\bar{T}_{im} - \bar{T}_{amv})}{F_R(\overline{\tau\alpha})} \text{ (W/m}^2\text{)}$$

where $\bar{T}_{im}$ - average inlet temperature for the month (°C)

$\bar{T}_{amv}$ - average ambient temperature for the month (°C)

4.7.2.3 Value $\bar{X}_C$

The ratio of the critical radiation to the radiation at noon for the average day during the month (on which the total radiation for the day is the same as the average for the month), $\bar{X}_C$, is given by

$$\bar{X}_C = I_{TC} / (r_{t,n} R_n \bar{H})$$

4.7.2.4 Calculation of utilizability coefficient $\bar{\phi}$

$\bar{\phi}$ is the fraction of the total radiation during the month which is above the critical radiation (I_c). The value of $\bar{\phi}$ for a one-month period depends upon the distribution of daily solar radiation.

$$\bar{\phi}_c = \exp\{[a + b (R_n / \bar{R})] [\bar{X}_C + c \bar{X}_c^2]\}$$

where coefficients a, b and c are calculated as

$$a = 2.943 - 9.271 \bar{K}_T + 4.031 \bar{K}_T^2$$
$$b = - 4.345 + 8.853 \bar{K}_T - 3.602 \bar{K}_T^2$$
$$c = - 0.170 - 0.306 \bar{K}_T + 2.936 \bar{K}_T^2$$

4.7.2.5 Useful heat delivery

The total useful monthly energy output of a collector can be determined using the following expression:

$$Q_{useful} = A_c F_R (\bar{\tau\alpha}) \bar{\phi} \bar{H}_T N$$

where A_c is the area of the solar collector

$(\bar{\tau\alpha})$ - average transmittance-absorptance product for the collector.

N - number of days in the month

Calculations were based on 1995 weather conditions. The parameters that are needed to determine the useful heat output of the solar collector are shown below. A summary of the calculated values is given in tables 4.7 and 4.8.

Slope of the collector = 90°

$\bar{F}_R(\alpha\tau)_n = 0.264$ (average value of $F_R(\alpha\tau)_n$ from the collector testing)

$F_RU_L = 5.40$ W/m^{2}C (average value of F_RU_L from the collector testing)

$(\alpha\tau)_n = 0.93*0.9*0.78 = 0.65$ (normal transmittance-absorptance product multiply by coefficient of angle of incidence for vertical position of the collector)

$F_R = 0.264/0.65 = 0.408$

Collector area = 95 m^2

Month	$(\bar{\tau\alpha})$	$F_R(\bar{\tau\alpha})$	$r_{d,n}$	$r_{t,n}$	R_n	I_c W/m^2	$\bar{X}_c$	$\bar{\phi}_c$
Jan.	0.7	0.29	0.19	0.20	2.63	487	0.68	0.25
Feb.	0.7	0.28	0.16	0.17	1.68	489	1.10	0.16
Mar.	0.6	0.26	0.14	0.15	1.32	468	0.64	0.25
Apr.	0.6	0.25	0.15	0.16	0.95	369	0.55	0.35
May	0.6	0.23	0.18	0.20	0.69	245	0.31	0.56
Jun	0.5	0.22	0.20	0.21	0.62	146	0.19	0.71
Jul.	0.6	0.22	0.19	0.20	0.64	112	0.16	0.76
Aug.	0.6	0.24	0.16	0.17	0.79	149	0.21	0.70
Sep.	0.6	0.26	0.13	0.15	1.08	173	0.25	0.64
Oct.	0.7	0.27	0.15	0.16	1.47	296	0.50	0.39
Nov.	0.7	0.28	0.18	0.20	2.09	473	0.88	0.21
Dec.	0.7	0.28	0.20	0.21	2.78	583	0.97	0.15

Table 4.7 Calculation parameters for solar air heater analysis

	Out_temp	Degree Day	Monthly $Q_{utilizability}$	$Q_{utilizability}$ total	$Q_{useful\ gain}$
Month	To, C	°C	MJ/m2	GJ	GJ
Jan.	-6.0	774	123	12	3
Feb.	-5.0	671	47	4	1
Mar.	-2.2	653	138	13	3
Apr.	3.1	466	146	14	4
May	9.5	292	217	21	5
Jun	14.1	148	242	23	5
Jul.	15.4	107	276	26	6
Aug.	13.5	155	312	30	7
Sep.	11.8	209	300	28	7
Oct.	5.3	432	182	17	5
Nov.	-4.2	665	70	7	2
Dec.	-9.8	861	59	6	2
			Yearly total	201	50

Table 4.2.3.2 Useful solar heat gain for 1995

According to Mansour [29], solar gain is about 65 GJ per annual. In this study, annual heat gain from solar collector was found less than the previous study. Major reasons of deviation in results are given below:

- different values for monthly incident radiation
- method of calculation

Low performance of the solar collectors is due to the following reasons:

- high heat loss from collectors
- low flow rate of working fluid
- low convective heat transfer between working fluid and absorber plate due to excessive air gap dimension
- shapes of the collectors

CHAPTER 5

COMPUTER SIMULATION MODEL OF THE CHURCH

This chapter details the application of the DOE-2 building energy simulation program [34] to the modeling of the church. It describes the program and its capabilities. An energy use analysis based on the DOE-2 simulation model for the building is presented.

5.1 The DOE-2 simulation program

The use of building energy analysis computer programs is becoming a standard procedure for estimating energy use in buildings. This is done to identify ways to design buildings or to modify existing buildings to be more energy efficient.

The DOE-2 program is an extremely large and complex computer program and it requires special knowledge on the part of users. It simulates the interaction of building systems in response to given conditions. These include the fabric, HVAC systems, and plant equipment. To obtain a completely correct model would require infinite detail, which would be impossible. Therefore, a level of abstraction must be selected that is adequate for calibration of the model.

DOE-2 is capable of detailed simulations of energy consumption in buildings. It comprises one translation program and four simulation subprograms. The translation program is called Building Description Language (BDL) processor. It translates user input into simulation code. The DOE-2 simulation subprograms are called LOADS, SYSTEMS, PLANT, and ECONOMICS. A DOE-2 program flow chart is shown in figure 5.1.

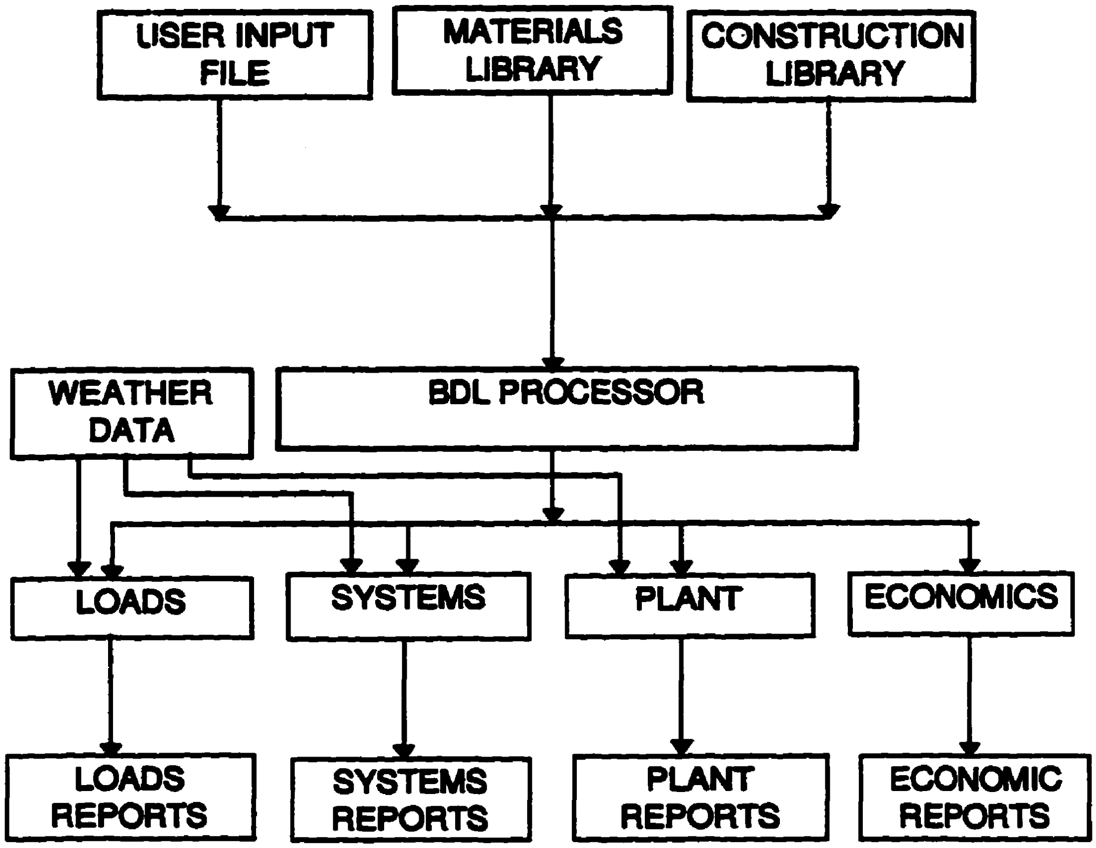

Figure 5.1 DOE-2 program flow chart

5.1.1 DOE-2 subprograms

The LOADS program calculates peak loads and hourly space heating and cooling loads based on the indoor air temperature set for simulation. Results of the LOADS program are a function of ambient weather conditions, occupancy, lighting, infiltration of outside air, orientation of the building,

building shape, building materials, and miscellaneous internal loads. The LOADS program does not compute load due to ventilation of buildings.

The SYSTEMS program is capable of simulating the operation of secondary HVAC systems (e.g., fans, economizers, humidifiers) based on the results from the LOADS program and additional user-defined instructions regarding HVAC systems, ventilation quantity, equipment operation schedules and temperature and humidity set-points.

The PLANT program simulates the operation of the primary HVAC equipments (e.g., boiler, chillers, electrical generation equipment, specified solar heating and cooling systems) based on the results received from the SYSTEMS program and additional user-defined instructions. The program calculates the energy consumption by the equipment on an hourly basis.

The ECONOMICS analysis program calculates life-cycle cost of building components, and equipments based on capital costs and the utility rate structure defined by the user. In addition, it is capable of generating statistics for economic comparison of alternative approaches.

5.2 Data collection

The following five types of data were collected for the DOE-2 simulation:

- Data obtained from the construction documents and building plans, including building dimensions and material characteristics of walls, windows, roofs, and floors. Data on HVAC, lighting, and hot water systems and equipment were obtained from mechanical and electrical plans.

- Data obtained by performing a visual inspection and interviews with facility staff: these include schedules, lighting control, control settings, occupancy levels, equipment operation and other human factors that are associated with energy use in the building.

- Data obtained from measurement and testing such as room temperature and energy contribution from the solar system.

- Data obtained from standards such as ventilation rates, infiltration rates etc.

- Data obtained from utility bills (e.g., natural gas and electricity consumption).

5.3 Calibration of the DOE-2 model

The main purpose of the calibration of the DOE-2 model was to make a reference model that could be used as a base case for evaluation of later retrofitting options. The retrofitting options are detailed in Chapter 6.

To determine the accuracy of the simulation model for predicting future energy consumption (i.e., after retrofitting), it was essential to compare the results of simulation with building utility data. In using a building simulation model, both technical and occupant behaviors related to building energy consumption are very important. Often, occupant behaviors are difficult to study and to model, and this could make the simulation results different from the actual.

Calibration of the building model for analysis was done according to the flow chart shown in figure 5.2. Input data were obtained as described above. However, alteration in building operation or other factors that relate to energy consumption could affect the simulation results.

A complete DOE-2.1E model for the investigated building is presented in Appendix A3.

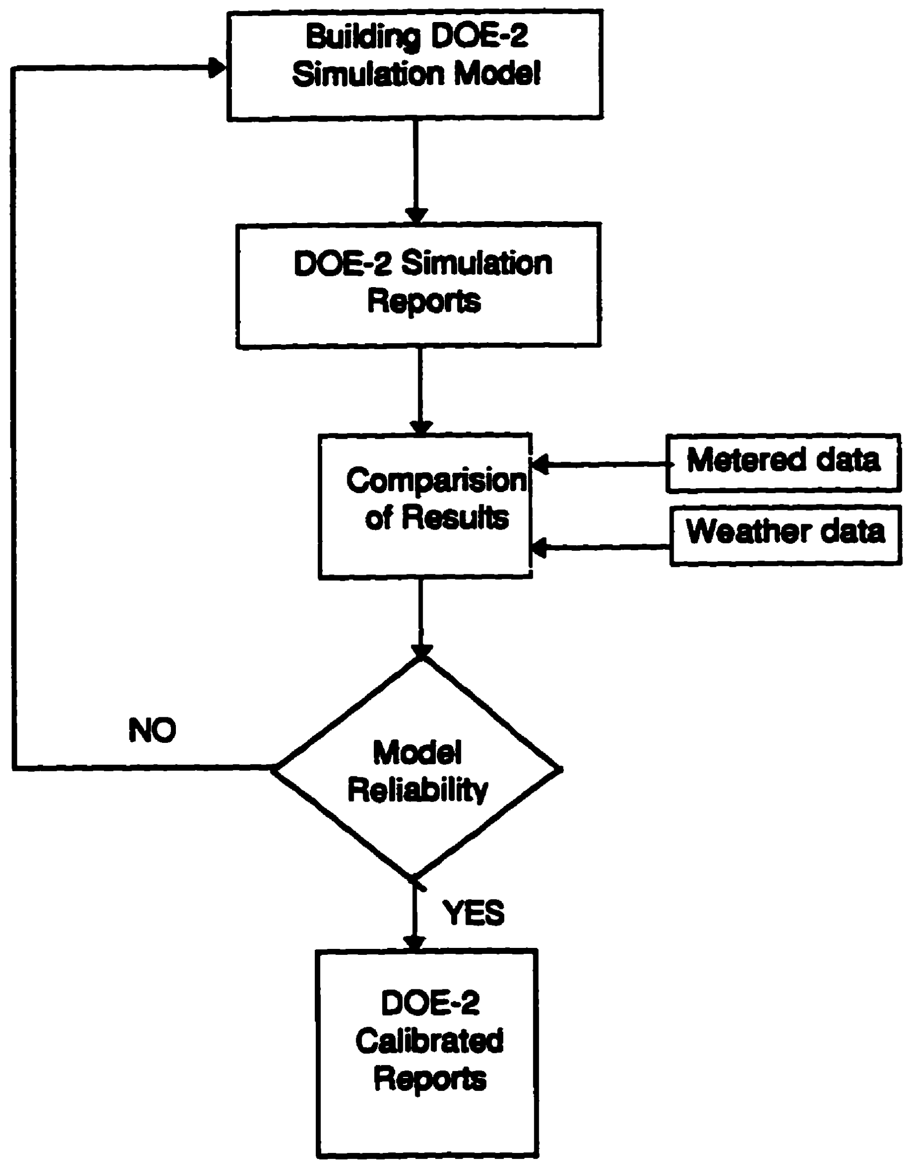

Figure 5.2 Flow chart of data analysis

5.4 Important assumptions to run DOE-2

- 20° C room temperature for winter.
- Free cooling during summer days.
- Air leakage according to ASHRAE Standard for tight building construction.
- Heat transfer to the ground through basement wall and basement floor at constant U-value. These values were taken from the ASHRAE Handbook of Fundamentals, 1981.
- Energy losses from ducts and pipes are negligible.
- Ventilation rate according to ASHRAE Standard 62-81.
- Weather data for 1995, the year for which gas and electricity use data were obtained.

5.5 Summary of building parameters

Summarized parameters set for the building simulation is given in table 5.1.

I. Building envelope

Area = 3,300 m^2
No. of floors = 3 floors
Window U-values:
single glazed = 6.2 W/m^2C
double glazed = 2.7 W/m^2C
triple glazed = 1.8 W/m^2C
Underg. wall U-value = 0.21 W/m^2C
Floor U-value = 0.13 W/m^2C

II. Operating condition

Lighting density = 15 W/m^2
Room temperature = 20 °C
Sp. relative humidity = min. 20 %

Occupancy heat gain:
Offices/sanctuaries/school = 120 W
Gymnasium/hall = 375 W

III. HVAC system and equipment

Constant volume system
Perimeter radiation heating
Ventilation:
AHU-1 = 4.7 L/s/person
AHU-2 and AHU-3 = 7.1 L/s/person
Economizer cycle
Natural gas-fired boiler

Table 5.1 Summary of building parameters

5.6 Data analysis and results

The results analysis is based on the calibrated model of the building. The energy consumption predictions for gas and electricity were compared with utility data. The results analysis includes building peak load components, comparison of metered and simulated monthly electricity and natural gas consumption, and annual energy consumption with solar system contribution.

5.6.1 Building peak load components

This report gives a breakdown of heating peak loads, according to the source of the load, for the building. It shows the amount of heat that must be added to the building per hour to maintain the air temperature set with the TEMPERATURE keyword in SPACE-CONDITIONS. Simulated values are for spaces that have been treated as conditioned spaces. The program excludes loads from unconditioned spaces such as the mechanical room and plenums. In addition, the program calculates building peak loads without ventilation. Building peak heating load components based on 1995 weather data are presented in the table 5.2.

Particulars	kW	kBTU/h
Wall conduction	-19.0	-65.2
Roof conduction	-11.0	-38.0
Window glass + frm. cond	-26.0	-88.4
Window glass solar	1.1	3.8
Door conduction	-2.2	-7.4
Underground surface cond	-5.5	-18.7
Occupants to space	0.5	1.8
Light to space	3.3	11.0
Equipment to space	0.2	0.5
Infiltration	-25.0	-85.0
Total	-84	-286

Table 5.2 Simulated building peak heating load components

The following paragraph describes particulars that have been used in the building peak load components (for heating only) :

Wall conduction - heat loss due to conduction through exterior walls

Roof conduction - heat loss due to conduction through roof areas

Window glass+frm cond - heat loss due to UAΔT heat gain through all exterior windows (glass plus frames). It also includes solar energy absorbed by windows and frames and conducted into the space.

Window glass solar - heat gain caused by direct and diffuse solar radiation transmitted by the window glass.

Door conduction - heat loss due to conduction through exterior doors in the space.

Underground surface cond - heat loss due to the conduction through basement floors and the walls below grade.

Occupants to space - heat gain due to the occupants in the spaces.

Light to space - heat gain due to the lighting of the spaces.

Equipment to space - heat gain due to the equipment in the spaces.

Infiltration - heat loss due to the penetration of outside air.

Positive and negative signs in table 5.2 show whether heat is entering (+) or leaving (-) the space from corresponding components of the building.

Total load per unit area (excluding outside air ventilation load for the building) is approximately 30 W/m^2 (9.5 BTU/h m^2).

5.6.2 Building energy performance summary

Table 5.3 presents annual building energy use according to energy type (e.g., electricity and natural gas) and category of use (area lighting, equipment, heating, and ventilation). This report (generated by DOE-2.1 E) is for 1995. It excludes the energy gain from the solar system.

REPORT - BEPS
WEATHER FILE - CAL95.WYEC

ENERGY TYPE	Electricity, kWh	Natural gas, GJ
Category of use		
AREA LIGHTS	64476	0.
MISC EQUIPMT	5568	0.
SPACE HEAT	14654	1814
PUMPS & MISC	5861	0.
VENT FANS	53925	0.
DOHOT WATER	0.	303
TOTAL	144484	2118

TOTAL ELECTRICITY	144,484 kWh	48 kWh / m^2
TOTAL NATURAL GAS	2,118 GJ	0.7 GJ / m^2

Table 5.3 Simulated building energy summary for 1995

Brief description of categories of use in BEPS:

AREA LIGHTS	- electricity consumption associated with lighting.
MISC EQUIPMT	- electricity consumption associated with electric equipment.
SPACE HEAT	- electricity consumption of equipment whose primary purpose is heating and natural gas consumption to maintain the temperature set by users.
PUMPS & MISC	- electricity consumption of pumps and miscellaneous equipment.
VENT FANS	- electricity consumption by HVAC heating and exhaust fans.
DOMHOT WATER	- natural gas consumption of the hot water heater.

5.6.3 Comparison of monthly simulation results with utility data

Figures 5.3 and 5.4 illustrate monthly simulated and metered data for 1995 natural gas and electrical energy consumption. The main purpose of these illustrations is to show the accuracy of the simulation model. See Appendix A3 for complete information on the DOE-2.1E input data. This type of comparison helps to evaluate the quality of the base case used in assessing retrofit options.

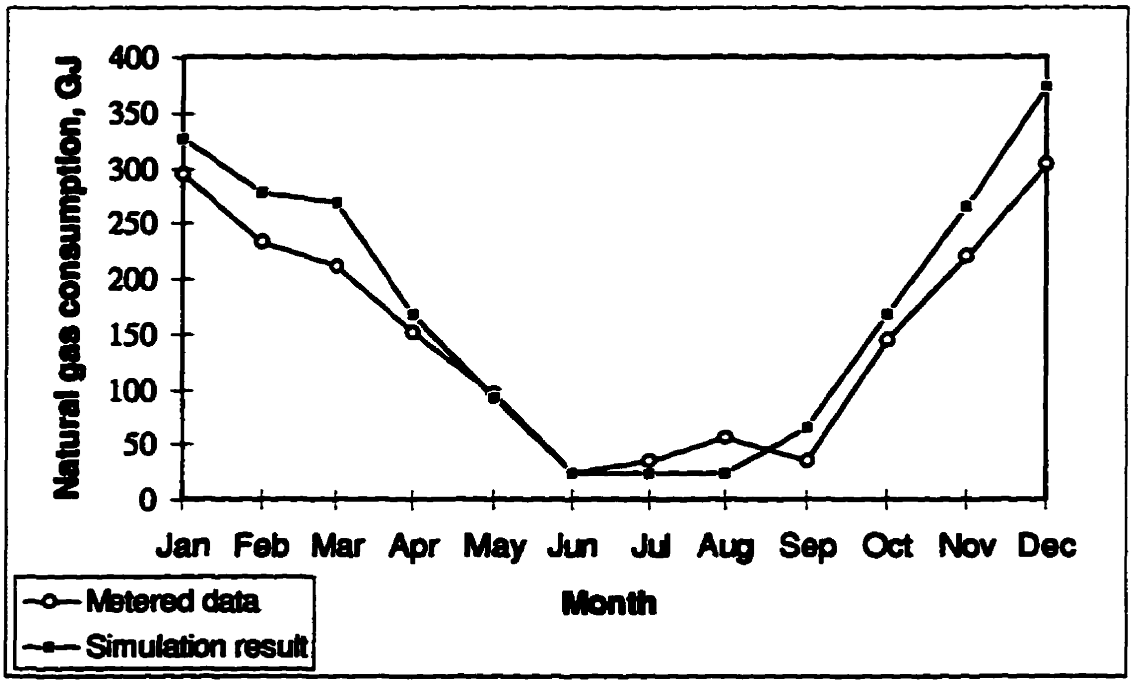

Figure 5.3 Simulated and metered natural gas consumption for 1995

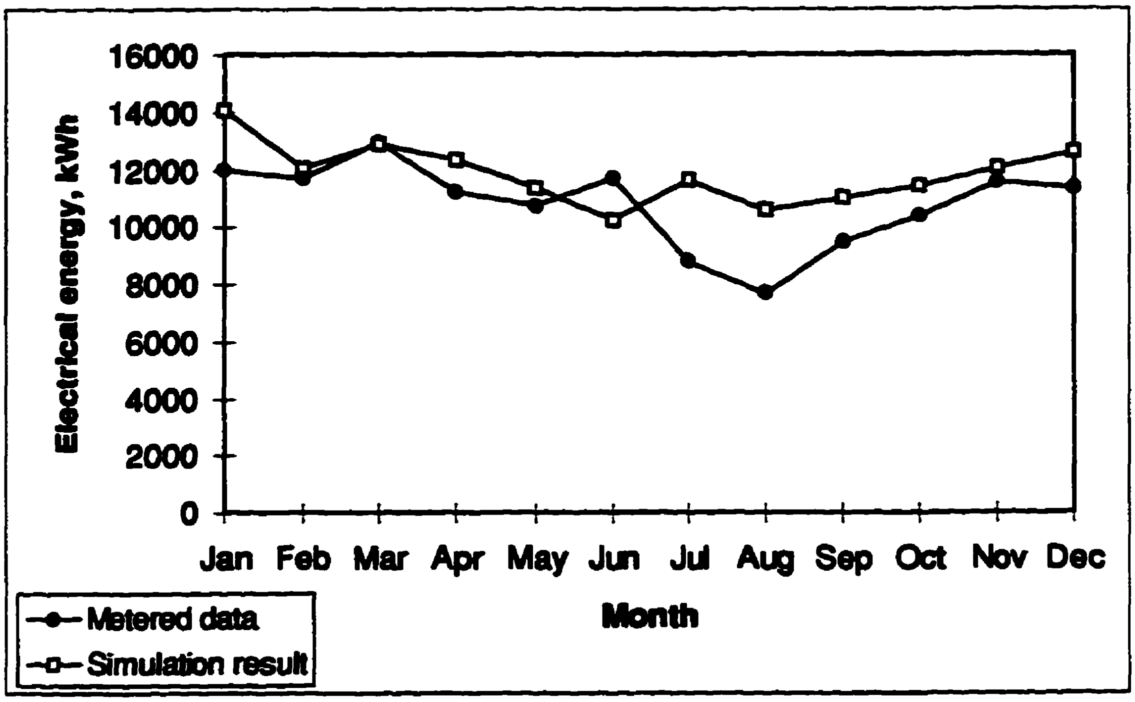

Figure 5.4 Simulated and metered electrical energy consumption for 1995

Monthly deviations between predicted and measured data for electrical energy are smaller than for natural gas. The absolute difference between predicted and measured data for individual months ranged from 10 to 46 percent for natural gas, and from 3 to 15 percent for electricity, except June, July, and August because these months are not considered for space heating in the simulation. Despite the large differences for a few individual months, annual results show deviations of 13 and 9 percent for natural gas and electricity respectively.

Comparisons on a monthly basis show significantly higher deviations than the annual comparisons and it is probably due to following reasons:

- Underpredictions in some months tend to compensate for overpredictions in other months, resulting in an improved annual comparison.

- The effect of the variations from standard schedules for parameters such as occupants, lights, and DHW tend to average out in the long-term annual results.

In these simulation results, the solar contribution to building and hot water heating is not included. Assuming all heat gain from the solar system converts into energy to heat the building and water, the annual error of the simulation reduces from 13 to 11 percent for natural gas consumption.

CHAPTER 6

ENERGY SAVING OPTIONS

The purpose of this chapter is to present the concepts and procedures for retrofit programs for the building and to illustrate the benefit of such retrofits in terms of energy use. It contains results of an elimination parametrics analysis and a system retrofit study. At the end of this chapter, a possible retrofitting procedure to improve the performance of the solar system is presented.

6.1 Elimination parametrics

The elimination parametrics technique is used to determine the significant building energy systems parameters and their interaction. It is generally used during building design. However, the technique can also be used to evaluate major retrofit options. To compare effects on energy use of building parameters or components, a single parameter at a time is eliminated from the base case. If the energy use changes significantly, then the parameter needs to be considered carefully.

In this study, components such as ventilation, wall insulation, infiltration, and occupants were evaluated using elimination parametrics. These parameters were selected based on the simulation of energy use by the building (see Chapter 5). Figure 6.1 shows annual electricity consumption for the base building and for base building with each of the variables eliminated. Similarly, figure 6.2 shows results for natural gas consumption.

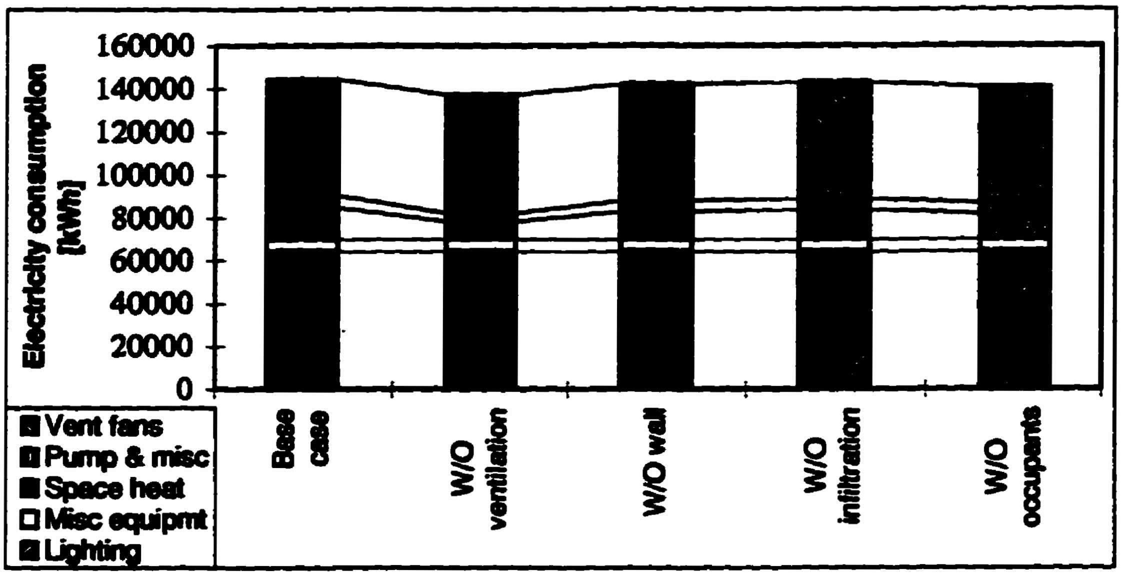

Figure 6.1 Simulated annual electricity conumption for the building, elimination parametrics

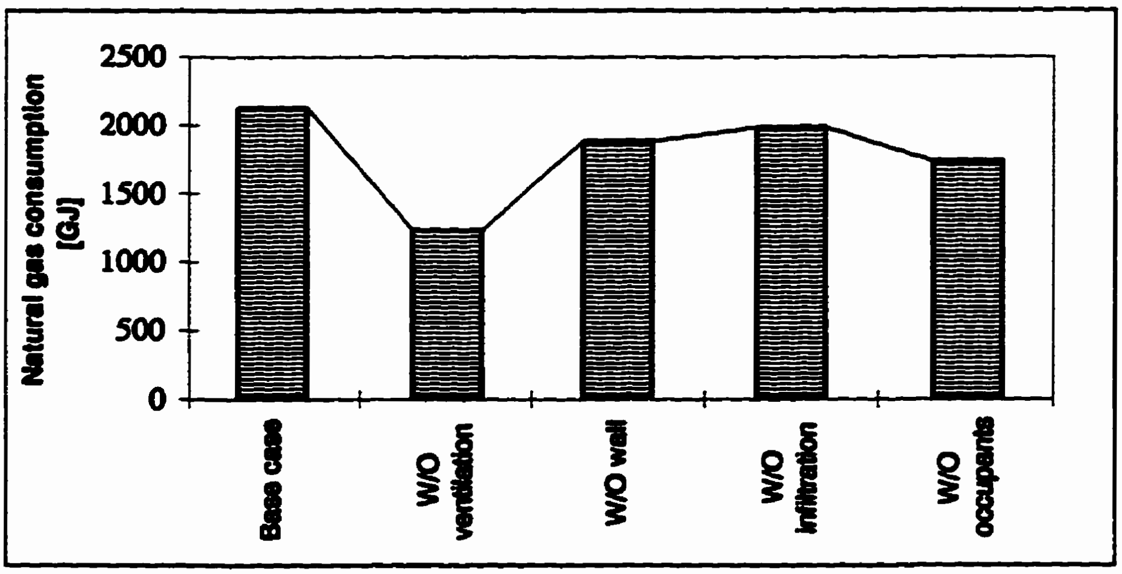

Figure 6.2 Simulated annual natural gas conumption for the building, elimination parametrics

Elimination parametrics results show that electrical energy consumption remains almost constant. Lighting and ventilation fans are the major loads for electricity consumption. On the other hand, natural gas consumption was significantly reduced with ventilation eliminated.

Viewing the results of the elimination parametrics analysis, it can be concluded that ventilation fans are the major load for electricity and heating of ventilation air is major use of natural gas.

6.2 Retrofit options

In the following subsections, results of retrofit simulations are presented for comparison of energy savings. Energy savings from retrofit measures are compared with the baseline energy use. This section focused on two retrofit measures and illustrates their potential to conserve energy.

6.2.1 Increase in wall insulation

This is a measure which is commonly recommended for buildings in cold climates. Originally, the building had R-11 wall insulation of fiberglass batts. To decrease the heat loss from the conduction through wall, wall insulation was doubled. Simulated energy use is presented in table 6.1.

ENERGY TYPE	Electricity, kWh	Natural gas, GJ
Category of use		
AREA LIGHTS	64476	0.
MISC EQUIPMT	5510	0.
SPACE HEAT	14009	1728
PUMPS & MISC	5627	0.
VENT FANS	53954	0.
DOHOT WATER	0.	303
TOTAL	143576	2031

TOTAL ELECTRICITY 143576 kWh 47.7 kWh / m^2
TOTAL NATURAL-GAS 2031 GJ 0.67 GJ / m^2

Table 6.1 Simulated building annual energy use summary after thermal insulation retrofit

Figures 6.3 and 6.4 show the annual electrical and heating energy consumption of the modified design compared to the base case building.

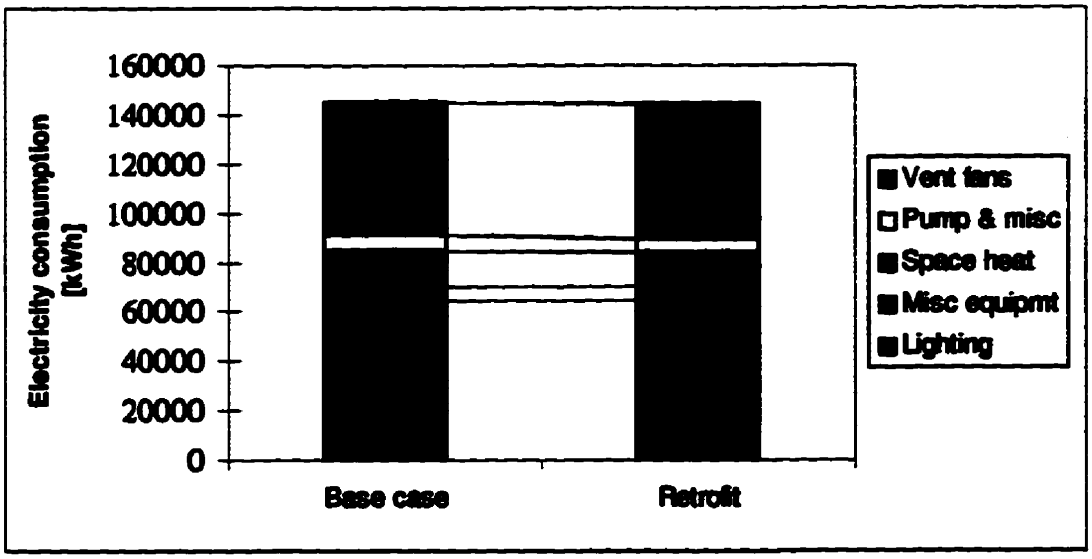

Figure 6.3 Simulated annual electricity consumption: base case envelope and envelope with double insulation

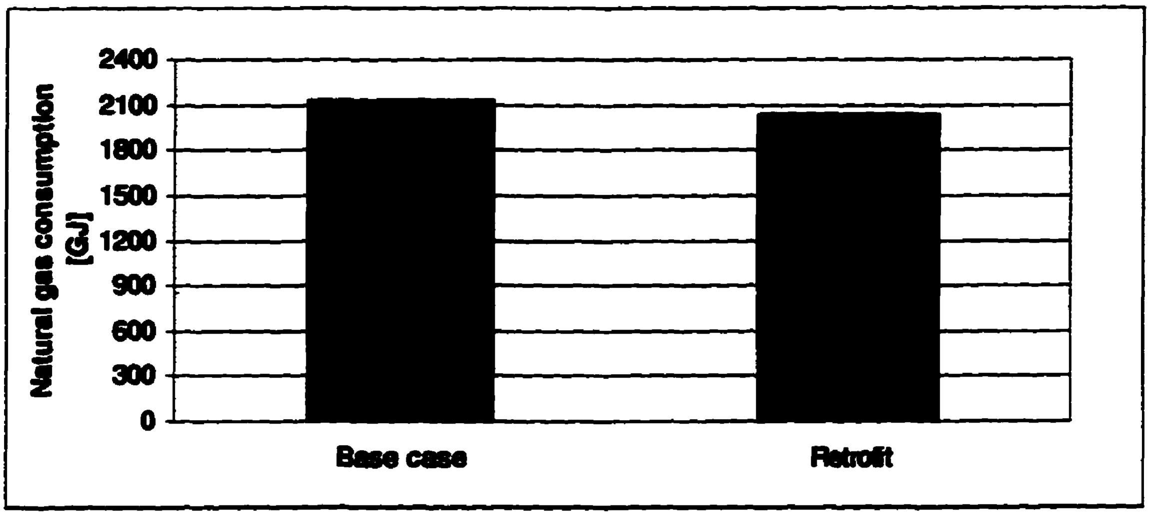

Figure 6.4 Simulated annual natural gas consumption: base case envelope and envelope with double insulation

Electrical consumption remained almost the same, while natural gas consumption was reduced by 4 percent.

This retrofit idea would not be economically feasible because of the insignificant saving in total energy use.

6.2.2 Retrofit of heating systems

As mentioned earlier, spaces in the building have varying occupancy, especially in the Catholic and Lutheran sanctuaries (see Chapter 3). Both these sanctuaries are used very little compared with the other spaces on the same air-handling system (a single constant volume fan). About 24 percent of the area of the building is used for the Lutheran and Catholic sanctuaries. Therefore, separate zoning of the sanctuaries would reduce fan operation and allow reductions in heating of these spaces during unoccupied periods. The elimination parametrics studies show that ventilation fans consumed a large portion of total electricity use. These considerations show that a separate

HVAC system for the Catholic and Lutheran sanctuaries might give good results in total energy savings. Figure 6.5 shows the existing and retrofit option of HVAC system for the investigated building.

Retrofit of the HVAC system has been considered only for air-handling unit 1 (AHU-UNIT 1), which controls the zones shown in figure 6.5. In the existing system, all zones shown in the figure are controlled by a air-handling-unit (AHU-UNIT 1). In the retrofit model, these zones are separated; zones MZ4 and MZ5 (sanctuaries) are controlled by an individual air-handling unit. These changes were implemented in the simulation model. Detailed changes in the DOE-2 model are given in Appendix A4.

Other AHU-UNITs or HVAC heating systems for the spaces (AHU-UNIT 2 and AHU-UNIT 3) remained the same.

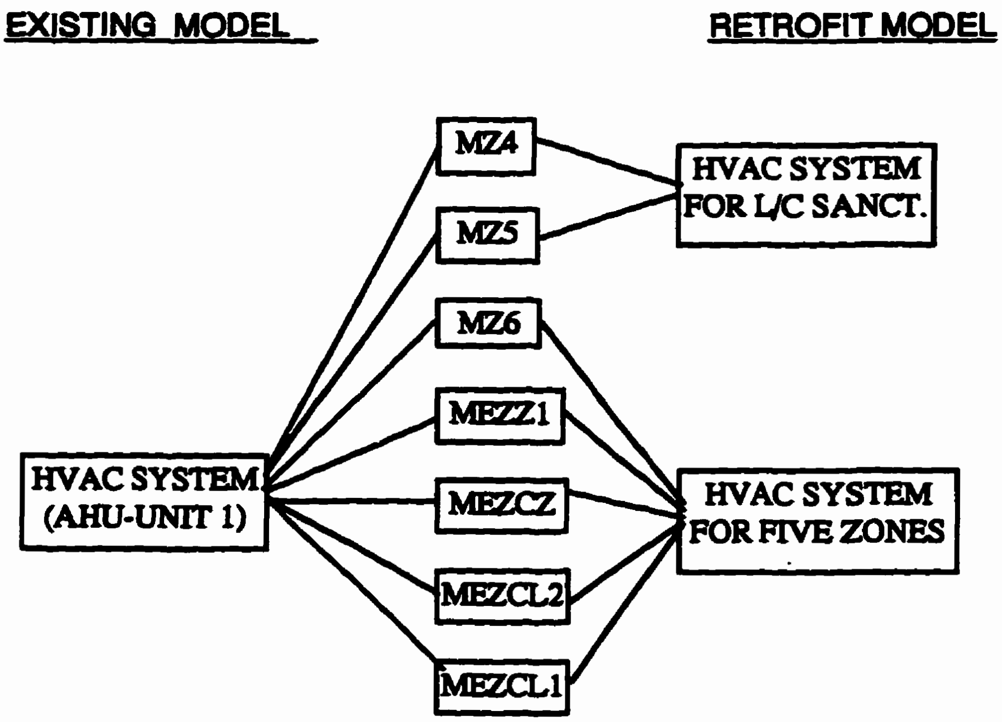

Figure 6.5 Retrofit HVAC system model

MZ4 - Main floor zone no. 4 (Catholic sanctuary)

MZ5 - Main floor zone no. 5 (Lutheran sanctuary)

MZ6 - Main floor zone no. 6 (Lobby)

MEZZ1 - Mezzanine floor zone no. 1 (Office)

MEZCZ - Mezzanine floor core zone (Service zone)

MEZCL1 & MEZCL2 - Mezzanine floor zone no. 4 (Class rooms)

Results of the retrofit are illustrated in figure 6.6 for electrical energy consumption.

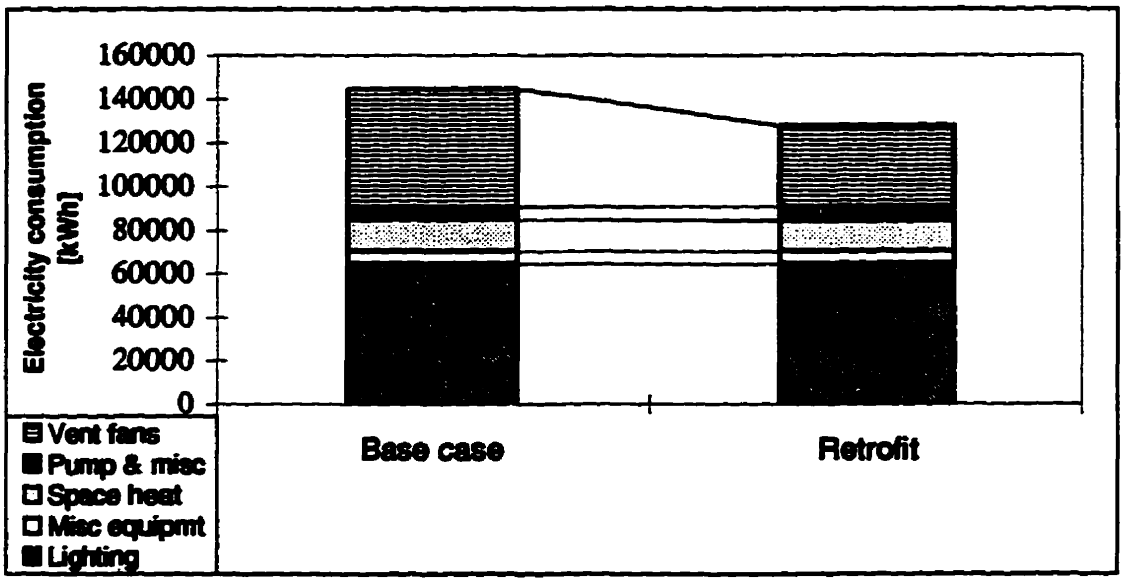

Figure 6.6 Annual electricity consumption for the base case and system retrofit building

Comparing the annual electrical energy use with the base case model, the largest saving was found in ventilation (VENT FANS) followed by space heating (SPACE HEAT). The reductions in electrical energy consumption, as compared to the base case are 32 percent and 5 percent for VENT FANS and SPACE HEAT respectively. However, in PUMPS & MISC category, electrical consumption increased by 15 percent from the base case building.

Total electricity use is reduced by approximately 12 percent from the base case model.

These reductions in electricity use are primarily due to following reasons:

- fewer fan running hours for the sanctuaries
- reduction in fan power to circulate air during periods when the sanctuaries would be unoccupied.

The annual natural gas consumption for the base case and the retrofit building is illustrated in the figure 6.7.

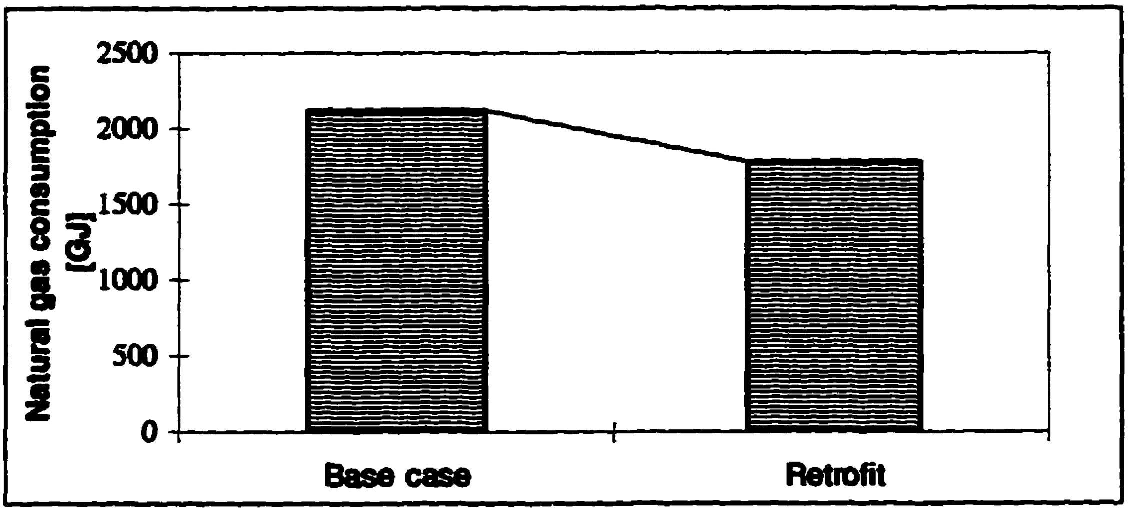

Figure 6.7 Simulated annual natural gas consumption for the base case and system retrofit building

Simulation results show that the retrofit building consumed about 16 percent less natural gas energy than the base case building. The actual amount of reduction in natural gas is about 340 GJ per year.

These reductions in natural gas consumption are primarily due to following reason:

- temperature of the spaces is controlled by a space-specific occupancy schedule rather than with other zones as shown in figure 6.5.

NOTE: Simulation results would differ if the solar energy gains from the collector were considered. The solar heat gain from the collector (about 50 GJ/year) is not included here to simplify comparison.

6.3 Retrofit of the solar system parameters

This section details reasons for poor performance of the solar system. It describes procedures that would help to improve solar system performance. To determined the performance of the solar collector, the procedure suggested by Duffie and Beckman [6] is followed.

6.3.1 Factors governing performance

Generally the performance of the solar collector depends on parameters such as:

- Choice of materials (properties of material: α, τ, and ε)
- Ambient conditions (T_a, v_w , and G_T)
- Geometry of collector: length, height, and thickness of collector
- Flow rate: m (or G)
- Inlet temperature of working fluid, T_i
- Characteristics of the working fluid: C_p, λ, μ, and ρ

Kay's relation defined by Biondi et. al. [17] for the convective heat transfer coefficient inside an asymmetrical heated rectangular smooth duct and for fully developed turbulent flow is:

$$h_c = 0.0158\,\lambda\,(GK/\mu)^{0.8} \quad (1)$$

where, mass flow rate per unit area $G = m / A$ (kg/s per m^2)

geometric coefficient of collector $K = L / (bD_e^{0.25})$ ($m^{-0.25}$)

λ - air thermal conductivity (W/m°C)

μ - air dynamic viscosity (Pa × s)

h_c - convective heat transfer coefficient (W/m^2°C)

L - length of the collector (m)

b - thickness of air flow channel (m)

D_e - (2 × b) equivalent diameter of the duct (m)

If λ and μ in equation (1) are treated as constant, h_c depends only on the product GK. Thus, the efficiency of the solar air heater is a function of these two parameters, if ambient conditions and material properties are considered constant.

The following calculation to determine the performance of the solar collector is based on:

- the recommended value for mass flow rate of air in rectangular ducts (i.e., 0.013 kg/s per m^2) [35].
- reduction of the flow path to approximately one third of its original value, (i.e., 20 mm). However, optimum thickness of air flow channel is recommended to determine to obtain higher value of heat transfer coefficient and at the same time low power to drive required flow rate.

- each collector dimension is assumed as shown in figure 6.8.

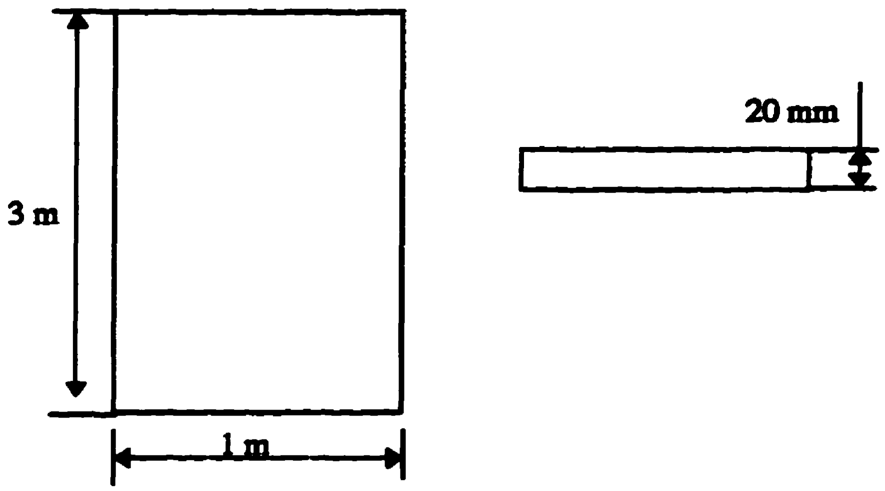

Figure 6.8 Assumed collector dimension

6.3.2 Calculation of parameters needed to determine efficiencies

6.3.2.1 Top heat loss of the flat plate solar collector

It is very important to estimate heat losts from the collector plate. It is related to collector performance factors such as heat removal factor F_R, flow factor F' and efficiency of the collector η. In this particular case, heat lost from the back and the edge was ignored, because the temperature difference between the plate and building interior (the rear side of the solar collector is exposed to room temperature) is not great, especially when the back of the collector is insulated.

Heat lost due to the temperature difference and other factors such as wind, material emittance, number of cover plates and tilt angle were formulated by Klein [36]. The following model can be used to calculate top heat loss (U_t) within ±0.3 W/m^{2}C for general operating range of flat plate collector [6].

$$U_t = \left\{ \frac{n}{\frac{C}{T_{mp}}\left[\frac{(T_{mp}-T_a)}{(n+f)}\right]^{e}} + \frac{1}{h_w} \right\}^{-1} + \frac{\sigma \cdot (T_{mp}+T_a)(T_{mp}^2 - T_a^2)}{(\varepsilon_p + 0.00591 \cdot n \cdot h_w)^{-1} + \frac{2 \cdot n + f - 1 + 0.133 \cdot \varepsilon_p}{\varepsilon_g} - n}$$

where,

n - number of glass covers

f - $(1 + 0.089\ h_w - 0.116\ h_w\ \varepsilon_p)(1 + 0.07866\ n)$

C - $520\ (1 - 0.000051\ \beta^2)$, $\beta = 70°$ for 90° tilt

e - $0.430\ (1 - 100/T_{mp})$

β - collector tilt (degree)

ε_p - emittance of plate

ε_g - emittance of the glass

T_a - ambient temperature (K)

T_{mp} - mean plate temperature (K)

h_w - wind heat transfer coefficient ($W/m^2\ °C$)

The major problem in solving this equation is the absorber plate temperature, which is a function of factors such as the collector design, the incident solar radiation, entering fluid temperature and ambient temperature. For design purposes, the plate temperature is taken as constant, whereas in practice it changes with the length of the plate.

6.3.2.2 Radiation heat transfer coefficient in rectangular duct of solar collector

The radiation coefficient between the two duct surfaces, assuming mean radiant temperature equal to mean fluid temperature, is estimated as:

$$h_r = \frac{4\sigma\overline{T}^3}{(1/\varepsilon_1)+(1/\varepsilon_2)-1} \quad (W/m^2\ °C)$$

where, σ - Stefan-Boltzmann constant

$\overline{T}$ - main fluid temperature (K)

ε_1, ε_2 - plate emittance

6.3.2.3 Reynolds number

To determine flow characteristic, the Reynolds number at an assumed average fluid temperature is given by:

$$Re = \dot{m}D_e / A_f\,\mu$$

where, D_e - eqivalent diameter (m)

A_f - fluid flowing area (m^2)

$\dot{m}$ - mass flow rate (kg/s)

6.3.2.4 Collector efficiency factor

The collector efficiency factor does not vary much with operating conditions, so it is treated as constant in practice [16]. It shows how effectively heat is transferred from the absorber surfaces to the working fluid. Mathematically it is expressed as:

$$F' = \left[1 + \frac{U_t}{h_c + \left[\left(\frac{1}{h_c}\right)+\left(\frac{1}{h_r}\right)\right]^{-1}}\right]^{-1}$$

where, U_t - top heat loss coefficient (W/m^2 °C)

h_c - convective heat loss coefficient $(W/m^2\,°C)$

h_r - radiative heat loss coefficient $(W/m^2\,°C)$

6.3.2.5 Collector flow factor

The collector flow factor is a function of a dimensionless collector capacitance rate $\dot{m}C_p / A_c\,U_t\,F'$. Mathematically it is expressed as:

$$F'' = \dot{m}C_P / A_c U_t F'[1 - \exp(- A_c U_t F'/ \dot{m}\, C_P)]$$

where, C_p - specific heat of air $(J/kg°C)$

6.3.2.6 Heat removal factor

The heat removal factor is a function of the fluid flow rate and the absorber plate design (thickness, material properties). It is nearly independent of solar radiation intensity and ambient and collector plate temperature. Mathematically it is expressed as:

$$F_R = F'\,F''$$

6.3.2.7 Useful energy gain

Maximum useful energy collected by the collector Q_u, is given by

$$Q_u = A_c F_R [I_T - U_t (T_i - T_a)] \qquad (W)$$

where, I_T - incident radiation (W/m^2)

6.3.2.8 Mean plate and fluid temperature

Theoretically mean plate temperature is expressed as:

$$T_{mp} = T_i - (Q_u / A_c) / (F_R U_l) (1 - F_R) \quad (°C)$$

Theoretically mean fluid temperature is expressed as:

$$T_{mf} = T_i - (Q_u / A_c) / (F_R U_l) (1 - F_R'') \quad (°C)$$

An iteration process is necessary if initial temperature estimates are found to differ from the values obtained from the above equations.

6.3.3 Efficiency

Efficiency of the air heater can be calculated as:

$$\eta = Q_u / A_c I_T$$

6.3.3.1 Summary of the efficiency calculation

An initial mean fluid temperature of 33 °C (306 K) and mean plate temperature of 50 °C (323 K) were assumed for calculation. Ambient temperature and radiation on the tilted surface were taken from table 4.1 (see Chapter 4) to allow performance comparisons. All air properties are based on mean fluid temperature.

A summary of calculated parameters is provided in the first row of table 6.2. To evaluate assumed initial plate temperature, iterations were performed. Results of the iteration process also presented in the second row of table 6.2.

Table 6.2 shows that parameters do not change much with a few degrees difference in plate temperature. Calculated parameters given in table 6.2 are based on a radiation value of 600 W/m^2.

	h_c	Re	h_r	U_t	F'	F"	Q_u	T_{mp}	T_{mf}
	8	4216	5.3	5.4	0.67	0.87	630	46	28
Iteration	8	4216	5.1	5.3	0.67	0.88	632	47	28

Table 6.2 Parameters to determine efficiency of the solar collector (based on incident radiation of 600 W/m^2)

Similar calculations were performed for incident radiation of 900 W/m^2 to determine efficiency of the "modified" collector.

For comparison purposes, performance of the existing solar collector (see Chapter 4) and "modified" solar collector are presented in table 6.3 for two different levels of solar radiation.

Radiation level (W/m^2)	Efficiency of the existing solar system	Efficiency of the "modified" solar system
600	7 %	35 %
900	16 %	38 %

Table 6.3 Efficiency of the solar collectors (existing and retrofit)

Results show that the efficiency is determined by the major factors mentioned above. Using this type of retrofit, the solar collector performance could be increased from the existing conditions by 5 to 2.4 times for low and high incident radiation respectively. In addition, results show that these factors are more sensitive to solar collector output at low radiation levels.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of work completed

This study has fulfilled the major objectives of the research which were: 1) to evaluate the performance of the building-integrated solar air heating system in a church building, and 2) to evalute other energy conservation alternatives relative to the solar heating option. A literature review of basic factors that govern building energy use, of factors that affect the performance of solar air heaters, and on the performance and validation of the DOE-2 building energy simulation program was conducted.

To increase accuracy in simulation and evaluation of the solar air heating system, an hourly weather file was prepared for Calgary for 1995.

To determine the fundamental characteristics (such as F_RU_L, $F_R(\tau\alpha)$) of the solar air heater, its thermal efficiency was determined by testing. Thereafter, these coefficients were used in calculation of monthly heating contribution (i.e., building and domestic hot water) of the solar air heater. The daily utilizability method proposed by Klein [33] was used to calculate solar contribution.

The DOE-2 building energy simulation program was used to analyze energy use in the building. Simulation results were compared with 1995 utility data obtained from the building administration. The DOE-2 model was calibrated to create a base case to which energy conserving retrofits could be compared.

Based on the calibrated simulation model, two retrofit options (i.e., increase in wall insulation and retrofit of heating system) were simulated for comparison of energy savings.

For theoretical analysis of the solar collector retrofit, procedures suggested by Duffie and Beckman [6] and Biondi et. al. [17] were used.

7.2 Summary of results and conclusions

7.2.1 Results and conclusions on the existing solar air heating system

The total contribution of the solar air heater was found to be about 50 GJ/year.

Tests revealed that the efficiency of the solar system at lower levels of radiation, for example 600 W/m^2, was only about 7 percent and for high radiation levels, for example 900 W/m^2, about 17 percent. Major reasons for poor performance of the solar air heater under existing conditions are as follows:

- The actual flow rate of the working fluid is lower than the design value.

- There must be some air leaks or obstructions in the solar air flow channels, which was confirmed by the measured inlet and outlet air velocities in the duct network.

- The air flow channel behind the absorber plate was too deep.

- The specific flow rate is much lower than recommended values.

- Improper operation of the control system (during investigation period; the solar air circulating fan was found running in the evening at 7.30 PM, when outside radiation was almost zero).

- Shape of the solar collector.

- Long ducting network (masonry wall for thermal storage is far from the solar collector panels)

7.2.2 Results and conclusions of retrofit options

The analysis of retrofit options provided a better understanding of energy use and revealed a large potential for energy conservation in buildings like the Sandstone Valley Ecumenical Centre.

Commonly recommended measures such as an increase in wall insulation may not be economically attractive. Simulated results showed that increasing wall insulation by double, did not affect electricity consumption and reduced natural gas consumption by only 4 percent.

Division of the large central system into a few systems sharing with more diverse operating, permits large savings in total energy use. Simulated results showed that, by implementing such a retrofit, total electricity use was reduced by approximately 12 percent and natural gas use was about 16 percent from the base case. The actual reduction for natural gas was about 340 GJ/year and for electricity about 17000 kWh/year.

From these results it can be seen that this option would provide a lower rate of energy consumption for the investigated building.

Solar collector parameters such as air gap and specific flow rate of the working fluid significantly influenced performance. Calculated results showed that decreasing the air gap by one-third and providing recommended flow rate of 11 l/s would increase the performance of the solar collector by 5 times under low levels of radiation and 2.7 times under high levels of radiation.

7.3 General conclusions

Solar air heating systems might not be feasible for places like Calgary where natural gas is relatively cheap. However, better design of the collectors and other associated features of the solar air heating system would permit thermal energy at a much lower cost than the existing systems.

Ventilation represents a major building heating load in a cold climate.

When designing buildings energy systems, building components and HVAC systems should be analyzed with simulation tools like DOE-2 to identify energy saving options.

7.4 Recommendation for future work

Due to complex factors of energy use and limited analysis tools were used to accomplish the defined tasks, following future works will help to improve the obtained results to this study.

- Life-cycle costing of the retrofit solar system should be carried out.
- Life-cycle cost analysis should be performed for the system retrofits that were modeled.

- A solar air heater simulation algorithm could be developed for the DOE-2 program. This would allow the concept to be evaluated for a wide range of climates.

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Appendix A1

Wall constructions:

Basement

- wall construction (below the ground level); 250 mm concrete foundation wall, fir studs of 38x140 mm @ 406 mm O.C.D., 89 mm (3.5 in.) insulation batt, polyethelene vapor barrier, and 25.9 mm drywall with interior finish.

- wall construction (above ground level); 90 mm brick, 25 mm air space, building paper, 12 mm plywood, fir studs of 38x140 mm @ 406 mm O.C.D., 89 mm (3.5 in.) insulation batt, fir studs of 38x140 mm @ 406 mm O.C.D., 89 mm (3.5 in.) insulation batt, vapor barrier, and 15.9 mm drywall with interior finish.

Main floor

- wall construction (above ground level); 90 mm brick, 25 mm air space, building paper, 12mm plywood, fir studs of 38x140 mm @ 406 mm O.C.D., 89 mm (3.5 in.) batt insulation, vapor barrier, 15.9 mm drywall with interier finish. Some sanctuary walls have extra brick construction of 90 mm facing inside the building and these are up to the valence.

Curtain wall

- wall construction (solar panel) : single-glazed tempered glass, air gap, sheet metal absorber plate, air gap (air flow channel), 38 mm rigid fiberglass insulation, fir studs of 38×140 mm @ 406 mm O.C.D., 89 mm (3.5 in.) batt insulation, and 15.9 mm drywall.

Roof constructions:

- roof construction (sanctuary): concrete roof tiles, 19×38 mm wooden strap in parallel and in perpendicular direction @ max 345 and 300 mm respectively, 350 mm nonregular cemented lap, 16 mm plywood sheating, 178 mm (7 in.) insualtion batt, vapor barrier, 12.7 mm gyption board. air space for ducting, and 12.7 mm veneer plywood ceiling.

- roof construction (gym/hall and administration): concrete roof tiles, 19×38 mm wooden strap in parallel and in perpendicular direction @ max 345 and 300 mm respectively, nongranular 350 mm cemented lap, 16 mm plywood sheathing, 178 mm (7 in.) batt insulation, vapour bassier, and 15.9 mm gypsum board.

Appendix A2

Building HVAC system and equipment

Capacity and specification of AHU units:

No.	Manufact.	Model	Type	Capacity (L/s)	St.press. kPa	HP
AHU-1	TRANE	Climate Changer #21	Low press.	5000	0.560	7.5
AHU-2	TRANE	Climate Changer #10	Low press.	2250	0.560	5.0
AHU-3	TRANE	Climate Changer #8	Low press.	2000	0.187	1.5

Capacity and specification of AHU (air handling unit)

Capacity and specification of exhaust fans:

No.	Manufact.	Model	Capacity (L/s)	St. press. kPa	HP
EXH-1	GREENHECK	DSQ-120-A	830	0.1	1/3
EXH-2	GREENHECK	DSQ-95-G	250	0.02	1/15
EXH-3	GREENHECK	CSP-15	50	0.05	1/150
EXH-4			30	0.02	

Capacity and specification of Exhaust fans

Capacity and specification of boiler:

				Gas flow rate (m^3/hr)		Thermal	
Boiler No.	MFG.	Model	Cap. (kW)	Stage 1	Stage 2	Stage	Stage
1	Superhot	AAE-1080-N-M	316	15.11	14.01	79.8	81.7
2	Superhot	AAE-1080-N-M	316	16.28	11.880	79.7	80.4

Heating boiler capacity and specification

Capacity and specification of Domestic Water Heater (DWH):

Heater No.	MFG.	S/N	Capacity	flow rate (m^3/hr)	Thermal Efficiency
DWH 1	Superhot	DA5891703	95	8.83	74.6
DWH 2	Superhot	DA5891700	95	9.42	73.4

DWH capacity and specification

Appendix 3

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

```
INPUT LOADS ..

TITLE     LINE-1   *SANDSTONE VALLEY ECUMENICAL CENTRE*
          LINE-2   *ALBERTA, CALGARY*
          LINE-3   *OVERALL BUILDING ENERGY SIMULATION* ..

ABORT        ERRORS ..
DIAGNOSTIC WARNINGS ..
RUN-PERIOD     JAN 1 1995 THRU  DEC 31 1995 ..
LOADS-REPORT SUMMARY=(LS-C) ..

$---BUILDING LOCATION---$

BUILDING-LOCATION
   LAT=51          LON=114
   ALT=3540        T-Z=7
   HOL=YES
   AZ=0

GROSS-AREA=32615 ..
ALT-HOLIDAYS=JAN 1 APR 14  MAY 22  JUL 1  AUG 7  SEP 4  OCT 1
                NOV 11  DEC 25  DEC 26 ..

$---BUILDING DESCRIPTION---$

$---CONS TYPES---$

$---WALL-EXTERIOR---$

DRYWALL=MAT  TH=0.0417    COND=0.0925    DENS=50     S-H=0.26 ..
                                                      $1/2"DRYWALL
RINSUL=MAT     TH=0.583      COND=0.025  DENS=60      S-H=0.2 ..
                                                   $7"INSULATION BATT
WALL-TYPE1=LAYERS
MAT=(BK05,AL21,BP03,PW03,IN02,BP03,DRYWALL)
       I-F-R=0.68 ..                               $W1
WALL-TYPE2 = LAYERS
MAT= (BK05,AL21,BP03,PW03,IN02,BP03,BK05)
       I-F-R=0.68 ..                      $SANCTUARY'S WALLS UPTO VALANCE
WALL-TYPE10=LAYERS
MAT=(BK05,AL21,BP03,PW03,IN02,IN02,BP03,DRYWALL)
       I-F-R=0.68 ..                      $RECCENTRE'S WALLS
```

```
WALL3=CONS    U=0.037 ..          $UNDERGROUND WALLS
WALL1=CONS       LAYERS=WALL-TYPE1       ABS =.88   ..
WALL2=CONS       LAYERS=WALL-TYPE2       ABS=.88    ..
WALL10=CONS      LAYERS=WALL-TYPE10      ABS=.88    ..

$---WALL-INTERIOR-----$

WALL5=CONS            U=0.32 ..       $GENERAL
WALL6 = CONS      U=2.7 ..            $NONEXISTING PARTITION
WALL-TYPE7 =LAYERS     MAT=(BK02) ..
WALL-TYPE8 =LAYERS     MAT=(BK01,AL11,GP01) ..
WALL7=CONS             LAYERS=WALL-TYPE7      ABS=.88   ..
WALL8=CONS             LAYERS=WALL-TYPE8  ABS=.88   ..

$---FLOOR---$

FLOOR-TYPE1=CONS      U=0.023 ..    $UNDERGROUND
FLOOR-TYPE2 = CONS    U=0.2 ..      $MAIN AND MEZZANINE

$---ROOF---$

ROOF-TYPE1 = LAYERS
MAT=(CC32,AL33,PW04,RINSUL,BP03,GP02)     I-F-R=0.68 ..

                       $ROOF OF THE BUILDING OTHER THAN
SANCTUARY
ROOF2=CONS    U=1.05 ..     $SKYLIGHT ROOF
ROOF-TYPE3=LAYERS
MAT=(CC32,AL33,BP01,PW04,RINSUL,BP03,GP01,PW03)      I-F-R=0.68 ..

                         $L/C ROOFING MATERIALS
ROOF1=CONS       LAYERS=ROOF-TYPE1 ABS=.85  RO=3 ..
ROOF3=CONS       LAYERS=ROOF-TYPE3 ABS=.85  RO=3 ..

$---WI GLASS-TYPE----$

GL-TYPE1= G-T      G-T-C=2004
                   SPACER-TYPE-CODE=1 .. $WALL WI GLASS
GL-TYPE2= G-T      G-T-C=3002
                   SPACER-TYPE-CODE=1 .. $ATTIC

DRGL-TYPE3=G-T   G-T-C=1001
                   SPACER-TYPE-CODE=1 .. $ GLASS DOOR

$--DOOR--$

DR=CONS       U=.629   ABS=.78 ..
```

```
$--OCCUPENCY SCHEDULES--$

OFF-OCC1=D-SCH          (1,8)(0) (9,13)(1)(14,24)(0) ..
OFF-OCC2=D-SCH          (1,24)(0) ..
OFF-OCC=W-SCH           (MON,FRI) OFF-OCC1
                        (WEH) OFF-OCC2 ..
OFF-OCC-SCH=SCH       THRU DEC 31 OFF-OCC ..

ADM-OCC1=D-SCH          (1,7)(0)(8,18)(1)(19,22)(0.5)
                        (23,24)(0) ..
ADM-OCC2=D-SCH          (1,13)(0)(14,18)(0.5)(19,24)(0) ..
ADM-OCC3=D-SCH          (1,8)(0)(9,15)(0.5)(16,24)(0) ..
ADM-OCC4=D-SCH          (1,24)(0) ..
ADM-OCC=W-SCH           (MON,FRI) ADM-OCC1 (SAT) ADM-OCC2
                        (SUN) ADM-OCC3 (HOL) ADM-OCC4 ..
ADM-OCC-SCH=SCH         THRU DEC 31 ADM-OCC ..

GYM-OCC1=D-SCH          (1,8)(0)(9,13)(1)(14,15)(0.3)
                        (16,18)(1)(19,24)(0) ..
GYM-OCC2=D-SCH          (1,24)(0) ..
GYM-OCC=W-SCH           (MON,FRI) GYM-OCC1
                        (WEH) GYM-OCC2 ..
GYM-OCC-SCH=SCH         THRU DEC 31 GYM-OCC ..

L/OCC1=D-SCH            (1,24)(0) ..
L/OCC2=D-SCH            (1,9)(0)(10,11)(1)(12,24)(0) ..
L/OCC-SCH=W-SCH         (MON,SAT) L/OCC1 (SUN,HOL) L/OCC2 ..
L/SANCT-OCC-SCH=SCH     THRU DEC 31 L/OCC-SCH ..

C/OCC1=D-SCH            (1,24)(0) ..
C/OCC2=D-SCH            (1,17)(0)(18,19)(1)(20,24)(0) ..
C/OCC3=D-SCH            (1,8)(0)(9,10)(1)(11,24)(0) ..
C/OCC4=D-SCH            (1,6)(0)(7,8)(1)(9,24)(0) ..
C/OCC5=D-SCH            (1,13)(0)(14,15)(1)(16,18)(0)(19,24)(0) ..
C/OCC6=D-SCH            (1,8)(0)(9,13)(1)(14,24)(0) ..
C/OCC-SCH=W-SCH       (MON) C/OCC1 (TUE) C/OCC2
                        (WED) C/OCC3 (THU) C/OCC4
                        (FRI) C/OCC4 (SAT) C/OCC5
                        (SUN) C/OCC6 (HOL) C/OCC1 ..
C/SANCT-OCC-SCH=SCH     THRU DEC 31 C/OCC-SCH ..

ED/CL-OCC1=D-SCH        (1,8)(0)(9,15)(1)(16,24)(0) ..
ED/CL-OCC2=D-SCH        (1,8)(0)(9,15)(1)(16,24)(0) ..
ED/CL-OCC3=D-SCH        (1,24)(0) ..
ED/CL-OCC=W-SCH       (MON,FRI) ED/CL-OCC1
                        (SAT) ED/CL-OCC2
                        (SUN,HOL) ED/CL-OCC3 ..
ED/CL-OCC-SCH=SCH       THRU DEC 31 ED/CL-OCC ..
```

```
SCHOOL-OCC1=D-SCH       (1,6)(0)(7,10)(1)(11,24)(0)  ..
SCHOOL-OCC2=D-SCH       (1,8)(0)(9,11)(1)(12,24)(0)  ..
SCHOOL-OCC3=D-SCH       (1,24)(0) ..
SCHOOL-OCC=W-SCH        (MON,FRI) SCHOOL-OCC1
                        (SUN) SCHOOL-OCC2
                        (SAT) SCHOOL-OCC3
                        (HOL) SCHOOL-OCC3 ..
SCHOOL-OCC-SCH=SCH      THRU DEC 31  SCHOOL-OCC  ..

NUR-OCC1=D-SCH          (1,8)(0)(9,13)(1)(14,18)(0)(19,21)(1)(22,24)(0)  ..
NUR-OCC2=D-SCH          (1,24)(0)  ..
NUR-OCC=W-SCH           (MON,FRI) NUR-OCC1 (WEH) NUR-OCC2 ..
NUR-OCC-SCH=SCH         THRU DEC 31  NUR-OCC  ..


$---LIGHTING SCHEDULE-----$

OFF-LT1=D-SCH           (1,8)(0)(9,13)(1,.9,.9,.9,.9)(14,24)(0)  ..
OFF-LT2=D-SCH           (1,24)(0)  ..
OFF-LT=W-SCH            (MON,FRI) OFF-LT1  (WEH)  OFF-LT2 ..
OFF-LT-SCH=SCH          THRU DEC 31 OFF-LT  ..

AD-LT1=D-SCH            (1,7)(.1)(8,17)(.9,.9,.9,.9,.5,.5,.5,.8,.8,.9)
                        (18,22)(0.8)(23,24)(.1) ..
AD-LT2=D-SCH            (1,13)(.1)(14,18)(0.4)(19,24)(.1) ..
AD-LT3=D-SCH            (1,8)(.1)(9,15)(0.4)(16,24)(.1)  ..
AD-LT4=D-SCH            (1,24) (0) ..
AD-LT=W-SCH             (MON,FRI) AD-LT1 (SAT) AD-LT2 (SUN)
                        AD-LT3 (HOL) AD-LT4 ..
ADM-LT-SCH=SCH          THRU DEC 31 AD-LT ..

GYM-LT1=D-SCH           (1,8)(.1)(9,13)(.6,.6,.4,.4,.5)
                        (14,15)(0)(16,18)(.5,.6,.7)(19,24)(0) ..
GYM-LT2=D-SCH           (1,24)(0) ..
GYM-LT=W-SCH            (MON,FRI) GYM-LT1   (WEH) GYM-LT2 ..
GYM-LT-SCH=SCH          THRU DEC 31 GYM-LT ..

L/LT1=D-SCH             (1,24)(0) ..
L/LT2=D-SCH             (1,9)(0)(10,11)(.7)(12,24)(0) ..
LT-SCH=W-SCH            (MON,SAT) L/LT1  (SUN,HOL) L/LT2 ..
L/SANCT-LT-SCH=SCH      THRU DEC 31 LT-SCH ..

C/LT1=D-SCH             (1,24)(0) ..
C/LT2=D-SCH             (1,17)(0)(18, 19)(.8)(20,24)(0) ..
C/LT3=D-SCH             (1,8)(0)(9,10)(.8)(11,24)(0) ..
C/LT4=D-SCH             (1,6)(0)(7,8)(.7)(9,24)(0) ..
C/LT5=D-SCH             (1,13)(0)(14,15)(.8)
```

```
                        (16,24)(0) ..
C/LT6=D-SCH             (1,8)(0)(9,13)(.6)(14,24)(0) ..
C/LT=W-SCH              (MON) C/LT1 (HOL) C/LT1
                        (TUE) C/LT2 (WED) C/LT3
                        (THU,FRI) C/LT4 (SAT) C/LT5 (SUN) C/LT6 ..
C/SANCT-LT-SCH=SCH      THRU DEC 31 C/LT ..

ED/CL-LT1=D-SCH         (1,8)(.1)(9,15)(.7)(16,24)(.1) ..
ED/CL-LT2=D-SCH         (1,8)(.1)(9,15)(.7)(16,24)(.1) ..
ED/CL-LT3=D-SCH         (1,24)(0) ..
ED/CL-LT=W-SCH          (MON,FRI) ED/CL-LT1 (SAT) ED/CL-LT2
                        (SUN,HOL) ED/CL-LT3 ..
ED/CL-LT-SCH=SCH        THRU  DEC 31 ED/CL-LT ..

SCHOOL-LT1=D-SCH        (1,6)(0)(7,10)(.8)(11,24)(0) ..
SCHOOL-LT2=D-SCH        (1,8)(0)(9,11)(.8)(12,24)(0)    ..
SCHOOL-LT3=D-SCH        (1,24)(0) ..
SCHOOL-LT=W-SCH         (MON,FRI) SCHOOL-LT1
                        (SUN) SCHOOL-LT2   (SAT) SCHOOL-LT3
                        (HOL) SCHOOL-LT3 ..
SCHOOL-LT-SCH=SCH       THRU DEC 31 SCHOOL-LT  ..

NUR-LT1=D-SCH           (1,8)(0)(9,13)(.8,.7,.7,.7,.7)
                        (14,18)(0)(19,21)(.8,.7,.7)(22,24)(0) ..
NUR-LT2=D-SCH           (1,24)(0) ..
NUR-LT=W-SCH            (MON,FRI) NUR-LT1  (WEH) NUR-LT2 ..
NUR-LT-SCH=SCH          THRU DEC 31 NUR-LT ..

$---EQUIPMENT SCHEDULE-----$

ADM-EQUIP1=D-SCH        (1,7)(0)(8,17)(.1,.3,.9,.5,.8,.8,.8,.9,.8,.5)
                        (18,19)(0.2)(20,24)(0) ..
ADM-EQUIP2=D-SCH        (1,24) (0) ..
ADM-EQUIP=W-SCH         (MON,FRI) ADM-EQUIP1
                        (WEH) ADM-EQUIP2 ..
ADM-EQUIP-SCH=SCH       THRU  DEC 31 ADM-EQUIP  ..

$---INFILTRATION SCHEDULE-----$

INF-SCH=SCH    THRU DEC 31    (ALL)(1,4)(1)(5,19)(0)(20,24)(1) ..

$----INFILTRATION-VESTIBULE-----$

INF-VES1=D-SCH          (1,5)(0)(6,7)(0.08,0.02)(8,9)(.8,.6)(10,11)(.3)
                        (12,14) (.5,.8,.5)(15,16) (.3)
                        (17,18) (.4,.8)(19,24) (0) ..
INF-VES2=D-SCH          (1,12)(0)(13,14)(0.5)(15,24)(0) ..
INF-VES3=D-SCH          (1,9)(0)(10,13)(0.8)(14,24)(0) ..
```

```
INF-VES4=D-SCH          (1,24)(0) ..
INF-VES=W-SCH           (MON,FRI) INF-VES1 (SAT) INF-VES2
                        (SUN) INF-VES3 (HOL) INF-VES4 ..
INF-VES-SCH=SCH         THRU DEC 31 INF-VES ..

$----SPACE CONDITIONS----$

OFFICE = S-C
                        PEOPLE-HG-SCHEDULE=OFF-OCC-SCH
                        PEOPLE-HG-LAT=190
                        PEOPLE-HG-SENS=230
                        NUMBER-OF-PEOPLE=10
                        LIGHTING-SCHEDULE=OFF-LT-SCH
                        LIGHTING-KW =0.08
                        LIGHTING-TYPE=SUS-FLUOR
                        INF-METHOD=AIR-CHANGE
                        INF-CFM/SQFT=0.039
                        INF-SCHEDULE=INF-SCH
                        ZONE-TYPE=CONDITIONED
                        FLOOR-WEIGHT=70

                        TEMPERATURE=(70)
                        DAYLIGHTING=NO ..          $OFFICE IN MEZZANINE

ADMINIST=S-C            LIKE OFFICE
                        NUMBER-OF-PEOPLE=6
                        PEOPLE-SCHEDULE=ADM-OCC-SCH
                        LIGHTING-SCHEDULE= ADM-LT-SCH
                        LIGHTING-W/SQFT=1.4
                        EQUIPMENT-W/SQFT=1.5
                        EQUIP-SCHEDULE=ADM-EQUIP-SCH ..
                                                   $ADMINISTRATION
GYM/HALL=S-C            LIKE OFFICE
                        PEOPLE-HG-LAT=615
                        PEOPLE-HG-SENS=345
                        NUMBER-OF-PEOPLE=30
                        PEOPLE-SCHEDULE=GYM-OCC-SCH
                        LIGHTING-W/SQFT=1.4
                        LIGHTING-TYPE=INCAND
                        FLOOR-WEIGHT=30.0 ..
                                                   $GYM/HALL
L/SANCT=S-C             LIKE OFFICE
                        NUMBER-OF-PEOPLE=100
                        PEOPLE-SCHEDULE= L/SANCT-OCC-SCH
                        LIGHTING-KW=4.2
                        LIGHTING-TYPE=INCAND
                        LIGHTING-SCHEDULE=L/SANCT-LT-SCH ..
                                                $LUTHERAN SANCTUARY
```

```
C/SANCT=S-C      LIKE OFFICE
                 NUMBER-OF-PEOPLE=125
                 PEOPLE-SCHEDULE= C/SANCT-OCC-SCH
                 LIGHTING-KW=5.1
                 LIGHTING-TYPE=INCAND
                 LIGHTING-SCHEDULE=C/SANCT-LT-SCH ..
                                       $CATHOLIC SANSTUARY
CHAP=S-C         LIKE C/SANCT
                 NUMBER-OF-PEOPLE=15
                 LIGHTING-W/SQFT=1.44 ..
                                       $CHAPEL
CLROOM1=S-C      LIKE OFFICE
                 NUMBER-OF-PEOPLE=20
                 PEOPLE-SCHEDULE= ED/CL-OCC-SCH
                 LIGHTING-KW=0.7
                 LIGHTING-TYPE=SUS-FLUOR
                 LIGHTING-SCHEDULE=ED/CL-LT-SCH ..
                                       $MEZZANINE CLASSROOM1
CLROOM2=S-C      LIKE OFFICE
                 NUMBER-OF-PEOPLE=20
                 PEOPLE-SCHEDULE=SCHOOL-OCC-SCH
                 LIGHTING-KW=1.28
                 LIGHTING-TYPE=SUS-FLUOR
                 LIGHTING-SCHEDULE= SCHOOL-LT-SCH ..
                                       $MEZZANINE CLASSROOM2
NURSERY=S-C      LIKE OFFICE
                 NUMBER-OF-PEOPLE=18
                 PEOPLE-SCHEDULE=NUR-OCC-SCH
                 LIGHTING-W/SQFT=1.5
                 LIGHTING-SCHEDULE=NUR-LT-SCH
                 LIGHTING-TYPE=SUS-FLUOR ..
                                       $NURSERY
BCZ2-1=S-C       AREA/PERSON=150
                 PEOPLE-SCHEDULE=GYM-OCC-SCH
                 LIGHTING-KW=1.36
                 LIGHTING-SCHEDULE=GYM-LT-SCH
                 LIGHTING-TYPE=SUS-FLUOR
                 DAYLIGHTING=NO
                 Z-TYPE=CONDITIONED
                 TEMPERATURE=(70)
                 INF-CFM/SQFT=0.0 ..
                                       $BASEMENT CORE ZONE2
BCZ4-1=S-C       LIKE BCZ2-1
                 AREA/PERSON=200
                 LIGHTING-KW=0.9 ..
                                  $BASEMENTCORE (CORIDOR) ZONE
BVES1-1=S-C      TEMPERATURE=(72)
                 ZONE-TYPE=CONDITIONED
```

```
                  LIGHTING-TYPE=SUS-FLUOR
                  LIGHTING-KW=0.3
                  INF-SCHEDULE= INF-VES-SCH
                  INF-METHOD=AIR-CHANGE
                  INF-CFM/SQFT=0.0          $NO INFILTRATION
                  AREA/PERSON=150
                  DAYLIGHTING=NO       ..
                                               $BASEMENT VESTIBULE
MVES1=S-C         LIKE BVES1-1
                  LIGHTING-TYPE=INCAND
                  LIGHTING-KW=0.45
                  DAYLIGHTING=NO  ..        $NO INFILTRATION
                                         $MAIN FLOOR VESTIBULE 1
MVES2-1=S-C       LIKE MVES1
                  INF-METHOD=AIR-CHANGE
                  INF-CFM/SQFT=1.6 ..       $MAIN FLOOR VESTIBULE 2

MSTR=S-C          LIKE OFFICE
                  LIGHTING-W/SQFT=1
                  PEOPLE-SCHEDULE= ED/CL-OCC-SCH
                  AREA/PERSON=150 ..
                                            $MAIN FLOOR STAIRCASE

LOBBY=S-C         LIKE ADMINIST
                  TEMPERATURE=(70)
                  LIGHTING-W/SQFT=1.3
                  LIGHTING-TYPE=INCAND
                  AREA/PERSON=250
                  EQUIPMENT-W/SQFT=0 ..
                                            $MAIN LOBBY
MEZCZ1=S-C        AREA/PERSON=250
                  LIGHTING-KW=2.55
                  LIGHTING-SCHEDULE= ED/CL-OCC-SCH
                  LIGHTING-TYPE=INCAND
                  DAYLIGHTING=NO
                  Z-TYPE=CONDITIONED
                  TEMPERATURE=(70)
                  INF-CFM/SQFT=0.0 ..
                                          $MEZZANINE CORE ZONE1
MECHANICAL=S-C      Z-TYPE=UNCONDITIONED
                    LIGHTING-W/SQFT=1
                    LIGHTING-TYPE=INCAND
                    INF-METHOD=AIR-CHANGE
                    INF-CFM/SQFT=0.02
                    DAYLIGHTING=NO     ..
                                       $MECHANICAL PLUS MEZ. STORE
PLAYROOM=S-C        Z-TYPE=CONDITIONED
                    TEMPERATURE=(70)
```

```
                          NUMBER-OF-PEOPLE=20
                          PEOPLE-SCHEDULE= SCHOOL-OCC-SCH
                          LIGHTING-SCHEDULE =SCHOOL-LT-SCH
                          LIGHTING-W/SQFT=1.5
                          LIGHTING-TYPE=SUS-FLUOR
                          FLOOR-WEIGHT=30.0
                          INF-SCHEDULE= INF-SCH
                          INF-CFM/SQFT=0.039
                          DAYLIGHTING=NO    ..
                                   $MEZZANINE FLOOR PLAYROOM
RECCENTER=S-C             LIKE NURSERY
                          NUMBER-OF-PEOPLE=17
                          PEOPLE-SCHEDULE=SCHOOL-OCC-SCH
                          LIGHTING-W/SQFT=1.5
                          LIGHTING-SCHEDULE=SCHOOL-LT-SCH
                          LIGHTING-TYPE=SUS-FLUOR
                          INF-SCHEDULE=INF-SCH ..


$----SPACEFIC SPACE DETAIL------$
$----BASEMENT------$
$--BASEMENT FL ZONE1---$

BZ1=SPACE                 SPACE-CONDITIONS=GYM/HALL
                          AREA=3845   VOLUME=95873 ..

BZ1FL=U-F                 CONS=FLOOR-TYPE1
                          AREA=3845 ..
BZ1WUNG1=U-W              CONS=WALL3
                          AZ=180   HEIGHT=8.2     WIDTH=22 ..
BZIW1=E-W                 CONS=WALL1
                          AZ=180   HEIGHT=11.5 WIDTH=26 ..
BZ1WIN1=WI                G-T=GL-TYPE1
                          HEIGHT=4.92    WIDTH=6.56 ..
BZ1WUNG2=U-W              CONS=WALL3
                          AZ=-90   HEIGHT=8.2     WIDTH=80.7 ..
BZIW2=E-W                 CONS=WALL1
                          AZ=-90   HEIGHT=11.5   WIDTH=62 ..
BZ1WIN2=WI                LIKE BZ1WIN1  ..
BZIWUNG3= U-W             CONS=WALL3
                          AZ= 0    HEIGHT=8.2     WIDTH=52 ..
BZIW3=E-W                 CONS=WALL1
                          AZ= 0    HEIGHT=11.5   WIDTH=55.77 ..
BZ1WIN3=WI                LIKE  BZ1WIN1 ..

BZ1IW1=I-W                CONS=WALL7
```

```
                        NEXT-TO BZ2    AREA=2403 ..
BZ1IW2=I-W              CONS=WALL8
                        NEXT-TO  BZ4   AREA=668 ..
BZ1RF=ROOF              CONS=ROOF1
                        HEIGHT=50.5  WIDTH=80.7 TILT=15 ..

$--BASEMENT FL ZONE2 ---$

BZ2=SPACE               S-C=BCZ2-1      VOLUME=18249 AREA=1918 ..
BZ2FL=U-F               CONS=FLOOR-TYPE1
                        AREA=1918 ..
BZ2WUNG2=U-W            CONS=WALL3
                        HEIGHT=4.75   WIDTH=14 ..
BZ2W1=E-W               CONS=WALL10
                        HEIGHT=4.6       WIDTH=14   AZ=0 ..
BZ2IW1=I-W              LIKE BZ1IW1  NEXT-TO  BZ3      AREA=1027 ..
BZ2IW2=I-W              CONS=WALL5   NEXT-TO BZ4       AREA=225.74 ..
BZ2IW3=I-W              AREA=1918  NEXT-TO MZ1
                        CONS=WALL5   TILT=0 ..      $ CEILING

$--BASEMENT FL ZONE 3---$
$--REC CENTER---$

BZ3=SPACE                  S-C=RECCENTER
                           AREA=1836       VOLUME=16952 ..
BZ3FL1= U-F                CONS=FLOOR-TYPE1       AREA=1836 ..
BZ3WUNG1=U-W               CONS=WALL3
                           AZ=0  HEIGHT=4.75   WIDTH=30.7 ..
BZ3W1=E-W                  CONS=WALL10
                           AZ=0  HEIGHT=4.6   WIDTH=30.7 ..
 BZ3WUNG2=U-W              CONS=WALL3
                           AZ=90  HEIGHT=4.75   WIDTH=62.14 ..
BZ3W2=E-W                  CONS=WALL10
                           AZ=90      HEIGHT=4.9   WIDTH=62.14 ..
BZ3WIN1=WI                 G-T=GL-TYPE1
                           HEIGHT=4.6      WIDTH=16.4 ..
BZ3WUNG3=U-W               CONS=WALL3
                           AZ=135   HEIGHT=4.75      WIDTH=13.12 ..
BZ3W3=E-W                  CONS=WALL10
                           AZ=135    HEIGHT=4.6      WIDTH=13.12 ..
BZ3WIN2=WI                 G-T=GL-TYPE1
                           HEIGHT=4.6  WIDTH=9.84 ..
BZ3W4=E-W                  CONS=WALL10
                           AZ=180   HEIGHT=9.35    WIDTH=9.84 ..
BZ3IW1=I-W                 AREA=12.8 NEXT-TO BZ4
                           CONS=WALL5 ..
BZ3IW2=I-W                 AREA=1968.6  NEXT-TO  MZ2
                           TILT=0  CONS=WALL5 ..  $CEILING
```

```
$---BASEMENT FL ZONE4----$
$---BASEMENT CORIDOR----$

BZ4=SPACE          S-C= BCZ4-1
                   AREA=585  VOLUME=2048 ..
BZ4FL1= U-F        CONS=FLOOR-TYPE1
                   AREA=585 ..
BZ4WUNG1=U-W       CONS=WALL3        AREA=632.25  ..
BZ4IW1=I-W         CONS=WALL8        AREA=60.3  NEXT-TO BZ2  ..
BZ4IW2=I-W         CONS=WALL6  NEXT-TO BZ2  AREA=45.2 ..
BZ4IW3=I-W         CONS=WALL5    AREA=585    NEXT-TO MZ6

                                 TILT=0 ..                $CEILING
$---BASEMENT VESTIBULE---$

BVES1=SPACE        S-C=BVES1-1
                   AREA=97  VOLUME=271.6
                   DAYLIGHTING=NO ..
BVESW1=E-W         CONS=WALL1        HEIGHT=9.8  WIDTH=13  ..
BVESD1=DOOR        CONS=DR           HEIGHT=7  WIDTH=5.9  ..
BVESFL1= U-F       CONS=FLOOR-TYPE1        AREA=97 ..
BVESWUNG1=U-W      CONS=WALL3
                   HEIGHT=9.8  WIDTH=7.5 ..
BVESC=I-W          CONS=WALL5
                   NEXT-TO MZ3  TILT=0  AREA=97 ..
                                              $CEILING
$----MAIN FLOOR  ZONE1----$

$---NURSERY ---$

MZ1=SPACE          S-C=NURSERY
                   AREA=1372  VOLUME=10803 ..
MZ1C1=I-W          CONS=FLOOR-TYPE2
                   NEXT-TO MEZZ1  AREA=1699.6  TILT=0  ..
                                                $CEILING
MZ1W1=E-W          CONS=WALL1
                   AZ= 0  HEIGHT=7.87    WIDTH=22 ..
MZ1WIN1=WI         G-T=GL-TYPE1      HEIGHT=4.92 WIDTH=6.56 ..
MZ1D1=DOOR         CONS=DR           HEIGHT=7          WIDTH=5.9 ..
MZ1IW1=I-W         CONS=WALL7        NEXT-TO  MZ2  AREA=468   ..
MZ1IW2=I-W            CONS=WALL6  NEXT-TO  MZ6AREA=51.7  ..
MZ1IW3=I-W         CONS=WALL5  AREA=573  NEXT-TO BZ1 ..

$---MAIN FL ZONE 2---$
$---ADMINISTRATION----$

MZ2=SPACE          S-C=ADMINIST  AREA=2121  VOLUME=26791 ..
```

```
MZ2W1=E-W          CONS=WALL1
                   HEIGHT=9.18 WIDTH=31.17  AZ=0 ..
MZ2WIN1=WI         G-T=GL-TYPE1      HEIGHT=4.92     WIDTH=9.84 ..
MZ2W2=E-W          CONS=WALL1        HEIGHT=9.18      WIDTH=63.65

                                     AZ=90 ..
MZ2WIN2=WI         G-T=GL-TYPE1
                   HEIGHT=4.92      WIDTH=26.24 ..
MZ2IW3=I-W         CONS=WALL7    NEXT-TO MZ3
                   AREA=258.33 ..
MZ2IW4=I-W         CONS=WALL7
                   NEXT-TO MZ6  AREA=90.4 ..
MZ1RF=ROOF         CONS=ROOF1
                   HEIGHT=25      WIDTH=80.7   TILT=15 ..
$---MAIN FL ZONE3----$
$---CHAPEL---$

MZ3=SPACE          S-C=CHAP  AREA=371.7    VOLUME=4878 ..
MZ3W1=E-W          CONS=WALL1
                   AZ=90  HEIGHT=13.12   WIDTH=13.12 ..
MZ3WIN1=WI         LIKE  BZ1WIN1     HEIGHT=6.56 WIDTH=6.56 ..
MZ3IW1=I-W         CONS=WALL7        AREA=323         NEXT-TO MZ4 ..
MZ3IW2=I-W         CONS=WALL7        AREA=161.5       NEXT-TO MZ6 ..
MZ3RF=ROOF         CONS=ROOF1
                   HEIGHT=25       WIDTH=13.12TILT=15 ..
MZ3FL1=U-F            CONS=FLOOR-TYPE2   AREA=371.7 ..

$---MAIN FL ZONE4----$
$---C/SANCTURY----$

MZ4=SPACE          S-C= C/SANCT   AREA=4345 VOLUME=74654 ..
MZ4FL1= U-F        CONS=FLOOR-TYPE1        AREA=4345 ..
MZ4RF=ROOF         CONS=ROOF3        HEIGHT=60  WIDTH=52

                                     TILT=15 ..
MZ4W1=E-W          CONS=WALL2   AZ=0  HEIGHT=2     WIDTH=25 ..
MZ4W2=E-W          CONS=WALL1   AZ=0  HEIGHT=17.3  WIDTH=25 ..
MZ4WIN1=WI         LIKE  BZ1WIN1     WIDTH=6.56 ..
MZ4W3=E-W          CONS=WALL2    AZ=45  HEIGHT=2   WIDTH=13 ..
MZ4W4=E-W          CONS=WALL1    AZ=45  HEIGHT=12.5 WIDTH=13 ..
MZ4WIN2=WI         LIKE  BZ1WIN1 ..
MZ4W5=E-W          CONS=WALL2   AZ=90  HEIGHT=2  WIDTH=4 ..
MZ4W6=E-W          CONS=WALL1   HEIGHT=12 WIDTH=4 AZ=90 ..
MZ4W7=E-W          CONS=WALL2   AZ=45  HEIGHT=2 WIDTH=21 ..
MZ4W8=E-W          CONS=WALL1   AZ=45  HEIGHT=10 WIDTH=21 ..
MZ4W9=E-W          CONS=WALL2   HEIGHT=2  WIDTH=8.2  AZ=90 ..
MZ4W10=E-W         CONS=WALL1   HEIGHT=6.5  WIDTH=8.2  AZ=90 ..
MZ4WIN3=WI         LIKE  BZ1WIN1     HEIGHT=3.28  WIDTH=6.56 ..
```

```
MZ4W11=E-W          CONS=WALL2  AZ=135 HEIGHT=2 WIDTH=21 ..
MZ4W12=E-W          CONS=WALL1  AZ=135 HEIGHT=8.5 WIDTH=21 ..
MZ4W13=E-W          CONS=WALL2  AZ=90  HEIGHT=14 WIDTH=4 ..
MZ4W14=E-W          CONS=WALL2  AZ=135  HEIGHT=2  WIDTH=13 ..
MZ4W15=E-W          CONS=WALL1  AZ=135 HEIGHT=12.5
                    WIDTH=13 ..
MZ4WIN4=WI          LIKE BZ1WIN1 ..
MZ4W16=E-W          CONS=WALL2  AZ=180  HEIGHT=2

                                WIDTH=15.7 ..
MZ4W17=E-W          CONS=WALL1  AZ=135 HEIGHT=13.7 WIDTH=21 ..
MZ4W18=E-W          CONS=WALL2  AZ=90 HEIGHT=2  WIDTH=7.54 ..
MZ4W19=E-W          CONS=WALL1  AZ=135 HEIGHT=8 WIDTH=21 ..
MZ4W20=E-W          CONS=WALL1  AZ=180  HEIGHT=13.5

                                WIDTH=21 ..
MZ4WIN5=WI          LIKE BZ1WIN1  HEIGHT=5.9     WIDTH=19.7 ..
MZ4W26=E-W          CONS=WALL1  HEIGHT=8   WIDTH=20 AZ=180 ..
MZ4RF1=ROOF         CONS=ROOF3  HEIGHT=19  WIDTH=6.5
                    TILT=15 ..
MZ4IW1=I-W          CONS=WALL7  AREA=500.5 NEXT-TO MZ6 ..
MZ4IW2=I-W          CONS=WALL5  AREA=368 NEXT-TO MZ6 ..
MZ4W21=E-W          CONS=WALL1  AZ=0 HEIGHT=2.3 WIDTH=14 ..
MZ4WIN6=WI          LIKE BZ1WIN1  HEIGHT=1.8     WIDTH=6.6 ..
MZ4W22=E-W          CONS=WALL1  AZ=90  HEIGHT=8.2

                                WIDTH=10.5 ..
MZ4WIN7=WI          LIKE BZ1WIN1  HEIGHT=5.8    WIDTH=5.8 ..
MZ4W23=E-W          CONS=WALL1  AZ=45 HEIGHT=6  WIDTH=8.8 ..
MZ4WIN8=WI          LIKE BZ1WIN1  HEIGHT=4    WIDTH=5.8 ..
MZ4W24=E-W          CONS=WALL1  AZ=180  HEIGHT=2.3

                                WIDTH=14 ..
MZ4WIN9=WI          LIKE BZ1WIN1  HEIGHT=1.8    WIDTH=6.6 ..
MZ4W25=E-W          CONS=WALL1  AZ=135 HEIGHT=6  WIDTH=8.8 ..
MZ4WIN10=WI         LIKE BZ1WIN1  HEIGHT=4    WIDTH=5.8 ..

$---MAIN FL VESTIBULE---$

MVES=SPACE          S-C= MVES2-1  AREA=201.8 VOLUME=1986.4
                    DAYLIGHTING=NO ..
MVESW1=E-W          CONS=WALL1 AZ=180 HEIGHT=9.8 WIDTH=24.6 ..
MVESWIN1=WI         LIKE BZ1WIN1     HEIGHT=4.9    WIDTH=6.6 ..
MVESD1=WI           G-T=DRGL-TYPE3  HEIGHT=6.9    WIDTH=11.8 ..
MVESW2=E-W          CONS=WALL1  AZ=-90 HEIGHT=9.84 WIDTH=9.84 ..
MVESIW1=I-W         CONS=WALL5  AREA=96.9 NEXT-TO MFLSTR ..
MVESIW2=I-W         CONS=WALL7  AREA=145.4   NEXT-TO MZ5 ..
MVESD2=I-W          CONS=WALL5  AREA=81  NEXT-TO MZ5 ..
```

```
MVESCL=I-W           CONS=WALL5    NEXT-TO MEZZ1  TILT=0
AREA=201.82  ..

   $CEILING
MVESFL1= U-F         CONS=FLOOR-TYPE1   AREA=201.82  ..


$---MAIN FL STAIRCASE ZONE---$

MFLSTR=SPACE         S-C= MSTR      AREA=113   VOLUME=2907  ..
MFLSTRW1=E-W         CONS=WALL1     AZ= 180   HEIGHT=23.4  WIDTH=14
..
MFLSTRD1=DOOR        CONS= DR       HEIGHT=3.28 WIDTH=9.18  ..
MFLSTRWIN1=WI        LIKE BZ1WIN1   HEIGHT=4.9   WIDTH=6.6  ..
MFLSTRW2=E-W         CONS=WALL1     AZ= 90  HEIGHT=21.33  WIDTH=9.84
..
MFLSTRWIN2=WI        LIKE BZ1WIN1   HEIGHT=4.26 WIDTH=6.56  ..
MFLSTRIW1=I-W        CONS=WALL7     AREA=210  NEXT-TO MVES   ..
MFLSTRIW2=I-W        CONS=WALL7     AREA=324  NEXT-TO MZ5  ..
MFLSTRFL= U-F        CONS=FLOOR-TYPE1       AREA=113  ..
MFLSTRRF=ROOF        CONS=ROOF1     HEIGHT=13    WIDTH=9.84
                     TILT=15  ..
$---MAIN FL ZONE5----$
$--L/SANCTURY---$

MZ5=SPACE            S-C= L/SANCT   AREA=2906   VOLUME=51449  ..
MZ5FL1= U-F          CONS=FLOOR-TYPE1       AREA=2906  ..
MZ5W1=E-W            CONS=WALL2     AZ=0  HEIGHT=2    WIDTH=24  ..
MZ5W2=E-W            CONS=WALL1     AZ=0  HEIGHT=17  WIDTH=24  ..
MZ5D1=DOOR           CONS=DR        HEIGHT=7  WIDTH=5.9  ..
MZ5W3=E-W            CONS=WALL2     AZ=-90   HEIGHT=2   WIDTH=13  ..
MZ5W4=E-W            CONS=WALL1     AZ=-45 HEIGHT=12.5  WIDTH=24  ..
MZ5WIN2=WI           LIKE BZ1WIN1  ..
MZ5W5=E-W            CONS=WALL2     AZ=-90  HEIGHT=2  WIDTH=4  ..
MZ5W6=E-W            CONS=WALL1     AZ=-90  HEIGHT=12  WIDTH=4  ..
MZ5W7=E-W            CONS=WALL1     AZ=-45    HEIGHT=10.5  WIDTH=21  ..
MZ5W8=E-W            CONS=WALL1     HEIGHT=8.5  WIDTH=8.2  AZ=-90  ..
MZ5WIN3=WI           LIKE BZ1WIN1      HEIGHT=3.28  WIDTH=6.56  ..
MZ5W9=E-W            CONS=WALL1     AZ=-135 HEIGHT=10.5 WIDTH=21.3  ..
MZ5W10=E-W           CONS=WALL2     AZ=-90  HEIGHT=2  WIDTH=4  ..
MZ5W11=E-W           CONS=WALL1     AZ=-90  HEIGHT=12  WIDTH=4  ..
MZ5W12=E-W           CONS=WALL2     AZ=-135   HEIGHT=2    WIDTH=13  ..
MZ5W13=E-W           CONS=WALL1     AZ=-135   HEIGHT=12.5 WIDTH=13  ..
MZ5WIN4=WI           LIKE BZ1WIN1  ..
MZ5W14=E-W           CONS=WALL2      AZ=-180   HEIGHT=2    WIDTH=15  ..
MZW15=E-W            CONS=WALL1      AZ=-180   HEIGHT=13.7  WIDTH=15  ..
MZ5W16=E-W           CONS=WALL2       AZ=-90   HEIGHT=2    WIDTH=7.5  ..
MZ5W17=E-W           CONS=WALL2       AZ=-90   HEIGHT=8     WIDTH=7.5  ..
```

```
MZ5W18=E-W          CONS=WALL1    AZ=180 HEIGHT=11.8 WIDTH=7.54
..
MZ5WIN5=WI             G-T=GL-TYPE1  HEIGHT=5.9      WIDTH=6.6 ..
MZ5IW1=I-W          CONS=WALL7   AREA=371.4 NEXT-TO MZ6 ..
MZ5IW2=I-W          CONS=WALL5   AREA=465 NEXT-TO MZ6 ..
MZ5W19=E-W          CONS=WALL1      AZ=0 HEIGHT=2.3   WIDTH=14 ..
MZ5WIN6=WI          LIKE BZ1WIN1    HEIGHT=1.8   WIDTH=6.6 ..
MZ5W20=E-W          CONS=WALL1      AZ=90 HEIGHT=8.2  WIDTH=10.5
..
MZ5WIN7=WI          LIKE BZ1WIN1    HEIGHT=5.8   WIDTH=5.8 ..
MZ5W21=E-W          CONS=WALL1      AZ=45 HEIGHT=6  WIDTH=8.8 ..
MZ5WIN8=WI          LIKE BZ1WIN1    HEIGHT=4    WIDTH=5.8 ..
MZ5W22=E-W          CONS=WALL1      AZ=180 HEIGHT=2.3 WIDTH=14 ..
MZ5WIN9=WI          LIKE BZ1WIN1    HEIGHT=1.8      WIDTH=6.6 ..
MZ5W23=E-W          CONS=WALL1      AZ=135 HEIGHT=6  WIDTH=8.8 ..
MZ5WIN10=WI         G-T=GL-TYPE1    HEIGHT=4    WIDTH=5.8 ..
MZ5RF=ROOF        CONS=ROOF1     HEIGHT=42  WIDTH=45
                                 TILT=15 ..

$---MAIN FL ZONE6----$
$---LOOBY------$

MZ6=SPACE           S-C=LOBBY     AREA=4637   VOLUME=45627 ..
MZ6W1=E-W           CONS=WALL2    HEIGHT=9.8 WIDTH=13AZ=180 ..
MZ6WIN1=WI          LIKE BZ1WIN1  HEIGHT=6.6  WIDTH=9.8 ..
MZ6W2=E-W           CONS=WALL2    HEIGHT=9.4  WIDTH=23    AZ=180 ..
MZ6WIN2=WI          LIKE BZ1WIN1  HEIGHT=6.6   WIDTH=22.9 ..
MZ6IW1=I-W          CONS=WALL6    AREA=738     NEXT-TO MEZSTR ..
MZ6IW2=I-W          CONS=WALL5    AREA=3899    NEXT-TO MEZCL1
                                  TILT=0 ..
MZ6RF=ROOF          CONS=ROOF1
                    HEIGHT=30  WIDTH=6.5   TILT=15 ..
$MAIN FL VEST2---$

MVES2=SPACE         S-C= MVES1     AREA=113 VOLUME=1112
                    DAYLIGHTING=NO ..
MVES2W1=E-W         CONS=WALL1  AZ=-90 HEIGHT=8.86 WIDTH=9.84 ..
MVES2D1= WI         G-T=DR   GL-TYPE3HEIGHT=6.9   WIDTH=8.53 ..
MVES2IW1=I-W        CONS=WALL5       AREA=103    NEXT-TO BZ1 ..
MVES2IW2=I-W        CONS=WALL7       AREA=103    NEXT-TO MZ6 ..
MVES2D2=I-W         CONS=WALL5       AREA=59 NEXT-TO MZ5 ..
MVES2CL=I-W         CONS=WALL5       NEXT-TO MEZCL2
                    TILT=0  AREA=113 ..          $CEILING
MVESFL2= U-F        CONS=FLOOR-TYPE1      AREA=113 ..

$---MEZZANINE FL---$
$---OFF ZONE1---$
```

```
MEZZ1=SPACE          S-C=OFFICE  AREA=165  VOLUME=1621  ..
MEZZ1W1=E-W          CONS=WALL1  AZ=180  HEIGHT=9.84  WIDTH=14.43  ..
MEZZ1W2=E-W          CONS=WALL1   AZ=-90 HEIGHT=9.84 WIDTH=11.15  ..
MEZZ1WIN1=WI         LIKE  BZ1WIN1   HEIGHT=4.26   WIDTH=6.56  ..
MEZZ1IW1=I-W         CONS=WALL5        AREA=371.4  NEXT-TO MEZSTR  ..
MEZZ1IW2=I-W         CONS=WALL5        AREA=165  NEXT-TO MEZZP1
                     TILT=0  ..
$----UNCONDITIONED SPACE OF MEZZANINE ZONE1

MEZZP1=SPACE         Z-T=PLENUM AREA=165  VOLUME=429
                     FLOOR-WEIGHT=5  ..
MEZZP1W1=E-W         CONS=WALL1    HEIGHT=2.46       WIDTH=14.46
                     AZ= -90  ..
MEZZP1IW=I-W         CONS=WALL5    AREA=48.43  NEXT-TO MEZCZ  ..
MEZZP1RF=ROOF        CONS=ROOF1    HEIGHT=15        WIDTH=11
                     TILT=15  ..
$---MEZZANINE CORE ZONE---$

MEZCZ=SPACE          S-C= MEZCZ1    AREA=1880.8    VOLUME=29568  ..
MEZCZIW1=I-W         CONS=WALL5    AREA=516.7   NEXT-TO MEZCL1   ..
MEZCZIW2=I-W         CONS=WALL5    AREA=516.7   NEXT-TO MEZCL2   ..
MEZCZIW3=I-W         CONS=WALL5    AREA=403     NEXT-TO MEZSTR   ..
MEZCW1=E-W           CONS=WALL1    HEIGHT=14.76   WIDTH=21.3
                     AZ= 90  ..
MEZCWIN1=WI          G-T=GL-TYPE2  HEIGHT=4.92   WIDTH=19.68  ..
 MEZCW2=E-W          CONS=WALL1    HEIGHT=14.76  WIDTH=21.3
                     AZ= -90  ..
MEZCWIN2=WI          G-T=GL-TYPE2      HEIGHT=4.92   WIDTH=19.68  ..
MEZCW3=E-W           CONS=WALL1    HEIGHT=10.7  WIDTH=26.3
                     AZ= 0  ..
MEZCW4=E-W           CONS=WALL1    HEIGHT=13  WIDTH=26.3
                     AZ=180  ..
MEZCWIN3=WI          G-T=GL-TYPE1   HEIGHT=3.3   WIDTH=23  ..
MEZCW5=E-W           CONS=WALL1     HEIGHT=9  WIDTH=43  AZ=0  ..
MEZCWIN4=WI          G-T=GL-TYPE1   HEIGHT=4  WIDTH=4.75  ..
MEZCRF1=ROOF         CONS=ROOF1     HEIGHT=20  WIDTH=24.6
                     TILT=15  ..
$--MEZZANINE CLASS ROOM1 AT THE TOP OF THE C/SANCTURY---$

MEZCL1=SPACE         S-C=CLROOM1       AREA=927.85 VOLUME=9132.3  ..
MEZCL1W1=E-W         CONS=WALL1    HEIGHT=9  WIDTH=10   AZ=180  ..
MEZCL1WIN3=WI        G-T=GL-TYPE1      HEIGHT=4  WIDTH=4.75  ..
MEZCL1W3=E-W         CONS=WALL1    HEIGHT=9  WIDTH=27.5AZ=0  ..
MEZCL1WIN4=WI        G-T=GL-TYPE1   HEIGHT=4  WIDTH=4.75  ..
MEZCL1IW1=I-W        CONS=WALL5     AREA=791  NEXT-TO MZ4  ..
MEZCL1IW2=I-W        CONS=WALL5     AREA=742.7  NEXT-TO MEZCZ  ..
MEZCL1FL=I-W         CONS=WALL5    AREA=927.85  NEXT-TO MZ6  ..
MEZCL1C=I-W          CONS=WALL5    AREA=927.85  NEXT-TO  MEZCL1P
```

```
                    TILT=0 ..                                  $CEILING
$----UNCONDITIONED SPACE OF MEZZANINE CLASS ROOM1

MEZCL1P=SPACE       ZONE-TYPE=PLENUM  AREA=927.85 VOLUME=329
                                      FLOOR-WEIGHT=5 ..
MEZCL1RF=ROOF       CONS=ROOF1        HEIGHT=12.8 WIDTH=69.55
                                      TILT=15 ..
$--MEZZANINE CLASS ROOM2 AT THE TOP OF THE L/SANCTURY--$

MEZCL2=SPACE        S-C=CLROOM2       AREA=1266 VOLUME=12460 ..
MEZCL2W1=E-W        CONS=WALL1        HEIGHT=9 WIDTH=15.7
                                      AZ=180 ..
MEZCL2WIN1=WI       G-T=GL-TYPE1      HEIGHT=4.75 WIDTH=4 ..
MEZCL2IW1=I-W       CONS=WALL5        AREA=791 NEXT-TO MZ5 ..
MEZCL2IW2=I-W       CONS=WALL5        AREA=742.7 NEXT-TO MEZCZ ..
MEZCL2W2=E-W        CONS=WALL1        HEIGHT=9 WIDTH=26 AZ=0 ..
MEZCL2WIN2=WI       G-T=GL-TYPE1      HEIGHT=4.75      WIDTH=4 ..
MEZCL2FL=I-W        CONS=WALL5        AREA=927.85 NEXT-TO MZ4 ..
MEZCL2C=I-W         CONS=WALL5        AREA=1266 NEXT-TO MEZCL2P
                                      TILT=0 ..
$CEILING

$----UNCONDITIONED SPACE OF MEZZANINE CLASS ROOM2

MEZCL2P=SPACE       ZONE-TYPE=PLENUM  AREA=1266
                                      VOLUME=3115 FLOOR-WEIGHT=5 ..
MEZCL2RF=ROOF       CONS=ROOF1        HEIGHT=17   WIDTH=69.55
                                      TILT=15 ..
$--MENZANINE STAIRCASE----$

MEZSTR=SPACE        S-C= MSTR   AREA=667   VOLUME=12011 ..
MEZSTRW1=E-W        CONS=WALL1        HEIGHT=13 WIDTH=26 AZ= 0 ..
MEZSTRIW1=I-W       CONS=WALL5         AREA=700 NEXT-TO MEZCL2 ..
MEZSTRIW2=I-W       CONS=WALL5         AREA=646 NEXT-TO MEZCZ ..
MEZSTRW3=E-W        CONS=WALL1           HEIGHT=21  WIDTH=18  AZ=90 ..
MEZSTRWIN=WI        G-T=GL-TYPE1      HEIGHT=3.3      WIDTH=6.6 ..
MEZSTRFL=U-F        CONS=FLOOR-TYPE1  AREA=667 ..
MFLSTRRF1=ROOF      CONS=ROOF1        HEIGHT=42.65   WIDTH=39.37
                                      TILT=15 ..

$---MECHANICAL ROOM---$
$--ZONE WHICH IS NOT CONDITIONED---$

MECRM=SPACE         S-C= MECHANICAL  AREA=2258  VOLUME=22224.4 ..
MECIW1=I-W          CONS=WALL5        AREA=888  NEXT-TO BZ1 ..
MECIW2=I-W          CONS=WALL5        AREA=290  NEXT-TO PLRM ..
MECIW3=I-W          CONS=WALL5        AREA=409  NEXT-TO BZ3 ..
MECIW4=I-W          CONS=FLOOR-TYPE2
```

```
                     AREA=2258       NEXT-TO BZ2    TILT=0  ..
MECRF1=ROOF          CONS=ROOF1      HEIGHT=29 WIDTH=63
                                     TILT=15  ..
MECRF2=ROOF          CONS=ROOF2      HEIGHT=9.5     WIDTH=16
                                     TILT=0  ..
$---PALY ROOM ---$

PLRM=SPACE           S-C=PLAYROOM AREA=503  VOLUME=4951  ..
PLRMW1=E-W           CONS=WALL1      HEIGHT=11    WIDTH=19   AZ=0  ..
PLRMWIN1= WI         G-T=GL-TYPE1    HEIGHT=4.6  WIDTH=6.5  ..
PLRMIW1=I-W          CONS=WALL5      AREA=320  NEXT-TO MEZFLST  ..
PLRMFL=I-W           CONS=WALL5      AREA=503  NEXT-TO MZ1  ..
PLRMRF=ROOF          CONS=ROOF1      HEIGHT=17.7 WIDTH=28
                                     TILT=15  ..

$---MEZZANINE FL STAIRCASE ZONE---$

MEZFLST=SPACE        S-C=MSTR        AREA=188  VOLUME=5563  ..
MEZFLSTW1=E-W        CONS=WALL1      AZ= 0  HEIGHT=8.2  WIDTH=12.5  ..
MEZFLSTIW1=I-W       CONS=WALL7      AREA=183  NEXT-TO MZ2   ..
MEZFLSTIW2=I-W       CONS=WALL7      AREA=66   NEXT-TO MECRM   ..
MEZFLSTRF=ROOF       CONS=ROOF1      HEIGHT=11 WIDTH=14.7
                                     TILT=15  ..
END ..
COMPUTE LOADS ..

INPUT SYSTEMS ..

$----HVAC SYSTEMS SCHEDULES FOR AHU-1

FAN-ON1=SCH       THRU DEC 31   (ALL)(1,4)(0) (5,19)(1) (20,24)(0)  ..

$--- HVAC SYSTEMS SCHEDULES FOR AHU-2

FAN-ON2=SCH       THRU DEC 31   (ALL)(1,4)(0) (5,19)(1) (20,24)(0)  ..

$---- HVAC SYSTEMS SCHEDULES FOR AHU-3

FAN-ON3=SCH       THRU DEC 31    (MON,FRI)(1,7)(0) (8,21)(1) (22,24)(0)
                                    (WEH)(1,24)(0)  ..
HEATSETPT1=SCH  THRU DEC 31    (ALL)(1,5)(61)(6,19)(70) (20,24)(61)  ..
HEATSETPT2=SCH  THRU DEC 31    (ALL)(1,5)(61)(6,19)(68) (20,24)(61)  ..
HEATSETPT3=SCH  THRU DEC 31    (MON,FRI)(1,7)(61) (8,22)(68)

                 (23,24)(60)(WEH)(1,24)(61)  ..
$BASEBOARD RESET SCHEDULE
```

```
DRS1=DAY-RESET-SCH   SUPPLY-HI=1 SUPPLY-LO=0 OUTSIDE-HI=68
OUTSIDE-LO=0 ..
DRS= RESET-SCH       THRU DEC 31 (ALL) DRS1 ..

COOL-OFF=SCH      THRU DEC 31 (ALL)(1,24)(0) ..

HEATON=SCH           THRU MAY 15 (ALL)(1,24)(1)
                     THRU AUG 31 (ALL)(1,24)(0)
                     THRU DEC 31 (ALL)(1,24)(1) ..

SUMMER-VENT=SCH      THRU MAY 31 (ALL)(1,24)(0)
                     THRU OCT 31 (ALL)(1,24)(1)
                     THRU DEC 31 (ALL)(1,24)(0) ..
VENT-SETPT=SCH       THRU DEC 31 (ALL)(1,24)(74) ..

$ZONE SUB-COMMANDS

ZCON1=Z-C       DESIGN-HEAT-T=68
                HEAT-TEMP-SCH=HEATSETPT1
                BASEBOARD-CTRL=THERMOSTATIC
                THERMOSTAT-TYPE=PROPORTIONAL
                THROTTLING-RANGE=4 ..
ZCON2=Z-C       DESIGN-HEAT-T=68
                HEAT-TEMP-SCH=HEATSETPT2
                B-C=THERMOSTATIC
                THERMOSTAT-TYPE=PROPORTIONAL
                THROTTLING-RANGE=4 ..
ZCON3=Z-C       DESIGN-HEAT-T=68
                HEAT-TEMP-SCH=HEATSETPT3
                B-C=THERMOSTATIC
                THERMOSTAT-TYPE=PROPORTIONAL
                THROTTLING-RANGE=4 .. $GYM/HALL

ZAIR1=Z-A       OA-CFM/PER=10
                AIR-CHANGES/HR=4 ..

ZAIR2=Z-A       OA-CFM/PER=15
                AIR-CHANGES/HR=4 ..

ZAIR3=Z-A       OA-CFM/PER=10
                AIR-CHANGES/HR=4 ..

$---SYSTEM DESCRIPTION
$---GYM/HALL; AHU-3

BZ1=ZONE        Z-T=CONDITIONED
                Z-C=ZCON3
                Z-A=ZAIR3
```

```
                BASEBOARD-RATING=-5120 ..    $BTU/HR

$---SERVICE ZONES; AHU-2

BZ2=ZONE        Z-T=CONDITIONED
                Z-C=ZCON2
                Z-A=ZAIR2
                ASSIGNED-CFM=106
                BASEBOARD-RATING=-512 .. $BASEMENT CORE ZONE
BZ3=ZONE        LIKE BZ2 ASSIGNED-CFM=1430
                EXHAUST-CFM=450 B-R=-2816 ..      $REC CENTER
BZ4=ZONE        LIKE BZ3 ASSIGNED-CFM=318 EXHAUST-CFM=225
                B-R=-0 ..                   $BASEMENT CORIDOR
MZ1=ZONE        LIKE BZ4 ASSIGNED-CFM=954       EXHAUST-CFM=225

                B-R=-1280 ..                $NUR/CORE ZONE
MZ2=ZONE        LIKE MZ  ASSIGNED-CFM=1059  EXHAUST-CFM=450
                B-R= -24403 ..              $ADMINISTRATION
MZ3=ZONE        LIKE MZ2 ASSIGNED-CFM=424 EXHAUST-CFM=150

                B-R=-1024    ..             $CHAPEL
PLRM=ZONE       LIKE MZ3 ASSIGNED-CFM=424   EXHAUST-CFM=100

                B-R= -1024  ..          $PLAYROOM IN MANZZANINE FL

$---SANCTURIES,LOBBY,CLASS ROOMS AND OTHER AREA; AHU-1

MZ4=ZONE        Z-T=CONDITIONED
                Z-C=ZCON1
                Z-A=ZAIR1
                ASSIGNED-CFM=3952
                EXHAUST-CFM=64
                BASEBOARD-RATING=-7781 ..

                           $C/SANCTUARY
MZ5=ZONE        LIKE MZ4    ASSIGNED-CFM=2702   EXHAUST-CFM=0
                B-R=-81912 ..                   $L/SANCTUARY
MZ6=ZONE        LIKE MZ5 ASSIGNED-CFM=2236  B-R=-41843 ..
                                            $LOBBY
MEZZ1=ZONE      LIKE MZ5 ASSIGNED-CFM=170   B-R=-512    ..

                                $MENZZANINE OFFICE
MEZZP1=ZONE       Z-T=PLENUM ..       $MEZZANINE OFFICE PLENUM
MEZCZ=ZONE        LIKE MEZZ1  ASSIGNED-CFM=848    B-R=-179 ..

                                  $SPACE ABOVE THE LOBBY
MEZCL1=ZONE       LIKE MEZZ1 ASSIGNED-CFM=477     B-R=-2389 ..
```

```
                                    $CLASSROOM ABOVE C/SANCT
MEZCL1P=ZONE     LIKE MEZZP1 ..      $CLASSROOM1 PLENUM
MEZCL2=ZONE      LIKE MEZCL1  ASSIGNED-CFM=477 ..

                                    $CLASSROOM ABOVE L/SANCT
MEZCL2P=ZONE     LIKE MEZCL1P ..

                                    $CLASSROOM2 PLENUM
MECRM=ZONE       Z-T=UNCONDITIONED ..

                                    $MECHANICAL ROOM

$UNIT HEATER SYSTEMS DESCRIPTION

FAN-ON4=SCH      THRU DEC 31    (MON,FRI)(1,7)(0) (8,19)(.8) (20,24)(0)
                                    (SAT)(1,13)(0) (14,18)(.5) (19,24)(0)
                                    (SUN)(1,8)(0) (9,15)(.5) (16,24)(0)
                                    (HOL) (1,24)(0) ..
HEATSETPT4=SCH   THRU DEC 31    (MON,FRI)(1,7)(55)(8,19)(72) (20,24)(0)
                                    (SAT)(1,7)(55) (8,19)(70)(20,24)(55)
                                    (SUN)(1,8)(55)(9,19)(70)(20,24)(55)
                                    (HOL)(1,24)(55) ..

BVES1=ZONE       Z-T=CONDITIONED
                 DESIGN-HEAT-T=72
                 HEAT-TEMP-SCH=HEATSETPT4
                 H-CAP= -5802 ..        $BASEMENT VESTIBULE
MVES=ZONE        LIKE BVES1  H-CAP= -18430 ..
                                        $MAIN FLOOR VESTIBULE 1
MFLSTR=ZONE      LIKE MVES  H-CAP= -5802 ..
                                        $MAIN FLOOR STAIRCASE
MVES2=ZONE       LIKE MVES  H-CAP=-24232 ..
                                        $MAIN FLOOR VESTIBULE 2
MEZFLST=ZONE     LIKE MVES  H-CAP=-5802 ..
                                        $MEZZANINE STAIRCASE
MEZSTR=ZONE      LIKE MFLSTR ..

$SYSTEM SUBCOMMAND FOR UNIT HEATERS

S-CONT4=S-C      MAX-SUPPLY-T=105 ..
AC-SYS4=SYST     S-TYPE=UHT
                 FAN-SCHEDULE=FAN-ON4
                 H-SCH=HEATON
                 S-C=S-CONT4
                 HEAT-SOURCE=HOT-WATER
                 ZONE-NAMES=(BVES1, MVES, MFLSTR, MVES2,
                             MEZFLST,MEZSTR) ..
```

```
$SYSTEM SUBCOMMANDS FOR OTHER SYSTEMS
$SYSTEM HAS NO COOLING COIL.SYSTEM NAME IS SZRH BUT $WITHOUT
REHEATING COIL

S-CONT1=S-C        MAX-SUPPLY-T=105
                   C-SCH=COOL-OFF
                   MIN-HUMIDITY=25
                   B-SCH=DRS
                   ECONO-LIMIT-T=60 ..
S-CONT2=S-C        MAX-SUPPLY-T=105
                   C-SCH=COOL-OFF
                   MIN-HUMIDITY=25
                   BASEBOARD-SCH=DRS
                   ECONO-LIMIT-T=60 ..
S-CONT3=S-C        MAX-SUPPLY-T=105
                   C-SCH=COOL-OFF
                   MIN-HUMIDITY=25
                   BASEBOARD-SCH=DRS
                   ECONO-LIMIT-T=60 ..

$SUBCOMANDS OF SYSTEM-AIR

S-AIR1=S-A         SUPPLY-CFM=10595
                   RETURN-CFM=10065
                   OA-CONTROL=TEMP ..

S-AIR2=S-A         SUPPLY-CFM=4768
                   RETURN-CFM=3179
                   OA-CONTROL=TEMP ..

S-AIR3=S-A         SUPPLY-CFM=4238
                   RETURN-CFM=3814
                   OA-CONTROL=TEMP
                   RECOVERY-EFF=0.6 ..
                              $RUN AROUND HEAT RECOVERY SYSTEM
SYS-F1=S-FANS      F-SCH=FAN-ON1
                   F-C=CONSTANT-VOLUME
                   SUPPLY-STATIC=2.25
                   SUPPLY-EFF=0.6
                   RETURN-STATIC=0.75
                   RETURN-EFF=0.6
                   NIGHT-VENT-CTRL=SCHEDULED+DEMAND
                   NIGHT-VENT-SCH=SUMMER-VENT
                   NIGHT-VENT-RATIOS=(1,1,1,0,0,0)
                   NIGHT-CYCLE-CTRL=CYCLE-ON-ANY ..

SYS-F2=S-FANS      LIKE SYS-F1
                   F-SCH=FAN-ON2
```

```
SYS-F3=S-FANS      LIKE SYS-F2
                   F-SCH=FAN-ON3

$AC SYSTEM FOR THE AHU-1

AC-SYS1=SYST       S-TYPE=SZRH
                   S-C=S-CONT1
                   S-A=S-AIR1
                   S-FANS=SYS-F1
                   HEAT-SOURCE=HOT-WATER
                   B-SCH=DRS
                   BASEB-S=HOT-WATER
                   RETURN-AIR-PATH=DUCT
                   HUMIDIFIER-TYPE=HOT-WATER
                   H-SCH=HEATON
                   COOLING-SCHEDULE=COOL-OFF
                   VENT-TEMP-SCH=VENT-SETPT
                   ZONE-NAMES=(MZ4,MZ5,MZ6,MEZZ1,MEZZP1,
                   MEZCZ,MEZCL1,MEZCL1P,MEZCL2,
                   MEZCL2P,MECRM) ..

AC-SYS2=SYST       S-TYPE=SZRH
                   S-C=S-CONT2
                   S-A=S-AIR2
                   S-FANS=SYS-F2
                   HEAT-SOURCE=HOT-WATER
                   B-SCH=DRS
                   BASEB-S=HOT-WATER
                   RETURN-AIR-PATH=DUCT
                   H-SCH=HEATON
                   C-SCH=COOL-OFF
                   VENT-TEMP-SCH=VENT-SETPT
                   ZONE-NAMES=(BZ2,BZ3,BZ4,MZ1,MZ2,MZ3,PLRM) ..

AC-SYS3=SYST       S-TYPE=SZRH
                   S-C=S-CONT3
                   S-A=S-AIR3
                   S-FANS=SYS-F3
                   B-SCH=DRS
                   HEAT-SOURCE=HOT-WATER
                   BASEB-S=HOT-WATER
                   RETURN-AIR-PATH=DUCT
                   HUMIDIFIER-TYPE=HOT-WATER
                   H-SCH=HEATON
                   C-SCH=COOL-OFF
                   VENT-TEMP-SCH=VENT-SETPT
```

```
                  ZONE-NAMES=(BZ1) ..

PLANT1=PLANT-ASSIGNMENT
                  SYSTEM-NAMES=(AC-SYS1,AC-SYS2,AC-SYS3,AC-SYS4)
                  DHW-GAL/MIN=1
                  DHW-SCH=DHW ..

DHW=SCH   THRU DEC 31  (MON,FRI)(1,7)(0 ) (8,19)(1) (20,24)(0)
                       (SAT)(1,8)(0) (9,15)(1) (16,24)(0)
                       (SUN)(1,9)(0) (10,15)(1) (16,24)(0)
                       (HOL)(1,24)(0) ..

$AC-SYS1:AHU-1
$AC-SYS2:AHU-2
$AC-SYS3:AHU-3
$AC-SYS4:CUH
END ..
COMPUTE SYSTEMS ..
INPUT PLANT ..

PLANT1=PLANT-ASSIGNMENT ..
PLANT-REPORT     SUMMARY=(BEPS) ..
SYSBOILER=PLANT-EQUIPMENT TYPE=HW-BOILER   SIZE=-999

                          INSTALLED-NUMBER=2 ..
DHWH=PLANT-EQUIPMENT      TYPE=DHW-HEATER  SIZE=-999

                          INSTALLED-NUMBER=1 ..
END ..
COMPUTE PLANT ..
STOP ..
```

Appendix 4

Major changes in the base case input file for HVAC system retrofit

Under LOADS program

CHANGED INFILTRATION SCHEDULE FOR SEPARATE HVAC SYSTEM

```
L/SANCT-INF-SCH1=D-SCH        (1,24) (1) ..
L/SANCT-INF-SCH2=D-SCH        (1,7) (1) (8,11) (0) (12,24)(1) ..
L/SANCT-INF-SCH3=W-SCH        (MON,SAT) L/SANCT-INF-SCH1
                              (SUN,HOL) L/SANCT-INF-SCH2 ..
L/SANCT-INF-SCH=SCH       THRU DEC 31 L/SANCT-INF-SCH3 ..

C/SANCT-INF-SCH1=D-SCH        (1,24) (1) ..
C/SANCT-INF-SCH2=D-SCH        (1,15) (1) (16,19)(0) (20,24)(1) ..
C/SANCT-INF-SCH3=D-SCH        (1,7)(1) (8,11)(0) (12,24) (1) ..
C/SANCT-INF-SCH4=D-SCH        (1,6)(1) (7,9)(0) (10,24)(1) ..
C/SANCT-INF-SCH5=D-SCH        (1,12)(1) (13,15)(0) (16,24)(1) ..
C/SANCT-INF-SCH6=D-SCH        (1,7)(1) (8,13)(0) (14,24)(1) ..
C/SANCT-INF-SCH7=W-SCH        (MON) C/SANCT-INF-SCH1
                              (TUE)C/SANCT-INF-SCH2
                              (WED) C/SANCT-INF-SCH3
                              (THU) C/SANCT-INF-SCH4
                              (FRI) C/SANCT-INF-SCH4
                              (SAT) C/SANCT-INF-SCH5
                              (SUN) C/SANCT-INF-SCH6
                              (HOL) C/SANCT-INF-SCH1 ..
C/SANCT-INF-SCH=SCH       THRU DEC 31 C/SANCT-INF-SCH7 ..
```

Under SYSTEMS program

```
$----HVAC SYSTEMS SCHEDULES

FAN-ON1=SCHEDULE     THRU DEC 31    (ALL)(1,4)(0) (5,19)(1) (20,24)(0) ..

FAN-ON2=SCHEDULE     THRU DEC 31    (ALL)(1,4)(0) (5,19)(1) (20,24)(0) ..

FAN-ON3=SCHEDULE     THRU DEC 31    (MON,FRI)(1,7)(0) (8,21)(1)
(22,24)(0)
                                           (WEH)(1,24)(0) ..

$----FOR AHU-5; C/SANCTUARY SCHEDULE
```

```
C-S-FAN-ON1=D-SCH        (1,24) (0) ..
C-S-FAN-ON2=D-SCH        (1,15) (0) (16,19)(1) (20,24)(0) ..
C-S-FAN-ON3=D-SCH        (1,7)(0) (8,11)(1) (12,24) (0) ..
C-S-FAN-ON4=D-SCH        (1,6)(0) (7,9)(1) (10,24)(0) ..
C-S-FAN-ON5=D-SCH        (1,12)(0) (13,15)(1) (16,24)(0) ..
C-S-FAN-ON6=D-SCH        (1,7)(0) (8,13)(1) (14,24)(0) ..
C-S-FAN-ON7=W-SCH        (MON) C-S-FAN-ON1  (TUE) C-S-FAN-ON2
                         (WED) C-S-FAN-ON3  (THU) C-S-FAN-ON4
                         (FRI) C-S-FAN-ON4  (SAT) C-S-FAN-ON5
                         (SUN) C-S-FAN-ON6  (HOL) C-S-FAN-ON1 ..
C/SANCT-FAN-ON=SCH  THRU DEC 31 C-S-FAN-ON7 ..

$---HEATSETPT FOR DIFF. SYSTEMS

HEATSETPT1=SCH  THRU DEC 31   (ALL)(1,5)(61) (6,19)(70) (20,24)(61) ..

HEATSETPT2=SCH  THRU DEC 31   (ALL)(1,5)(61) (6,19)(68) (20,24)(61) ..

HEATSETPT3=SCH  THRU DEC 31   (MON,FRI)(1,7)(61) (8,22)(68) (23,24)(60)
                              (WEH)(1,24)(61) ..

C-S-HEATSETPT1=D-SCH          (1,24) (61) ..
C-S-HEATSETPT2=D-SCH          (1,15) (61) (16,19)(70) (20,24)(61) ..
C-S-HEATSETPT3=D-SCH          (1,7)(61) (8,11)(70) (12,24) (61) ..
C-S-HEATSETPT4=D-SCH          (1,6)(61) (7,9)(70) (10,24)(61) ..
C-S-HEATSETPT5=D-SCH          (1,12)(61) (13,15)(70) (16,24)(61) ..
C-S-HEATSETPT6=D-SCH          (1,7)(61) (8 ,13)(70) (14,24)(61) ..
C-S-HEATSETPT7=W-SCH          (MON) C-S-HEATSETPT1
                              (TUE) C-S-HEATSETPT2
                              (WED) C-S-HEATSETPT3
                              (THU) C-S-HEATSETPT4
                              (FRI) C-S-HEATSETPT4
                              (SAT) C-S-HEATSETPT5
                              (SUN) C-S-HEATSETPT6
                              (HOL) C-S-HEATSETPT1 ..
C/SANCT-HEATSETPT=SCH  THRU DEC 31 C-S-HEATSETPT7 ..

$--DAY-RESER-SCH FOR ALL SYSTEMS

DRS1=DAY-RESET-SCH     SUPPLY-HI=1  SUPPLY-LO=0  OUTSIDE-HI=68

                       OUTSIDE-LO=0 ..
DRS= RESET-SCH    THRU DEC 31 (ALL) DRS1 ..

$--COOLING AND HEATING SCHEDULE FOR ALL SYSTEMS

COOL-OFF=SCHEDULE      THRU DEC 31 (ALL)(1,24)(0) ..
```

```
HEATON=SCH          THRU MAY 15 (ALL)(1,24)(1)
                    THRU AUG 31 (ALL)(1,24)(0)
                    THRU DEC 31 (ALL)(1,24)(1) ..

SUMMER-VENT=SCH           THRU MAY 31 (ALL)(1,24)(0)
                          THRU OCT 31 (ALL)(1,24)(1)
                          THRU DEC 31 (ALL)(1,24)(0) ..
VENT-SETPT=SCH            THRU DEC 31 (ALL)(1,24)(74) ..

$ZONE SUB-COMMANDS

ZCON1=Z-C           D-H-T=68               H-T-SCH=HEATSETPT1
                    B-C=THERMOSTATIC       T-TYPE=PROPORTIONAL
                    T-R=4 ..

ZCON2=Z-C           D-H-T=68               H-T-SCH=HEATSETPT2
                    B-C=THERMOSTATIC       T-TYPE=PROPORTIONAL
                    T-R=4 ..

ZCON3=Z-C           D-H-T=68               H-T-SCH=HEATSETPT3
                    B-C=THERMOSTATIC       T-TYPE=PROPORTIONAL
                    T-R=4 ..                           $GYM/HALL

ZCON5=Z-C           D-H-T=70               H-T-SCH=C/SANCT-
HEATSETPT
                    B-C=THERMOSTATIC       T-TYPE=PROPORTIONAL
                    T-R=4 ..

ZAIR1=Z-A           OA-CFM/PER=10     AIR-CHANGES/HR=4 ..
ZAIR2=Z-A           OA-CFM/PER=15     AIR-CHANGES/HR=4 ..
ZAIR3=Z-A           OA-CFM/PER=10
                    AIR-CHANGES/HR=4 ..
ZAIR4=Z-A           OA-CFM/PER=10     AIR-CHANGES/HR=4 ..

$---SYSTEM DESCRIPTION
$---GYM/HALL; AHU-3

BZ1=ZONE            Z-TYPE=CONDITIONED     Z-C=ZCON3
                    Z-A=ZAIR3              B-R= -5120 ..      $BTU/HR

$---SERVICE ZONES; AHU-2

BZ2=ZONE            Z-TYPE=CONDITIONED           Z-C=ZCON2
                    Z-A=ZAIR2
                    ASSIGNED-CFM=106
                    B-R= -512 ..
BZ3=ZONE            LIKE BZ2  ASSIGNED-CFM=1430
```

```
                EXHAUST-CFM=450  B-R=-2816 ..
BZ4=ZONE        LIKE BZ3  ASSIGNED-CFM=318     EXHAUST-CFM=225

                B-R= -0  ..
MZ1=ZONE        LIKE BZ4  ASSIGNED-CFM=954  EXHAUST-CFM=225
                B-R= -1280  ..
MZ2=ZONE        LIKE MZ1  ASSIGNED-CFM=1059   EXHAUST-CFM=450
                B-R=-24403   ..
MZ3=ZONE        LIKE MZ2  ASSIGNED-CFM=424    EXHAUST-CFM=150

                B-R= -1024   ..
PLRM=ZONE       LIKE MZ3  ASSIGNED-CFM=424    EXHAUST-CFM=100

                B-R= -1024   ..

$---C/L SANCTUARY; AHU-5

MZ4=ZONE        Z-T=CONDITIONED          Z-C=ZCON5
                Z-A=ZAIR4                ASSIGNED-CFM=3952
                EXHAUST-CFM=64           B-R= -7781  ..
                                                $C/SANCTUARY
MZ5=ZONE        LIKE MZ4     ASSIGNED-CFM=2702
                Z-C=ZCON5  B-R=-81912 ..
                                                $L/SANCTUARY

$---LOBBY, CLASS ROOMS AND OTHER AREA; AHU-1

MZ6=ZONE        Z-TYPE=CONDITIONED    Z-C=ZCON1
                Z-A=ZAIR1   ASSIGNED-CFM=2236
                B-R=-41843 ..                 $LOBBY
MEZZ1=ZONE      LIKE MZ6  ASSIGNED-CFM=170    B-R=-512   ..
                                              $MENZZANINE OFFICE
MEZZP1=ZONE     Z-TYPE=PLENUM ..

                              $MEZZANINE OFFICE PLENUM
MEZCZ=ZONE      LIKE MEZZ1  ASSIGNED-CFM=848        B-R=-179 ..

                              $SPACE ABOVE THE LOBBY
MEZCL1=ZONE     LIKE MEZZ1  ASSIGNED-CFM=477        B-R=-2389 ..

                              $CLASSROOM ABOVE C/SANCT
MEZCL1P=ZONE    LIKE MEZZP1 ..

                              $CLASSROOM1 PLENUM
MEZCL2=ZONE     LIKE MEZCL1   ASSIGNED-CFM=477 ..

                              $CLASSROOM ABOVE L/SANCT
```

```
MEZCL2P=ZONE     LIKE MEZCL1P ..

                                              $CLASSROOM2 PLENUM
MECRM=ZONE    Z-TYPE=UNCONDITIONED ..

                                              $MECHANICAL ROOM

$----UNIT HEATER SYSTEMS DESCRIPTION

FAN-ON4=SCH    THRU DEC 31    (MON,FRI)(1,7)(0) (8,19)(.8) (20,24)(0)
                                   (SAT)(1,13)(0) (14,18)(.5) (19,24)(0)
                                   (SUN)(1,8)(0) (9,15)(.5) (16,24)(0)
                                   (HOL) (1,24)(0) ..
HEATSETPT4=SCH  THRU DEC 31  (MON,FRI)(1,7)(55)(8,19)(72) (20,24)(0)
                                   (SAT)(1,7)(55) (8,19)(70)(20,24)(55)
                                   (SUN)(1,8)(55)(9,19)(70)(20,24)(55)
                                   (HOL)(1,24)(55) ..

BVES1=ZONE       Z-TYPE=CONDITIONED
                 D-H-T=72
                 H-T-SCH=HEATSETPT4
                 H-CAP=-5802 ..                  $BASEMENT
VESTIBULE
MVES=ZONE        LIKE BVES1 H-CAP= -18430 .. $MAIN FLOOR VESTIBULE 1
MFLSTR=ZONE      LIKE MVES  H-CAP= -5802 ..  $MAIN FLOOR STAIRCASE
MVES2=ZONE       LIKE MVES  H-CAP= -24232 .. $MAIN FLOOR VESTIBULE 2
MEZFLST=ZONE     LIKE MVES  H-CAP= -5802 ..  $MEZZANINE STAIRCASE
MEZSTR=ZONE      LIKE MFLSTR ..

$SYSTEM SUBCOMMAND FOR UNIT HEATERS

S-CONT4=S-C      MAX-SUPPLY-T=105 ..
 AC-SYS4=SYST    S-TYPE=UHT        F-SCH=FAN-ON4     H-SCH=HEATON
                 S-C=S-CONT4       HEAT-S=HOT-WATER
                 ZONE-NAMES=(BVES1, MVES, MFLSTR, MVES2,
                                   MEZFLST,MEZSTR) ..

S-CONT1=S-C      MAX-SUPPLY-T=105        C-SCH=COOL-OFF
                 MIN-HUMIDITY=25         B-SCH=DRS
                 ECONO-LIMIT-T=60 ..
S-CONT2=S-C      MAX-SUPPLY-T=105        C-SCHEDULE=COOL-OFF
                  MIN-HUMIDITY=25        B-SCH=DRS
                 ECONO-LIMIT-T=60 ..
S-CONT3=S-C      MAX-SUPPLY-T=105        C-SCH=COOL-OFF
                 MIN-HUMIDITY=25         B-SCH=DRS
                 ECONO-LIMIT-T=60 ..

$SUBCOMANDS OF SYSTEM-AIR
```

```
S-AIR1=S-A          OA-CONTROL=TEMP ..

S-AIR2=S-A          SUPPLY-CFM=4768
                    RETURN-CFM=3179
                    OA-CONTROL=TEMP ..

S-AIR3=S-A          SUPPLY-CFM=4238
                    RETURN-CFM=3814
                    OA-CONTROL=TEMP
                    RECOVERY-EFF=0.6 ..
                              $RUN AROUND HEAT RECOVERY SYSTEM
SYS-F1=S-FANS       F-SCH=FAN-ON1
                    FAN-CONTROL=CONSTANT-VOLUME
                    SUPPLY-STATIC=2.25
                    SUPPLY-EFF=0.6
                    RETURN-STATIC=0.75
                    RETURN-EFF=0.6
                    NIGHT-VENT-CTRL=SCHEDULED+DEMAND
                    NIGHT-VENT-SCH=SUMMER-VENT
                    NIGHT-VENT-RATIOS=(1,1,1,0,0,0)
                    NIGHT-CYCLE-CTRL=CYCLE-ON-ANY ..

SYS-F2=S-FANS       LIKE SYS-F1
                    F-SCH=FAN-ON2 ..

SYS-F3=S-FANS       LIKE SYS-F1
                    F-SCH=FAN-ON3
                    NIGHT-CYCLE-CTRL=STAY-OFF ..

SYS-F5=S-FANS       LIKE SYS-F3
                    F-SCH=C/SANCT-FAN-ON ..

$AC SYSTEM FOR THE AHU-1

AC-SYS1=SYST        S-TYPE=SZRH        S-C=S-CONT1        S-A=S-AIR1
                    S-FANS=SYS-F1      HEAT-S=HOT-WATER
                    B-SCH=DRS          BASEB-S=HOT-WATER
                    RETURN-AIR-PATH=DUCT
                    HUMIDIFIER-TYPE=HOT-WATER
                    H-SCH=HEATON       C-SCH=COOL-OFF
                                              $NO MECHANICAL COOLING
                    VENT-TEMP-SCH=VENT-SETPT
                     ZONE-NAMES=(MZ6,MEZZ1,MEZZP1,
                                       MEZCZ,MEZCL1,MEZCL1P,MEZCL2,
                                       MEZCL2P,MECRM) ..

AC-SYS2=SYST        S-TYPE=SZRH        S-C=S-CONT2        S-A=S-AIR2
```

```
                    S-FANS=SYS-F2     HEAT-S=HOT-WATER  B-SCH=DRS
                    BASEB-S=HOT-WATER    RETURN-AIR-PATH=DUCT
                    H-SCH=HEATON     C-SCH=COOL-OFF
                                        $NO MECHANICAL COOLING
                    VENT-TEMP-SCH=VENT-SETPT
                    ZONE-NAMES=(BZ2,BZ3,BZ4,MZ1,MZ2,MZ3,PLRM) ..

AC-SYS3=SYST        S-TYPE=SZRH      S-C=S-CONT3      S-A=S-AIR3
                    S-FANS=SYS-F3    B-SCH=DRS    HEAT-S=HOT-WATER
                    BASEB-S=HOT-WATER    RETURN-AIR-PATH=DUCT
                    HUMIDIFIER-TYPE=HOT-WATER  H-SCH=HEATON

                    C-SCH=COOL-OFF  VENT-TEMP-SCH=VENT-SETPT
                    ZONE-NAMES=(BZ1) ..

AC-SYS5=SYSTEM            S-TYPE=SZRH  S-C=S-CONT1  S-A=S-AIR1
                          S-FANS=SYS-F5    HEAT-S=HOT-WATER
                          B-SCH=DRS        BASEB-S=HOT-WATER
                          RETURN-AIR-PATH=DUCT H-SCH=HEATON
                          C-SCH=COOL-OFF
                          ZONE-NAME=(MZ4, MZ5) ..

PLANT1=PLANT-ASSIGNMENT    SYSTEM-NAMES=(AC-SYS1,AC-SYS2,

                                     AC-SYS3, AC-SYS4,AC-SYS5)
                           DHW-GAL/MIN=1
                           DHW-SCH=DHW ..

DHW=SCHEDULE  THRU DEC 31  (MON,FRI)(1,7)(0) (8,19)(1) (20,24)(0)
                           (SAT)(1,8)(0) (9,15)(1) (16,24)(0)
                           (SUN)(1,9)(0) (10,15)(1) (16,24)(0)

                           (HOL)(1,24)(0) ..

$AC-SYS1:AHU-1
$AC-SYS2:AHU-2
$AC-SYS3:AHU-3
$AC-SYS4:CUH
$AC-SYS5:AHU4    (FOR SANCTUARIES)
END ..
COMPUTE SYSTEMS ..
INPUT PLANT ..
PLANT1=PLANT-ASSIGNMENT ..
PLANT-REPORT                  SUMMARY=(BEPS) ..
SYSBOILER=PLANT-EQUIPMENT     TYPE=HW-BOILER  SIZE=-999

                              INSTALLED-NUMBER=2 ..
```

```
DHWH=PLANT-EQUIPMENT          TYPE=DHW-HEATER SIZE=-999
                              INSTALLED-NUMBER=1 ..
END ..
COMPUTE PLANT ..
STOP ..
```