# A COMPUTATIONAL ANALYSIS ON ENERGY CONSUMPTION OF A RYERSON BUILDING

by

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# Abstract

This project analyses the energy consumption of 44 Gerrard St. East. This site is primarily used as the Ryerson University Theatre School and it consists of four classrooms, seventeen offices, six studios, and two theatre auditoriums. Since it is a three-storey building, plus a basement, thus, the energy level for this building is supposed to be moderate. However, because it is an old structure, constructed back in the early 1940s, this building seemingly has considerable energy consumption.

The main objective of this energy assessment is to reduce the building load[1]. This goal can be achieved by simplifying and controlling certain parameters that directly and indirectly involve energy consumption. For example, indoor temperature and relative humidity can be maintained at low level in winter and at high level in summer. In addition, monitoring heat loss, heat gain, infiltrations through the building surrounds, and the level of illumination for various types of lights helps to reduce overall energy consumption. Several other factors such as operating costs, maintenance costs, and repair costs influence the energy management of the site. With the help of energy management software, eQUEST, the structure, outlook of all the walls, windows, roof, and the type of HVAC[2] system can be developed for analysis. Through eQUEST, various tasks such as heat transfer involvement, energy consumption load calculations and load balancing in comparison with energy saving guidelines will be discussed in detail.

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# NOMENCLATURE

Throughout this project, all measurements and calculations are in imperial units. Most of the units are either posted after the calculations or mentioned in the Appendix. Below is the list of the commonly used units.

| Symbols | Descriptions | Units |
|---|---|---|
| $a$ | Ambient air temperature | $^{\circ}F$ |
| $A$ | Area | $ft^2$ |
| $c$ | Heat Transfer with convection | $Btu/h$ |
| $C$ | Thermal conductance | $Btu/h \cdot ft^2 \cdot {}^{\circ}F$ |
| | heat capacity flow rate | $Btu/\min$ |
| $CFM$ | Cubic feet minute (Airflow) | $ft^3/\min$ |
| $C_p$ | Pressure coefficient | *dimensionless* |
| $COP$ | Coefficient of performance | *dimensionless* |
| $D$ | percentage of persons dissatisfied | % |
| | Diameter | $ft$ |
| $E$ | Energy | $Btu$ |
| | Irradiance | $Btu/ft^2$ |
| $f$ | Fuel to air ratio | *dimensionless* |
| $F$ | Factor (Lighting) | *dimensionless* |
| $FHLV$ | Fuel lower heating value | $Btu/lb$ |
| $h$ | Film conductance | $Btu/ft^2 \cdot hr \cdot {}^{\circ}F$ |
| | Enthalpy | $Btu/lb_{fg}$ |
| $H$ | Height | $ft$ |
| $IAC$ | Shading attenuation coefficient | *dimensionless* |
| $k$ | Thermal conductivity | $Btu/h \cdot ft \cdot {}^{\circ}F$ |
| $l, L$ | Length | $ft$ |
| $\dot{m}$ | Mass flow rate | $lb/\min$ |
| $M$ | permanence coefficient | *perm* |
| $NTU$ | Counterflow heat exchanger | *dimensionless* |
| $olf$ | Emission rate of pollutant concentrations | *olf* |
| $p$ | Pressure | *psi* |
| | | *psf* |
| | | *in WG* |
| | | *in Hg* |
| $P$ | Power | *hp* |
| $Q$ | Time rate of heat transfer | $Btu/h$ |
| | | *MBH* |
| $q$ | Ventilation/Emission ratio | *cfm* |
| | Solar heat gain | *Btu* |
| $R$ | Thermal resistance | $h \cdot ft^2 \cdot {}^{\circ}F/Btu$ |
| $R_c$ | Total resistance | $h \cdot ft^2 \cdot {}^{\circ}F/Btu$ |
| $SHGC$ | solar heat gain coefficient | *dimensionless* |
| $t$ | Time | *sec* |

| | | |
|---|---|---|
| $T$ | Temperature | $°F$ |
| $\Delta T$ | Temperature Difference | $°F$ |
| $r_j$ | Weighting factor | *dimensionless* |
| $\delta$ | Layer Thickness | $ft$ |
| $U$ | Wind speed | $ft/s$ |
| | U-factor (Overall heat transfer coefficient) | $Btu/h \cdot ft^2 \cdot° F$ |
| | Mass transfer rate | $grains/hr$ |
| $W$ | Light wattage | $W$ |
| | Work | $Btu$ |
| $W_s$ | Saturated moist air | $lb/ft^3$ |
| $X, Y, Z$ | Response factors | *dimensionless* |

## Greek Symbols:

| | | |
|---|---|---|
| $\omega$ | Flow of water vapor | $lb \cdot ft^2/s$ |
| $\phi$ | Relative humidity | $\%$ |
| $\theta$ | Incident angle | $deg$ |
| | Time to freeze | $hr$ |
| $\delta$ | Layer Thickness | $ft$ |
| $\mu$ | Permeability | $perm - in$ |
| | Degree of saturation | *dimensionless* |
| $\overline{\mu}$ | average permeability | $ft^2$ |
| $\rho$ | density | $lbm/ft^3$ |
| $\eta$ | Efficiency | *dimensionless* |
| $x$ | Mole fraction of water vapor | *dimensionless* |
| $\Delta$ | Time interval | $sec$ |
| $\Delta x$ | Total thickness | $ft$ |
| $\varepsilon$ | Effectiveness for Heat Exchanger | *dimensionless* |

## Subscripts/Superscripts:

| | |
|---|---|
| *1* | Surface 1 |
| *2* | Surface 2 |
| *3* | Surface 3 |
| *a* | Ambient (outdoor) |
| *A* | Shaft |
| *b* | Beam |
| *c* | Conductive |
| *d* | Dew-point |
| *D* | Belt drive |
| *b* | Beam |
| *d* | Diffuse |
| *f* | Flue |
| *fg* | Flue gas |
| *F* | Fan |
| *g* | glass |
| *gw* | Gas/water |

| | |
|---|---|
| *H* | Height |
| *i* | Integer |
| *in* | Indoor |
| *j* | Finite integer |
| *met* | Meteorological |
| *M* | Motor |
| *n* | Integer indicates time |
| *out* | Outdoor |
| *r* | Ground-reflected |
| *s* | Surface |
| *sa* | Special allowance |
| *T* | Total |
| *ul* | Lighting use |
| *v* | Wind Velocity |
| *w* | Water vapor |
| *ws* | Water vapor saturated |

# CHAPTER 1 - INTRODUCTION

Energy management is described as the use of computer-based controllers that establish the equipment and procedures through which actual results of energy efficiency can be obtained.

Energy management is one of the most challenging tasks facing today's industry. Challenging energy management questions revolve around from how to build a sustainable new facility to how to choose an energy-efficient and cost-effective system. HVAC engineers constantly try to find opportunities to improve energy efficiency and the use of renewable energy technologies in areas such as new constructions and retrofits, equipment procurement, operations and maintenance, and utility management.

HVAC accounts for forty to sixty percentage of the energy used in commercial and residential buildings. This percentage represents an opportunity for energy savings by using proven technologies and design concepts.

In addition to energy issues, HVAC systems have raised a significant concern in health, comfort, and productivity of occupants, especially in office buildings. Issues such as user discomfort, improper ventilation, and poor indoor air quality are all linked to HVAC system designs and operations. However, these issues can be improved by better mechanical and ventilation systems.

There are some principles of the energy management program that are as follows,

- Overview of the site; location, structure, occupancy rate at any time of the day, its climatic conditions, the examination of the mechanical and electrical systems.
- Classify the annual energy consumption by means of fuel and electricity usage of each system.
- Set a target on reduction of energy usage based on the potential saving of each system.
- Reduce the energy consumption that corresponds to mechanical and electrical systems.
- Manage thermal losses and power requirement for the HVAC distribution system.
- Upgrade old and ineffective equipments and improve the existing energy conversion system by implementing energy efficient program thus reduce the energy cost.
- Appoint personnel to continuously monitor the system and keep a record of the monthly energy usage for the energy conservation goals.

Three factors consume a building's considerable amount of energy. First are the prime energy consumption equipments such as boilers, furnaces, refrigeration chillers, and electrical lighting that consume most of the energy. Secondly is a building's relevant structure such as its walls, windows, floor, and roof. Lastly, mechanical and electrical components such as pipes, ducts, and filters that do not affect the energy consumption directly, but they influence the amount of energy that is being consumed.

The efficiency of the primary energy conversion equipment, which converts fuel to heat, ultimately determines the actual amount of energy consumed to supply both loads (heating and cooling load). Energy usage then depends upon two main factors: the magnitude and duration of the loads and the seasonal efficiency of the primary energy conversion equipment.

## 1.1 - SITE DESCRIPTION

The location of the selected site is 44 Gerrard St. East Toronto, Ontario with coordinates of Latitude 43.65°N and Longitude 79.38°W. The climate of Toronto is cold with the average dry bulb temperature[3] ranging from 80°F in summer to 21°F in winter season. The average wet bulb temperature[4] is 70°F in summer with an average relative humidity of 74%. 44 Gerrard St. East is an educational facility namely, Ryerson Theatre School, composed of three floors plus a basement, whose front is facing the South. The basement is mainly filled with control valves, meters, and drainage system with an area of 1,488 square feet. All three floors of the building resemblance rectangular shape with an estimated total area of 21,873 square feet occupied with classrooms, offices, and studios. The first floor is composed of two classrooms, six offices, a music room, a design studio, four washrooms/locker rooms, storage, a boiler, and a mechanical room with an estimated combined area of 6,919 square feet. Similarly, second floor has two classrooms, two offices, a typing room, a conference room, a kitchen, a washroom, a wardrobe room, and a prop room with an estimated combined area of 6,745 square feet. Finally, the third floor is composed of two washrooms, two shower stalls, and two locker rooms with an estimated combined area of 6,720 square feet. The building is composed mainly of brick (exterior) and wood (interior) with attachment of insulation. There are windows in certain places on the East and the North sides but with the majority on the West and the South sides. Complete layouts of the site are found in Appendix E and the distributed total area in Table 1.

**TABLE 1: Site's Total Area Distribution**

| Area | A (sqr ft) | Floor Area, ft² | Total Area, ft² |
|---|---|---|---|
| Basement | | 1,488 | *1,488* |
| 1st Floor | *Offices* | 1,835 | |
| | *Classrooms* | 347 | |
| | *Studios* | 1,934 | |
| | *Washrooms* | 1,512 | ***total*** |
| | *Hallways* | 1,289 | ***6,919*** |
| 2nd Floor | *Offices* | 967 | |
| | *Classrooms* | 1,736 | |
| | *Studios* | 3,447 | |
| | *Washrooms* | 148 | ***total*** |
| | *Hallways* | 446 | ***6,745*** |
| 3rd Floor | *Offices* | 1,748 | |
| | *Classrooms* | - | |
| | *Studios* | 4,377 | |
| | *Washrooms* | 148 | ***total*** |
| | *Hallways* | 446 | ***6,720*** |
| | ***Total Area*** | ***21,873*** | |

## 1.2 - OBJECTIVE

The purpose of this project is to reduce the building loads and to find a better energy management program. This report summarizes valuable experience and findings from current engineering journals, technical papers, ASHRAE handbooks and other relevant publications that yield the importance of energy conservation in institutional buildings.

## 1.3 - OUTLINE

This report has been divided into seven chapters that cover this energy audit. The second and the third chapters look at various aspects of heating and cooling load of the HVAC system. The fourth chapter deals with the electrical systems mainly lighting. The fifth chapter covers various types of HVAC systems, including the hot water usage because a large amount of energy is consumed in heating water. The sixth chapter deals with the observed and calculated results. The last chapter concludes this energy audit. A number of references and appendices are available at the end of the report.

## 1.4 - SOFTWARE DESCRIPTION

eQUEST is a sophisticated building energy analysis tool, which provides professional-level results. A user can perform any task without requiring extensive experience in the "art" of building performance modeling. eQUEST is designed to perform detailed comparative analysis of building designs and technologies. This is accomplished by combining schematic model creation wizards, design development creation wizards, an energy efficiency measure (EEM) wizard and a graphical results display module with a complete up-to-date building energy simulation program. Additionally, eQUEST has a detail-building description interface mode that includes 2-D and 3-D displays of building geometry. It also has AUTOCAD file import for drawing layout, graphical display of HVAC equipment layout and the summary or hourly report data. The graphical display of results includes multi-run comparison graphics. The detailed interface also includes the capability to describe and perform parametric runs.

# CHAPTER 2 - HEATING

Heating is the transfer of energy to a space by virtue of a difference in temperature between the source and the air. This process may take several forms such as direct radiation to the space, direct heating of the circulated air or through the heating of water. One of the solutions for reducing the heating load is by weather-stripping the building envelope[5] and by reducing the distribution system loads[6]. One of the major factors that will reduce the building load is by increasing the efficiency of the primary energy conversion equipment.

There are several methods to find the heating load of the site; one of the easiest ways is to determine the average difference between indoor and outdoor temperatures. For example, in Nov 2004 the average temperature outside, $T_{out}$, was recorded to be 38°F, while at the site, the temperature, $T_{in}$, was 73°F. Thus, the temperature difference, $\Delta T$, between the two is 35°F. It can conclude that as the temperature difference increases, the heating load also increases. In other words, the site will consume more energy.

$$\left.\begin{aligned} T_{in} &= 73^\circ F \\ T_{out} &= 38^\circ F \end{aligned}\right\} \Delta T = T_{in} - T_{out} = 73^\circ - 38^\circ \qquad \rightarrow \qquad \Delta t = 35^\circ F$$

The other factor that reduces the heating loads is by reducing the indoor temperature and keeping it low for longer periods. Another factor is the amount of heat produced internally from the lights, people, business machines (computers, fax machines and printers), and the direct sunlight striking through the windows. Thus, all these sources help in reducing the overall heating load.

## 2.1 - HEAT TRANSFER

Heat transfer, Q (Btu/h), by conduction is proportional to the temperature difference, $\Delta T$ (°F), between the warm and cold sides of the building envelope element. Conduction is also proportional to the area, A, through which the heat is transferred. In addition to area, conduction also depends on the insulating quality of the wall, which is measured by resistance, R $\left(\mathrm{h \cdot ft^2 \cdot {}^\circ F/Btu}\right)$.

### 2.1.1 - Heat Transfer for Walls

The heat transfer of the surface of a wall slab depends on the conduction, convection and the algebraic sum of the heat transfer components. The algebraic sum of the energy management of heat transfer must be balanced.

Theoretically, in one-dimensional and linear heat conduction, the surface heat fluxes and the temperatures are related by three sets of response factors; *X, Y,* and *Z*. Computation can be done with the help of time series technique. Time series analysis is a method of collecting data points over time that may have an internal structure (such as autocorrelation, trend, or seasonal variation) for which they can be accounted for.

$$Q_{1,n} = \sum_{j=0}^{\infty} T_{1,n-j} X_j - \sum_{j=0}^{\infty} T_{2,n-j} Y_j \qquad (2.1.1)$$

$$Q_{2,n} = -\sum_{j=0}^{\infty} T_{2,n-j} Z_j - \sum_{j=0}^{\infty} T_{2,n-j} Y_j \qquad (2.1.2)$$

where, $Q_{1,n}$, $Q_{2,n}$, $T_{1,n}$ and $T_{2,n}$ are the terms in the time series for heat flux and temperature respectively.

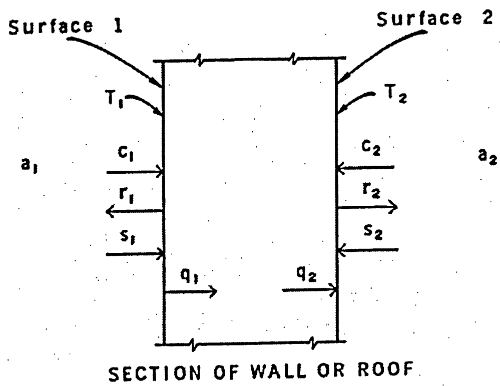


**FIGURE 1: Heat Flux Components at the surface of a slab**

The subscript $n$ is an integer that indicates time; for simplicity $n$ is used instead of $n\Delta$ where $\Delta$ is the time interval. Subscripts *1* and *2* denotes the two sides of the slab. By definition, the heat flux is in the direction from surface *1* to surface *2*. The upper limits of summation can be replaced by a finite integer *j* since $X_j$, $Y_j$ and $Z_j$ tend to reach zero as *j* becomes large.

For the case of response factors for non-linear or for multi-dimension cases, eQUEST develops heat transfer criterion with the help of given surroundings (hollow tile, brick or concrete block case).

Heat transfer by convection between slab surface *1* and the adjacent air is given by,

$$c_{1,n} = h_{1,n}\left(a_{1,n} - T_{1,n}\right) \qquad (2.1.3)$$

where, $h_{1,n}$ is the film conductance and $a_{1,n}$ is the ambient air temperature.

In general, the film conductance depends on the ambient temperature, the slab surface temperature, and the air motion. For example, natural convection at vertical surface *1 is*,

$$h_{1,n} = 0.18\left(a_{1,n} - T_{1,n}\right)^{1/3} Btu/ft^2hrF \qquad (2.1.4)$$

Replace the subscript from *1* to *2* for equations (2.1.2 - 2.1.4) and apply for surface *2*. Therefore, by applying the above notations, the heat balance equations for the two surfaces are,

$$c_{1,n} - Q_{1,n} = 0 \qquad (2.1.5)$$

$$c_{2,n} + Q_{2,n} = 0 \qquad (2.1.6)$$

Substituting the expressions for $c_{1,n}$ and $Q_{1,n}$ and collect the unknowns on the left hand side gives,

$$\left(-h_{1,n} - X_o\right)T_{1,n} + Y_oT_{2,n} + h_{1,n}a_{1,n} = \sum_{j=1}^{J} T_{1,n-j}X_j - \sum_{j=1}^{J} T_{2,n-j}Y_j \qquad (2.1.7)$$

$$\left(-h_{1,n} - Z_o\right)T_{2,n} + Y_oT_{1,n} + h_{2,n}a_{2,n} = \sum_{j=1}^{J} T_{2,n-j}Z_j - \sum_{j=1}^{J} T_{1,n-j}Y_j \qquad (2.1.8)$$

These equations (2.1.7 and 2.1.8) are solved by using an iterative procedure. Normally, the slab temperature histories (right hand side of equations 2.1.7 and 2.1.8) are unknown at the start of the computation. Thus, eQUEST starts the calculations well advance in time for which the solution is required. This procedure makes the results independent of the assumed surface temperature values prior to the start of calculations.

### 2.1.2 - Heat Transfer for Windows/Doors

The loss of energy through windows and doors, excluding air leakage, follows a simple heat transfer relation. This heat loss is,

$$Q = \frac{A\Delta T}{R_T} = UA\Delta T \qquad (2.1.9)$$

$$R_T = \frac{1}{h_i} + \frac{\Delta x}{k_g} + R_c + \frac{1}{h_o} = \sum_{i=1}^{N} R_i \qquad (2.1.10)$$

where, $\Delta T = T_i - T_o$ is the overall temperature difference across windows/doors, $A$ is windows/doors area, and $R_T$ is the total thermal resistance of heat transfer. $U$ is the overall coefficient of heat transfer, $R_i$ is the thermal resistance of each layer of the window/door, $h_i = 1.46 Btu/hr\, ft^2\, {}^\circ F$ is the inside surface conductance of air, and $h_o = 6.0 Btu/hr\, ft^2\, {}^\circ F$ is the outside surface conductance of air (function of wind speed $15 mph$). $\Delta x$ is the total thickness of all the glass, $k_g$ is the thermal conductivity of glass (□ $0.44 Btu/ft \cdot hr\, {}^\circ F$), and $R_c$ is the total resistance of all the gaps trapped between glass.

The conductance of air gap is a complicated function for such terms as mean air gap temperature, temperature difference, and the thickness of the air gap. Table 2 provides reasonable estimates of $R_c$ for each air gap.

**TABLE 2: Air Gap Resistance**

| Thickness of Gap (in) | Air Gap Resistance | | | |
|---|---|---|---|---|
| | T = 0°F | 0 | -50 | -50 |
| | Δ = 20°F | 10 | 20 | 10 |
| 0.5 | 1.13 | 1.14 | 1.39 | 1.46 |
| 0.75 | 1.18 | 1.26 | 1.29 | 1.56 |
| 1.5 | 1.12 | 1.23 | 1.33 | 1.48 |
| 3.5 | 1.14 | 1.23 | 1.37 | 1.50 |

The temperature drop across any part of a series system can be evaluated from,

$$\frac{R_i}{R_T} = \frac{\Delta T_i}{\Delta T} \qquad (2.1.11)$$

where, $\Delta T_i$ is the temperature drop across a region and $R_i$ is the thermal resistance of the region.

The resistance and the overall coefficient for any number of glass layers can be evaluated using equation (2.1.11) and Table 2. A sample of such calculations has been set up in Table 2 for $\frac{1}{8} in$ glass with a mean temperature of 0°F, a temperature difference of 20°F and a $\frac{3}{4} in$ air gap.

**TABLE 3: Glass Layers Resistance**

| No. of Glass Layers | R $(hr \cdot ft^2 \cdot {}^\circ F)/Btu$ | U $Btu/hr \cdot ft^2 \cdot {}^\circ F$ |
|---|---|---|
| 1 | 0.69 | 1.450 |
| 2 | 1.89 | 0.528 |
| 3 | 3.09 | 0.323 |
| 4 | 4.29 | 0.233 |
| 5 | 5.49 | 0.182 |

For example, a six inch insulated wall will have a resistance of about 25.9. According to studies, an eight-layer window will lose heat at 2.8 times the wall rate. Thus, windows are certain to be thermally expensive unless insulation is added either inside or outside. The proper locations to install insulated covers are on the exterior side to avoid condensation. eQUEST shows that insulation on windows and doors improves the resistance of windows and doors.

## 2.2 - Building Envelope

The term building envelope generally refers to those building components that enclose conditioned spaces, and through which thermal energy is transferred to or from the outdoor environment.

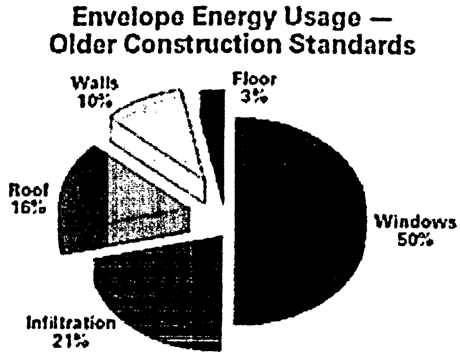


**Figure 2: ASHRAE standard affects energy loss from the Building Envelope**

Figure 2 shows how much energy is lost through the envelope of an older building. Approximately half of the energy is lost through the windows, twenty-one percent to the unintentional leakage of outside air, and nearly thirty percent can be attributed to other opaque elements in the building envelope, the walls, the roof, and the floor.

In the heating season, one of the biggest setbacks is a process called convection. The flow of water vapor through the walls of the building is a process that can lead to problems as the temperature in the walls will often drop below the dew point level and condensation can occur. This leads to buildup of ice that may structurally damage the walls, and the moisture may degrade the thermal performance of the unit. Nevertheless, the flow of water carried with airflow through the cracks and leaks is probably a greater problem than vapor diffusion[7] as far as severe condensation is concerned.

If the inside relative humidity is less than thirty percent then the condensation problems caused by windows, joints, and the connectors can be controlled. However, relative humidities this low may lead to discomfort for occupants.

Boarding the structure is not always the answer to stop the flow of water. The structure should have a flow of fresh air either for aesthetic purposes or to control humidity. According to ASHRAE standards, recommended airflow rate should be 10*cfm* (cubic feet per minute) per person.

The flow of water vapor in a medium is given by Fick's law,

$$\omega = -\mu \frac{\partial p}{\partial x} \qquad (2.2.1)$$

Where $\omega$ is the mass of water vapor transmitted per unit area per unit time, $p$ is the vapor pressure, $x$ is the coordinate in x-direction of water flow, and $\mu$ is the permeability of medium for water vapor.

The water vapor pressure is a function of temperature. Thus, the diffusive flow of vapor will occur in the same direction as the flow of energy; from the warm side to the colder side. It is noticed that 44 Gerard St. East has a big change room and a large number of shower stalls. Therefore, placing the vapor barriers on the warm side (inside) can prevent the moisture from entering the walls. In other words, it can prevent the moisture from the inside of the building to the outside.

For average conditions of water vapor flow, equation (2.2.1) can be written as,

$$W = \bar{\mu} A \frac{\Delta p}{l} \qquad (2.2.2)$$

where, $W$ is the mass transfer rate, (grains/hr), $\bar{\mu}$ is the average permeability (perm-in) , $A$ is the cross-sectional area in x-direction, $l$ is the thickness of the medium, and $\Delta p$ is the pressure drop (in.Hg).

The unit for $\bar{\mu}$ is the perm-in. or some compatible unit where,

$$1\,perm = \frac{1\,grain}{hr\,ft^2 in.\,Hg\ vapor\ pressure\ difference} \qquad (2.2.3)$$

The permanence coefficient, $M$, is often used with $M = \frac{\bar{\mu}}{l}$ and the units of $M$ is the perm.

Then, the equation (2.2.2) becomes,

$$W = MA\Delta p \qquad (2.2.4)$$

If the wall is made of series of slabs, then the mass flow rate through each wall is same,

$$\frac{W}{A} = M_1(p_1 - p_2) = M_2(p_2 - p_3) = M_3(p_3 - p_4) = \cdots \qquad (2.2.5)$$

An overall permanence coefficient is defined as,

$$\frac{W}{A} = M_t \Delta p_t \qquad (2.2.6)$$

Solving equations (2.2.4 and 2.2.5) gives,

$$M_t = \frac{1}{\frac{1}{M_1}+\frac{1}{M_2}+\frac{1}{M_3}} = \frac{1}{\sum_i^N \frac{1}{M_i}} \qquad (2.2.7)$$

A similar analysis is done for a parallel wall, giving

$$A_T M_T = A_1 M_1 + A_2 M_2 + A_3 M_3 = \sum_i^N A_i M_i \qquad (2.2.8)$$

Air can hold some maximum amount of water vapor. As water vapor leaves the warm interior and enters the walls and crawl space, it cools off and gives up its moisture, which in turn saturates the insulation and framing. Too much moisture in the air or the large temperature difference between the inside and outside makes the insulation useless. In the extreme cases, the insulation becomes virtually useless, and severe rot can take place in structural members.

The condensed moisture frozen in the wall slabs remains immobile in a severe climate until it thaws out. This process usually takes place in mild weather. The basic cure is to insulate it properly, block the cracks and leakages from outside, and vapor barrier it from inside. This prevents the ingress of cold air and moisture.

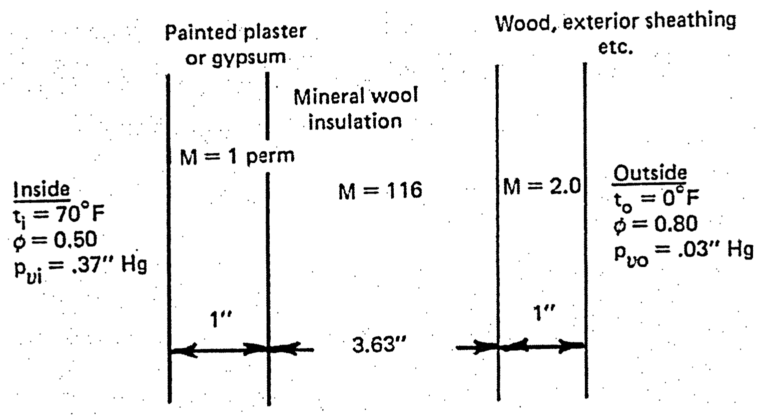


**FIGURE 3: Steady-State Vapor Diffusion**

Consider one of the walls of 44 Gerard St. East in Figure 3. Through the built-in system of equations (2.2.1 - 2.2.7) in eQUEST, the temperature profile in the wall is calculated. A saturated vapor pressure curve (Figure 4) is associated with this temperature profile.

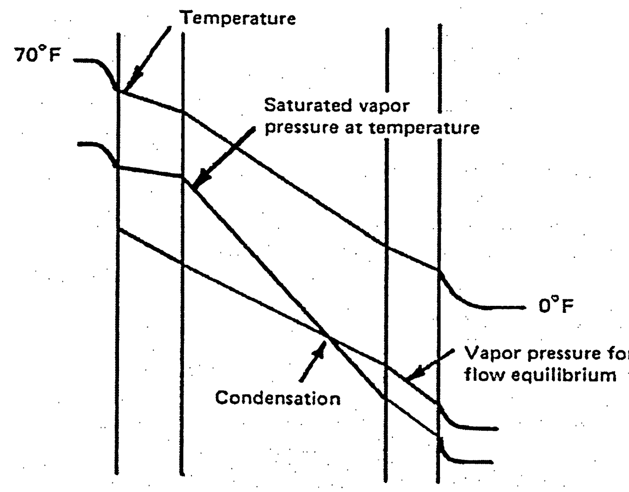


**FIGURE 4: Temperature and Pressure profiles**

***Problem Stating***

44 Gerrard St. East has heating degree-days of 4066; *refer to Appendix A – Degree-Days.* The fuel used on the site is Natural Gas, $\$12/1000ft^3$ (price of natural gas). Using the temperature difference of 35°F and regular working load of $40hrs/wk$, the energy savings are:

**TABLE 4: R-values for different areas of the building**

| Location | | Area, ft² | Resistance (R) | U-factor (1/R) |
|---|---|---|---|---|
| Roof | | 6720 | 8.900 | 0.112 |
| Floor | | 6919 | 10.750 | 0.093 |
| Walls | *North* | 360 | 4.920 | 0.203 |
| | *South* | 236 | 4.920 | 0.203 |
| | *East* | 557 | 4.920 | 0.203 |
| | *West* | 564 | 4.920 | 0.203 |
| Windows | *North* | 101 | 8.920 | 0.112 |
| | *South* | 187 | 8.920 | 0.112 |
| | *East* | 83 | 8.920 | 0.112 |
| | *West* | 111 | 8.920 | 0.112 |
| Basement | *Floor* | 1488 | 20.690 | 0.048 |
| | *Walls* | 1488 | 7.790 | 0.128 |

- With the help of equation (2.1.9), total heat loss can be calculated as:
- *Sample calculation for Roof,*

  $Q = 0.112 \times 6720 \times 35$ ➔ $Q = 26,346 Btu/hr$

- At 65% efficiency and at $\$12/1000ft^3$ (price of natural gas), thus use of natural gas is

$$\frac{\$12}{1000 ft^3} \times \frac{26{,}346 Btu/hr}{\left(1000 Btu/ft^3\right) \times 0.65} \times 5880 hrs/\text{winter} \approx \$1{,}859/year$$ ➔ Loss = $1,859/year

- Total Heat Loss: $Q_{Total} = 1995 \times 10^6 Btu/year$
- Total Cost: Total Loss $= \$16{,}065/year$

Therefore, there is a loss of $\$16{,}065/year$ without applying any renovations.

## 2.3 - Setting Back Indoor Temperature

Energy is likely to get wasted during unoccupied hours if there is no one to comfort. There can be a lot of savings with the amount of time and degrees the temperature can be set back. Due to the building old age (44 Gerrard St. East), ventilation, infiltration, and the building envelope make a huge contribution towards heat loss. Therefore, it can safely be assumed that the efficiency of the heating system should be approximately sixty-five percent.

At night the outdoor temperature is cooler than daytime, so neither solar heat gain nor internal heat gain helps to make up for the heat loss. A simple solution is, completely shut down the ventilation system since no ventilation is required at night to relieve the heating load. Another option is to reduce the indoor temperature below the normal setting. Analysis of 44 Gerrard St. East has been prepared with the indoor temperature reduced to ease heat load.

***Problem Stating***

44 Gerrard St. East has a heating degree days of 4066 and cooling degree days of 252 *(Refer to Appendix A- Degree Days)* whose total calculated floor area is $21{,}873 ft^2$ *(Refer to Table 1)*. The fuel used on the site is Natural Gas, $\$12/1000 ft^3$ (price of natural gas), whose heating consumption is $278 \times 10^6 Btu/ft^2/yr$. At night, setting back temperature by $15^\circ F$ can save energy and money.

- Energy saved by set back is $135 \times 10^6 Btu/yr$, *Refer to Appendix B, Figure 19*
- At 65% efficiency and at $\$12/1000 ft^3$ (price of natural gas), thus saving in natural gas is

$$\frac{\$12}{1000 ft^3} \times \frac{135 \times 10^6 Btu/yr}{\left(1000 Btu/ft^3\right) \times 0.65} \approx \$2492/year$$ ➔ Saving = $2492/year

Therefore, by setting back indoor temperature by 15°F, thus results in saving of $\$2492/year$.

## 2.4 - HUMIDITY

It is a well-known fact that the body retains more heat when the weather is hot and humid than it does during a drier but equally warm day. The excessive heat in the surrounding environment makes the person feel hot. Evaporation works best when the air is dry. In moist air, perspiration cannot evaporate as readily. The combination of excess heat and moisture will cause the person to feel hot and sticky. As a rule of thumb, higher humidity results in greater discomfort. A psychrometric chart graphically represents the thermodynamic properties of moist air. ASHRAE developed such a psychrometric chart (Chart No. 1) which is shown in Appendix B - Figure 20. This charts uses oblique angle coordinates of enthalpy and humidity ratio.

### 2.4.1 - Basic Parameters

*Humidity Parameters Involving Saturation*

The following definitions of humidity parameters involve the concept of moist air saturation:

**Saturation humidity ratio,** $W_s(T, p)$, is the humidity ratio of saturated moist air with respect to water (or ice) at the same temperature $T$ and pressure $p$.

**Degree of saturation,** $\mu$, is the ratio of air humidity ratio, $W$, to the humidity ratio, $W_s$, of saturated moist air at the same temperature and pressure:

$$\mu = \left.\frac{W}{W_s}\right|_{T,p} \qquad (2.4.1)$$

**Relative humidity,** $\phi$, is the ratio of the mole fraction of water vapor, $x_w$, in a given moist air sample to the mole fraction, $x_{ws}$, in an air sample saturated at the same temperature and pressure:

$$\phi = \left. \frac{x_w}{x_{ws}} \right|_{t,p} \qquad (2.4.2)$$

$$\mu = \frac{\phi}{1+(1-\phi)W_s/0.62198} \qquad (2.4.3)$$

**Dew-point temperature,** $T_d$, is the temperature of moist air saturated at pressure, $p$, with the same humidity ratio, $W$, as that of the given sample of moist air. It is also defined as the solution $T_d(p,W)$ of the following equation:

$$W_s(p,T_d) = W \qquad (2.4.4)$$

## 2.4.2 - Reducing Relative Humidity

Relative humidity (R.H) is the amount of moisture that the air contains compared to how much it can hold at a given temperature. For example, amount of 100 percent means that the air becomes saturated. At this point mist, fog, dew, and precipitation are likely to occur. When the temperature is at its lowest point of the day, at dawn, the relative humidity is normally at its maximum. Even though the absolute humidity may remain the same throughout the day, the changing temperature causes the ratio (R.H) to fluctuate.

In the building, the humidification system vaporizes water into the dry ventilating air to increase moisture content, and achieve the desired relative humidity. In the humidification process, 1,000Btu is usually required to evaporate one pound of water. This humidification process is taken into consideration for the health and comfort of occupants and to maintain the life of the building's material. However, it is required that building should reduce humidity during unoccupied periods. For ideal condition of R.H, usually thirty percent R.H is recommended to start the calculations.

***Problem Stating***

Assume that the outdoor air rate be $4000cfm$. Heat load is accomplished by reducing the R.H from 50% R.H (operational) to 30% R.H (unoccupied) in order to show energy saving opportunities. Under the regular working load of $40hrs/wk$, the energy saving can be calculated as,

- Degree Days = heating days + cooling days ➔ $4066 + 252 = 4318$ degree days
- At 4318 Degree Days ➔ 4318 degree days × 24 hr = 103,632 degree hrs

- For 50% R.H for 40hrs/wk ➔ Energy used is $30 \times 10^6 Btu/yr/1000cfm$

  *Refer to Appendix B, Figure 21*
- For 30% R.H for 40hrs/wk ➔ Energy used is $20 \times 10^6 Btu/yr/1000cfm$

  *Refer to Appendix B, Figure 21*
- Energy difference between the two relative humidity levels (50% R.H & 30% R.H) is $10 \times 10^6 Btu/yr/1000cfm$
- However, the scaling factor used in the graph is $1000cfm$; four times smaller than outside air at $4000cfm$, therefore, by comparison, the total energy saved is $40 \times 10^6 Btu/yr$.
- At 65% efficiency and at $\$12/1000ft^3$ (price of natural gas), thus saving in natural gas is

$$\frac{\$12}{1000ft^3} \times \frac{40 \times 10^6 Btu/yr}{(1000Btu/ft^3) \times 0.65} = \$738/year$$ ➔ Saving = \$738/year

Therefore, by changing the relative humidity from 50% R.H to 30% R.H, when the building is unoccupied results in saving of $\$738/year$.

## 2.5 - VENTILATION RATE

HVAC system introduces outside air in the building known as ventilation to dilute air contaminants and odours to the acceptable levels.

Sometimes scientists cannot successfully resolve complaints about the air in offices, schools, and other non-industrial environments. Usually, high-populated areas elevate high pollutant concentrations, which create complaints. Therefore, scientists came up with acceptable unit to calculate these complaints. Assume that the inability to find a difference between air pollutant levels in buildings with registered complaints and those without complaints is due to inadequacies of prevailing measurement techniques. Fanger and his colleagues changed the focus from chemical analysis to sensory analysis (Fanger 1987, 1988; Fanger et al. 1998). Fanger quantified air pollution sources by comparing them with a well-known source: a sedentary person in thermal comfort. A new unit, the *olf*, is defined as the emission rate of air pollutants (bioeffluents) from a standard person. A *decipol* is one *olf* ventilated at a rate of 20*cfm* of unpolluted air.

In order to use these units, Fanger generated a curve that relates the percentage of persons dissatisfied with the air polluted by human bioeffluents. The Fanger's curve is set up as a function of the outdoor air ventilation rate and obtained the following expression:

$$D = 295\exp\left(-3.66q^{0.36}\right) \qquad \text{for } q \geq 0.332 \qquad (2.5.1)$$
$$D = 100 \qquad \text{for } q < 0.332$$

where, $D$ is the percentage of persons dissatisfied and $q$ is the ventilation/emission ratio in *cfm*.

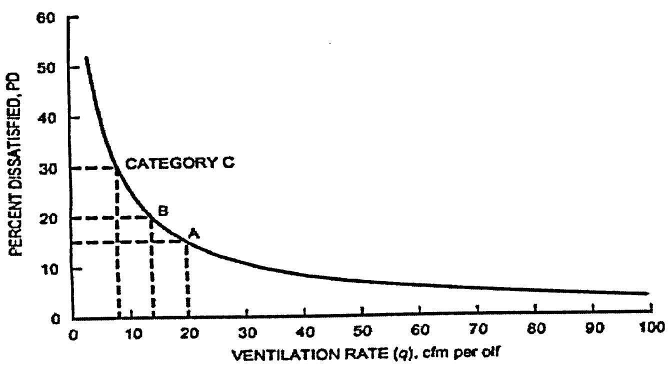


**FIGURE 5: Percentage of Dissatisfied Persons as a Function of Ventilation Rate per Standard Person (i.e., per Olf)**

This curve (Figure 5) is based on experiments involving more than 1000 European subjects (Fanger and Berg-Munch 1983). The idea behind the *olf* is that, sensory sources other than humans can also be expressed in equivalent standard persons (i.e., in *olfs*). Therefore, a room should be ventilated to handle the total sensory load from persons and building. The *olf* concept is used to determine required ventilation rate for the building.

During cold weather, the air introduced into the building must be heated to the comfortable temperature level thus, adding the heat load. In order to maintain acceptable indoor air quality, there is a specified code of minimum values for outside air. Appendix D – Ventilation table incorporate model such codes (values) that are recommendation of ASHRAE Standards.

For 44 Gerrard St. East, there must be at least 10 to 15 people occupying the building at any given time of day. However, at the peak hours during class, it can range somewhere from 100 to 150 people. By looking at these numbers, it can be said that ventilation requirement at night is minimal. Appointing someone to shutoff or keeping the ventilation rate at the lowest rate thus help in reducing the heat load.

**TABLE 5: Ventilation Rate of each area**

| Area | | # of people | Ventilation | People * Vent |
|---|---|---|---|---|
| Basement | | 5 | 5 | 25 |
| | *total* | ***5*** | ***5*** | ***25*** |
| | | | | |
| 1st Floor | Offices | 5 | 5 | 25 |
| | Classrooms | 10 | 15 | 150 |
| | Studios | 15 | 15 | 225 |
| | Washrooms | 11 | 10 | 110 |
| | Hallways | 15 | 5 | 75 |
| | *total* | ***56*** | ***50*** | ***585*** |
| | | | | |
| 2nd Floor | Offices | 3 | 5 | 15 |
| | Classrooms | 15 | 15 | 225 |
| | Studios | 15 | 15 | 225 |
| | Washrooms | 4 | 10 | 40 |
| | Hallways | 7 | 5 | 35 |
| | *total* | ***44*** | ***50*** | ***540*** |
| | | | | |
| 3rd Floor | Offices | 5 | 5 | 25 |
| | Classrooms | - | - | - |
| | Studios | 15 | 15 | 225 |
| | Washrooms | 3 | 10 | 30 |
| | Hallways | 7 | 5 | 35 |
| | *total* | ***30*** | ***35*** | ***315*** |

*Problem Stating*

With 135 people occupying the site, the measured ventilation rate is $5000cfm$. Under the regular working load of $40hrs/wk$, the energy savings are,

- With $5000cfm$, each person will have a supply of ventilation rate of

  $$\frac{5000cfm}{135\text{persons}} \approx 37cfm/person$$

- If the ventilation is reduced to $20cfm$, this will result in ventilation reduction of

  135 persons $\times$ $20cfm$ =2700cfm ➔ $difference = 5000 - 2700 = 2300cfm$

  At 4318 Degree Days ➔ Energy used is $30 \times 10^6 Btu/yr/1000cfm$

  Energy used is $120 \times 10^6 Btu/yr$ *(Refer to Appendix B, Figure 22)*

- Saving in heating energy by $\dfrac{2300cfm}{1000cfm} \times 120 \times 10^6 Btu/yr = 276 \times 10^6 Btu/yr$

- At 65% efficiency and at $\$12/1000ft^3$ (price of natural gas), thus saving in natural gas is

  $$\frac{\$12}{1000ft^3} \times \frac{276 \times 10^6 Btu/yr}{\left(1000Btu/ft^3\right) \times 0.65} \approx \$5095/year$$ ➔ Saving = \$5095/year

Therefore, by reducing the ventilation rate from $37cfm/person$ to $20cfm/person$ thus results in saving of $\$5095/year$.

## 2.6 - INFILTRATION RATE

Generally, infiltration loads are depends on the amount of outside air leakage and the difference between the outside and inside air. When the wind speed escalates then the air entering the building through the cracks and openings increases thus increases the heat load. The determination of infiltration is an imprecise method. Therefore, a few generalizations based on assumptions can be made to solve the problem.

$$Q = 1.1 \times CFM \times \Delta T \qquad (2.6.1)$$

An equation of heat transfer in air can be derived when the given density of air at standard pressure is $0.076 lb/ft^3$, and the specific heat of air is $0.24 Btu/lb.^\circ F$

The turbulence or gustiness of approaching wind, and the unsteady character of separated flows affects the surface pressures to fluctuate. Pressures discussed here are time-averaged values with an averaging period of about 600s. This is approximately the shortest period for the "steady-state" condition when considering atmospheric winds. The longest period is typically 3600s. Instantaneous pressures may vary significantly above and below these averages (periods). Therefore, there is a possibility of peak pressures two or three times the mean values. Although peak pressures are important with respect to structural loads but mean values are more appropriate for computing infiltration and ventilation rates. Time-averaged surface pressures are proportional to wind velocity pressure $p_v$ and are given by Bernoulli's equation:

$$p_v = \frac{1}{2}\rho_a U_H^2 \qquad (2.6.2)$$

where, $U_H$ is the approaching wind speed at upwind wall height *H*, $\rho_a$ is the ambient (outdoor) air density.

The difference between the pressure, $p_s$, on the building surface and the local outdoor atmospheric pressure (at the same level in an undisturbed wind approaching the building) is given by,

$$p_s = C_p p_v \qquad (2.6.3)$$

where, $C_p$ is the local wind pressure coefficient for the building surface.

The local wind speed, $U_H$, at the top of the wall from equation (2.6.2) is estimated by applying terrain and height corrections to the hourly wind speed, $U_{met}$, from a nearby meteorological station.

$U_{met}$ is generally measured in correspondence terrain (i.e., category 1 in Table 6). The anemometer that records $U_{met}$ is located at height, $H_{met}$, usually 33 ft above ground level. The hourly average wind speed, $U_H$, at wall height, $H$, approaching a building can be calculated from $U_{met}$ as follows:

$$U_H = U_{met}\left(\frac{\delta_{met}}{H_{met}}\right)^{a_{met}}\left(\frac{H}{\delta}\right)^{a} \qquad (2.6.4)$$

**TABLE 6: Atmospheric Boundary Layer Parameters**

| Terrain Category | Description | Exponent $a$ | Layer Thickness $\delta$, ft |
|---|---|---|---|
| 1 | Large city centers, in which at least 50% of buildings are higher than 70 ft, over a distance of at least 0.5 mi or 10 times the height of the structure upwind, whichever is greater | 0.33 | 1500 |
| 2 | Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger, over a distance of at least 0.5 mi or 10 times the height of the structure upwind, whichever is greater | 0.22 | 1200 |
| 3 | Open terrain with scattered obstructions having heights generally less than 30 ft, including flat open country typical of meteorological station surroundings | 0.14 | 900 |
| 4 | Flat, unobstructed areas exposed to wind flowing over water for at least 1 mi, over a distance of 1500 ft or 10 times the height of the structure inland, whichever is greater | 0.10 | 700 |

When the hourly wind speed, $U_{met}$, at a specified probability level is desired then only the average annual wind speed, $U_{annual}$, is available from a given meteorological station ($U_{met}$ may be estimated from Table 7). The ratios $U_{met}/U_{annual}$ are based on long-term data available from 24 weather stations widely distributed over North America. At these stations, $U_{met}$ usually ranges from 7 to 15 mph. The values listed in Table 7 are one standard deviation of the wind speed ratios.

**TABLE 7: Typical Relationship of Hourly Wind Speed $U_{met}$ to Annual Average Wind Speed $U_{annual}$**

| Percentage of Hourly Values That Exceed $U_{met}$ | Wing Speed Ration, $U_{met}/U_{annual}$ |
|---|---|
| 90% | $0.2 \pm 0.1$ |
| 75% | $0.5 \pm 0.1$ |
| 50% | $0.8 \pm 0.1$ |
| 25% | $1.2 \pm 0.15$ |
| 10% | $1.6 \pm 0.2$ |
| 5% | $1.9 \pm 0.3$ |
| 1% | $2.5 \pm 0.4$ |

In cold climate, the wind penetrates the north or west exposures of the building. Since 44 Gerrard St. East has large number of windows on the west side of the building thus, a large amount of air infiltrates the building. It is also observed that the majority of the windows accompanied on the west side are in either classrooms or studios therefore, less attention paid towards closure or maintenance of the windows. The north side of the building has considerably less windows but has exit doors to the outside. There is no building on the north, south, and the west sides therefore, there is no direct wind blockage. In other words, it can accommodate a big rate of infiltration to the interior of the building.

**TABLE 8: Quantity/Perimeter of Windows and Doors**

| Side | # of Windows | Window's Perimeter | # of Doors | Door's Perimeter |
|---|---|---|---|---|
| North | 20 | 646.299 | 3 | 85.795 |
| South | 34 | 1157.606 | 2 | 79.244 |
| East | 16 | 525.858 | 1 | 38.047 |
| West | 25 | 744.095 | - | - |
| | *Total* | ***3073.858*** | | ***203.087*** |

Older buildings without weather-strips are expected to experience 1.0 air change per hour during the heating season. This means that a 10x10x10 ft room on the perimeter of a building may experience a 1,000 cubic feet per hour air exchange with the outdoor environment. By applying weather-strips to the existing windows and doors can decrease the amount of air penetrating the building. Detailed analysis of 44 Gerrard St. East has been prepared with the installation of weather-strips to the windows to reduce the heating load of the building.

***Problem Stating***

There are 20 windows to the north side with perimeter of $646 ft$ and 25 windows to the west side with perimeter of $744 ft$. All the windows are of Casement Steel type. Assume, there is a wind speed of $15 mph$ and indoor temperature to be calculated at $70^{\circ}F$.

- At $15 mph$, Casement Steel Windows correspond to $1.5 cfm/ft$ of crack. *(Refer to Appendix B, Figure 23)*
- $Total\ parameter = 646 + 744 = 1390 ft$
- $Total\ crack\ length = 1390 ft \times 1.5 cfm/ft \approx 2085 cfm$
- Again at $15 mph$, with installation of weather-strip, it correspond to $0.25 cfm/ft$ of crack. *(Refer to Appendix B, Figure 23)*
- $Total\ crack\ length\ = 1390 ft \times 0.25 cfm/ft \approx 348 cfm$

- Thus, Reduction in infiltration $= 1390cfm - 348cfm = 1042cfm$
- At 4318 Degree Days ➔ Energy used is $30 \times 10^6 Btu/yr/1000cfm$

  Energy used is $120 \times 10^6 Btu/yr$ *(Refer to Appendix B, Figure 22)*
- Saving in heating energy by $\dfrac{1042cfm}{1000cfm} \times 120 \times 10^6 Btu/yr = 125 \times 10^6 Btu/yr$
- At 65% efficiency and at $\$12/1000ft^3$ (price of natural gas), thus saving in natural gas is

  $\dfrac{\$12}{1000ft^3} \times \dfrac{125 \times 10^6 Btu/yr}{\left(1000Btu/ft^3\right) \times 0.65} \approx \$865/\text{winter}$ ➔ Saving = $2307/winter
- Therefore, by adding weather-strip to the windows, reduces the infiltration rate from $1.5cfm/ft$ to $0.25cfm/ft$, thus results in saving of $\$2307/\text{winter}$. However, this saving comes with cost of weather-strip installation.
- Assume, the cost of weather-strip for 45 windows of $40ft^2$ is about $50 each. Therefore,

  $\text{Cost} = 45 windows \times \$50 = \$2,250$ plus the installation,

  $\text{Installation} = 40 windows \times 100 each\ window\ labor = \$4000$, gives

  $\text{Total Cost} = \$2,250 + \$4,000 = \$6,250$.
- Then the payback period can be calculated, $\text{payback} = \dfrac{\$6,250}{\$2,307} \approx 2.7 years$

It will take 2 years and 7 months to pay back at the current rate of the natural gas price with the annual saving in heating costs.

## 2.7 - INSULATION

An obvious means to reduce energy usage is to insulate. Insulation is the practice of providing a surround barrier within a building or to slow down the conductive flow of heat in other objects. A reflective barrier is often added as an insulation to slow radiative heat flow.

Insulation material traps air in tiny pockets that restrict it from moving. Since the air cannot move freely thus, it slows down the heat transfer rate. There are various factors, which affect the material effectiveness. For example, some materials trap air more effectively than others, and produce the same results with less material thickness.

Adding another layer or replacing the existing layer of insulation generally solves the heat loss problem. The common insulations that are used commercially are made of cellulose or paper, rockwool such as asbestos, glass fibre, and foamed plastics such as poly-styrene, poly-isocyanurate, poly-urethane or urea formaldehyde foamed insulation (UFFI). A list of some of the typical insulations (R-value[8] Table 9) provides good indication that what type of insulation used in particular area of the building. The whole list of insulating material is available in Appendix D - Thermal Properties of Typical Building and Insulating Material.

**TABLE 9: Recommended R-values**

| Description | R-values |
|---|---|
| Ceiling | 13 |
| Crawl Space Under Floor | 13 |
| Crawl Space Perimeter (Interior) | 19 |
| Crawl Space Perimeter (Exterior) | 10 |
| Wall | 5 |
| Duct | 11 |
| Pipe | 3 |

Since most of 44 Gerrard St. East's area was restricted for building personnel, therefore, some values of the insulation thickness are assumed for calculation. However, Table 10 values give a good indication as to what type of insulation used.

**TABLE 10: Indoor Insulation in building**

| Location | Surface Area, $ft^2$ | Insulation (R-values) |
|---|---|---|
| Ceiling | 6720.813 | 13 |
| Floor | 6919.213 | 11 |
| Wall | 20629.922 | 5 |
| Pipe | 273.413 | 3 |
| Ducts | 685.530 | 11 |

From the Table 10, the insulation values used in various places around the building corresponds to heat transfer rate of that particular area. Thus, by analyzing the 44 Gerrard St. East and installing better insulation saves energy and money.

*Problem Stating*

44 Gerrard St. East has heating degree days of 4066. The efficiency of the heating unit is 65% and the price of the electricity is $\$0.08/KWh$. Using the temperature difference of 35°F, the energy that can be save by upgrading to new insulation are as follows:

- With the help of equation (2.1.9), total heat loss is,
- *Sample calculation for Ceiling,*

$$Q = \frac{(6720\,ft^2)\times(35^\circ F)}{(13hr\cdot ft^2\cdot{}^\circ F/Btu)\times(0.65)} = 0.028\times10^6\,Btu/hr \quad \rightarrow \quad Q = 0.028\times10^6\,Btu/hr$$

$$Q = (5880hr/\text{winter})\times(0.028\times10^6\,Btu/hr) = 164\times10^6\,Btu/\text{winter}$$

- At $\$12/1000ft^3$ (price of natural gas), thus saving is

$$\frac{\$12}{1000ft^3}\times\frac{164\times10^6\,Btu/yr}{1000Btu/ft^3}\approx \$1{,}964/year \quad \rightarrow \quad \text{Saving} = \$1964/year$$

**TABLE 11: Heat loss and Cost of Gas with existed insulation**

| Location | Surface Area, ft² | Insulation | Heat Loss | Cost of Natural Gas |
|---|---|---|---|---|
| Ceiling | 6720 | 13 | 1.64E+08 | $1,963.99 |
| Floor | 6919 | 11 | 1.99E+08 | $2,389.81 |
| Wall | 20629 | 10 | 6.53E+08 | $7,837.75 |
| Pipe | 273 | 3 | 2.88E+07 | $345.74 |
| Ducts | 685 | 11 | 1.97E+07 | $236.60 |
| | | *total* | ***1.06E+09*** | ***$12,773.90*** |

- Upgrading the insulation to reduce the heat loss and to save money and following the same procedure as above to calculate the heat loss and the cost of natural gas gives:

**TABLE 12: Heat loss and Cost of Gas with new insulation**

| Location | Surface Area, ft² | Insulation | Heat Loss | Cost of Natural Gas |
|---|---|---|---|---|
| Ceiling | 6720 | 21 | 1.01E+08 | $1,215.80 |
| Floor | 6919 | 21 | 1.04E+08 | $1,251.81 |
| Wall | 20629 | 21 | 3.11E+08 | $3,732.26 |
| Pipe | 273 | 3 | 2.88E+07 | $345.74 |
| Ducts | 685 | 19 | 1.14E+07 | $136.98 |
| | | *total* | ***5.57E+08*** | ***$6,682.59*** |

- Thus, difference in cost = \$12,773 - \$6,682 $\approx$ \$ 6,091/year
- Therefore, by upgrading the insulation, reduction of heat loss rate and savings of \$6,091/year.
- However, this saving comes with cost of insulation installation.
- Assume, the cost of insulation for $21{,}873 ft^2$ is about \$10,000 plus the cost of installation based on $\$10/ft^2$ is approximately \$22,000 then, Total Cost $= \$10{,}000 + \$22{,}000 = \$32{,}000$.
- The payback period can be calculated as, payback $= \dfrac{\$32{,}000}{\$6{,}091} \approx 5.3 years$

It will take 5 years and 3 months to payback at the current natural gas rate with the annual saving in heating costs. In summer, no calculations are taken into account because the insulation does not help in saving cooling load.

## 2.8 - HEAT GAINS

Heat gain is associated with different categories such as lighting, occupancy, solar, and machinery. Heat gain through lighting is the best solution to offset the reduction in heat load. According to current I.E.S (Illuminating Engineering Society) standards, lighting can account to half of the heating load. Secondly, the number of occupants at the site could add up the heat gain along with the lighting, which normally has an intermittent use. Therefore, it is worth to consider that lights can provide the preoccupancy heating and thereby, saving in the heat load. One of the most important factors is the solar heat gain. When light strikes through the building envelope, it raises the surface temperature and reduces the conduction losses. In the case of 44 Gerrard St. East, most of the windows are facing the south side. This helps in the overall heat load.

For fenestration heat gain, the following equations (2.8.1 – 2.8.4) have been generated in eQUEST,

Direct beam solar heat gain $q_b$:

$$q_b = AE_D SHGC(\theta) IAC \qquad (2.8.1)$$

Diffuse solar heat gain $q_d$:

$$q_d = A(E_D + E_r)\langle SHGC \rangle_D IAC \qquad (2.8.2)$$

Conductive heat gain $q_c$:

$$q_c = UA(T_{out} - T_{in}) \qquad (2.8.3)$$

Total fenestration heat gain $Q$:

$$Q = q_b + q_d + q_c \qquad (2.8.4)$$

where, $A$ is the window area in $ft^2$, $E_b$, $E_d$, and $E_r$ are the direct, diffuse, and ground-reflected irradiance calculated using the equations in Appendix A - Solar Equations. $SHGC(\theta)$ is the direct solar heat gain coefficient as a function of incident angle $\theta$, and $\langle SHGC \rangle_D$ is the diffuse solar heat gain coefficient (also referred to as hemispherical $SHGC$). $T_{in}$ is the inside temperature in °$F$, and $T_{out}$ is the outside temperature in °$F$. $U$ is the overall U-factor including frame and mounting orientation from ASHRAE HANDBOOKS in $Btu/h \cdot ft^2 \cdot° F$, and $IAC$ is the shading attenuation coefficient, which is equal to 1.0, if there is no inside shading device.

# CHAPTER 3 - COOLING

Cooling is the transfer of energy by virtue of a difference in temperature between the cooling source and the space or air. In the usual cooling process, air circulates over a surface maintained at a low temperature. This surface may be in the space to be cooled or at some remote location from it. Usually water or a volatile refrigerant is used as a cooling medium. Similar to heating, the cooling load is reduced by tightening the building envelope. Therefore, reducing the cooling load required by the building will directly reduce the distribution system loads. In addition, one of the major factors that will reduce the building load is by increasing the efficiency of the primary energy conversion equipment.

There are generally two components to cooling such as sensible heat, and latent heat. The amount of moisture that liberates or absorbs by air is measured by its initial and final absolute humidities. Through these humidities, building cooling load is determined. The difference between the dry bulb temperature (which measures sensible heat), and the wet bulb temperature (which measures latent heat) must be controlled for the comfort of the occupants.

Just as ventilation and infiltration adds the heating load in the winter, it also increases the cooling load in the summer. Unlike heating load calculations, a simple temperature difference between inside and outside air will not calculate overall cooling load of the building. Maintaining higher indoor temperatures and relative humidity for longer period can decrease sensible heat gain. This will directly reduce the amount of cool air supply and saves energy due to the reduction in the required fan horsepower. Similarly, improving the coefficient of performance *(COP)* of refrigeration chillers or compressors will result in significant savings.

$$COP = \frac{Q}{W} \qquad (2.8)$$

where, COP is the ratio of refrigeration produced, $Q$ (heat pump) in *BTU*, to the energy required to operate the equipment, $W$ (work consumed) in *BTU.*

## 3.1 - COOLING LOAD CAUSED BY LIGHTS

One of the major components of heat gain in the interior zones is the power supplied to the lights. Heat produced by electrical energy of the lights, which puts an extra burden on cooling load. Based on the study from various publications, the storage factors from light fixtures that affect the cooling load is discussed in detail below.

Cooling loads have been calculated for fluorescent fixtures recessed into the ceiling as shown in Figure 6,

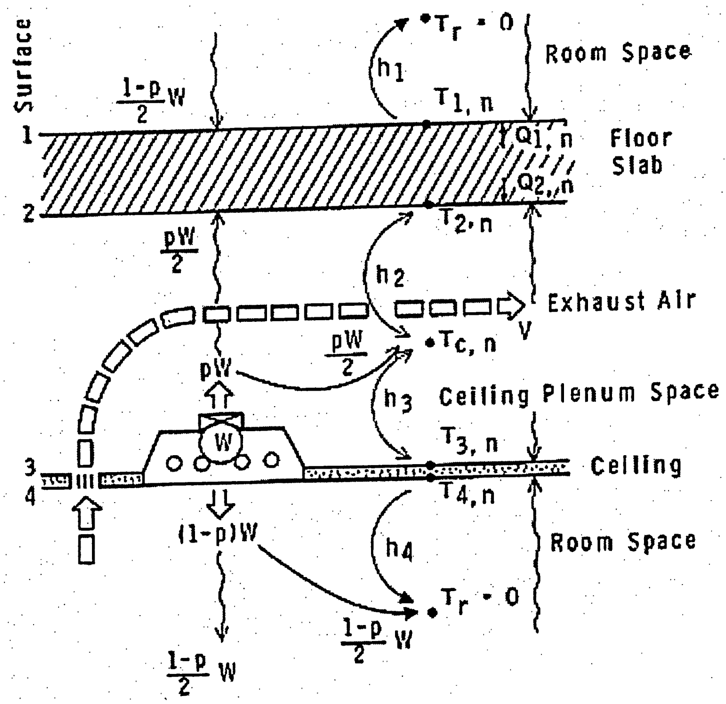


**FIGURE 6: Thermal System of suspended ceiling with processed lights**

The temperatures at each surface of the floor, ceiling, and in the space above the ceiling are found by solving the set of heat balance equations. This set of equations is available in Appendix-A: Cooling Calculations in Matrix form. The following graph (Figure 7) has been plotted with the help of Appendix A: Cooling Calculations.

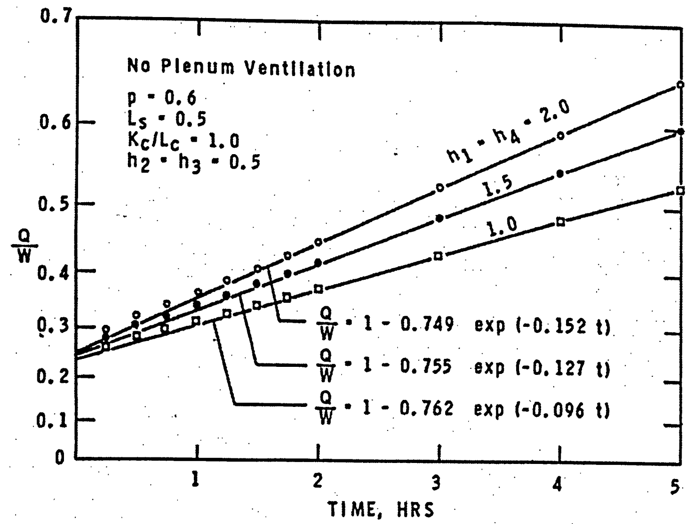


**FIGURE 7: Cooling Load for unventilated plenum, calculated using different convection coefficients**

The variation of the load with respect to time is represented by this expression,

$$\frac{Q}{W} = 1 - Ae^{-Bt} \tag{3.1.1}$$

The rate at which heat is being stored is,

$$W - Q = WAe^{-Bt} \tag{3.1.2}$$

Thus, the total heat stored when the steady-state conditions are reached is,

$$\int_0^{\infty} WAe^{-Bt}dt = \frac{WA}{B} \tag{3.1.3}$$

where, the values of A can be computed from Figure 7, which is based on time the lights were on. The variable B is a dummy variable and also be calculated from Figure 7.

The cooling load does not stop even after the power input to the lights has stopped, because of the stored heat from the lights is released to the room air for quite a long period. If it is assumed that the heat transfer coefficients remain the same whether the lights are on or off, then the cooling load after the lights are turned off is given by,

$$\left(\frac{Q}{W}\right)_{t>M} = \left(1 - Ae^{-Bt}\right) - \left(1 - Ae^{-B(t-M)}\right) = A\left(e^{BM} - 1\right)e^{-Bt} \tag{3.1.4}$$

where, the lights are on from $t = 0$ to $t = M$ hrs.

When $t = 24hrs$, the values of B (heat to work load ratio factor, Figure 7) are small enough so the term $e^{-Bt}$ can be ignored. Assuming, that the lights are on for $M\ hours$ and off for $M - 24\ hours$, then the cumulative cooling load is,

$$\sum_d \left(\frac{Q}{W}\right)_{t \le M} = 1 - Ae^{-Bt} + \left(1 - Ae^{-B(t+24)}\right) - \left(1 - Ae^{-B(t+24-M)}\right) + \left(1 - Ae^{-B(t+48)}\right) - \left(1 - Ae^{-B(t+48-M)}\right) + \cdots \tag{3.1.5}$$

These infinite geometric series can be summed into,

$$\sum_d \left(\frac{Q}{W}\right)_{t \le M} = 1 - Ae^{-Bt}\frac{1 - e^{-B(24-M)}}{1 - e^{-24B}} \tag{3.1.6}$$

and when $M < t < 24$

$$\sum_d \left(\frac{Q}{W}\right)_{M<t<24} = \frac{A\left(e^{BM} - 1\right)e^{-Bt}}{1 - e^{-24B}} \tag{3.1.7}$$

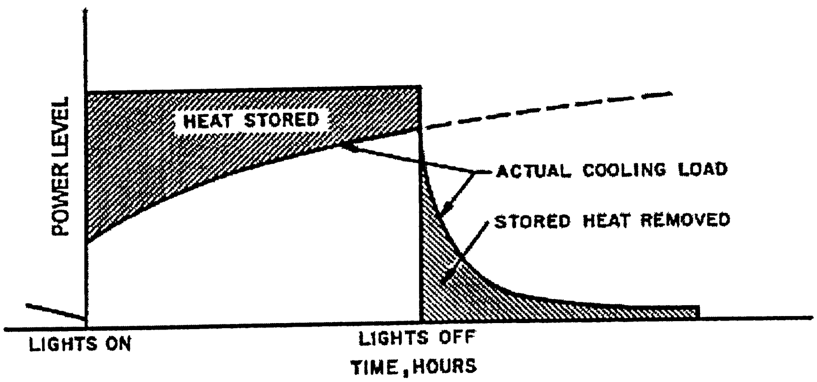


**FIGURE 8: Storage Load factor for unventilated plenum**

The above graph (Figure 8) shows the relationship between the stored heat and the actual cooling load. As the lights turned off, there is a dramatic drop in the actual cooling load curve but it does not completely stop the cooling load till the next day when the lights turned back on.

### 3.1.1 - Cooling Load Weighting Factors for Lights

Due to the irregular schedule of lights operation, a weighting factor method can help in calculating the cooling load of lights. Thus, the cooling load at any time, $t$, is

$$Q = \sum_{j=0}^{\infty} r_j * W_{t-j\Delta} \qquad (3.1.8)$$

where, $W_{t-j\Delta}$ is average power input of the lights during the interval between $t - j\Delta$ and $t-(j+1)\Delta$ hrs.

The weighting factors $r_j$ are simply the values of $Q/W$ at $t = (j+1)\Delta\, hr$ for the case where the lights are on from $t = 0$ to $t = \Delta$, and are off thereafter,

$$\begin{aligned} &\text{for } j = 0 \quad r_\circ = 1 - Ae^{-B\Delta} \\ &\text{for } j \geq 1 \quad r_\circ = A\left(1 - e^{-B\Delta}\right)e^{-jB\Delta} \end{aligned} \qquad (3.1.9)$$

The values of $r_j$ get progressively small as $j$ increases and therefore, they becomes negligible for large values of $j$. Thus, the summation for $Q$ can be stopped after a finite number of terms; the actual number of terms depends on the magnitude of $B\Delta$, and the precision required.

## 3.2 - INCREASING INDOOR TEMPERATURE

If there is no one to comfort during unoccupied hours then most of the energy goes to waste. Therefore, there can be a lot of saving with the amount of time the cooling unit allows temperature, and humidity to rise.

Based on the analysis of 44 Gerrard St. East, raising the indoor dry bulb temperature during unoccupied hours from 70°F to 78°F will decrease the cooling load. Below is the energy saving table of relative humidity when the temperature rises by different intervals.

**TABLE 13: Energy Saving with Increasing Indoor Temperature**
**(*Btu/hr/1000cfm* for each *1°F* increase)**

| | Relative Humidity | | |
|---|---|---|---|
| | Energy in Btu/hr/1000cfm | | |
| Dry bulb temperature | 50% | 60% | 70% |
| 72°F | 0 | 0 | 0 |
| 73°F | 2700 | 2433 | 3000 |
| 74°F | 2657 | 2400 | 3257 |
| 75°F | 3000 | 2572 | 3000 |
| 76°F | 3000 | 2572 | 3000 |
| 77°F | 3000 | 2572 | 3429 |
| 78°F | 3000 | 2572 | 3429 |
| *Total* | *17357* | *15121* | *19115* |

***Problem Stating***

Assume, the outdoor air rate is $4000cfm$, the relative humidity is $50\%$, and the *COP* is at 3.5.

- In order to get the relative humidity level from $70°\mathrm{F}$ to $78°\mathrm{F}$, add all the energy savings over the total temperature change,

  $0+2700+2657+3000+3000+3000+3000=17{,}357 Btu/hr/1000cfm$
- For an outdoor air rate of $4000cfm$, savings will be, $4\times 17{,}357=69{,}428 Btu/hr$
- Under the off-office hours of $128 hrs/wk$ and the cooling season of about 17 weeks, then the yearly energy saving is, $(69{,}428 Btu/hr)\times(128 hrs/wk)\times(17 wk)=151\times 10^6 Btu/yr$
- Energy saved for a mechanical refrigeration system with a *COP* of 3.5 will be

$$\frac{151\times 10^6}{3.5}=43.14\times 10^6 Btu/yr \quad \text{or} \quad \frac{43.14\times 10^6 Btu/yr}{3{,}413 Btu/KWh}\approx 12640 KWh/yr$$

At $\$0.08/KWh$, thus saving for mechanical refrigeration system is $\$0.08/kWh \times 12640kWh/yr = \$1{,}011/year$. ➔ Saving = $1011/year

Therefore, by raising the indoor dry temperature, reduces the cooling load, thus saves $\$1011/year$.

## 3.3 - Increasing Relative Humidity

The recommended dry bulb temperature for most of the building during peak loads is from 72°F to 78°F, and the relative humidity is 50%. Table 13 is used as a guideline for the recommended dry bulb temperatures at different intervals and relative humidities.

Applying these guidelines while controlling the dry bulb temperatures and the relative humidities accurately and logically for short periods can accumulate savings without discomforting the occupants. Analyzing 44 Gerrard St. East by applying these suggestions and raising the relative humidity from 50°F to 60°F saves energy through the following steps:

***Problem Stating***

Assume, the outdoor air rate is $4000cfm$, wet bulb temperature is 8500 degree hours, and the $COP$ is at 3.5.

At annual wet bulb temperature degree hours of 8500

- At $50\%RH$ gives $27\times10^6 Btu/yr/1000cfm$ *(Refer to Appendix B, Figure 24)*
- At $60\%RH$ gives $23\times10^6 Btu/yr/1000cfm$ *(Refer to Appendix B, Figure 24)*
- Therefore, the difference between the two relative humidites gives,

  $$Energy\ Saving = \left(27\times10^6\right)-\left(23\times10^6\right)=4\times10^6 Btu/yr/1000cfm$$

- For an outdoor air rate of $4000cfm$, savings will be, $16\times10^6 Btu/yr$
- Energy saved for a mechanical refrigeration system with a $COP$ of 3.5 will be

  $$\frac{16\times10^6}{3.5}=4.6\times10^6 Btu/yr \quad \text{or} \quad \frac{4.6\times10^6 Btu/yr}{3{,}413 Btu/KWh}\approx 1{,}347 KWh/yr$$

- At $\$0.08/KWh$ (price of electricity), thus saving for mechanical refrigeration system is $\$0.08/kWh \times 1{,}347kWh/yr \approx \$108/year$ ➔ Saving = $108/year

Therefore, raising the indoor relative humidity reduces the cooling load, thus saving of $\$108/year$.

## 3.4 - VENTILATION RATE

Outside air introduced through air-conditioning equipment results in sensible and latent loads. Cooling and dehumidifying outdoor air consumes a large amount of energy. Reducing the quantity of ventilation to a minimum (which also falls in the comfort zone) results in substantial energy and money savings. Usually, the recommended ventilation rates for summer follow the same suit as winter. Appendix D - Ventilation Chart shows the ventilation rate for summer season as well as winter season. Since the wet bulb temperature can be closely approximated with the enthalpy[9], therefore, the difference in wet bulb temperature between outdoor air and room conditions can also be used to determine the energy required for cooling and dehumidification.

Most of the analysis here resembles heating season ventilation rate. Therefore, examining 44 Gerrard St. East by reducing the ventilation rate of the building for cooling season provides similar results.

***Problem Stating***

With 135 people occupying the site and at the regular working load of $40 hrs/wk$, calculate the energy savings if the indoor relative humidity is 50%, annual wet bulb degree hours are 8500, and the $COP$ is at 3.5.

- Reduce the ventilation rate from $25 cfm$ to $15 cfm$ with 135 people occupying the building, thus, the difference between the two ventilation rates gives,
- *Energy Saving* $= 135 \times (25cfm - 15cfm) = 1350cfm$
- *Annual Energy Usage* $= 24.5 \times 10^6 Btu/yr/1000cfm$ *(Refer to Appendix B, Figure 22)* with $40 hrs/wk$, 50% of indoor relative humidity, 68°F of indoor temperature, and 4318 degree days.
- *Total Energy Saving* $= \left(\dfrac{1350cfm}{1000cfm}\right)(24.5 \times 10^6 Btu/yr/1000cfm) = 33.1 \times 10^6 Btu/yr$
- Energy saved for a mechanical refrigeration system with a $COP$ of 3.5 will be

  Reduction in Energy input $= \dfrac{33.1 \times 10^6 Btu/yr}{3.5} = 9.5 \times 10^6 Btu/yr$ or

  Reduction in Energy input $= \dfrac{18.9 \times 10^6 Btu/yr}{3{,}413 Btu/KWh} \approx 2{,}783 KWh/yr$
- At $\$0.08/KWh$ (price of electricity), thus saving for mechanical refrigeration system is $\$0.08/KWh \times 2783 KWh/yr = \$223/year$ ➔ Saving = $223/year

Therefore, by reducing the ventilation rate from $25 cfm/person$ to $15 cfm/person$ saves $\$223/year$.

## 3.5 - INFILTRATION RATE

The amount of infiltration is much lower during hot weather than cold weather because the difference between the milder winds and the lower temperature cause less of a chimney effect. The chimney effect is the tendency of heated air or gas to rise in a duct or other vertical passage, such as in a chimney, small enclosure or building, due to its lower density compared to the surrounding air or gas. Therefore, the occupants of the lower floors will feel cold drafts, while the occupants of the upper floors will be suffering from the heat. For that reason, air changes rate should be estimated lower for summer than for winter.

Even though the infiltration level is small in summer compared to cold weather, it still affects the cooling load. Unlike ventilation, infiltration increases the load as an additional room load. Since leakage occurs all year around, therefore, it creates a big load especially during night time because temperature is usually less than most of the day.

According to the study, if windows and doors are weather-stripped in older buildings then the infiltration rate can be reduced by approximately one-third. The calculations for the cooling season follow the same pattern as the heating season. However, due to the low wind velocity and infiltration rate, the savings will be less with weather-strips add-ons.

***Problem Stating***

There are 20 windows to the north side with perimeter of $646ft$ and 25 windows to the west side with perimeter of $744ft$. All the windows are of Casement Steel type. Assuming there is a wind speed of $10mph$ and indoor temperature at $68^{\circ}F$. Under the regular working load of $40hrs/wk$, the energy saving can be calculated if the indoor relative humidity is kept at 50%. Assume, annual wet bulb degree hours are 8500 and the *COP* is at 3.5.

- At $10mph$, casement steel windows correspond to $0.95cfm/ft$ of crack. *(Refer to Appendix B, Figure 23)*
- $Total\ parameter = 646 + 744 = 1390ft$
- $Total\ crack\ length = 1390ft \times 0.95cfm/ft \approx 1321cfm$
- Again at $10mph$, with installation of weather-strip addition, it correspond to $0.2cfm/ft$ of crack, *(Refer to Appendix B, Figure 23)*
- $Total\ crack\ length\ = 1390ft \times 0.2cfm/ft \approx 278cfm$

- Thus, Reduction in infiltration $= 1321cfm - 278cfm = 1043cfm$
- *Annual Energy Usage* $= 24.5 \times 10^6 Btu/yr/1000cfm$ *(Refer to Appendix B, Figure 22)* with $40hrs/wk$, 50% of indoor relative humidity, 68°F of indoor temperature, and 4318 degree days.
- Saving in cooling energy by

$$\left(\frac{1043cfm}{1000cfm}\right)\left(24.5 \times 10^6 Btu/yr/1000cfm\right) = 25.6 \times 10^6 Btu/yr \qquad \text{or}$$

$$\left(\frac{25.6 \times 10^6 Btu/yr}{3,413 Btu/KWh}\right) \approx 7501 KWh/yr$$

- At $\$0.08/KWh$ (price of electricity), the saving for mechanical refrigeration system is $\$0.08/KWh \times 7501 KWh/yr \approx \$600/summer$ ➔ Saving = \$600/summer
- Therefore, by adding weather-strip to the windows, reduces the infiltration rate from $0.95cfm/ft$ to $0.2cfm/ft$, thus results in saving of $\$600/summer$.

The savings of winter season through infiltration is \$2,307/winter with cost of weather-strip installation of \$6,250 and the payback period of 2.2 years. However, by adding the savings of summer with winter, thus gives, Total Savings $= \$2,307 + \$600 = \$2,907/year$ ➔ Total Saving = \$2907/year

Then the total payback period can be calculated, Total payback $= \dfrac{\$6,250}{\$2,907} \approx 2.2 years$

It will take 2 years and 2 months to pay back at the current rate of the electricity prices.

## 3.6 - SOLAR HEAT GAIN

A significant amount of solar energy is available for heating, which needs considerable effort to design cost-effective applications. One that has proven successful is the heating of domestic hot water. Most solar applications will require some form of subsidy for the project to be economically viable for the user.

Many older buildings have windows that were installed only for their aesthetic value. Such windows contribute to unnecessary heat losses. This problem can be eliminated by blocking up the window openings with insulation such as installing wood furring covered with gypsum board. However, installing the insulation around the windows sometimes costs more than it can save. Therefore, altering the solar radiation by treating the windows with shading screens is a good solution.

Solar heat gain plays a big part to the cooling load of 44 Gerrard St. East. The ratio of window to wall area on the east, west, and the south sides is 20 percent or more with insulated glass and 50 percent or more with clear un-shaded glass exposed to direct sunlight. Annually, almost 80 percent of the solar radiation strikes vertical single sheet of clear glass surface transmits through the windows. Overall, in order to reduce solar gain in the summer, without limiting winter heating, awnings are installed over the windows.

**TABLE 14: List of Devices to increase Shading Coefficient**

| Shading Device | With 1/4" Clear Plate Glass | With 1" Clear Insulating Glass |
|---|---|---|
| Blinds light color fully closed | 0.055 | 0.51 |
| Shades light color fully drawn | 0.39 | 0.37 |
| Drapes fabric semi open | 0.55 | 0.48 |
| Reflective polyester Film | 0.24 | 0.2 |
| 23 Louvers/inch | 0.15-0.35 | 0.10-0.29 |
| 17 Louvers/Inch | 0.18-0.51 | 0.12-0.45 |

Table 14 shows various shading devices that provide screen against the direct sunlight by increasing the shading coefficient. Shading coefficient is the measure of the average solar radiation that passes through the window or shading device, compared to the radiation that passes through the window of standard clear one-eight inch double strength glass of the same size and orientation.

Energy can be conserved by blocking the solar heat to enter the building through windows. Table 14 shows that the shading coefficient increases with insulating glass and blind closed. Therefore, simple solution is to install blinds and tint the windows.

# CHAPTER 4 - Lighting

## 4.1 - Electrical Systems

The electric system is an integral part of a building's overall design. Nearly all mechanical equipment such as air conditioners, pumps, fans, and lighting systems, is powered by electricity. Lighting takes up 50 percent of the building's total load.

## 4.2 - Lighting

Lighting is the essential part of the building and occupant's comfort. However, this comfort comes at a major expense to the building's energy usage. Electric lighting also holds significant contribution to the internal heat gain in buildings. In order to conserve energy through lighting, consider the following points:

1. Utilize available daylight more effectively for illumination.
2. Improve lighting system efficiency by making more frequent fixture maintenance.
3. Control the levels of illumination for different task locations or reduce them in between the tasks.
4. Switch off the lights at night time and possibly during unoccupied hours and areas of the building.
5. Use more efficient light sources for better quality of lighting.

Table 15 shows all the major lighting gain units for 44 Gerrard St. East, and Appendix D - Light Fixtures for detailed lighting power-density chart. Table 15 clearly shows that the majority of the lighting system consists of Incandescent type A-99 bulbs. However, there are a number of Fluorescent type Medium Bipin lights located either in the classrooms or in hallways. Since Incandescent bulbs consumes large amount of energy than Medium Bipin therefore, replacing the Incandescent bulbs with Medium Bipin lights helps save energy.

**Table 15: Lighting Power Density**

| Area | | # of light fixtures | Light type | Watt per lamp, W | Peak Lighting Gain, W/ft$^2$ |
|---|---|---|---|---|---|
| Basement | | 47 | A-99 | 53 | 1.67 |
| | *total* | *47* | | | |
| 1st Floor | *Offices* | 43 | A-99 | 53 | 2.33 |

| | | | | | |
|---|---|---|---|---|---|
| 1st Floor | | 100 | Medium Bipin | 20 | |
| | *Classrooms* | 41 | Medium Bipin | 20 | 2.36 |
| | *Studios* | 95 | A-99 | 53 | 2.60 |
| | *Washrooms* | 40 | A-99 | 53 | 1.40 |
| | *Change Room* | | | | |
| | *Hallways* | 90 | Medium Bipin | 20 | 1.40 |
| | ***total*** | ***409*** | | | |
| 2nd Floor | *Offices* | 18 | A-99 | 53 | 2.33 |
| | | 65 | Medium Bipin | 20 | |
| | *Classrooms* | 201 | Medium Bipin | 20 | 2.32 |
| | *Studios* | 169 | A-99 | 53 | 2.60 |
| | *Washrooms* | 4 | A-99 | 53 | 1.42 |
| | *Hallways* | 31 | Medium Bipin | 20 | 1.39 |
| | ***total*** | ***488*** | | | |
| 3rd Floor | *Offices* | 40 | A-99 | 53 | 2.36 |
| | | 100 | Medium Bipin | 20 | |
| | *Classrooms* | - | - | - | - |
| | *Studios* | 215 | A-99 | 53 | 2.60 |
| | *Washrooms* | 4 | A-99 | 53 | 1.42 |
| | *Hallways* | 31 | Medium Bipin | 20 | 1.39 |
| | ***total*** | ***390*** | | | |

Generally, the instantaneous rate of heat gain from electric lighting is calculated from,

$$q_{el} = 3.41 W F_{ul} F_{sa} \qquad (4.2.1)$$

where, $q_{el}$ is the heat gain in $Btu/h$, $W$ is the total light wattage in W, $F_{ul}$ is the lighting use factor, $F_{sa}$ is the lighting special allowance factor, and 3.41 is the conversion factor. An analysis was conducted to indicate the potential savings for the 44 Gerrard St. East by controlling lighting systems.

***Problem Stating***

There are 675 A-99 light bulb fixtures and 394 Medium Bipin lights fixtures installed on the site. A-99 carries 53W/lamp whereas, Medium Bipin lights carries only 20W/lamp. The light intensity for A-99 bulb and Medium Bipin light is $1.7W/ft^2$ and $1.6W/ft^2$ respectively. There are total 130 days of summer, and the total size of this location is $21{,}873 ft^2$. Reduce the lamp watts by installing dimmers.

- If the lamp power (watts) have been reduced by 50% then,

  Reduction in A-99 watts $= 675 lamps \times 0.5 \times 53W/lamp = 17{,}888W$

  Reduction in Medium Bipin watts $= 394 lamps \times 0.5 \times 20W/lamp = 3{,}940W$

- Overall Reduction in watts $= 43655 - (17888 + 3940) = 21,827W$
- Since there are 365 days in a year, therefore,

  Total Power $= 365days \times 24hrs/day \times 21827W \approx 191 \times 10^3 KWh$
- With mechanical refrigeration of 3.5,

  Reduction in energy input $= \dfrac{191 \times 10^3 KWh}{3.5} \approx 55 \times 10^3 KWh$
- At 50% reduction and at $\$0.08/kWh$ (price of electricity), thus saving of

  Savings $= 0.08/KWh \times 55 \times 10^3 KWh \approx \$4,400/year$ ➔ Savings = $4400/year

Therefore, by reducing the lighting watts by 50% saves $\$4400/year$. However, this saving comes with cost of dimmers installation.

- Assume, the cost of dimmers for 675 A-99 light bulb and 394 Medium Bipin lights are about \$9 and \$40 each respectively. Therefore, Cost $= (675 \times \$9) + (394 \times \$40) = \$21,835$ plus the installation, ➔ Installation $= (675 + 375)$lamps $\times$ (\$10 each dimmer labor) $= \$1,050$ gives, Total Cost $= \$21,835 + \$1,050 = \$22,885$.
- Then the payback period can be calculated, payback $= \dfrac{\$22,885}{\$4,400} \approx 5.2years$

It will take 5 years and 2 months to pay back at the current rate of the natural gas price with the annual saving in heating costs.

## 4.3 - Using Daylight for Illumination

The sun is the earth's source of free abundant light. It is the oldest and the most reliable light source. Diffuse light from the sky (natural light) can be used to light the building's interior.

Natural light creates an ideal match to control peak electrical demand by reducing the lighting systems operation. When daylight availability is greatest, it provides energy reduction at the most important periods (during peak hours). In addition to energy savings, there are many other benefits of day lighting. Sunlight strikes the buildings adds variation and excitement to interior spaces and enhance occupants comfort. Furthermore, the window size can play an important role in sunlight transmitting. For this site, it is noticed that blinds are not used in most parts of the building. This helps decrease the heating load but it will increase the cooling load so it should be adjusted according to the situation and weather.

## 4.4 - USING HIGHER EFFICIENCY LAMPS

Efficiency of lamps is usually measure in lumens or total useable light output per unit watt of electrical power input. The efficiency of the lamp should include the power consumed by its accessories such as lamp efficiency (lumens/watts), and net lamp efficacy. When considering high efficiency lamps, the lamps with low lumens, low lamp efficiency, and low lamp rated life should be replaced. Higher efficiency provides various benefits such as smaller heat load on the air conditioning.

Incandescent lamps are generally short-lived, and the real life of such lamps is even shorter when it is installed in a fixture. They are among the poorest lamps in terms of efficacy compared to compact fluorescent (PL) lamps. These lamps are about one-fifth as efficient as compact fluorescent (PL) lamps.

Replacing the existing incandescent lamps with compact fluorescent (PL) lamps shows that with the same or improved intensity and properties, energy is conserved and hence saves money.

***Problem Stating***

*Existing Medium Bipin type lamp Lighting System*

There are total of 394 fixtures of Medium Bipin type bulb with output of 20W, 3000hrs of operation, 1280 lumens, and ballast power loss of 15000. The price of A-99 is $8.95.

*Proposed Low Pressure Sodium Lighting System*

For 250 fixtures of Low Pressure Sodium lamp with output of 17W, 3000hrs of operation, 3060 lumens, and ballast power loss of 8000. The price of PL is $12.95.

- Since, the lumens for this new type of light are almost 2 times greater then the existing light therefore, not as many fixtures are required.
- Difference = 15000 – 8000 = 7,000 W
- At $\$0.08/kWh$ , thus saving of,

$$\text{Savings} = \frac{7000 \times 0.08 \times 3000hr}{1000} = \$1680/year \quad \rightarrow \quad \boxed{\text{Savings} = \$1,680/year}$$

- Therefore, by replacing the existing lights saves $\$1680/year$. However, this savings comes with cost of new low-pressure sodium lamps. Assume, the cost of low-pressure sodium is $12.95 each, cost of fixture is $19.90 each, and installation cost is $10 per lamp fixture. Thus,
- Cost of lamps $= \$12.95 \times 250 lamps \approx \$3238$

- Cost of fixtures $= \$19.90 \times 250 lamps = \$4975$
- Cost of installation $= \$10 \times 250 lamps = \$2500$
- Hence, Total Cost $= 3238 + 4975 + 2500 = \$10,713$ to install then the payback period is calculated as, payback $= \dfrac{\$10713}{\$1680} = 6.4 years$.

It will take 6 years and 4 months to pay back at the current rate of the electricity price.

## 4.5 - Installing Timer

Many buildings are left vacant after hours with equipment running. Usually, it is assumed that the last person to leave will turn off the equipment but it hardly happens and the left-on equipment costs energy. If there are no maintenance associates to keep the equipment off at night then installing timers will solve the problem. Any equipment such as compressors, pumps, and the lights that are not needed after hours should be turned off through timers.

At 44 Gerrard St. East, during unoccupied hours, at nights, and on weekends, the equipment runs most of the time, thus wasting energy. Turning off the lights and equipment after hours helps conserve energy.

***Problem Stating***

If one timer is installed on each floor to control the lighting timings for the power of 1000W per timer wattage consumption,

- If majority (50%) of the lights are to turned off for 365 days, for $10 hrs$ at night, Total Energy saved $= 365 days \times 10 hrs / day \times 1000W = 3650 KWh$
- At $\$0.08 / kWh$, thus saving of, Savings $= 0.08 / KWh \times 3650 KWh \approx \$292$ ➔ Savings = \$292/year

Therefore, by turning off the lights saves $\$292 / year$. However, this savings comes with cost of timers. Assume, the cost of timers is \$250 each, and installation cost is \$200 per timer.

Hence, Total Cost $= (3 \times \$250) + (3 \times \$200 labor) = \$1,350$ to install then the payback period can be calculated, payback $= \dfrac{\$1350}{\$292} \approx 4.6 years$.

It will take 4 years and 6 months to pay back at the current rate of the electricity price.

# CHAPTER 5 - HVAC SYSTEM

Heating, ventilating and air-conditioning (HVAC) systems can play several roles to reduce the environmental impact of buildings. For example, by improving the performance of the air system, air handling units, ductwork system, hot water piping, pumps, and motors. The primary function of HVAC systems is to provide a healthy and comfortable environment for occupants.

Even the best HVAC equipments and systems cannot compensate for a building design with inherently high cooling and heating needs. The greatest opportunities to conserve non-renewable energy are through architectural design that controls solar gain, while taking advantage of passive heating, daylighting, natural ventilation, and cooling. Therefore, the most critical factors in mechanical system are reducing the energy consumption, and capital cost through heating, and cooling loads. By reducing the energy used for moving and conditioning air, HVAC systems can save energy. However, a large amount of energy is required to move air though ducts, dampers, coils, filters, louvers, diffusers, and grilles.

In order to conserve energy, the following points for the HVAC system should be considered:

- Improve the performance of the terminal devices to reduce their resistance to fluid flow.
- Lower the resistance of flow in the duct and piping system.
- Decrease fluid leakages and thermal losses from the piping.
- Reduce the fan and pump operation time.
- Improve the performance of the fan, pumps, and motors by maintenance.
- Adjust the control systems to reduce simultaneous heating and cooling.

Overall, an HVAC system is simply a group of components working together. These components move heat to where it is wanted (the conditioned space), or remove heat from where it is not wanted (the unconditioned space), and put it where it is unobjectionable (the outside air).

## 5.1 - DESCRIPTION OF THE TECHNOLOGY

A central or built-up HVAC system is custom-designed for a building. The components of a central system fall into two broad categories: "primary components" and "secondary components".

### 5.1.1 - Primary Components

Primary components, often called "central plant" equipment, convert energy from fuel or electricity into heating and cooling energy in the form of hot water, steam, chilled water, or refrigerant.

- *Refrigeration* equipment includes water chillers, and direct-expansion (DX) equipment. Chillers use a refrigeration cycle to cool water from 42°F to 50°F and pump it to the chilled water-cooling coils. Then, air is blown over the chilled water cooling coils to provide cool air.
- *Boilers* produce hot water or steam to distribute to the heating coils. Though hot water is the most common fluid, steam is sometimes used because of its high heat per unit volume. Both types of boiler are typically 80-85 percent efficient. Gas is the most common fuel used in these boilers.
- *Pumps* circulate chilled water, hot water, and the cooling tower water. Centrifugal pumps driven by electric motors are usually the most common type of pumps. When water flow varies with changing loads, then pumps can be efficiently controlled with adjustable speed drives (ASDs).

### 5.1.2 - Secondary Components

Secondary components, sometimes called "system" equipment, deliver heating and cooling to the occupied spaces.

- *Air handling equipment* may be centrally located or several air handlers may be distributed throughout a facility. Most facilities use packaged air handlers but built-up air handle may only be found in large facilities. All air handlers adjust air temperature, humidity, and remove dust and other particles from air before distributing through ducts and shaft. This is accomplished through a series of coils, filters, humidifiers, fans, and dampers.
- *Terminal units* are devices at the end of the duct or pipe that transfer desired heating or cooling. Commonly used types with central HVAC systems include fan-coil units, induction units, and convectors.
- *Controls* are used to make components work together efficiently. They turn equipment on/off, adjust energy outputs (chillers, boilers), adjust flow rates (fans, pumps, coils), adjust temperatures (air, water, thermostats in conditioned spaces), and adjust pressures (ducts, pipes, conditioned space).

## 5.2 - TYPE OF HVAC SYSTEM USED

### 5.2.1 - Packaged Multi-Zone with HW Reheat

After the inspection of the site and various documents, it is determined that the building is equipped with Multi-Zone packaged with hot water coils. As the HVAC name implies, it is a direct packaged expansion cooling system with hot water heating. System includes a variable volume, and a single duct fan/distribution system serving multiple zones, each with its own thermostat. Warm and cold air is mixed for each zone to meet thermostat control requirements.

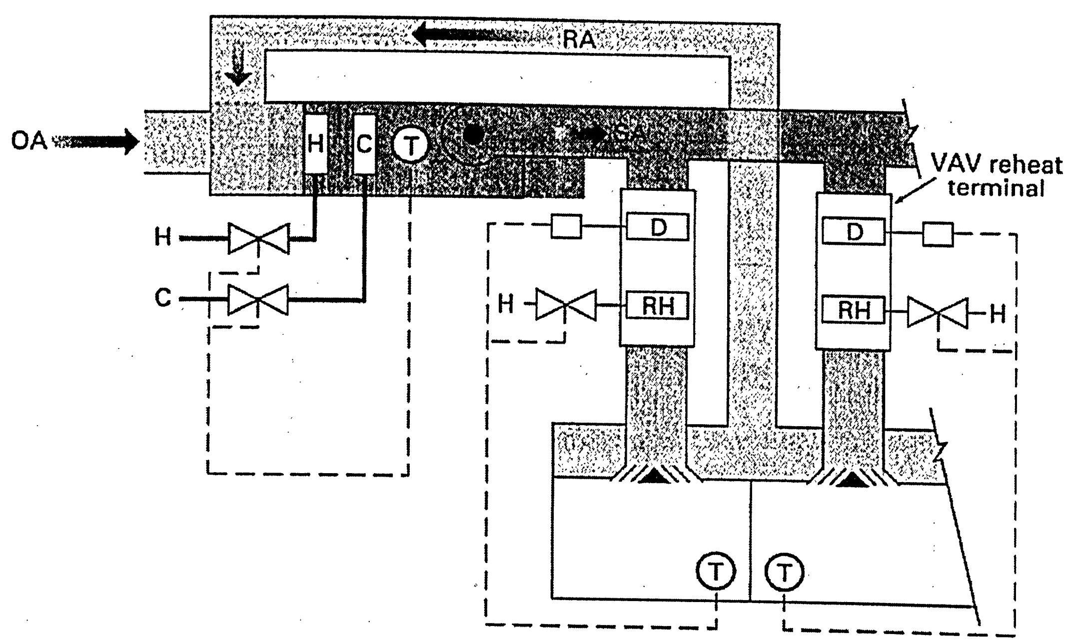


FIGURE 9: Multiple-Zone terminal Reheat VAV

Variable Air Volume (VAV) systems adjust the amount of cool air that flows to the zone. As the cooling load decreases, a damper in VAV control box starts to close thus reduces the supply of cool air. A VAV system saves fan energy because of this reduced airflow. If the VAV system serves zones at the perimeter, which requires winter heating, then hot water coils in the VAV box reheats the air. In the VAV system, energy efficiency can be imposed only after the VAV box has already reduced the cool supply air to the minimum requirement for ventilation.

Complete schematics of the HVAC system is designed by inputting data into the eQUEST. The layout of the system is available in Appendix C – Figure 28.

## 5.3 - TYPE OF HVAC UNITS USED

### 5.3.1 - Horizontal Fan Coil Unit

It has two to four horizontal pipes that drive this unit by belt. It has a galvanized casing model fan coil unit. It is installed above the ceiling or within a floor-mounted cabinet, with full access to internal components. Its size ranges from 600 to 4000 nominal *cfm*.

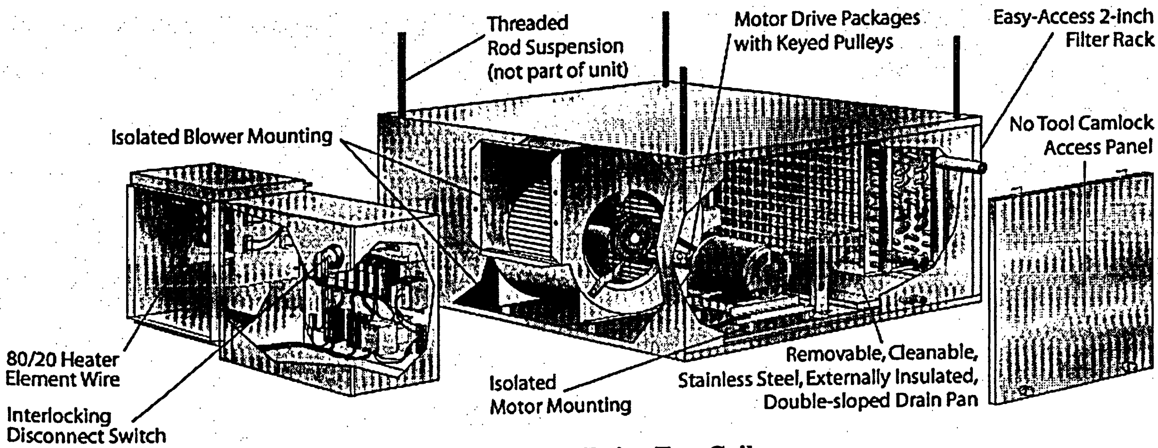


**FIGURE 10: Belt Drive Fan Coils**

### 5.3.2 - Air-Cooled Condenser Unit

A rooftop unit consists of direct-drive motors, propeller fans, fan guards, motor mounts, and condenser coils with optional integral subcooling circuit, and electrical junction box.

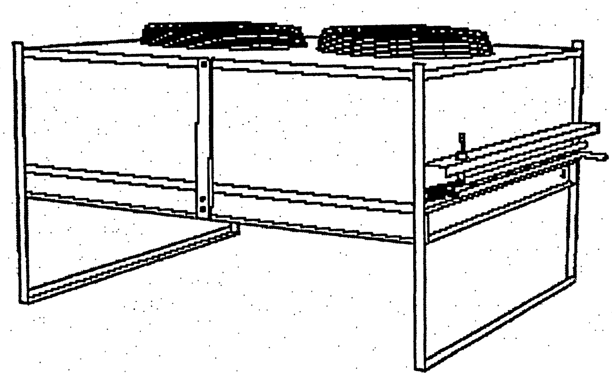

**FIGURE 11: Air-Cooled Condensers**

## 5.4 - BOILER & FURNACE

A variety of boilers and furnaces that operate today tends to lose a significant amount of heat through the chimney or stack. They all have common characteristics and similar techniques that can be applied to improve their efficiency. Conventional boilers and furnaces generally operate with low seasonal efficiencies of fifty to eighty percent. They can achieve high efficiencies of eighty to eighty-five percent but mostly they operate at part of a load.

Theoretically, for maximum efficiency, the combustion of natural gas requires a given fuel/oxygen ratio. For complete combustion, air (the mixture of oxygen and nitrogen) is used in excess to provide the necessary oxygen for burning.

There are many suggestions that can provide a solution for the complete combustion and make the boiler and furnace run at an optimum level. Following points proves better efficiency and saves in twenty to thirty percent. Below is the list of some of the suggestions:

- Clean airsides and maintain water level, or pressure to radiator.
- Seal all leaks into combustion chamber.
- Cleans and adjust burners each year, and monitor them periodically during the year.
- Maintain the lowest possible hot water temperature to meet the desired hot water needs.
- Schedule the boiler blow-down when needed, rather than fixed timetable.

The boiler model is characterized by two parameters, which represent the following heat transfer coefficients:

- $UA_{ge}$ : between the flue gas and the environment in CC (Combustion Chamber)
- $UA_{gw}$ : between the flue gas and the water in HEX

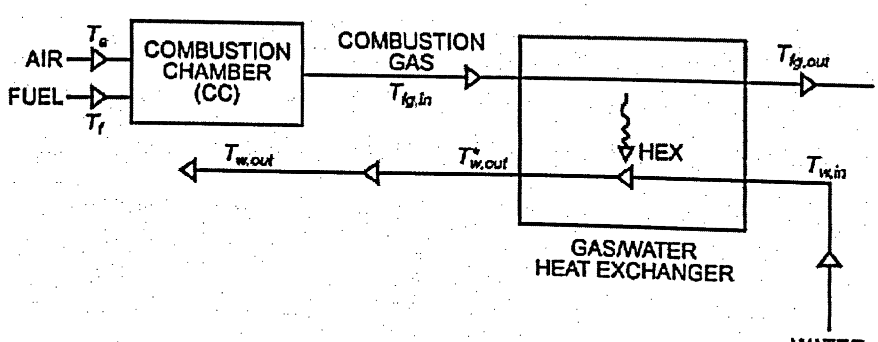


**FIGURE 12: Boiler Steady-State Modeling**

### 5.4.1 - Combustion Chamber Model

A mathematical description of this model helps calculate the flue gas mass flow rate and enthalpy, $h_{fg,in1}$ ($in Btu/lb_{fg}$), at the flue gas/water heat exchanger (HEX) inlet. The calculated flue gas mass flow rate is not necessarily the one associated with the specified value of the flue gas/water heat transfer coefficient/area product. Therefore, the following empirical relationship is used to adjust the value of this coefficient to the calculated value of the flue gas mass flow rate.

$$\dot{m}_{fg} = \left(1 + \frac{1}{f}\right)\dot{m}_f \qquad (5.4.1)$$

$$h_{fg,in} = \frac{h_{fg,in1}}{1 + 1/f} \qquad (5.4.2)$$

$$\left(UA_{gw}\right)_{calc} = UA_{gw}\left[\frac{\dot{m}_{fg}}{\left(\dot{m}_{fg}\right)_{rated}}\right]^{0.65} \qquad (5.4.3)$$

where, $h_{fg,in1}$ is the known function of composition of combustion products and the flue gas temperature at inlet of gas/water heat exchanger in $Btu/lb_{fg}$, and $h_{fg,in}$ is the gas enthalpy at outlet of gas/water heat exchanger in $Btu/lb_f$. $f$ is the fuel to air ratio, and $\left(\dot{m}_{fg}\right)_{rated}$ is the flue gas mass flow rate associated with the specified value of gas/water heat transfer coefficient/area product in $lb/\min$.

### 5.4.2 - Flue Gas - Water Heat Exchanger Model

The first step is to calculate the heat transfer rate, $q_{gw}$, across HEX1:

$$q_{gw} = \varepsilon_{gw} C_{fg}\left(T_{fg,in} - T_{w,in}\right) \qquad (5.4.4)$$

where, $C_{fg} = c_{p,fg}\dot{m}_{fg}$ is the heat capacity flow rate of flue gas and,

$\varepsilon_{gw} = \dfrac{1 - \exp\left[-NTU(1-C)\right]}{1 - C\exp\left[-NTU(1-C)\right]}$ is the effectiveness for HEX1.

For a counterflow heat exchanger,

$$NTU = \frac{UA_{gw}}{C_{fg}} \quad \text{and} \quad C = \frac{C_{fg}}{C_w} \qquad (5.4.5)$$

where, $C_{fg} \le C_w$ and $C_w = c_{p,w}\dot{m}_w$ .

The temperature of flue gas leaving HEX1, $T_{fg,out}$, can be calculated from,

$$\varepsilon_{gw}\left(T_{fg,in} - T_{w,in}\right) = \left(T_{fg,in} - T_{fg,out}\right) \qquad (5.4.6)$$

In HEX1, heat is transferred from hot flue gas to the water,

$$q_{gw} = C_w\left(T^{*}_{w,out} - T_{w,in}\right) \qquad (5.4.7)$$

Boiler efficiency is given by,

$$\eta = \frac{q_{gw}}{\dot{m}_f \times FLHV} \qquad (5.4.8)$$

In order to show that the energy can be saved from boilers improved settings, the effect of amount of excess air is the relative efficiency of a boiler.

***Problem Stating***

Boiler uses Natural gas as its fuel whose design heat output and the operating heat output is $265{,}000 Btu/hr$ and $210{,}000 Btu/hr$ respectively. The measured $O_2\%$ is about 8% and the unit-heat exit temperature is about 350°F. If the unit runs $8420 hrs/yr$, then the cost of natural gas is $\$12/1000 ft^3$.

- The ratio of the operating heat output to design heat output is,
  $OD = \dfrac{\text{Operating Heat Unit}}{\text{Design Heat Unit}} = \dfrac{210000}{265000} \approx 0.79$
- The ratio of average operation run to the whole year run is,
  $AT = \dfrac{\text{Average Yearly Hr of Operation}}{\text{Total Yearly Hr of Operation}} = \dfrac{8420}{8760} \approx 0.96$
- In order to estimate the annual cost of the excess air for the boiler, *(Refer to Appendix B, Figure 25)*
- If running at measured level, 8% $O_2$ is cost $= \$6{,}000$
- However, if the boiler runs at optimize level of 2% $O_2$ is cost $= \$3{,}000$
- Thus, difference $= 6{,}000 - 3{,}000 = 3{,}000$ ➔ Savings = \$2,632/*year*

Therefore, by running the boiler at an optimum level can save a lot in energy and money. Hence, economically this could be the most favorable energy saving scheme.

## 5.5 - Reducing the Energy Consumption of Fans

Another major energy conservation technique is to reduce the fan operation hours, and the resistance to air movement. During unoccupied hours, shutting off, or reducing the quantity of air supplied from the fan can save heating and cooling loads.

The power required to provide airflow and static pressure could be determined from the following equation:

$$P_A = 0.000157Vp \qquad (5.5.1)$$

where, $P_A$ is the air power in *hp*, $V$ is the flow rate in *cfm*, and $p$ is the pressure of water.

At standard air conditions, air density is equal to $0.075lb/ft^3$. The power necessary at the fan shaft involves inefficiencies of the fan, which may vary from fifty to seventy percent. This can be determined from,

$$P_F = \frac{P_A}{\eta_F} \qquad (5.5.2)$$

where, $P_F$ is the power required at fan shaft in hp, and $\eta_F$ is the fan efficiency in dimensionless.

Fan motor efficiencies generally vary from eighty to ninety-five percent, and drive losses for a belt drive are three percent of the fan power. This can be determined from,

$$P_M = (1+DL)\frac{P_F}{E_M E_D} \qquad (5.5.3)$$

where, $P_M$ is the power required at input to motor in hp, $E_D$ is the belt drive efficiency in dimensionless, $E_M$ is the fan motor efficiency in dimensionless, and $DL$ is the drive loss in dimensionless.

By analyzing the 44 Gerrard St. East, it is noticed that fans and ventilation system runs at high rate. Thus improving the efficiency and reducing the fan speed saves money and energy.

***Problem Stating***

Assume if the fan runs at $7000cfm$, and its pressure inch water gauge is $2.5inch$. Also, if it runs for $8hrs/day$ for whole year i.e, $3000hrs/yr$, then,

- At $7000cfm$ with $2.5"w.g$ and $3000hrs/yr$ of operation, the energy consumed is $40\times10^6 Btu/yr$ *(Refer to Appendix B, Figure 26)*
- Assume if the fan runs at $5500cfm$, with $2"w.g$ and $3000hrs/yr$, then the energy consumed is $25\times10^6 Btu/yr$ *(Refer to Appendix B, Figure 26)*
- The difference between the two is,

  $difference = 40\times10^6 Btu/yr - 25\times10^6 Btu/yr = 15\times10^6 Btu/yr$ or

  $$\frac{15\times10^6 Btu/yr}{3413 Btu/KWh} \approx 4395 KWh/yr$$
- At $\$0.08/KWh$ (price of electricity), the saving is,

  Savings $= \$0.08/KWh \times 4395 \approx \$352/year$ ➔ $\boxed{\text{Savings} = \$352/year}$

Therefore, by reducing the fan operation run from $7000cfm$ to $5500cfm$ saves $\$352/year$. However, even more energy can be cut back if fan can be shut off or its $cfm$ reduced during unoccupied hours.

# 5.6 - WATER SYSTEM

## 5.6.1 - Low-Flow Shower Head

Showers use significant amount of heated water at an expense of heating cost, and water consumption. Heating cost can be controlled by reducing the temperature of the domestic hot water (DHW) to the lowest possible level of the occupant's comfort. Keeping the lowest acceptable water flow can save the cost of both energy and the water.

By reducing the water flow, other options such as upgrading the showerheads can also decrease the water consumption. Most conventional showerheads use about 5gpm and they are restricted to control water flow rate. Installing new showerheads that can operate at a rate of about 2.5gpm can save money, and provide satisfactory spray pattern rather than high flow rate showerheads. Analyze the replacement of old showerheads to new ones.

***Problem Stating***

There are about 15 showerheads installed at 44 Gerrard St. East and the average duration of shower is about 7 minutes. In other words, the flow rate per showerhead measured at 5gal in 65 seconds. The hot shower water temperature is about 104°F, and the cold-water temperature is about 45 °F .

*Showerheads*

- $Flow\ rate = \left(\dfrac{5\,\text{gal}}{65\,\text{s}}\right) 60\,\text{min} = 4.62\,gpm$
- If 10 showers are used each day for $5 days/week$, weekly water consumption is,

$$Water\ consumption = (4.62 gpm \times 15 heads) \times (7\,\text{min} \times 10 showers \times 5 days/week) = 24{,}255 gal/week$$

- Installing new shower heads rated at 2.5gpm, then the weekly water consumption is reduced to,

$$Water\ consumption = (2.5 gpm \times 15 heads) \times (7\,\text{min} \times 10 showers \times 5 days/week) = 13{,}125 gal/week$$

- Weekly water saving is, $Water\ saving = 24{,}255 gal - 13{,}125 gal = 11{,}130 gal/week$
- At $\$0.006/gal$ (price of water consumption), the saving in water is,

$\text{Savings} = (11{,}130 gal/week) \times (\$0.006/gal) \approx \$67/week$ ➔ Savings = \$3216/ year

Therefore, installing new showerheads saves $\$3216/year$. However, this savings comes with cost of new showerheads. Assume the cost for new showerhead is \$50 each. Hence, $\text{Cost} = 15 \times \$50 = \$750$ plus the installation, Installation $= 15 \times \$10 labor = \$150$.

Therefore, Total Cost $= 750 + 150 = \$900$

Then the payback period is, payback $= \dfrac{\$900}{\$3216} \approx 0.3 years$

It will take 3 months to pay back at the current rate of the water consumption.

*Water Heating Savings*

- The energy required to heat the water at hot shower water temperature of 104°F, cold water temperature of 45 °F,

$$Energy\ required = 24{,}255\text{gal} \times (104 - 45)^{\circ} F \times \left( \frac{10 lb}{gal} \times \frac{1 Btu}{lb^{\circ}F} \right) = 14.3 \times 10^{6} Btu$$

- Assume water heating boiler runs at 70% efficiency, then the gas required to heat is,

$$Gas\ required = \frac{1.43 \times 10^{7} Btu}{0.7 \times 1000 Btu/ft^{3}} = 20443.5 ft^{3}$$

- If the water heating temperature been reduced to 100°F from 104°F with the installation of new heads, then the energy required to heat the water is,

$$Energy\ required = 13{,}125\text{gal} \times (100 - 45) \times \left( \frac{10 lb}{gal} \times \frac{1 Btu}{lb^{\circ}F} \right) = 7.22 \times 10^{6} Btu$$

- At 70% boiler efficiency with the new heads installed, then the gas required to heat is,

$$Gas\ required = \frac{7.22 \times 10^{6} Btu}{0.7 \times 1000 Btu/ft^{3}} = 10314.29 ft^{3}$$

- At $\$12/1000 ft^{3}$ (price of natural gas), the saving in natural gas is,

$$\text{Savings} = \frac{\$12}{1000 ft^{3}} \times \left(20443.5 ft^{3} - 10314.29 ft^{3}\right) \approx \$46/week \quad \rightarrow \quad \boxed{\text{Savings} = \$2208/year}$$

- Total Savings $= \$3216 + \$2208 = \$5424/year$ $\rightarrow$ $\boxed{\text{Total Savings} = \$5424/year}$

Therefore, installing new showerheads and reducing the water heating temperature saves $\$5424/year$.

### 5.6.2 - Water Savings

All the water of the buildings comes from the treatment plants, ends up in drainage, and is then processed a sewage treatment plants. This process costs money, which comes out of the building energy bill. Thus, reducing the water consumption reduces the cost, and the energy usage.

There are certain parameters that can be helpful for saving in water bills, such as:

- Fixing the malfunctioned water fountains.
- Turn off the water in the toilets basins and installing automatic or one push button water taps.
- Installing manual urinal flush tanks.
- The flow of water should be reduced by modifying the water-cooling pumps, not by throttling the flow.

### 5.6.3 - Plumbing System

Supplying water to the building is among the most critical services. A building is not suitable for human occupation without water. Piping is required for water to transfer to different part of the building. Pipes are generally made of copper, plastic, galvanized steel, and stainless steel. Copper is the most commonly used water-piping material because of its strength and durability.

In order to keep the water temperatures maintained, piping insulation with thermal material such as fibreglass, mineral wool, and the foam plastic are used. In 44 Gerrard St. East, the piping material is copper, and the insulation material is mineral wool with an R-value of three.

It is important to recognize that the insulation retards heat flow but it does not stop it completely. If the surrounding air temperature remains low enough for an extended period, insulation cannot prevent freezing of still water, or water flowing at a rate insufficient for the available heat content to offset heat loss. Insulation can prolong the time required for freezing or prevent freezing, if flow is maintained at a sufficient rate. To calculate the time, $\theta$ in hours, required by water to cool to 32°$F$ with no flow, the following equation has been included in eQUEST:

$$\theta = \rho C_p \pi \left(\frac{D_1}{2}\right)^2 R_T \ln\left[\frac{T_i - T_a}{T_f - T_a}\right] \qquad (5.6.1)$$

where, $\theta$ is the time to freeze, $\rho$ is the density of water (62.4 $lb/ft^3$), $C_p$ is the specific heat of water (1.0 $Btu/lb°F$), $D_1$ is the inside diameter of pipe in *ft* (see Figure 13), and $R_T$ is the combined thermal resistance of pipe wall, insulation, and the exterior air film (for a unit length of pipe). $T_i$ is the initial water temperature in °*F*, $T_a$ is the ambient air temperature in °*F*, and $T_f$ is the freezing temperature in °*F*.

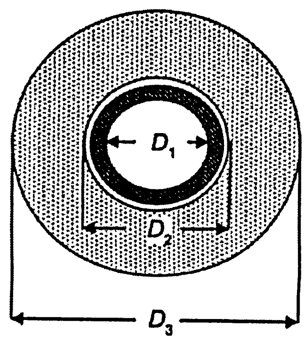

**FIGURE 13: Time to Freeze Nomenclature**

Thermal resistances of pipe walls and the exterior air film are usually neglected. Resistance of the insulation layer for a unit length of pipe is calculated as,

$$R_T = \frac{12}{2\pi k}\ln\left(\frac{D_3}{D_2}\right) \qquad (5.6.2)$$

where, $D_3$ is the outer diameter of insulation in *ft*, $D_2$ is the inner diameter of insulation in *ft*, and $k$ is the thermal conductivity of insulation material in $Btu\ in/ft^2\ °F$.

# CHAPTER 6 - RESULTS

Throughout the report, it is noticed that altering one or more parameters in the HVAC system is not always beneficial. For example, fixing the infiltration problem for the cooling season indirectly ends up costing more for the acceptable period. According to the ASHRAE standards, a payback period exceeding six years is considered a loss in an investment. In the case of high payback periods, decisions are made by the owners of the building to invest in such part of the project. Other factors can cover up the bad investment part. For example, fixing the infiltration problem for the heating season saves a lot of energy and money, and it can cover the cost in a reasonable amount of time. The infiltration payback period for both seasons averages out to be two years. Brief descriptions of the observed results are explained in the following paragraphs.

In the heating chapter, one of the issues that are discussed is reducing the indoor temperature during unoccupied periods. After conducting the analysis, it is realized that when the temperature is set back by $15^{\circ}F$, $\$2492$ is saved annually. Furthermore, this simple procedure conserves $135\times10^{6}Btu/ft^{2}/yr$ of energy. Subsequently, it is found that by reducing the relative humidity from 50% R.H to 30% R.H $\$738$ is capitally saved annually. Along with that, the ventilation system of the site is also examined. By conducting a detailed analysis on the system, it is concluded that by reducing the ventilation rate from $37cfm/person$ to $20cfm/person$, an energy saving opportunity of $276\times10^{6}Btu/yr$ is introduced. This translated to a capital gain of $\$5095$ annually. Infiltration is a big problem to any type of building and can cause big damage to the annual cost of energy bill. Infiltration is hard to control, and generally, resolves based on the assumptions from various researches. In order to reduce the energy consumption, proper precautions such as installation of weather strip to each window is advised. The installation will approximately cost $\$6250$, and it yields a capital gain of $\$2307$ annually. Evaluating the project in terms of the payback period, it is found that the return on investment of weather-strip installation is covered within three years. The insulation plays an important role in the heat transfer of the building's interior and exterior. Applying the insulation to various parts of the building can introduce a capital gain of $\$6091$. Assume that the insulation will cost approximately $32000, for which the payback period is approximately five years. Figure 14 summarizes the capital saving opportunities for the heating season.

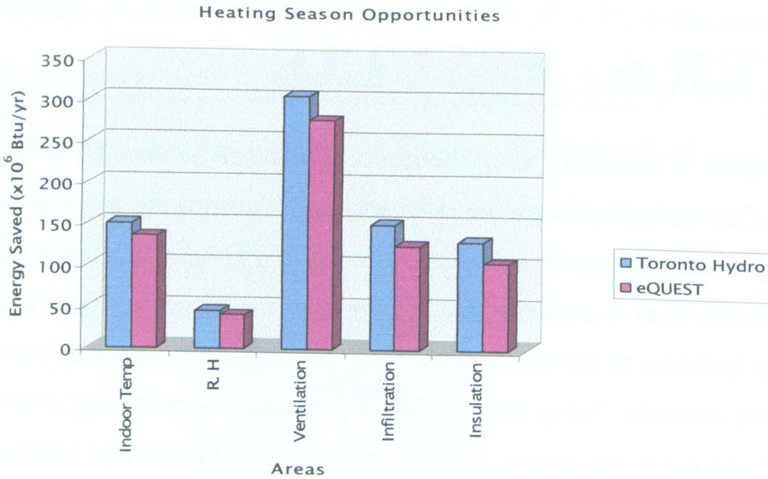


**FIGURE 14: Heating Season Opportunities**

Similar to the first chapter, the second chapter deals with the cooling season. When discussing the cooling load, lights play a big role in the overall effect of the energy consumption, discussed later in this chapter. One of the simple cooling load energy saving techniques is increasing the indoor temperature from $70^{\circ}F$ to $78^{\circ}F$; a capital gain of $\$1011$ annually is achieved. Increasing the relative humidity and maintaining a comfortable zone for the personnel at the site shows an additional saving of $\$108$ annually. In addition, when the ventilation rate is reduced from $25cfm/person$ to $15cfm/person$, savings of $\$223$ annually is realized. As per infiltration discussed earlier in chapter 3.5, the savings are not great compared to rest of the parameters because wind velocities are generally slower in summer. However, a savings of $\$600$ annually is found with the installation of weather strips. The cumulative savings from the winter and summer season for infiltration are $\$2907$ with an unacceptable payback period of two years. The figure below summarizes the capital saving opportunities for the cooling season.

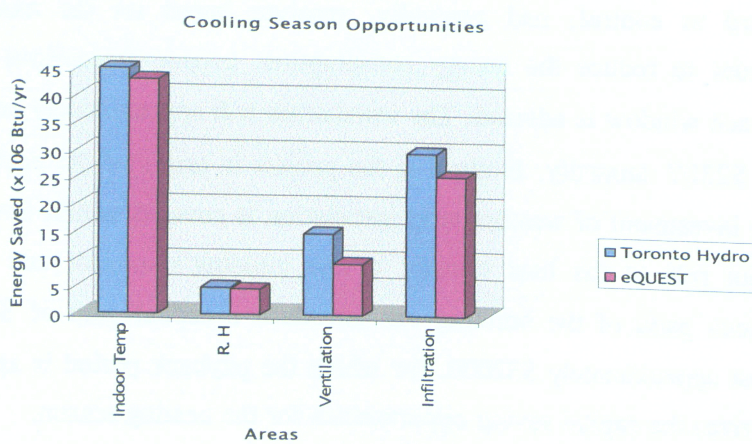


**FIGURE 15: Cooling Season Opportunities**

The fourth chapter, lighting, covers a major portion of the energy load. The simplest procedure to save energy consumed by lighting is to switch off lights in areas that are not required. It is most often realized that lights are left on overnight when there is no one in the building, which enforces a load on electricity. Reducing the lighting wattage by 50% by installing dimmers gains a capital of $4400 annually with a payback period of approximately five years. Installing higher efficiency lamps or by installing timers to control the light timings proved to be beneficial. Proposing low-pressure sodium light compared to Medium Bipin fluorescent lights translates into a capital gain of $1680 annually. This lighting modification provides a payback period of six years and four months. Installing timers saves up to $292 annually with an initial investment of $1350, and it has a payback period of six years and four months. During daytime, natural light can be a good source for various needs such as, it can reduce the electric load as well as the cooling load.

At the end, the HVAC system of the site is studied to determine any potential saving. An analysis is conducted to determine how much energy can be saved from lowering the speed of a forward blade fan. Optimizing the fan operation run from $7000cfm$ to $5500cfm$ gained a savings of $352 annually. Theoretically speaking, if the boiler is able to operate at its optimum condition, a tremendous saving of $2632 is achieved each year. It is very crucial to keep the boiler in an excellent condition, primarily because it operates throughout the year. Thus, the energy wastage can be enormous. A complete layout of the HVAC distribution system is designed in eQuest software that aids this energy audit and is available in Appendix C – Figure 28. Since 44 Gerrard St. East has large number of shower stalls, therefore, installing new showerheads saves $\$3216/year$ with the initial investment of $900, which gives payback period of only three months. Also, conserving the hot water consumption at 70% boiler efficiency with the new heads installed saves $\$2208/year$.

Table 16 gives the cost-reducing chart by practicing the methods mentioned throughout the report to conserve energy.

TABLE 16: Summary of Energy Saving Translated to Capital Savings

| Case | Description | One-Time Costs $ | Savings per year $ | Simple Payback yrs |
|---|---|---|---|---|
| Alt #1 | Set Back Indoor Temp | $0 | $2,492 | 0.0 |
| Alt #2 | Raise Indoor Temp | $0 | $1,101 | 0.0 |
| Alt #3 | Reduce R. H | $0 | $738 | 0.0 |
| Alt #4 | Incr. R. H | $0 | $108 | 0.0 |
| Alt #5 | Vent (Heat Season) | $0 | $5,095 | 0.0 |
| Alt #6 | Vent (Cool Season) | $0 | $223 | 0.0 |
| Alt #7 | Infiltration | $6,250 | $2,907 | 2.1 |
| Alt #8 | Insulation | $32,000 | $6,091 | 5.3 |
| Alt #9 | Dimmers | $22,865 | $4,400 | 5.2 |
| Alt #10 | Replace lamps | $10,713 | $1,680 | 6.4 |
| Alt #11 | Timers | $1,350 | $292 | 4.6 |
| Alt #12 | Improve Boiler eff | $0 | $2,632 | 0.0 |
| Alt #13 | Reduce Fan Energy | $0 | $352 | 0.0 |
| Alt #14 | Improve Shower eff | $900 | $3,216 | 0.3 |
| Alt #15 | Water Heating | $0 | $2,208 | 0.0 |
| | Total | $74,078 | $33,535 | 2.21 |

Figure 16 shows the payback period for all the parameters calculated based on various techniques after the initial investment.

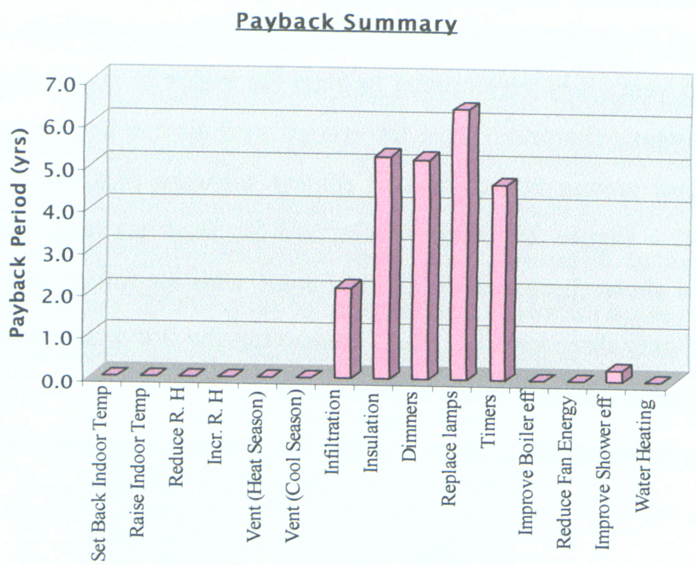


FIGURE 16: Payback Period

The above graph (Figure 16) shows that replacing lamps incorporates a long payback period. Installing timers help gain capital but due to the moderate payback period, they also might not be the foremost parameters for the client. Therefore, the parameters that are most likely to attract the customer are those with minimum payback period.

# CHAPTER 7 - CONCLUSION

Energy Management is the conservation of energy in order to achieve the lowest cost. By analyzing 44 Gerrard St. East, the rate at which the energy is conserved is remarkable. There are various proportional observations through which energy is conserved that are discussed throughout the report. These conservation techniques arise from the simple task of switching off lights when not needed, to more complicated tasks suck as upgrading a complete heating unit. Each task comes with a different price, but there is always a payback to cover the expenditure.

Inputting all the required parameters in eQUEST software provided interesting outcomes. Diagrams of 2D and 3D models of the building along with the view of the entire HVAC system showed great help in solving the energy conservation problem. Some of the inputs that are introduced in the software are either based on various assumptions or based on researched studies.

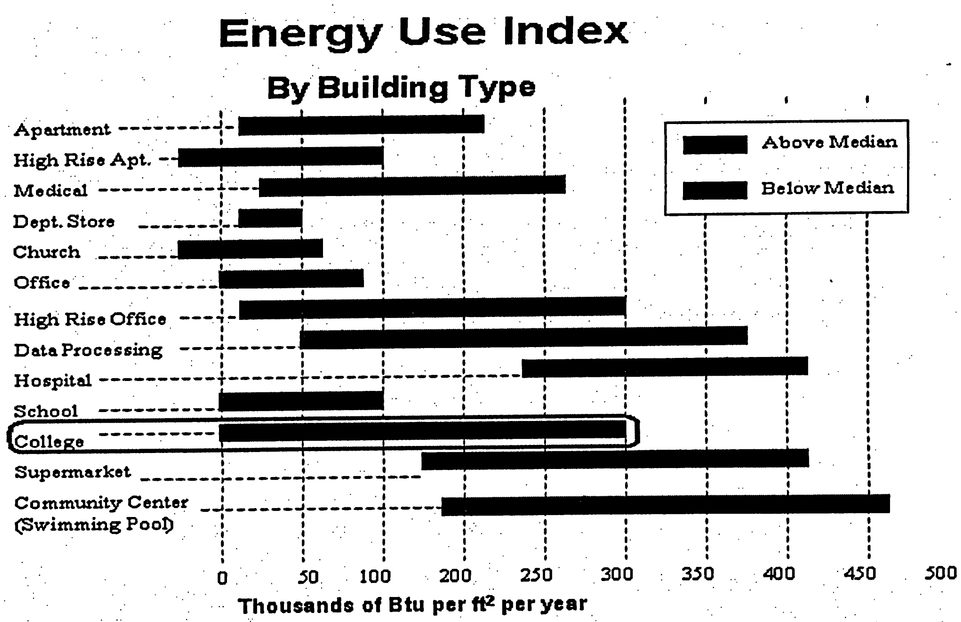


**FIGURE 17: Average Building Energy Consumption Rate**

The access to different parts of the site was restricted to building personnel only. Thus, most of the time values are assumed. However, carefully calculated assumptions led to close annual energy consumption numbers. Figure 17 shows that the annual energy consumption for an average college is in the range of $150\times10^{6} Btu/ft^{2}/yr$ to $300\times10^{6} Btu/ft^{2}/yr$. However, the calculated annual energy usage from eQUEST came out to be $278\times10^{6} Btu/ft^{2}/yr$ (Appendix C - Table 19). Similarly, Appendix C - Figure 33 shows the annual electricity consumption report for Ryerson Theatre School (44 Gerrard St.

East) is $246{,}534 KWh/yr$, and the calculated annual site energy from eQUEST came out be $244{,}450 KWh/yr$; a percentage error of less than 1%.

**TABLE 17: Monthly Total Electric Energy Comparison**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| eQUEST | 17.070 | 20.950 | 20.820 | 17.860 | 19.880 | 20.340 | 25.800 | 20.550 | 22.850 | 20.330 | 20.370 | 17.630 | ***244.450*** |
| Hydro | 19.590 | 21.582 | 22.246 | 22.578 | 16.602 | 15.273 | 24.571 | 17.93 | 23.242 | 23.242 | 22.744 | 16.934 | ***246.534*** |

Table 17 shows the monthly energy consumption from the eQUEST, and the Toronto Annual Hydro Report for 44 Gerrard St. East. In comparison, Figure 18 shows the close resemblance between the two results.Therefore, eQUEST results can be used as a guide to prove the energy conservation facts.

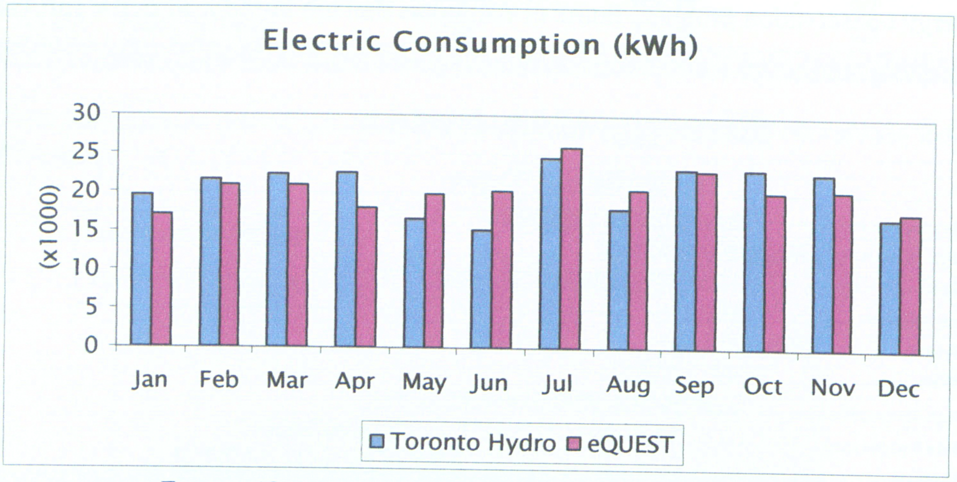


**FIGURE 18: Monthly Total Electric Energy Comparison**

If the cost of $1KWh$ is 8 cents, this means that the 44 Gerrard St. East spends $\$19{,}722$ each year on electricity plus the gas bill (approximately $\$16{,}500$); a total of $\$36{,}222$ annually. After conducting the energy audit analysis, it is found that adjusting the usage of energy in various areas can reduce the cost to $\$33{,}535$ annually. This reduction shows an energy saving of approximately 9%. The energy audit of this site is conducted in detail to illustrate energy saving opportunities.

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# REMARKS

[1] **Building load** is the magnitude of the building heating, cooling and the amount of energy required to maintain the desired indoor space conditions, temperature, and humidity levels and to operate the building equipment.

[2] **HVAC** (heating, ventilating, and air-conditioning) refers to the equipment, distribution network and terminals that provide either collectively or individually the heating, ventilating or air-conditioning processes to a building.

[3] **Wet-bulb temperature** is measured using a standard mercury-in-glass thermometer, with the thermometer bulb wrapped in muslin, which is kept wet. The evaporation of water from the thermometer has a cooling effect, so the temperature indicated by the wet bulb thermometer is less than the temperature indicated by a dry-bulb (normal, unmodified) thermometer. The rate of evaporation from the wet-bulb thermometer depends on the humidity of the air evaporation, which is slower when the air is already full of water vapor. For this reason, the difference in the temperatures indicated by the two thermometers gives a measure of atmospheric humidity.

[4] **Dry-bulb temperature** is the usual measurement for determining the standard of heating.

[5] **Building Envelope** is a critical component of any facility since it protects the building occupants and plays a major role in regulating the indoor environment. It consists of building's roof, walls, windows, and doors. The envelope controls the flow of energy between the interior and the exterior of the building. The building envelope can be considered the selective pathway for a building to work with the climate-responding to heating, cooling, ventilating, and natural lighting needs.

[6] **Distribution system load** is a measure of the energy required to deliver energy from the primary conversion equipment to supply the building load. In other words, the energy used in heating, ventilating and air-conditioning systems to distribute hot or cold air or water is mainly for motor fans and hot or chilled water or condenser water motor driven pumps.

[7] **Vapor Diffusion** is the process by which water vapor spreads or moves through permeable materials caused by a difference in water vapor pressure. It is the movement of water vapor molecules from regions of higher absolute humidity to regions of lower absolute humidity.

[8] **R Value** -"R" stands for resistance to winter heat loss and summer heat gain. Even though one type or brand of insulation is thicker or thinner than another is, it will provide identical resistance to heat loss if the R-value is the same. R-values can be added such as: if one has R-11 attic insulation and wants R-30, then one can add an insulation material rated at R-19.

[9] **Enthalpy** is a thermodynamic function of a system. It is equivalent to the sum of the internal energy of the system and the product of its volume multiplied by the pressure exerted on it by its surroundings.

# APPENDIX – A (ASSOCIATED FORMAULAS)

## Degree Days

The determination of the Degree Days is based upon the daily maximum $t_{max}$ and the minimum $t_{min}$ outdoor temperatures and the temperature rise resulting from the internal heat gain.

### Heating Degree Days

$$H_{DD} = B - \frac{1}{2}(t_{max} + t_{min})$$

$$H_{DD} = \frac{1}{2}(B - t_{min}) - \frac{1}{4}(t_{max} - B)$$

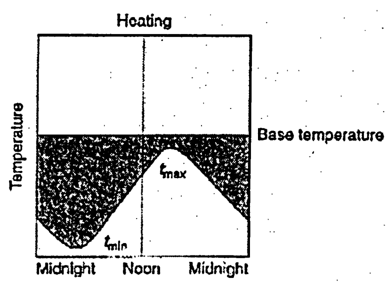
$$H_{DD} = \frac{1}{4}(B - t_{min})$$

### Cooling Degree Days

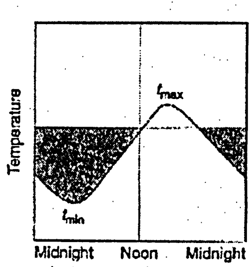
$$C_{DD} = \frac{1}{2}(t_{max} + t_{min}) - B$$

$$C_{DD} = \frac{1}{2}(t_{max} - B) - \frac{1}{4}(B - t_{min})$$

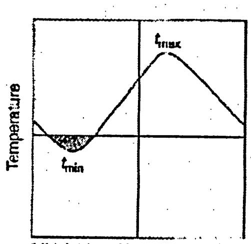
$$C_{DD} = \frac{1}{4}(t_{max} - B)$$



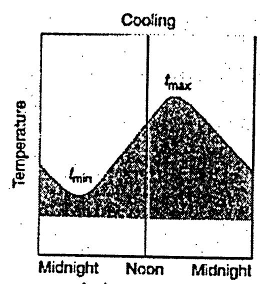

$B - 1/2\,(t_{max} + t_{min})$



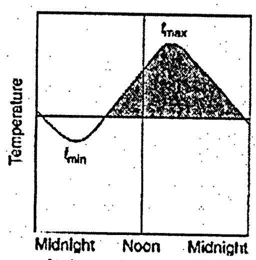

$1/2\,(B - t_{min}) - 1/4\,(t_{max} - B)$



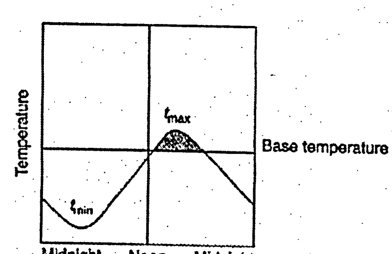

$1/4\,(B - t_{min})$




$1/2\,(t_{max} + t_{min}) - B$




$1/2\,(t_{max} - B) - 1/4\,(B - t_{min})$




$1/4\,(t_{max} - B)$

Heating and cooling degree-days is usually found at any weather network and in this case, from Toronto weather network.

## Simple Payback

$$Simple\ Payback = \frac{\text{cost of energy proposal}}{\text{annual saving - annual cost of saving}}$$

***Cooling Calculations***

Here, the cooling at each time interval is just the sum of the heat transferred to the room air by convection from the floor and the ceiling plus $^{(1-P)}\!/_2$ of the input power.

Heat balance equations can be set up as follows, using the room air temperature as the zero bases:

- At the surface of floor slab

$$Q_{1,n} + \frac{1-P}{2} - h_1 T_{1,n} + h_{r41}\left(T_{4,n} - T_{1,n}\right) = 0$$

where, $$Q_{1,n} = \sum_{j=0}^{\infty} T_{2,n-j} Y_j - \sum_{j=0}^{\infty} T_{1,n-j} X_j$$

- At the lower surface of floor slab

$$Q_{2,n} + \frac{P}{2} W - h_2\left(T_{c,n} - T_{2,n}\right) + h_{r32}\left(T_{3,n} - T_{2,n}\right) = 0$$

where, $$Q_{2,n} = \sum_{j=0}^{\infty} T_{1,n-j} Y_j - \sum_{j=0}^{\infty} T_{2,n-j} Z_j$$

- At the upper surface of ceiling panel

$$\frac{k_c}{L_c}\left(T_{4,n} - T_{3,n}\right) + h_3\left(T_{c,n} - T_{3,n}\right) - h_{r32}\left(T_{3,n} - T_{2,n}\right) = 0$$

- At the lower surface of ceiling panel

$$\frac{k_c}{L_c}\left(T_{3,n} - T_{4,n}\right) + h_4 T_{4,n} - h_{r41}\left(T_{4,n} - T_{1,n}\right) = 0$$

- At the ceiling plenum

$$h_2\left(T_{2,n} - T_{c,n}\right) + h_3\left(T_{c,n} - T_{3,n}\right) - \frac{P}{2} W - 2C_{p\gamma} V T_{c,n} = 0$$

These above equations can be expressed in matrix form for the simplicity of calculation in the form of $T_{1,n}$, $T_{2,n}$, $T_{3,n}$, $T_{4,n}$ and $T_{c,n}$.

$$[M]\cdot[T] = [K]$$

$$[M] = \begin{bmatrix} -h_1 - h_{r41} & -X_o, Y_o & 0 & h_{r41} & 0 \\ Y_o & -h_2 - h_{r32} - Z_o & h_{r32} & 0 & h_2 \\ 0 & h_{r32} & -\frac{k_c}{L_c} - h_3 - h_{r32} & \frac{k_c}{L_c} & h_3 \\ h_{r41} & 0 & \frac{k_c}{L_c} & -\frac{k_c}{L_c} - h_4 - h_{r41} & 0 \\ 0 & h_2 & h_3 & 0 & -h_2 - h_3 - 2C_{p\gamma} V \end{bmatrix}$$

$$[T]=\begin{bmatrix} T_{1,n} \\ T_{2,n} \\ T_{3,n} \\ T_{4,n} \\ T_c \end{bmatrix} \qquad [K]=\begin{bmatrix} -\frac{1-P}{2}W+\sum_{j=1}^{\infty}T_{1,n-j}X_j-\sum_{j=1}^{\infty}T_{2,n-j}Y_j \\ -\frac{P}{2}W+\sum_{j=1}^{\infty}T_{2,n-j}Z_j-\sum_{j=1}^{\infty}T_{1,n-j}Y_j \\ 0 \\ 0 \\ -\frac{P}{2}W \end{bmatrix}$$

The cooling load due to lights after switched on,

$$Q_n = h_1 T_{1,n} + h_4 T_{4,n} + \frac{1-P}{2}W$$

The first term represents the convection heat transfer from the upper surface of floor slab to the room air. The second term is the transfer from the lower surface of ceiling to the room air. The third term is the instantaneous heat gain from fixtures.

## *Solar Equations*

### Solar Angles

All angles are in degrees. The solar azimuth $\phi$ and the surface azimuth $\gamma$ are measured in degrees from south; angles to the east of south are negative, and angles to the west of south are positive. Calculate solar altitude, azimuth, and surface incident angles as follows:

Apparent solar time AST, in decimal hours: $AST = LST + \dfrac{ET}{60} + \dfrac{(LSM - LON)}{15}$

Hour angle *H*, degrees: $H = 15(\textit{hour of time from local solar noon}) = 15(AST - 12)$

Solar altitude $\beta$: $\sin\beta = \cos L \cos\delta \cos H + \sin L \sin\delta$

Solar azimuth $\phi$: $\sin\phi = \dfrac{(\sin\beta \sin L - \sin\delta)}{\cos\beta \cos L}$

Surface-solar azimuth $\gamma$ : $\gamma = \phi - \psi$

Incident angle $\theta$: $\cos\theta = \cos\beta \cos\gamma \sin\Phi + \sin\beta \cos\Phi$

where,

| | |
|---|---|
| ET | = equation of time, decimal minutes |
| $L$ | = latitude |
| LON | = local longitude, decimal degrees of arc |
| LSM | = local standard time meridian, decimal degrees of arc |
| | = 60° for Atlantic Standard Time |
| | = 75° for Eastern Standard Time |
| | = 90° for Central Standard Time |
| | = 105° for Mountain Standard Time |
| | = 120° for Pacific Standard Time |
| | = 135° for Alaska Standard Time |
| | = 150° for Hawaii-Aleutian Standard Time |
| LST | = local standard time, decimal hours |
| $\delta$ | = solar declination, *deg* |
| $\psi$ | = surface azimuth, *deg* |
| $\Phi$ | = surface tilt from horizontal, horizontal = 0° |

Values of *ET* and $\delta$ are given in National Weather Report for the 21st day of each month.

### Direct, Diffuse, and Total Solar Irradiance

***Direct normal irradiance*** $E_{DN}$

If $\beta > 0$ $\quad E_{DN} = \left[\dfrac{A}{\exp(B/\sin\beta)}\right] CN$ $\quad$ Otherwise, $E_{DN} = 0$

***Surface direct irradiance*** $E_D$

If $\cos\theta > 0$ $\quad E_D = E_{DN}\cos\theta$ $\quad$ Otherwise, $E_D = 0$

Ratio *Y* of sky diffuse on vertical surface to sky diffuse on horizontal surface

If $\cos\theta > -0.2$ $\quad Y = 0.55 + 0.437\cos\theta + 0.313\cos^2\theta$ $\quad$ Otherwise, $Y = 0.45$

***Diffuse irradiance*** $E_d$

Vertical surfaces $E_d = CYE_{DN}$

Surfaces other than vertical $E_d = CE_{DN}(1+\cos\Phi)/2$

Ground-reflected irradiance $E_r = E_{DN}(C+\sin\beta)\rho_g(1-\cos\Phi)/2$

Total surface irradiance $E_t = E_D + E_d + E_r$

*where*

$A$ = apparent solar constant
$B$ = atmospheric extinction coefficient
$C$ = sky diffuse factor
$CN$ = clearness number multiplier for clear/dry or hazy/humid locations. See Figure 5 in Chapter 33 of the 2003 *ASHRAE Handbook—HVAC Applications* for CN values.
$E_d$ = diffuse sky irradiance
$E_r$ = diffuse ground-reflected irradiance
$\rho_g$ = ground reflectivity

Values of *A, B,* and *C* can be found from National Weather Report for the 21st day of each month. Values of ground reflectivity $\rho_g$ are given in Table 19.

**TABLE 18: Solar Reflectances of Foreground Surfaces**

| | **Incident Angle** | | | | | |
|---|---|---|---|---|---|---|
| **Foreground Surface** | **20°** | **30°** | **40°** | **50°** | **60°** | **70°** |
| New concrete | 0.31 | 0.31 | 0.32 | 0.32 | 0.33 | 0.34 |
| Old concrete | 0.22 | 0.22 | 0.22 | 0.23 | 0.23 | 0.25 |
| Bright green grass | 0.21 | 0.22 | 0.23 | 0.25 | 0.28 | 0.31 |
| Crushed rock | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Bitumen and gravel roof | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| Bituminous parking lot | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | 0.12 |

# APPENDIX – B (RELATED GRAPHS)

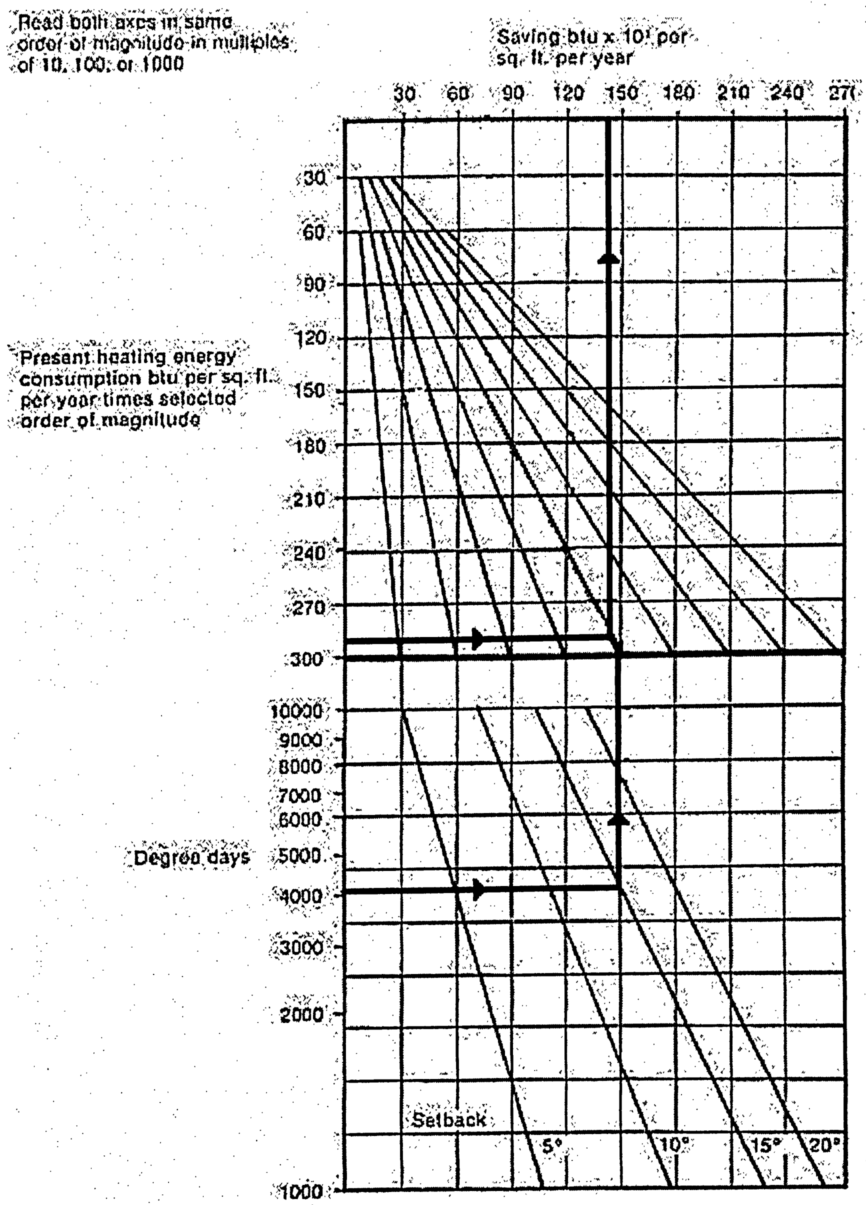



**FIGURE 19: Energy Saved by Night Setback**

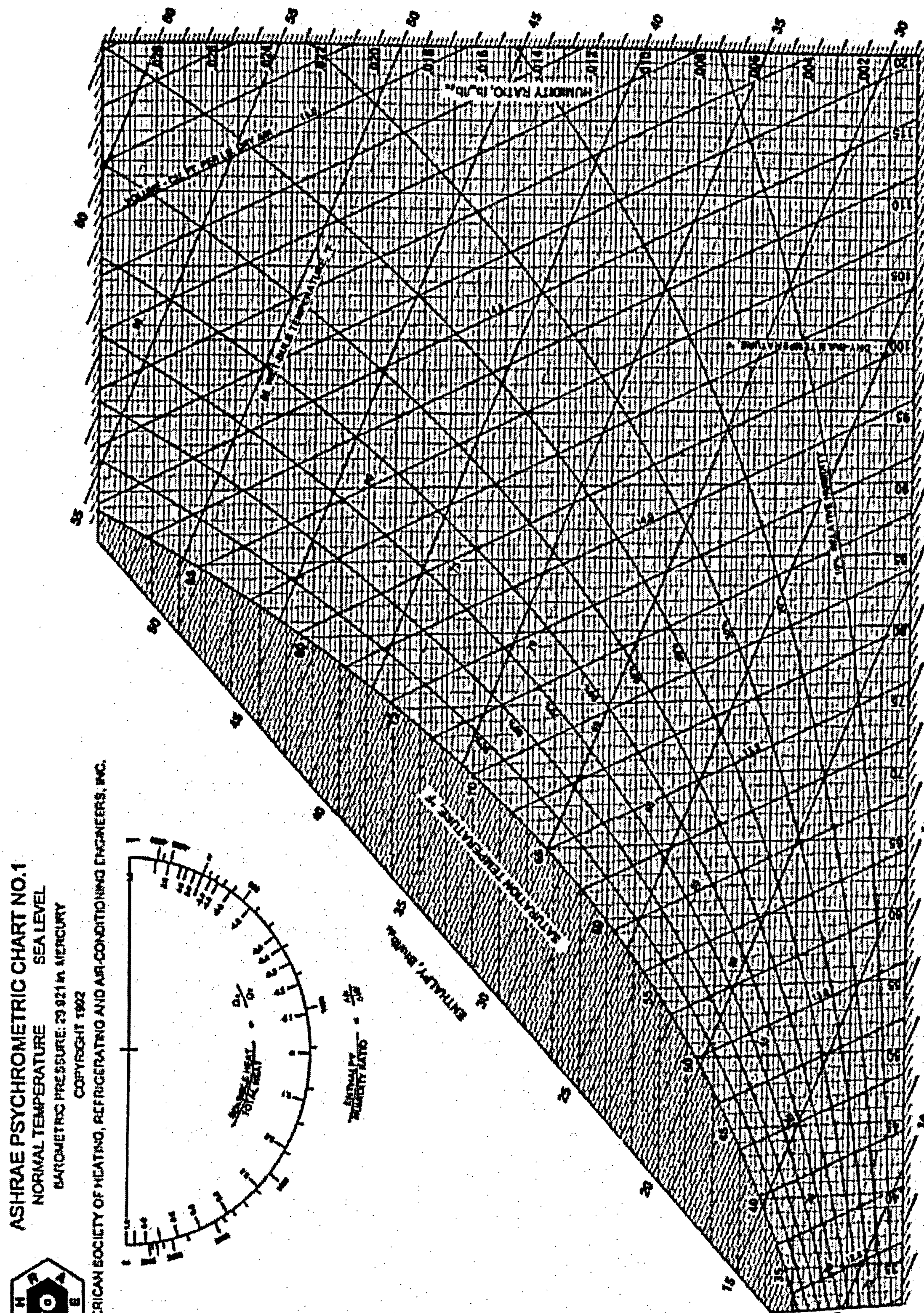



**FIGURE 20: ASHRAE Psychrometric Chart No. 1**

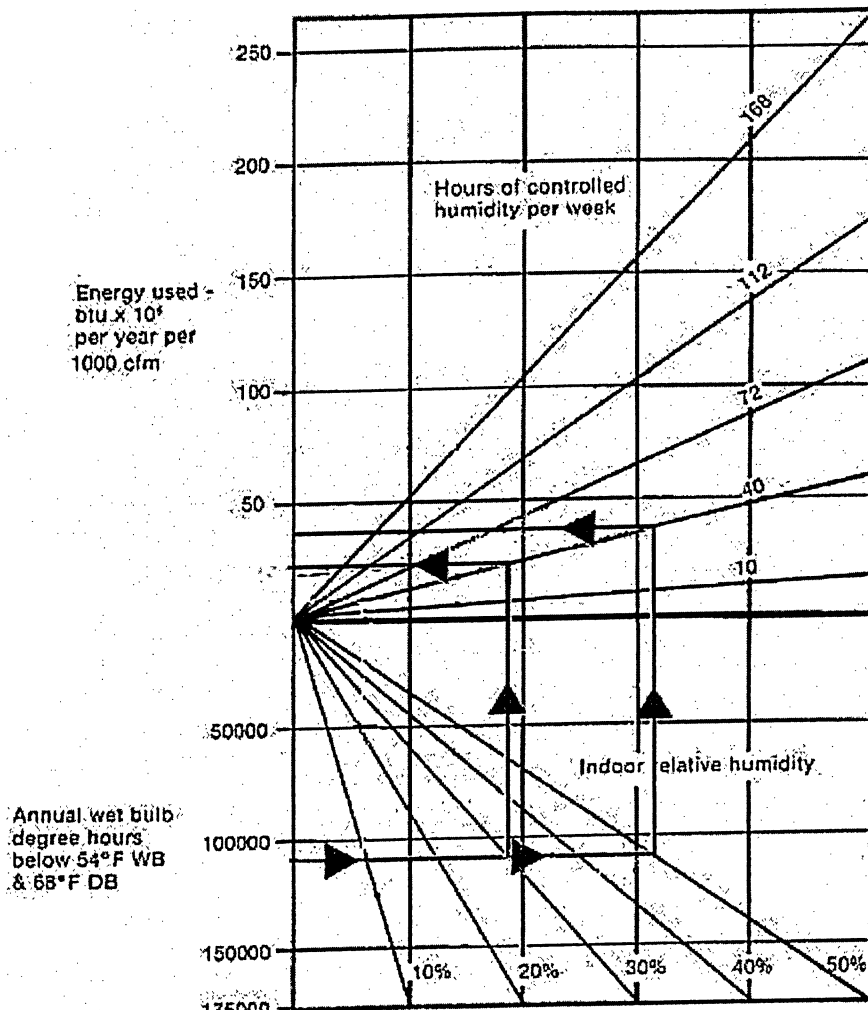



**FIGURE 21: Energy Used by reducing Relative Humidity for Heating Season**

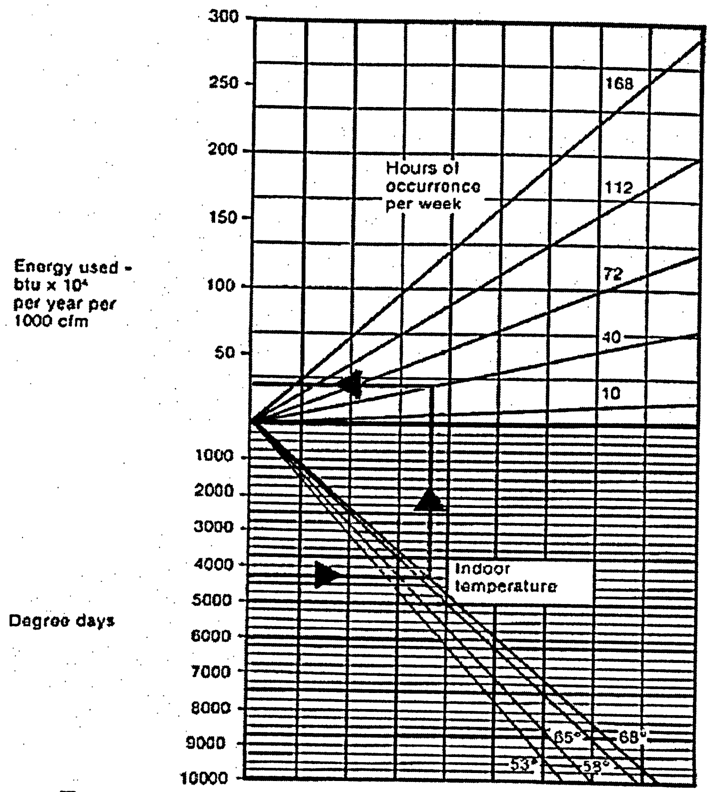



**FIGURE 22: Energy Used to Ventilate Outdoor Air**

Key to window infiltration chart
(leakage between sash & frame)

| | Type | Material | Weather stripped? | Fit |
|---|---|---|---|---|
| 1 | All hinged | Wood | Yes | Avg. |
| | | Metal | Yes | Avg. |
| 2 | All hinged dbl. hung | Wood | No | Avg |
| | | Metal | No | Avg. |
| | | Steel | No | Avg. |
| 3 | All dbl. hung | Wood | Yes | Loose |
| | | Steel | Yes | Avg |
| 4 | Casement | Steel | No | Avg. |
| 5 | All hinged | Wood | No | Loose |

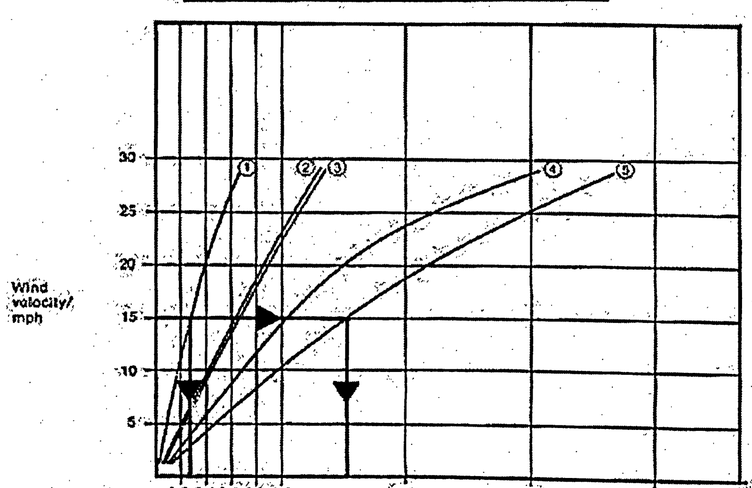



**FIGURE 23: Rate of Infiltration through Window Frames**

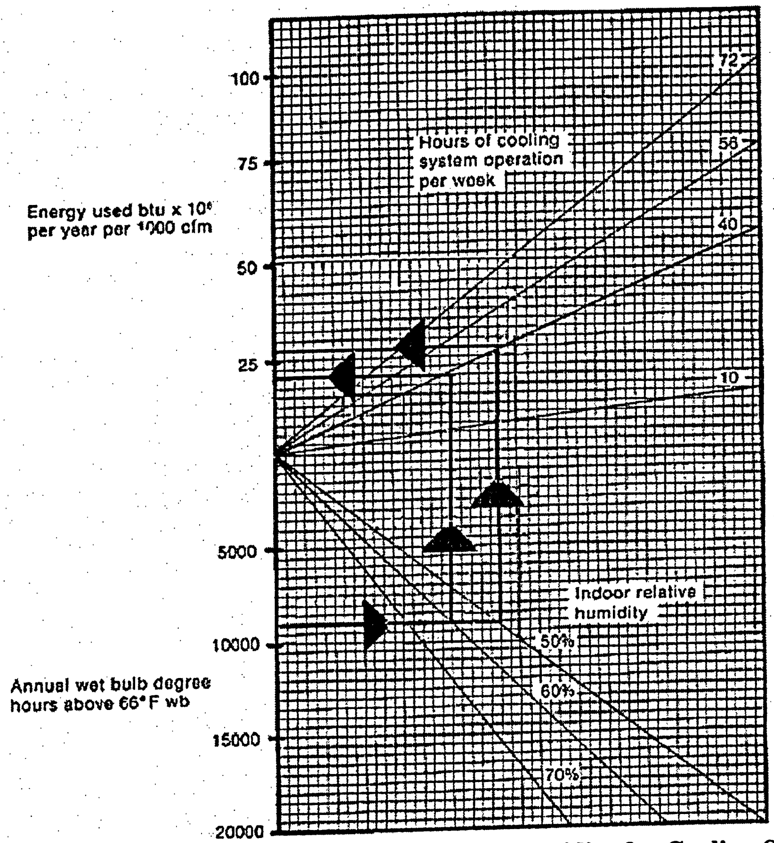



**FIGURE 24: Energy Used by increasing Relative Humidity for Cooling Season**

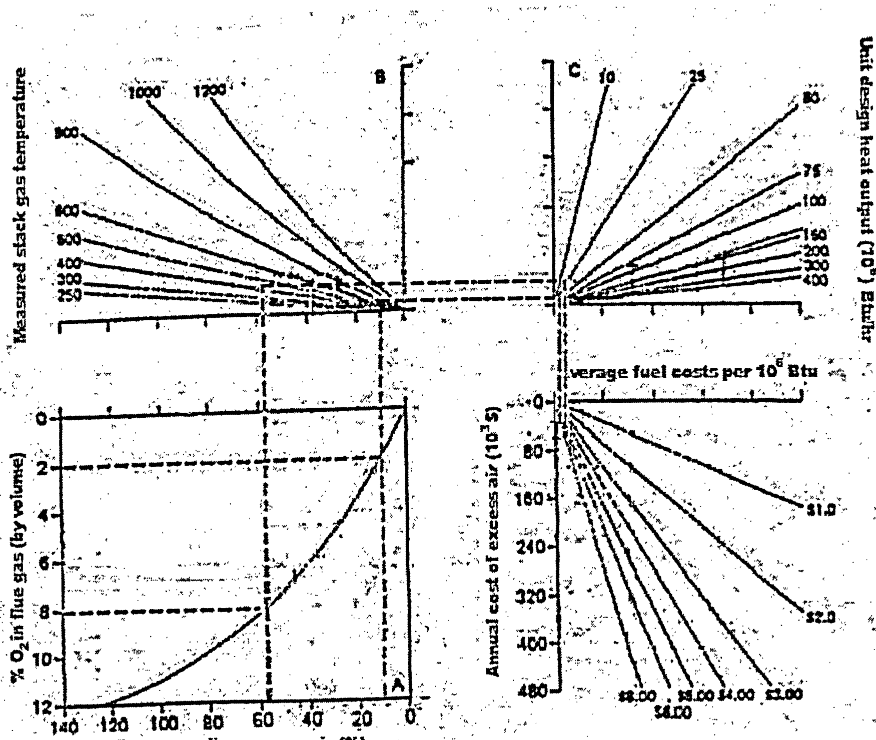



**FIGURE 25: Natural Gas chart to determine Annual Savings**

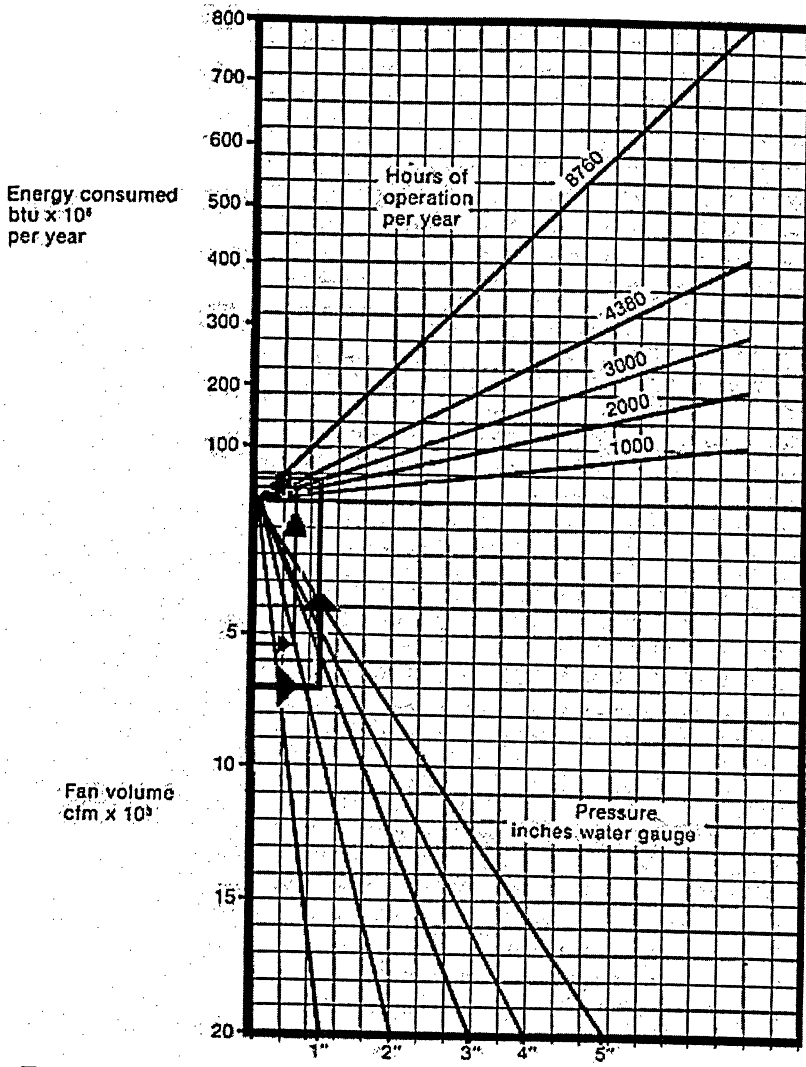



**FIGURE 26: Annual Energy Consumption for Forward Blade fans**

# APPENDIX – C (EQUEST REPORT)

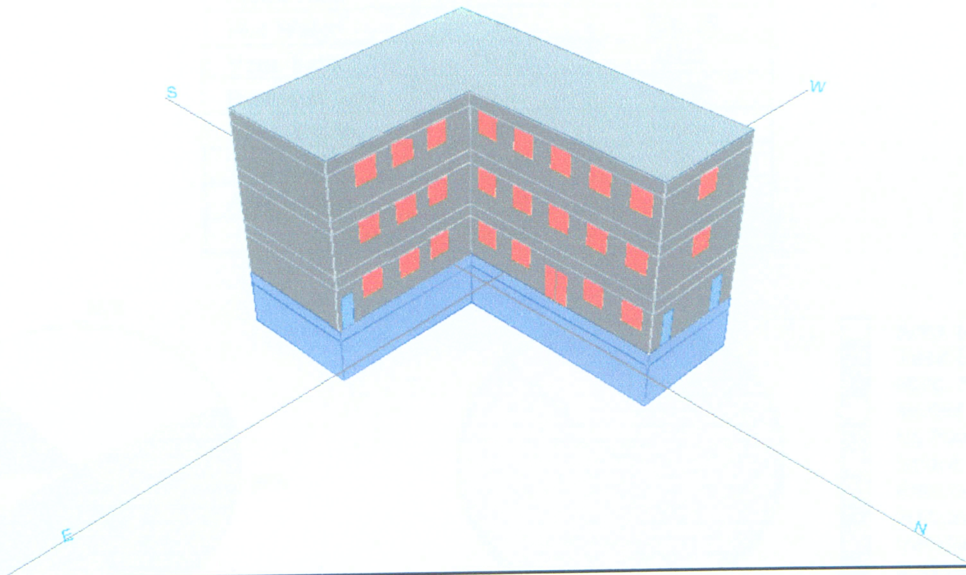



FIGURE 27: eQUEST generated 44 Gerrard St. East Outlook

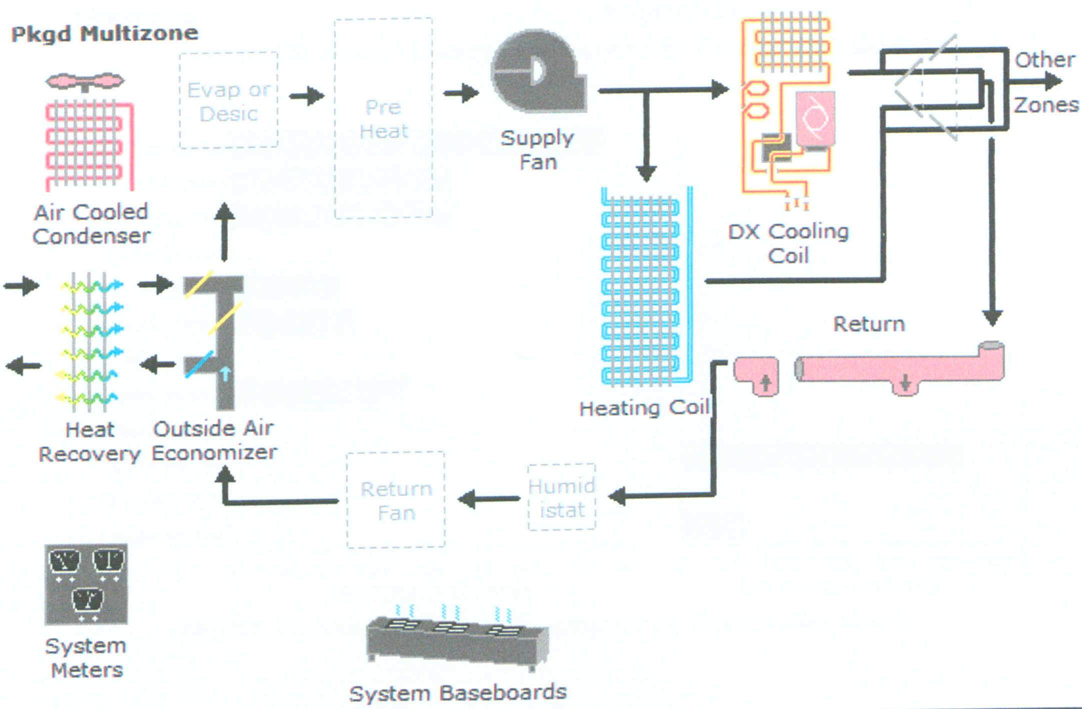



FIGURE 28: eQUEST generated HVAC System

## ANNUAL ENERGY CONSUMPTION BY ENDUSE

TABLE 19: Annual Energy Consumption by Enduse

| | Electricity | Natural Gas |
|---|---|---|
| | kWh (x000) | MBtu |
| Space Cool | 35.3 | 0 |
| Space Heat | 0 | 535.2 |
| Hot Water | 0 | 126.18 |
| Vent. Fans | 19.85 | 0.00 |
| Pumps & Aux. | 25.51 | 0.00 |
| Misc. Equip. | 44.93 | 0 |
| Task Lights | 43.84 | 0 |
| Area Lights | 75.03 | 0 |
| ***Total*** | ***244.46*** | ***661.38*** |

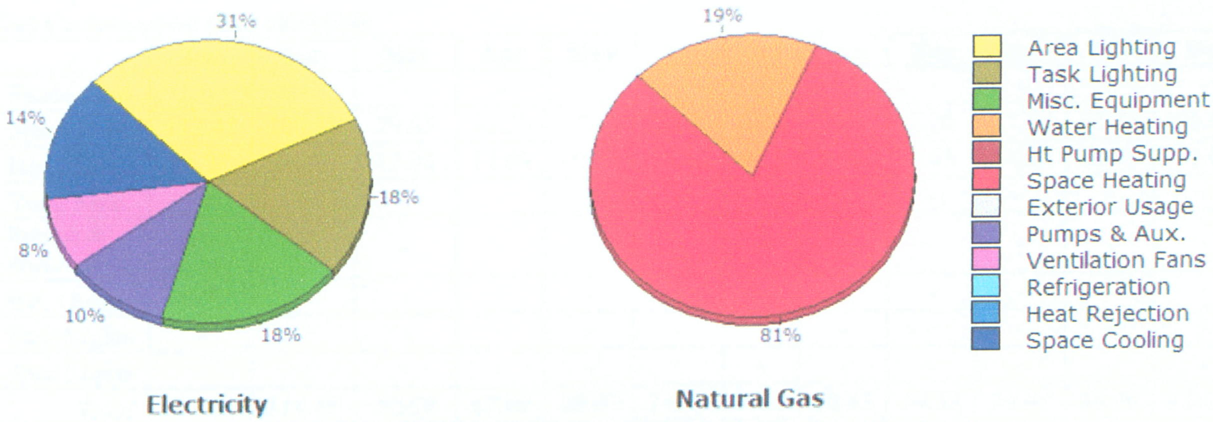



FIGURE 29: Annual Energy Consumption by Enduse (Pie chart)

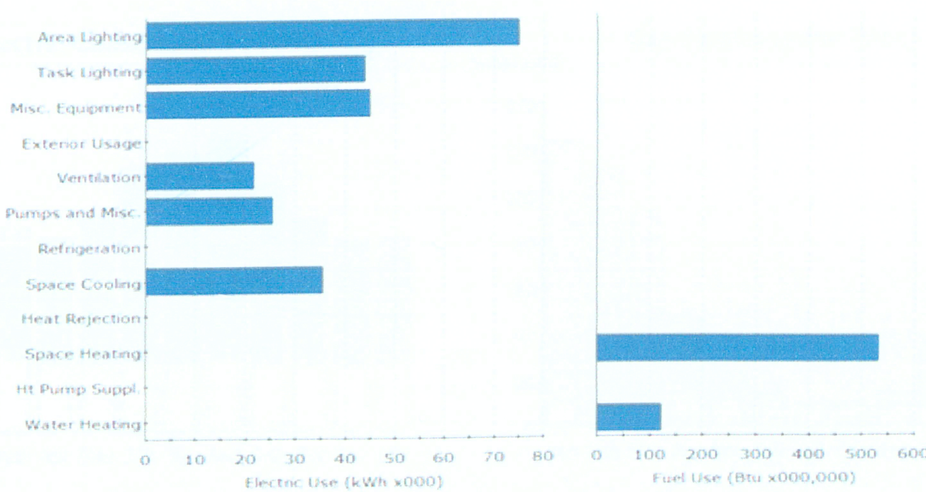



FIGURE 30: Annual Energy Consumption by Enduse (Bar chart)

## Monthly Energy Consumption by Enduse

**Electric Consumption (kWh x000)**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Space Cool | - | - | - | 0.40 | 2.36 | 5.40 | 8.84 | 7.00 | 5.56 | 2.86 | 1.55 | 0.00 | *33.97* |
| Space Heat | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Hot Water | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Vent. Fans | 1.70 | 1.74 | 1.72 | 1.64 | 1.63 | 1.63 | 1.70 | 1.59 | 1.59 | 1.64 | 1.63 | 1.69 | *19.90* |
| Pumps & Aux. | 2.21 | 2.50 | 2.21 | 2.12 | 2.15 | 2.04 | 2.10 | 2.10 | 2.06 | 2.27 | 2.13 | 2.21 | *26.10* |
| Misc. Equip. | 3.61 | 4.10 | 4.09 | 3.76 | 3.76 | 3.92 | 3.61 | 3.58 | 3.75 | 3.61 | 3.58 | 3.76 | *45.13* |
| Task Lights | 3.53 | 3.92 | 3.97 | 3.67 | 3.67 | 3.81 | 3.53 | 3.53 | 3.65 | 3.53 | 3.49 | 3.67 | *43.97* |
| Area Lights | 6.02 | 6.82 | 6.82 | 6.27 | 6.29 | 6.02 | 6.02 | 6.00 | 6.25 | 6.29 | 6.29 | 6.29 | *75.38* |
| ***Total*** | ***17.07*** | ***19.08*** | ***18.81*** | ***17.86*** | ***19.86*** | ***22.82*** | ***25.80*** | ***23.80*** | ***22.86*** | ***20.20*** | ***18.67*** | ***17.62*** | ***244.45*** |

**Gas Consumption (Btu x000,000)**

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Space Cool | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Space Heat | 112.41 | 100.56 | 79.65 | 35.35 | 17.13 | 3.61 | 0.47 | 0.63 | 5.30 | 27.67 | 55.82 | 96.61 | *535.21* |
| Hot Water | 11.27 | 10.91 | 12.94 | 11.69 | 10.94 | 10.47 | 9.13 | 9.80 | 9.05 | 9.22 | 9.74 | 11.02 | *126.18* |
| Vent. Fans | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Pumps & Aux. | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Ext. Usage | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Task Lights | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Area Lights | - | - | - | - | - | - | - | - | - | - | - | - | - |
| ***Total*** | ***123.68*** | ***111.47*** | ***92.59*** | ***47.04*** | ***28.07*** | ***14.08*** | ***9.60*** | ***10.43*** | ***14.35*** | ***36.89*** | ***65.56*** | ***107.63*** | ***661.39*** |

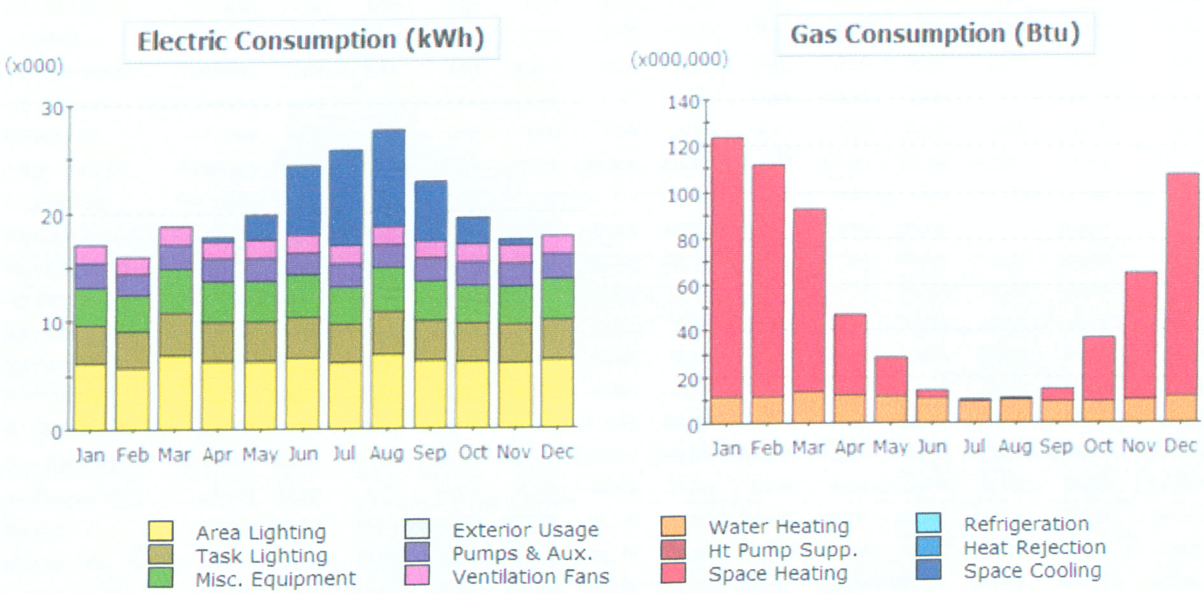
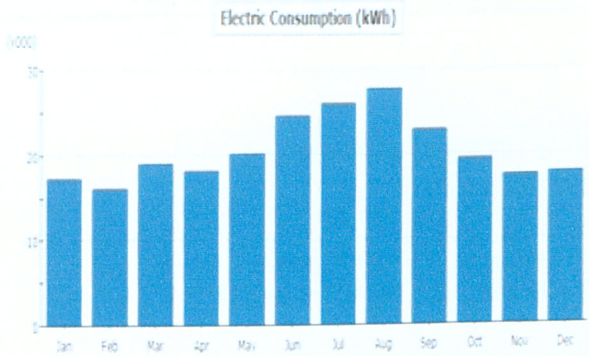



**Figure 31: Monthly Energy Consumption by Enduse**

## Monthly Total Energy Consumption



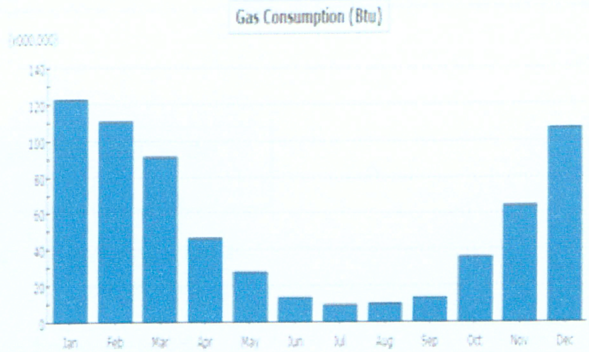




FIGURE 32: Monthly Total Energy Consumption

**Monthly Electric Energy Consumption**

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17.070 | 20.950 | 20.820 | 17.860 | 19.880 | 20.340 | 25.800 | 20.550 | 22.850 | 20.330 | 20.370 | 17.630 | ***244.450*** |

**Monthly Gas Consumption**

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | *Total* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 123.17 | 110.99 | 92.02 | 46.52 | 27.55 | 13.53 | 9.1 | 9.86 | 13.83 | 36.38 | 65.05 | 107.1 | ***655.1*** |

**Ryerson University**

*Hydro Kwh Report*

*Fiscal Year 2003*

| BUILDING | Total Of KWH | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 GERRARD ST. | 133,228 | 13,696 | 8,093 | 11,829 | 9,961 | 9,587 | 9,463 | 9,587 | 13,447 | 12,700 | 11,206 | 11,829 | 11,829 |
| 111 BOND ST. | 130,032 | 12,389 | 9,214 | 9,152 | 7,907 | 14,879 | 9,525 | 9,338 | 7,969 | 11,123 | 15,439 | 11,517 | 11,580 |
| 111 GERRARD ST. | 133,581 | 11,372 | 8,633 | 9,380 | 10,210 | 9,795 | 10,127 | 10,044 | 10,127 | 16,622 | 14,277 | 14,111 | 8,882 |
| 112 BOND ST | 93,695 | 8,467 | 5,230 | 8,809 | 6,973 | 5,447 | 8,560 | 13,696 | 20,046 | 16,467 | | | |
| 137 BOND ST. | 78,966 | 6,558 | 6,641 | 6,931 | 5,836 | 5,520 | 6,350 | 5,313 | 5,188 | 10,127 | 6,641 | 8,301 | 5,562 |
| 160 MUTUAL ST. | 6,063,637 | 387,978 | 472,374 | 592,560 | 577,945 | 641,414 | 513,340 | 502,089 | 426,135 | 503,384 | 473,473 | 515,694 | 457,249 |
| 17 GOULD ST. | 2,333 | 122 | 98 | 145 | 141 | 131 | 108 | 181 | 245 | 415 | 332 | 228 | 187 |
| 240 JARVIS ST. | 1,940,602 | 115,796 | 98,863 | 156,209 | 140,574 | 182,410 | 147,422 | 172,327 | 205,544 | 298,206 | | 219,919 | 203,331 |
| 285 VICTORIA ST. | 3,243,410 | 267,452 | 249,957 | 256,249 | 242,568 | 260,762 | 295,071 | 284,795 | 261,460 | 279,785 | 273,829 | 301,320 | 270,161 |
| 300 VICTORIA ST. | 486,427 | 36,524 | 28,887 | 30,879 | 24,902 | 29,883 | 36,025 | 42,832 | 48,975 | 58,106 | 49,805 | 49,805 | 49,805 |
| 302 CHURCH ST. | 1,053,538 | 90,977 | 48,477 | 84,004 | 61,426 | 73,711 | 95,625 | 105,586 | 91,973 | 96,289 | 97,949 | 101,270 | 106,250 |
| 325 CHURCH ST. | 908,456 | 66,563 | 59,167 | 80,122 | 71,493 | 76,424 | 78,889 | 83,820 | 73,958 | 77,656 | 77,656 | 72,726 | 89,983 |
| 341 CHURCH ST. | 452,394 | 31,958 | 28,223 | 58,521 | 46,069 | 41,504 | 36,524 | 35,278 | 34,033 | 36,524 | 33,203 | 35,278 | 35,278 |
| 361 VICTORIA ST. | 4,970,796 | 377,953 | 393,752 | 423,749 | 391,535 | 414,785 | 439,006 | 429,164 | 388,588 | 411,277 | 417,530 | 457,861 | 425,597 |
| 380 VICTORIA ST. | 13,310,940 | 987,581 | 1,306,190 | 1,576,779 | 1,347,610 | 1,308,817 | 1,016,884 | 957,914 | 860,807 | 903,930 | 917,503 | 1,004,311 | 1,122,615 |
| 44 GERRARD ST. | 246,534 | 16,602 | 15,273 | 24,571 | 17,930 | 23,242 | 23,242 | 22,744 | 16,934 | 19,590 | 21,582 | 22,246 | 22,578 |
| 50 GOULD ST. | 2,329,204 | 275,587 | 166,016 | 210,840 | 175,977 | 199,219 | 182,618 | 202,540 | 204,200 | 187,598 | 141,114 | 189,258 | 194,239 |
| 63 GOULD ST. | 562,379 | 33,618 | 26,563 | 37,354 | 20,752 | 35,278 | 41,504 | 47,730 | 56,030 | 76,782 | 74,707 | 62,256 | 49,805 |
| 87 GERRARD ST. | 4,145,409 | 332,656 | 314,878 | 284,749 | 289,324 | 327,189 | 355,954 | 356,561 | 332,261 | 412,422 | 402,498 | 404,417 | 332,502 |
| | 40,285,560 | 3,073,847 | 3,246,525 | 3,862,831 | 3,449,134 | 3,659,998 | 3,306,238 | 3,291,539 | 3,057,921 | 3,429,003 | 3,028,746 | 3,482,347 | 3,397,429 |

FIGURE 33: Ryerson University Annual Energy Consumption Report

# APPENDIX – D (RELATED TABLES & FIGURES)

**TORONTO LESTER B. PEARSON INT'L A**
**ONTARIO**

**Latitude:** 43° 40' N  **Longitude:** 79° 36' W  **Elevation:** 173.40 m
**Climate ID:** 6158733  **WMO ID:** 71624  **TC ID:** YYZ

Toronto Annual Temperature

**Monthly Data Report for 2004**

| Month | Mean Max Temp °C | Mean Temp °C | Mean Min Temp °C | Extr Max Temp °C | Extr Min Temp °C | Total Rain mm | Total Snow cm | Total Precip mm | Snow Grnd Last Day cm | Dir of Max Gust 10's Deg | Spd of Max Gust km/h |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | -5.2 | -9.4 | -13.5 | 13.8 | -24.3 | 4.8 | 63.2 | 49.6 | 46 | 28 | 74 |
| Feb | 0.5 | -3.8 | -8.0 | 10.7 | -19.2 | 5.4 | 17.2 | 20.8 | 4 | 29 | 70 |
| Mar | 6.1 | 2.3 | -1.6 | 18.5 | -10.3 | 51.8 | 14.2 | 63.4 | 0 | 33* | 74* |
| Apr | 11.9 | 7.0 | 2.0 | 25.0 | -6.6 | 63.6 | 0.6 | 64.2 | 0 | 31S | 78S |
| May | 18.4 | 13.2 | 7.8 | 27.5S | -1.7 | 98.8 | T | 98.8 | 0 | 31 | 57 |
| Jun | 23.0 | 17.6 | 12.1 | 31.8 | 6.6 | 62.8 | 0.0 | 62.8 | 0 | 30* | 78* |
| Jul | 25.2 | 20.7 | 16.1 | 30.5 | 11.4 | 119.8 | 0.0 | 119.8 | 0 | 29 | 57 |
| Aug | 24.4 | 19.5 | 14.6 | 29.9 | 9.3 | 60.0 | 0.0 | 60.0 | 0 | 27 | 67 |
| Sep | 23.8 | 18.4 | 12.9 | 29.1 | 6.3 | 25.2 | 0.0 | 25.2 | 0 | 34 | 57 |
| Oct | 15.0 | 10.7 | 6.4 | 27.2 | 0.7 | 35.2 | 0.0 | 35.2 | 0 | 28 | 69 |
| Nov | 9.2 | 5.4 | 1.5 | 14.9 | -4.6 | 62.0 | 2.8 | 64.8 | 0 | 31 | 78 |
| Dec | 1.2 | -2.8 | -6.7 | 11.9 | -24.3 | 53.9 | 36.9 | 90.4 | 8 | 23 | 72 |
| Sum | | | | | | 643.3 | 134.9 | 755.0 | | | |
| Avg | 12.8 | 8.2 | 3.6 | | | | | | | | |
| Xtrm | | | | 31.8 | -24.3 | | | | | 23 | 78* |

| Outdoor Air Requirements | | | | |
|---|---|---|---|---|
| *Application* | *Estimated Maximum Occupants per 1000 sq ft* | *cfm/ person* | *cfm/ sq ft* | *cfm/ room* |
| **Dry Cleaners, Laundries[a]** | | | | |
| Commercial laundry | 10 | 25 | | |
| Commercial dry cleaner | 30 | 30 | | |
| **Food and Beverage Service** | | | | |
| Dining rooms | 70 | 20 | | |
| Cafeteria, fast food | 100 | 20 | | |
| **Hotels, Motels, Resorts, Dormitories** | | | | |
| Bedrooms | | | | 30 |
| Living rooms | | | | 30 |
| Baths[c] | | | | 35 |
| Conference rooms | 50 | 20 | | |
| Assembly rooms | 120 | 15 | | |
| **Offices** | | | | |
| Office space[d] | 7 | 20 | | |
| Reception areas | 60 | 15 | | |
| Conference rooms[b] | 50 | 20 | | |
| **Public Spaces** | | | | |
| Corridors and utilities | | | 0.05 | |
| Public restrooms, cfm/wc or cfm/urinal[e] | | 50 | | |
| Locker and dressing rooms | | | 0.5 | |
| **Retail Stores, Sales Floors, and Showroom Floors** | | | | |
| Basement and street | 30 | | 0.30 | |
| Upper floors | 20 | | 0.20 | |
| Malls and arcades | 20 | | 0.20 | |
| Warehouses | 5 | | 0.05 | |
| **Specialty Shops** | | | | |
| Beauty | 25 | 25 | | |
| Clothiers, furniture | | | 0.30 | |
| Supermarkets | 8 | 15 | | |
| Pet shops | | | 1.00 | |
| **Sports and Amusement** | | | | |
| Spectator areas | 150 | 15 | | |
| Ice arenas (Playing areas) | | | 0.50 | |
| Swimming pools (pool and deck area)[f] | | | 0.50 | |
| Playing floors (gymnasium) | 30 | 20 | | |
| **Theaters[g]** | | | | |
| Lobbies | 150 | 20 | | |
| Auditoriums | 150 | 15 | | |
| Stages, studios | 70 | 15 | | |
| **Transportation[h]** | | | | |
| Waiting rooms | 100 | 15 | | |
| Vehicles | 150 | 15 | | |
| Workrooms | 10 | 15 | | |
| **Education** | | | | |
| Classroom | 50 | 15 | | |
| Laboratories[i] | 30 | 20 | | |
| Libraries | 20 | 15 | | |
| Locker rooms | | | 0.50 | |
| Auditoriums | 150 | 15 | | |
| **Hospitals, Nursing and Convalescent Homes** | | | | |
| Patient rooms[j] | 10 | 25 | | |
| Operating rooms | 20 | 30 | | |
| Autopsy rooms[k] | | | 0.50 | |
| Physical therapy | 20 | 15 | | |

**Thermal Properties of Typical Building and Insulating Material**

| Description | Density, lb/ft³ | Conductivity, λ Btu·in/h·ft²·F | Conductance, C Btu/h·ft²F | Resistance, R: Thickness per inch, (1/λ) h·ft²F/Btu | Resistance, R: For thickness listed 1/C h·ft²·F/Btu |
|---|---|---|---|---|---|
| **BUILDING BOARD** | | | | | |
| **Boards, Panels, Subflooring, Sheathing** | | | | | |
| **Woodboard Panel Products** | | | | | |
| Asbestos-cement board | 120 | 4.0 | — | 0.25 | — |
| Asbestos-cement board ........ 0.25 in. | 120 | — | 16.50 | — | 0.06 |
| Gypsum or plaster board ........ 0.5 in. | 50 | — | 2.22 | — | 0.45 |
| Plywood (Douglas fir) | 34 | 0.80 | — | 1.25 | — |
| Plywood (Douglas fir) ........ 0.25 in. | 34 | — | 3.20 | — | 0.31 |
| Plywood (Douglas fir) ........ 0.5 in. | 34 | — | 1.60 | — | 0.62 |
| Vegetable fiberboard | | | | | |
| Sheathing, regular density ........ 0.5 in. | 18 | — | 0.76 | — | 1.32 |
| Nail-base sheathing ........ 0.5 in. | 25 | — | 0.88 | — | 1.14 |
| Shingle backer ........ 0.375 in. | 18 | — | 1.06 | — | 0.94 |
| Sound-deadening board ........ 0.5 in. | 15 | — | 0.74 | — | 1.35 |
| Tile and lay-in panels, plain or acoustic | 18 | 0.40 | — | 2.50 | — |
| Laminated paperboard | 30 | 0.50 | — | 2.00 | — |
| Hardboard | | | | | |
| Medium density | 50 | 0.73 | — | 1.37 | — |
| High density, std. tempered | 63 | 1.00 | — | 1.00 | — |
| Particle board | | | | | |
| Low density | 37 | 0.54 | — | 1.06 | — |
| Medium density | 50 | 0.94 | — | 1.06 | — |
| Wood subfloor ........ 0.75 in. | | — | 1.06 | — | 0.94 |
| **BUILDING MEMBRANE** | | | | | |
| Vapor—permeable felt | — | — | 16.70 | — | 0.06 |
| Vapor—seal, plastic film | — | — | — | — | Negl. |
| **FINISHED FLOORING MATERIALS** | | | | | |
| Carpet and fibrous pad | — | — | 0.48 | — | 2.08 |
| Carpet and rubber pad | — | — | 0.81 | — | 1.23 |
| Terrazzo ........ 1 in. | — | — | 12.50 | — | 0.08 |
| Tile—asphalt, linoleum, vinyl, rubber | | | 20.0 | — | 0.05 |
| Wood, hardwood finish ........ 0.75 in. | — | — | 1.47 | | 0.68 |
| **INSULATING MATERIALS** | | | | | |
| **Blanket and Batt** | | | | | |
| Mineral fiber, fibrous form processed from rock, slag, or glass approx. 3.5 in | 0.3–2.0 | — | 0.077 | — | 13 |
| **Board and Slabs** | | | | | |
| Cellular glass | 8.5 | 0.35 | — | 2.86 | — |
| Glass fiber, organic bonded | 4–9 | 0.25 | — | 4.00 | — |
| Expanded rubber (rigid) | 4.5 | 0.22 | — | 4.55 | — |
| Expanded polystyrene, extruded | | | | | |
| Cut cell surface | 1.8 | 0.25 | — | 4.00 | — |
| Cellular polyurethane (R-11 exp.)(unfaced) | 1.5 | 0.16 | — | 6.25 | — |
| Cellular polyisocyanurate (R-11 exp.) (foil faced, glass fiber-reinforced core) | 2.0 | 0.14 | — | 7.20 | — |
| Nominal 1.0 in. | 15.0 | 0.29 | — | 3.45 | — |
| Mineral fiber with resin binder | 15.0 | 0.29 | — | 3.45 | — |
| Mineral fiberboard, wet felted | | | | | |
| Core or roof insulation | 16–17 | 0.34 | — | 2.94 | — |
| Acoustical tile | 18.0 | 0.35 | — | 2.86 | — |
| Mineral fiberboard, wet molded | | | | | |
| Acoustical title | 23.0 | 0.42 | — | 2.38 | — |
| Cement fiber slabs (shredded wood with Portland cement binder) | 25–27.0 | 0.50–0.53 | — | 2.0–1.89 | — |
| **LOOSE FILL** | | | | | |
| Wood fiber, softwoods | 2.0–3.5 | 0.30 | — | 3.33 | — |
| Perlite, expanded | 2.0–4.1 | 0.27–0.31 | — | 3.7–3.3 | — |
| ........ | 4.1–7.4 | 0.31–0.36 | — | 3.3–2.8 | — |
| ........ | 7.4–11.0 | 0.36–0.42 | — | 2.8–2.4 | — |
| Mineral fiber (rock, slag, or glass) | | | | | |
| approx. 3.75–5 in. | 0.6–2.0 | — | — | | 11.0 |
| approx. 6.5–8.75 in. | 0.6–2.0 | — | — | | 19.0 |
| Mineral fiber (rock, slag, or glass) approx. 3.5 in. (closed sidewall application) | 2.0–3.5 | — | — | — | 12.0–14.0 |
| Vermiculite, exfoliated | 7.0–8.2 | 0.47 | — | 2.13 | — |
| **FIELD APPLIED** | | | | | |
| Polyurethane foam | 1.5–2.5 | 0.16–0.18 | — | 6.25–5.26 | — |
| Spray cellulosic fiber base | 2.0–6.0 | 0.24–0.30 | — | 3.33–4.17 | — |
| **PLASTERING MATERIALS** | | | | | |
| Cement plaster, sand aggregate | 116 | 5.0 | — | 0.20 | — |
| Sand aggregate ........ 0.375 in. | — | — | 13.3 | — | 0.08 |
| Gypsum plaster: | | | | | |
| Lightweight aggregate ........ 0.5 in. | 45 | — | 3.12 | — | 0.32 |
| Lightweight aggregate on metal lath ........ 0.75 in. | — | — | 2.13 | — | 0.47 |

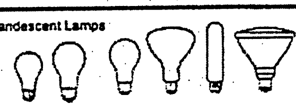
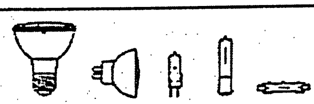
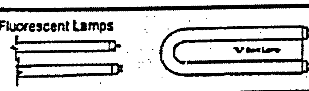
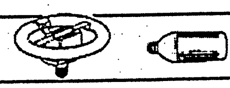
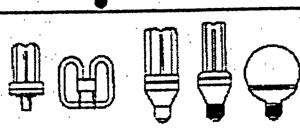
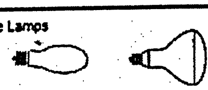
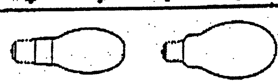
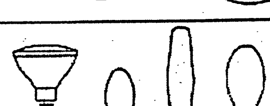
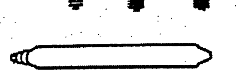
**Thermal Properties of Typical Building and Insulating Material**

| Description | Density, lb/ft³ | Conductivity, λ Btu·in/h·ft²·F | Conductance, C Btu/h·ft²F | Resistance, R: Thickness per inch, (1/λ) h·ft²F/Btu | Resistance, R: For thickness listed 1/C h·ft²·F/Btu |
|---|---|---|---|---|---|
| **MASONRY MATERIALS** | | | | | |
| **Concretes** | | | | | |
| Cement mortar | 11 | 5.0 | — | 0.20 | — |
| Lightweight aggregates including | 120 | 5.2 | — | 0.19 | — |
| slags; cinders; pumice; vermiculite | 80 | 2.5 | — | 0.40 | — |
| Perlite, expanded | 40 | 0.93 | — | 1.08 | — |
| Sand and gravel or stone aggregate (oven dried) | 140 | 9.0 | — | 0.11 | — |
| Sand and gravel or stone aggregate (not dried) | 140 | 12.0 | — | 0.08 | — |
| Stucco | 116 | 5.0 | — | 0.20 | — |
| **MASONRY UNITS** | | | | | |
| Brick, common | 20 | 5.0 | — | 0.20 | — |
| Brick, face | 130 | 9.0 | — | 0.11 | — |
| Clay tile, hollow: | | | | | |
| 1 cell deep ... 3 in. | — | — | 1.25 | — | 0.80 |
| 2 cells deep ... 6 in. | — | — | 0.66 | — | 1.52 |
| 3 cells deep ... 12 in. | — | — | 0.40 | — | 2.50 |
| Concrete blocks, three oval core: | | | | | |
| Sand and gravel aggregate ... 4 in. | — | — | 1.40 | — | 0.71 |
| ... 8 in. | — | — | 0.90 | — | 1.11 |
| cinder aggregate ... 4 in. | — | — | 0.90 | — | 1.11 |
| ... 8 in. | — | — | 0.58 | — | 1.72 |
| Lightweight aggregate (expanded shale, clay, slate ... 4 in. | — | — | 0.67 | — | 1.50 |
| or slag; pumice) ... 8 in. | — | — | 0.50 | — | 2.00 |
| Stone, lime, or sand | — | 12.50 | — | 0.08 | — |
| **ROOFING** | | | | | |
| Asbestos-cement shingles | 120 | — | 4.76 | — | 0.21 |
| Asphalt roll roofing | 70 | — | 6.50 | — | 0.15 |
| Asphalt shingles | 70 | — | 2.27 | — | 0.44 |
| Built-up roofing ... 0.375 in. | 70 | — | 3.00 | — | 0.33 |
| Slate ... 0.5 in. | — | — | 20.00 | — | 0.05 |
| **SIDING MATERIALS (on flat surface)** | | | | | |
| Shingles | | | | | |
| Asbestos-cement | 120 | — | 4.75 | — | 0.21 |
| Wood, 16 in., 7.5-in. exposure | — | — | 1.15 | — | 0.87 |
| Wood, plus insult. backer board, 0.3125 in. | — | — | 0.71 | — | 1.40 |
| Siding | | | | | |
| Asbestos-cement, 0.25 in., lapped | — | — | 4.76 | — | 0.21 |
| Asphalt roll siding | — | — | 6.50 | — | 0.15 |
| Asphalt insulating siding (0.5 in. Bed.) | — | — | 0.69 | — | 1.46 |
| Wood, bevel, 0.5 + 8 in. lapped | — | — | 1.23 | — | 0.81 |
| Aluminum or steel, over sheathing | | | | | |
| Hollow backed | — | — | 1.61 | — | 0.61 |
| Insulating-board backed nominal 0.375 in. | — | — | 0.55 | — | 1.82 |
| Architectural glass | — | — | 10.00 | — | 0.10 |
| **WOODS (12% moisture content)** | | | | | |
| Hardwoods | | | | | |
| Oak | 41.2–46.8 | 1.12–1.25 | — | 0.89–0.80 | — |
| Maple | 39.8–44.0 | 1.09–1.19 | — | 0.94–0.88 | — |
| Softwoods | | | | | |
| Southern pine | 35.6–41.2 | 1.00–1.12 | — | 1.00–0.89 | — |
| Douglas fir-larch | 33.5–36.3 | 0.95–1.01 | — | 1.06–0.99 | — |
| California redwood | 24.5–28.0 | 0.74–0.82 | — | 1.35–1.22 | — |

**General Characteristics of General Type Used Light Sources**

| Light Source | Wattage Range | Efficacy lpw | Life | Lumen Maintenance | Starting Time | Color Rendition | Ballast Required | Dimming Capability | Optical Control |
|---|---|---|---|---|---|---|---|---|---|
| Incandescent filament | 10 to 1500 | Very low | Very low to low | Fair to good | Very good | Very good | No | Very good | Good |
| Tungsten halogen | 10 to 2000 | Very low to low | Very low to low | Good to very good | Very good | Very good | No | Good | Very good |
| **Low-pressure discharge** | | | | | | | | | |
| Standard fluorescent | 15 to 40 | Low to good | Fair to very good | Fair to good | Good to very good | Low to very good | Yes | Good | Poor |
| Slimline fluorescent | 20 to 75 | Fair to good | Fair to good | Fair to good | Very good | Fair to very good | Yes | Low | Poor |
| High-output fluorescent | 35 to 110 | Fair to good | Fair to good | Fair to good | Very good | Fair to very good | Yes | Good | Poor |
| Very high-output fluorescent | 38 to 215 | Fair to good | Fair to good | Fair to good | Very good | Fair to very good | Yes | Good | Poor |
| Energy-saving fluorescent (T-12) | 30 to 185 | Fair to good | Fair to good | Fair to good | Very good | Low to very good | Yes | Low | Poor |
| High efficacy fluorescent | 18 to 40 | Good | Good | Good | Very good | Good to very good | Yes | Fair | Poor |
| Compact fluorescent | 5 to 40 | Good | Fair to good | Good | Good to very good | Good to very good | Yes | Very low | Fair |
| **High-intensity discharge** | | | | | | | | | |
| Mercury | 40 to 1000 | Low to Fair | Good to very good | Very low to fair | Low | Very low to fair | Yes | Fair | Poor |
| Self-ballasted mercury | 100 to 1500 | Very low | Fair to very good | Low to fair | Fair | Low to fair | No | Very low | Poor |
| Metal halide | 32 to 1500 | Good | Low to fair | Very low | Good | Low | Yes | Low | Good |
| High-pressure sodium | 35 to 1000 | Fair to good | Fair to very good | Fair to good | Fair | Low to good | Yes | Low | Good |
| **Miscellaneous** | | | | | | | | | |
| Low-pressure sodium | 10 to 180 | Fair to very good | Fair to good | Good to very good | Fair | Very low | Yes | Very low | Poor |
| Cold cathode | 10 to 150 | Low | Very good | Fair to good | Very good | Low to very good | Yes | Good | Poor |

**Comparison between types of lamps, efficacy, life and applications**

| Category | Type | Typical Efficacy, lpw | Rated Life, hours | Characteristic Features | Typical Application |
|---|---|---|---|---|---|
| Incandescent Lamps  | General Service and Reflector | 10 to 25 | 750 to 2000 | Easy to install, easy to use; many different versions; instant start; low cost; reflector lamps allow concentrated light beams | General lighting in the home, decorative lighting, localize lighting, accent and decorative lighting (reflector lamps) |
|  | Halogen | 15 to 38 | 1000 to 4000 | Compact; high light output, white light; easy to install; long life compared with normal incandescent lamps | Accent lighting, floodlighting |
| Fluorescent Lamps  | Tubular | 50 to 95 | 12,000 to 24,000 | Wide choice of light colors; high lighting levels possible; economical in use | All kinds of commercial and public buildings; streetlighting; home lighting |
|  | Screw in base | 50 to 80 | 9000 to 10,000 | Energy/effective; direct replacement for incandescent lamps | Most appellations where incandescent lamps were used before |
|  | Compact Fluorescent | 30 to 80 | 10,000 to 40,000 | Compact; long life; energy/effective | To create a pleasant atmosphere in social areas, local lighting; signs, security, orientation lighting and general lighting |
| Gas-Discharge Lamps  | Self-ballasted mercury | 20 to 25 | 12,000 to 16,000 | Long life; good color rendering; easy to install; better efficacy than incandescent lamps | Direct replacement for incandescent lamps; small industrial and public light projects; plant irradiation |
|  | High-pressure mercury | 50 to 60 | 12,000 to 24,000 | High efficacy; long life; reasonable color quality | Residential area lighting; sports grounds; factory lighting |
|  | Metal halide | 80 to 120 | 10,000 to 20,000 | Very high efficacy combined with excellent color rendering; long life | Floodlighting; especially for color TV; industrial lighting; road lighting; plant irradiation |
|  | High-pressure sodium | 60 to 140 | 10,000 to 24,000 | Very high efficacy; extremely long life; good color rendering | Public lighting, floodlighting, industrial lighting; plant irradiation; direct replacement for mercury lamps |
|  | Low-pressure sodium | 130 to 200 | 14,000 to 18,000 | Extremely high efficacy; very long life; high visual acuity; poor color rendering; monochromatic light | Many different application areas; wherever energy/cost effectiveness is important and color is not critical |

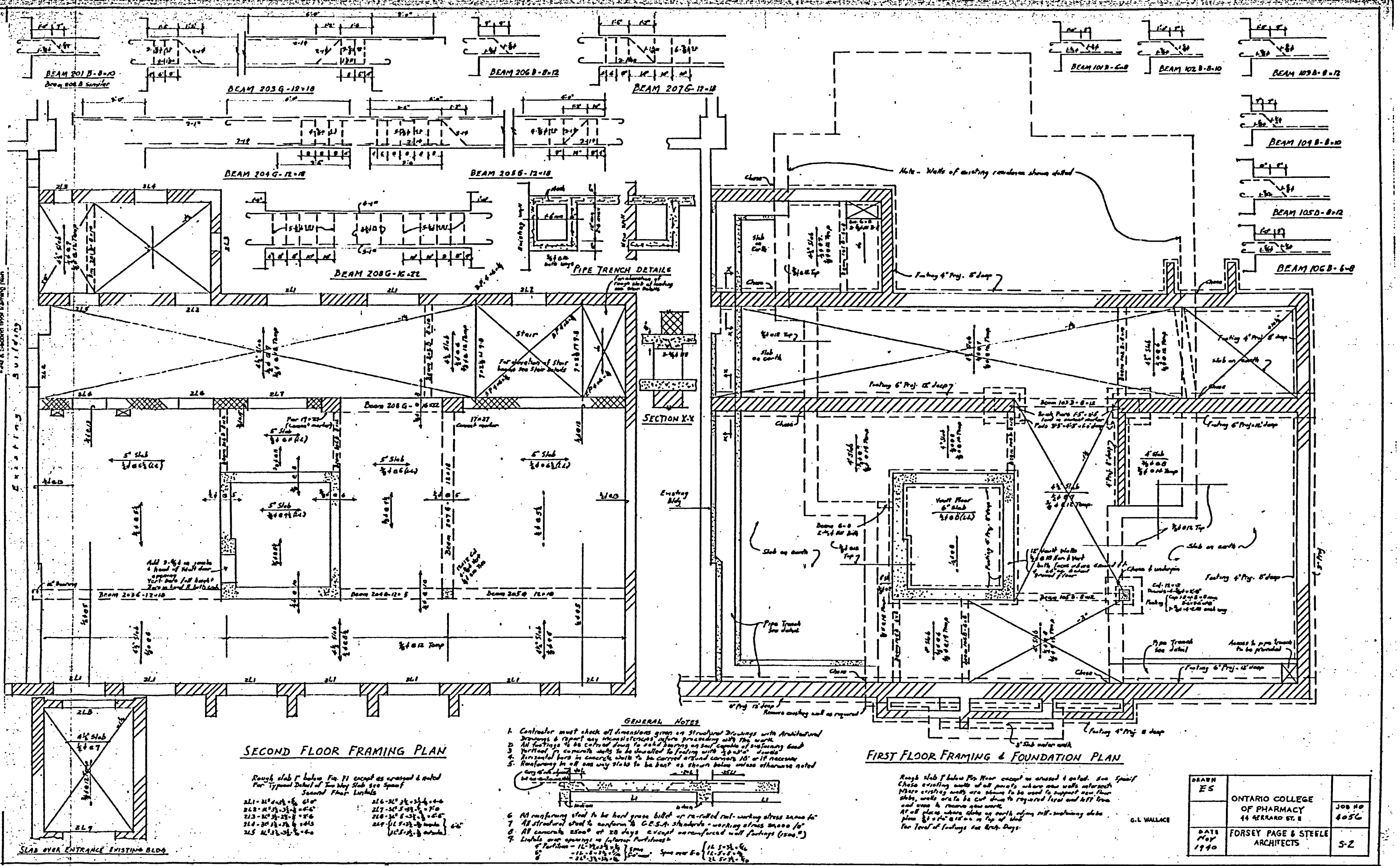
# Typical Non-incandescent Light Fixtures

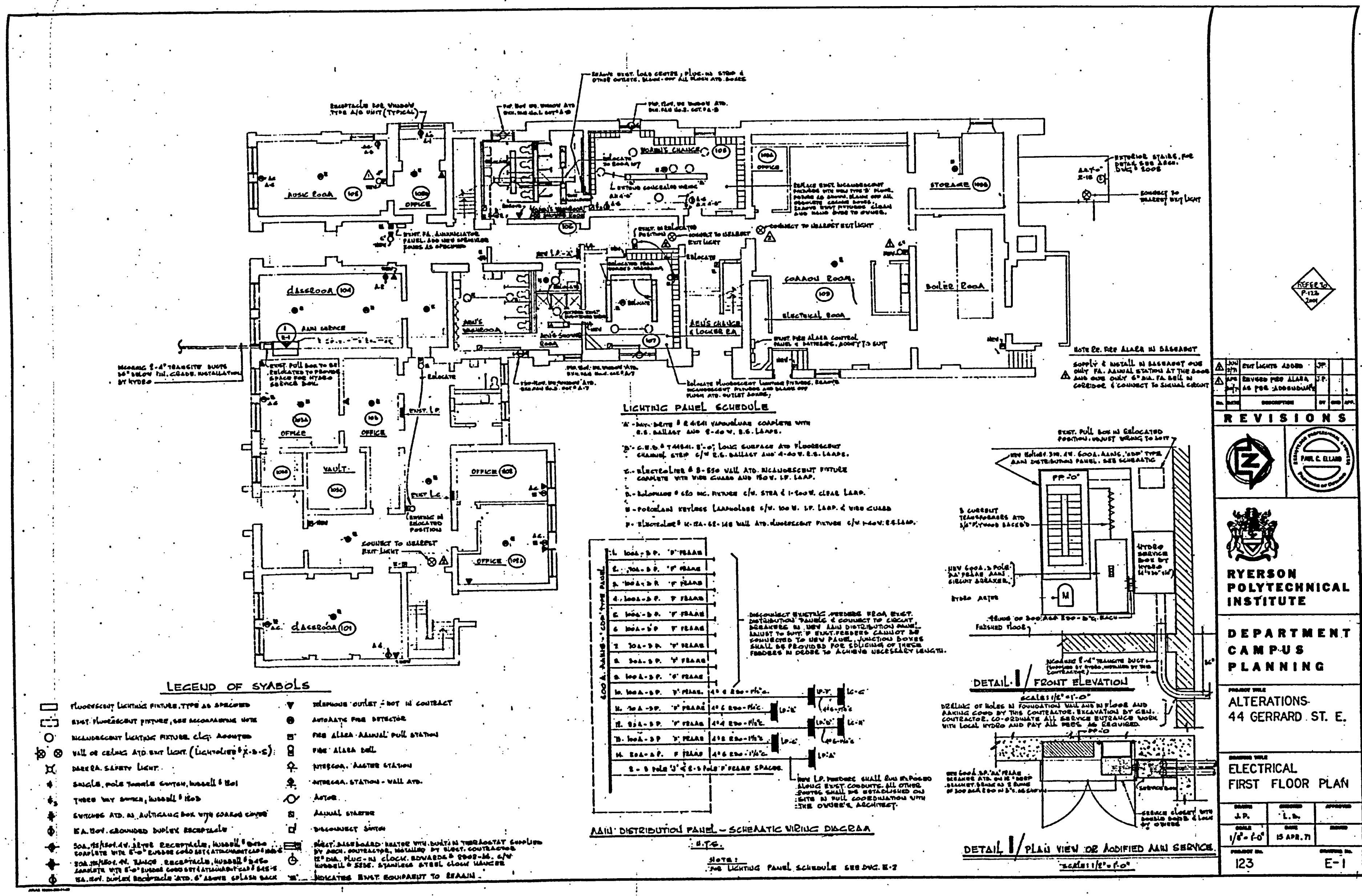
| Description | Ballast | Watts/Lamp | Lamps/Fixture | Lamp Watts | Fixture Watts | Special Allowance Factor |
|---|---|---|---|---|---|---|
| **Compact Fluorescent Fixtures** | | | | | | |
| Twin, (1) 5 W lamp | Mag-Std | 5 | 1 | 5 | 9 | 1.80 |
| Twin, (1) 7 W lamp | Mag-Std | 7 | 1 | 7 | 10 | 1.43 |
| Twin, (1) 9 W lamp | Mag-Std | 9 | 1 | 9 | 11 | 1.22 |
| Quad, (1) 13 W lamp | Mag-Std | 13 | 1 | 13 | 17 | 1.31 |
| Quad, (2) 18 W lamp | Mag-Std | 18 | 2 | 36 | 45 | 1.25 |
| Quad, (2) 22 W lamp | Mag-Std | 22 | 2 | 44 | 48 | 1.09 |
| Quad, (2) 26 W lamp | Mag-Std | 26 | 2 | 52 | 66 | 1.27 |
| Twin, (2) 40 W lamp | Mag-Std | 40 | 2 | 80 | 85 | 1.06 |
| Quad, (1) 13 W lamp | Electronic | 13 | 1 | 13 | 15 | 1.15 |
| Quad, (1) 26 W lamp | Electronic | 26 | 1 | 26 | 27 | 1.04 |
| Quad, (2) 18 W lamp | Electronic | 18 | 2 | 36 | 38 | 1.06 |
| Quad, (2) 26 W lamp | Electronic | 26 | 2 | 52 | 50 | 0.96 |
| Twin or multi, (2) 32 W lamp | Electronic | 32 | 2 | 64 | 62 | 0.97 |
| **Fluorescent Fixtures** | | | | | | |
| (1) 18 in., T8 lamp | Mag-Std | 15 | 1 | 15 | 19 | 1.27 |
| (1) 18 in., T12 lamp | Mag-Std | 15 | 1 | 15 | 19 | 1.27 |
| (2) 18 in., T8 lamp | Mag-Std | 15 | 2 | 30 | 36 | 1.20 |
| (2) 18 in., T12 lamp | Mag-Std | 15 | 2 | 30 | 36 | 1.20 |
| (1) 24 in., T8 lamp | Mag-Std | 17 | 1 | 17 | 24 | 1.41 |
| (1) 24 in., T12 lamp | Mag-Std | 20 | 1 | 20 | 28 | 1.40 |
| (2) 24 in., T12 lamp | Mag-Std | 20 | 2 | 40 | 56 | 1.40 |
| (1) 24 in., T12 HO lamp | Mag-Std | 35 | 1 | 35 | 62 | 1.77 |
| (2) 24 in., T12 HO lamp | Mag-Std | 35 | 2 | 70 | 90 | 1.29 |
| (1) 24 in., T8 lamp | Electronic | 17 | 1 | 17 | 16 | 0.94 |
| (2) 24 in., T8 lamp | Electronic | 17 | 2 | 34 | 31 | 0.91 |
| (1) 36 in., T12 lamp | Mag-Std | 30 | 1 | 30 | 46 | 1.53 |
| (2) 36 in., T12 lamp | Mag-Std | 30 | 2 | 60 | 81 | 1.35 |
| (1) 36 in., T12 ES lamp | Mag-Std | 25 | 1 | 25 | 42 | 1.68 |
| (2) 36 in., T12 ES lamp | Mag-Std | 25 | 2 | 50 | 73 | 1.46 |
| (1) 36 in., T12 HO lamp | Mag-Std | 50 | 1 | 50 | 70 | 1.40 |
| (2) 36 in., T12 HO lamp | Mag-Std | 50 | 2 | 100 | 114 | 1.14 |
| (2) 36 in., T12 lamp | Mag-ES | 30 | 2 | 60 | 74 | 1.23 |
| (2) 36 in., T12 ES lamp | Mag-ES | 25 | 2 | 50 | 66 | 1.32 |
| (1) 36 in., T12 lamp | Electronic | 30 | 1 | 30 | 31 | 1.03 |
| (1) 36 in., T12 ES lamp | Electronic | 25 | 1 | 25 | 26 | 1.04 |
| (1) 36 in., T8 lamp | Electronic | 25 | 1 | 25 | 24 | 0.96 |
| (2) 36 in., T12 lamp | Electronic | 30 | 2 | 60 | 58 | 0.97 |
| (2) 36 in., T12 ES lamp | Electronic | 25 | 2 | 50 | 50 | 1.00 |
| (2) 36 in., T8 lamp | Electronic | 25 | 2 | 50 | 46 | 0.92 |
| (2) 36 in., T8 HO lamp | Electronic | 25 | 2 | 50 | 50 | 1.00 |
| (2) 36 in., T8 VHO lamp | Electronic | 25 | 2 | 50 | 70 | 1.40 |
| (1) 48 in., T12 lamp | Mag-Std | 40 | 1 | 40 | 55 | 1.38 |
| (2) 48 in., T12 lamp | Mag-Std | 40 | 2 | 80 | 92 | 1.15 |
| (3) 48 in., T12 lamp | Mag-Std | 40 | 3 | 120 | 140 | 1.17 |
| (4) 48 in., T12 lamp | Mag-Std | 40 | 4 | 160 | 184 | 1.15 |
| (1) 48 in., T12 ES lamp | Mag-Std | 34 | 1 | 34 | 48 | 1.41 |
| (2) 48 in., T12 ES lamp | Mag-Std | 34 | 2 | 68 | 82 | 1.21 |
| (3) 48 in., T12 ES lamp | Mag-Std | 34 | 3 | 102 | 100 | 0.98 |
| (4) 48 in., T12 ES lamp | Mag-Std | 34 | 4 | 136 | 164 | 1.21 |
| (1) 48 in., T12 ES lamp | Mag-ES | 34 | 1 | 34 | 43 | 1.26 |
| (2) 48 in., T12 ES lamp | Mag-ES | 34 | 2 | 68 | 72 | 1.06 |
| (3) 48 in., T12 ES lamp | Mag-ES | 34 | 3 | 102 | 115 | 1.13 |
| (4) 48 in., T12 ES lamp | Mag-ES | 34 | 4 | 136 | 144 | 1.06 |
| (1) 48 in., T8 lamp | Mag-ES | 32 | 1 | 32 | 35 | 1.09 |
| (2) 48 in., T8 lamp | Mag-ES | 32 | 2 | 64 | 71 | 1.11 |
| (3) 48 in., T8 lamp | Mag-ES | 32 | 3 | 96 | 110 | 1.15 |
| (4) 48 in., T8 lamp | Mag-ES | 32 | 4 | 128 | 142 | 1.11 |
| (1) 48 in., T12 ES lamp | Electronic | 34 | 1 | 34 | 32 | 0.94 |
| (2) 48 in., T12 ES lamp | Electronic | 34 | 2 | 68 | 60 | 0.88 |
| (3) 48 in., T12 ES lamp | Electronic | 34 | 3 | 102 | 92 | 0.90 |
| (4) 48 in., T12 ES lamp | Electronic | 34 | 4 | 136 | 120 | 0.88 |
| (1) 48 in., T8 lamp | Electronic | 32 | 1 | 32 | 32 | 1.00 |
| (2) 48 in., T8 lamp | Electronic | 32 | 2 | 64 | 60 | 0.94 |
| (3) 48 in., T8 lamp | Electronic | 32 | 3 | 96 | 93 | 0.97 |
| (1) 96 in., T12 ES lamp | Electronic | 60 | 1 | 60 | 69 | 1.15 |
| (2) 96 in., T12 ES lamp | Electronic | 60 | 2 | 120 | 110 | 0.92 |
| (3) 96 in., T12 ES lamp | Electronic | 60 | 3 | 180 | 179 | 0.99 |
| (4) 96 in., T12 ES lamp | Electronic | 60 | 4 | 240 | 220 | 0.92 |
| (1) 96 in., T12 ES HO lamp | Electronic | 95 | 1 | 95 | 80 | 0.84 |
| (2) 96 in., T12 ES HO lamp | Electronic | 95 | 2 | 190 | 173 | 0.91 |
| (4) 96 in., T12 ES HO lamp | Electronic | 95 | 4 | 380 | 346 | 0.91 |
| (1) 96 in., T8 lamp | Electronic | 59 | 1 | 59 | 58 | 0.98 |
| (4) 48 in., T8 lamp | Electronic | 32 | 4 | 128 | 120 | 0.94 |
| (1) 60 in., T12 lamp | Mag-Std | 50 | 1 | 50 | 63 | 1.26 |
| (2) 60 in., T12 lamp | Mag-Std | 50 | 2 | 100 | 128 | 1.28 |
| (1) 60 in., T12 HO lamp | Mag-Std | 75 | 1 | 75 | 92 | 1.23 |
| (2) 60 in., T12 HO lamp | Mag-Std | 75 | 2 | 150 | 168 | 1.12 |
| (1) 60 in., T12 ES VHO lamp | Mag-Std | 135 | 1 | 135 | 165 | 1.22 |
| (2) 60 in., T12 ES VHO lamp | Mag-Std | 135 | 2 | 270 | 310 | 1.15 |
| (1) 60 in., T12 HO lamp | Mag-ES | 75 | 1 | 75 | 88 | 1.17 |
| (2) 60 in., T12 HO lamp | Mag-ES | 75 | 2 | 150 | 176 | 1.17 |
| (1) 60 in., T12 lamp | Electronic | 50 | 1 | 50 | 44 | 0.88 |
| (2) 60 in., T12 lamp | Electronic | 50 | 2 | 100 | 88 | 0.88 |
| (1) 60 in., T12 HO lamp | Electronic | 75 | 1 | 75 | 69 | 0.92 |
| (2) 60 in., T12 HO lamp | Electronic | 75 | 2 | 150 | 138 | 0.92 |
| (1) 60 in., T8 lamp | Electronic | 40 | 1 | 40 | 36 | 0.90 |
| (2) 60 in., T8 lamp | Electronic | 40 | 2 | 80 | 72 | 0.90 |
| (3) 60 in., T8 lamp | Electronic | 40 | 3 | 120 | 106 | 0.88 |
| (4) 60 in., T8 lamp | Electronic | 40 | 4 | 160 | 134 | 0.84 |
| (1) 72 in., T12 lamp | Mag-Std | 55 | 1 | 55 | 76 | 1.38 |
| (2) 72 in., T12 lamp | Mag-Std | 55 | 2 | 110 | 122 | 1.11 |
| (3) 72 in., T12 lamp | Mag-Std | 55 | 3 | 165 | 202 | 1.22 |
| (4) 72 in., T12 lamp | Mag-Std | 55 | 4 | 220 | 244 | 1.11 |
| (1) 72 in., T12 HO lamp | Mag-Std | 85 | 1 | 85 | 120 | 1.41 |
| (2) 72 in., T12 HO lamp | Mag-Std | 85 | 2 | 170 | 220 | 1.29 |
| (1) 72 in., T12 VHO lamp | Mag-Std | 160 | 1 | 160 | 180 | 1.13 |
| (2) 72 in., T12 VHO lamp | Mag-Std | 160 | 2 | 320 | 330 | 1.03 |
| (2) 72 in., T12 lamp | Mag-ES | 55 | 2 | 110 | 122 | 1.11 |
| (4) 72 in., T12 lamp | Mag-ES | 55 | 4 | 220 | 244 | 1.11 |
| (2) 72 in., T12 HO lamp | Mag-ES | 85 | 2 | 170 | 194 | 1.14 |
| (4) 72 in., T12 HO lamp | Mag-ES | 85 | 4 | 340 | 388 | 1.14 |
| (1) 72 in., T12 lamp | Electronic | 55 | 1 | 55 | 68 | 1.24 |
| (2) 72 in., T12 lamp | Electronic | 55 | 2 | 110 | 108 | 0.98 |
| (3) 72 in., T12 lamp | Electronic | 55 | 3 | 165 | 176 | 1.07 |
| (4) 72 in., T12 lamp | Electronic | 55 | 4 | 220 | 216 | 0.98 |
| (1) 96 in., T12 ES lamp | Mag-Std | 60 | 1 | 60 | 75 | 1.25 |
| (2) 96 in., T12 ES lamp | Mag-Std | 60 | 2 | 120 | 128 | 1.07 |
| (3) 96 in., T12 ES lamp | Mag-Std | 60 | 3 | 180 | 203 | 1.13 |
| (4) 96 in., T12 ES lamp | Mag-Std | 60 | 4 | 240 | 256 | 1.07 |
| (1) 96 in., T12 ES HO lamp | Mag-Std | 95 | 1 | 95 | 112 | 1.18 |
| (2) 96 in., T12 ES HO lamp | Mag-Std | 95 | 2 | 190 | 227 | 1.19 |
| (3) 96 in., T12 ES HO lamp | Mag-Std | 95 | 3 | 285 | 380 | 1.33 |
| (4) 96 in., T12 ES HO lamp | Mag-Std | 95 | 4 | 380 | 454 | 1.19 |
| (1) 96 in., T12 ES VHO lamp | Mag-Std | 185 | 1 | 185 | 205 | 1.11 |
| (2) 96 in., T12 ES VHO lamp | Mag-Std | 185 | 2 | 370 | 380 | 1.03 |
| (3) 96 in., T12 ES VHO lamp | Mag-Std | 185 | 3 | 555 | 585 | 1.05 |
| (4) 96 in., T12 ES VHO lamp | Mag-Std | 185 | 4 | 740 | 760 | 1.03 |
| (2) 96 in., T12 ES lamp | Mag-ES | 60 | 2 | 120 | 123 | 1.03 |
| (3) 96 in., T12 ES lamp | Mag-ES | 60 | 3 | 180 | 210 | 1.17 |
| (4) 96 in., T12 ES lamp | Mag-ES | 60 | 4 | 240 | 246 | 1.03 |
| (2) 96 in., T12 ES HO lamp | Mag-ES | 95 | 2 | 190 | 207 | 1.09 |
| (4) 96 in., T12 ES HO lamp | Mag-ES | 95 | 4 | 380 | 414 | 1.09 |
| (1) 96 in., T8 HO lamp | Electronic | 59 | 1 | 59 | 68 | 1.15 |
| (1) 96 in., T8 VHO lamp | Electronic | 59 | 1 | 59 | 71 | 1.20 |
| (2) 96 in., T8 lamp | Electronic | 59 | 2 | 118 | 109 | 0.92 |
| (3) 96 in., T8 lamp | Electronic | 59 | 3 | 177 | 167 | 0.94 |
| (4) 96 in., T8 lamp | Electronic | 59 | 4 | 236 | 219 | 0.93 |
| (2) 96 in., T8 HO lamp | Electronic | 86 | 2 | 172 | 160 | 0.93 |
| (4) 96 in., T8 HO lamp | Electronic | 86 | 4 | 344 | 320 | 0.93 |
| **Circular Fluorescent Fixtures** | | | | | | |
| Circlite, (1) 20 W lamp | Mag-PH | 20 | 1 | 20 | 20 | 1.00 |
| Circlite, (1) 22 W lamp | Mag-PH | 22 | 1 | 22 | 20 | 0.91 |
| Circline, (1) 32 W lamp | Mag-PH | 32 | 1 | 32 | 40 | 1.25 |
| (1) 6 in. circular lamp | Mag-RS | 20 | 1 | 20 | 25 | 1.25 |
| (1) 8 in. circular lamp | Mag-RS | 22 | 1 | 22 | 26 | 1.18 |
| (2) 8 in. circular lamp | Mag-RS | 22 | 2 | 44 | 52 | 1.18 |
| (1) 12 in. circular lamp | Mag-RS | 32 | 1 | 32 | 31 | 0.97 |
| (2) 12 in. circular lamp | Mag-RS | 32 | 2 | 64 | 62 | 0.97 |
| (1) 16 in. circular lamp | Mag-Std | 40 | 1 | 40 | 35 | 0.88 |
| **High-Pressure Sodium Fixtures** | | | | | | |
| (1) 35 W lamp | HID | 35 | 1 | 35 | 46 | 1.31 |
| (1) 50 W lamp | HID | 50 | 1 | 50 | 66 | 1.32 |
| (1) 70 W lamp | HID | 70 | 1 | 70 | 95 | 1.36 |
| (1) 100 W lamp | HID | 100 | 1 | 100 | 138 | 1.38 |
| (1) 150 W lamp | HID | 150 | 1 | 150 | 188 | 1.25 |
| (1) 200 W lamp | HID | 200 | 1 | 200 | 250 | 1.25 |
| (1) 250 W lamp | HID | 250 | 1 | 250 | 295 | 1.18 |
| (1) 310 W lamp | HID | 310 | 1 | 310 | 365 | 1.18 |
| (1) 360 W lamp | HID | 360 | 1 | 360 | 414 | 1.15 |
| (1) 400 W lamp | HID | 400 | 1 | 400 | 465 | 1.16 |
| (1) 1000 W lamp | HID | 1000 | 1 | 1000 | 1100 | 1.10 |
| **Metal Halide Fixtures** | | | | | | |
| (1) 32 W lamp | HID | 32 | 1 | 32 | 43 | 1.34 |
| (1) 50 W lamp | HID | 50 | 1 | 50 | 72 | 1.44 |
| (1) 70 W lamp | HID | 70 | 1 | 70 | 95 | 1.36 |
| (1) 100 W lamp | HID | 100 | 1 | 100 | 128 | 1.28 |
| (1) 150 W lamp | HID | 150 | 1 | 150 | 190 | 1.27 |
| (1) 175 W lamp | HID | 175 | 1 | 175 | 215 | 1.23 |
| (1) 250 W lamp | HID | 250 | 1 | 250 | 295 | 1.18 |
| (1) 400 W lamp | HID | 400 | 1 | 400 | 458 | 1.15 |
| (2) 400 W lamp | HID | 400 | 2 | 800 | 916 | 1.15 |
| (1) 750 W lamp | HID | 750 | 1 | 750 | 850 | 1.13 |
| (1) 1000 W lamp | HID | 1000 | 1 | 1000 | 1080 | 1.08 |
| (1) 1500 W lamp | HID | 1500 | 1 | 1500 | 1610 | 1.07 |
| **Mercury Vapor Fixtures** | | | | | | |
| (1) 40 W lamp | HID | 40 | 1 | 40 | 50 | 1.25 |
| (1) 50 W lamp | HID | 50 | 1 | 50 | 74 | 1.48 |
| (1) 75 W lamp | HID | 75 | 1 | 75 | 93 | 1.24 |
| (1) 100 W lamp | HID | 100 | 1 | 100 | 125 | 1.25 |
| (1) 175 W lamp | HID | 175 | 1 | 175 | 205 | 1.17 |
| (1) 250 W lamp | HID | 250 | 1 | 250 | 290 | 1.16 |
| (1) 400 W lamp | HID | 400 | 1 | 400 | 455 | 1.14 |
| (2) 400 W lamp | HID | 400 | 2 | 800 | 910 | 1.14 |
| (1) 700 W lamp | HID | 700 | 1 | 700 | 780 | 1.11 |
| (1) 1000 W lamp | HID | 1000 | 1 | 1000 | 1075 | 1.08 |

# APPENDIX – E (SITE'S BLUEPRINTS)

1st & 2nd Floor FRAMING

S2 - THR
First & Second floor framing plan





1st Floor ELECTRICAL PLAN

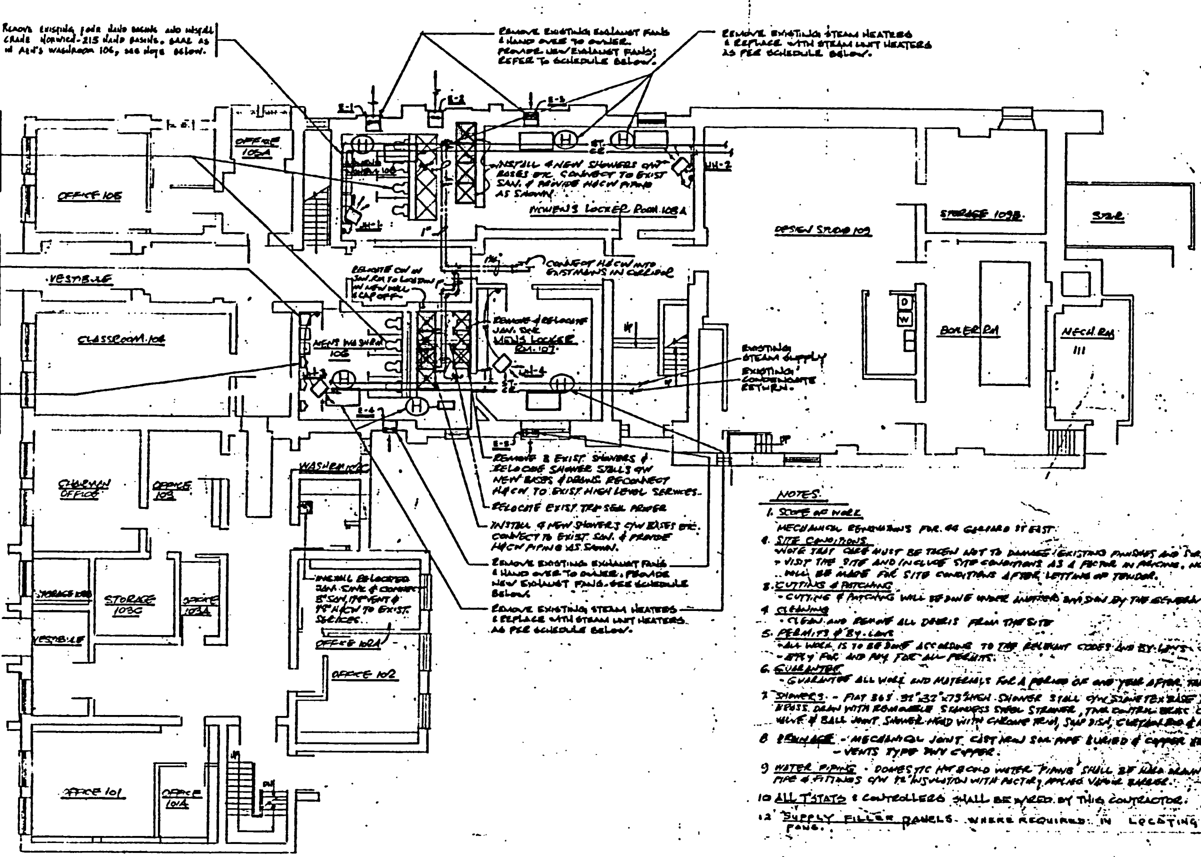
# 1st Floor MECHANICAL PLAN

REMOVE EXISTING WATER CLOSETS AND HAND OVER TO OWNER, REPLACE WITH CRANE NEW-PLACIDUS 3-459 VITREOUS CHINA, SIPHON JET WALL HUNG CLOSET BOWL WITH ELONGATED RIM AND WHIRLPOOL OUTLET ACTION - C-2021 1½" TOP SPUD, C/W WALL SUPPORT AND FRONT MOULDED PLASTIC SEATS.
TO BE EQUIPPED WITH PRESTO 402-YB EXPOSED CHROME PLATED FLUSH VALVE WITH OSCILLATING HANDLE, VACUUM BREAKER AND ESCUTCHEON.

REMOVE EXISTING FIVE HAND BASINS AND INSTALL THREE NEW CRANE NORMAN 1-215 8" (203 mm) CENTRES VITREOUS CHINA, WALL HUNG LAVATORIES WITH 4½" (114 mm) HIGH INTEGRAL BACK - RECTANGULAR BASIN - SPLASH LIP - FRONT OVERFLOW - NO SOAP DEPRESSION - C-1207 ONE-PIECE STEEL HANGER (DRILLED TO ACCOMODATE CONCEALED WALL CARRIERS). WASHBASINS TO BE EQUIPPED WITH SEPARATELY MOUNTED DRAWLY CHROMED TAPS AND MIXING FAUCET - SIMILAR TO EMCO DORIC 1163.
LAVATORY C/W C-1159 LATHER SOAP VALVE

REMOVE EXISTING URINALS AND REPLACE WITH THREE NEW CRANE CROMWELL 7-72 OV TOP INLET, VITREOUS CHINA, MODESTY WALL HUNG URINAL WITH FLUSHING RIM - EXTENDED SHIELDS - INTEGRAL TRAP - C-4004 STAINLESS STEEL STRAINER - C-4030 ¾" TOP SPUD - C-1206 STEEL SUPPORTING HANGERS.
TO BE EQUIPPED WITH PRESTO 451-YB EXPOSED CHROME PLATED FLUSH VALVE WITH OSCILLATING HANDLE, VACUUM BREAKER AND ESCUTCHEON.
FLUSH VALVES AS MFD BY WALTEC WILL ALSO BE ACCEPTABLE.

NOTES: ALL WASHROOM FIXTURES E.G. HAND BASINS, WATER CLOSETS, URINALS SHALL BE WHITE IN COLOUR UNLESS SPECIFIED OTHERWISE.




NOTES.

1. SCOPE OF WORK
MECHANICAL RENOVATIONS FOR 44 GERRARD ST EAST.
2. SITE CONDITIONS.
NOTE THAT CARE MUST BE TAKEN NOT TO DAMAGE EXISTING FINISHES AND SURFACES.
- VISIT THE SITE AND INCLUDE SITE CONDITIONS AS A FACTOR IN PRICING. NO ALLOWANCE WILL BE MADE FOR SITE CONDITIONS AFTER LETTING OF TENDER.
3. CUTTING & PATCHING
- CUTTING & PATCHING WILL BE DONE UNDER [illegible] BY THE GENERAL CONTRACTOR.
4. CLEANING
- CLEAN AND REMOVE ALL DEBRIS FROM THE SITE
5. PERMITS & BY-LAWS
- ALL WORK IS TO BE DONE ACCORDING TO THE RELEVANT CODES AND BY-LAWS.
- APPLY FOR AND PAY FOR ALL PERMITS.
6. GUARANTEE
- GUARANTEE ALL WORK AND MATERIALS FOR A PERIOD OF ONE YEAR AFTER TAKEOVER.
7. SHOWERS. - FIAT 36S 32"x32"x73¾"HIGH SHOWER STALL C/W STONETEX BASE ON STEEL PAN, BRASS DRAIN WITH REMOVABLE STAINLESS STEEL STRAINER, TWO CONTROL [illegible] COMPRESSION VALVE & BALL JOINT SHOWER HEAD WITH CHROME TRIM, SOAP DISH, CURTAIN ROD & HOOKS.
8. DRAINAGE - MECHANICAL JOINT CAST IRON SOIL PIPE BURIED & COPPER ABOVE FLOOR.
- VENTS TYPE DWV COPPER.
9. WATER PIPING - DOMESTIC HOT & COLD WATER PIPING SHALL BE HARD DRAWN TYPE 'L' COPPER PIPE & FITTINGS C/W ½" INSULATION WITH FACTORY APPLIED VAPOUR BARRIER.
10. ALL T'STATS & CONTROLLERS SHALL BE WIRED BY THIS CONTRACTOR.
12. SUPPLY FILLER PANELS WHERE REQUIRED IN LOCATING EXHAUST FANS.

## EXHAUST FAN SCHEDULE

| EXHAUST FAN NO. | C.F.M. | S.P. IN. | R.P.M. | B.H.P. | FAN MOTOR H.P. | MANUFACTURER | MODEL NO. | REMARKS |
|---|---|---|---|---|---|---|---|---|
| E-1. | 228 | .125 | 1550 | .014 | 1/80 | GREENHECK (E.H. PRICE) | SDE-8-32-D | ALL FANS C/W GUARD MOUNT, BACKDRAFT DAMPER & SPECIAL DEPTH WALL MOUNTING COLLAR. |
| E-2. | 428 | .125 | 1550 | .025 | 1/40 | GREENHECK | SDE-10-24-D | |
| E-6. | 117 | .125 | 1550 | .010 | 1/80 | GREENHECK | SDE-8-24-D. | " |
| E-4 | 1035 / 600 | .125 | HIGH / LOW | — | 60 WATTS | XPELAIR (CANTHERM ELEC) | WX 12 | WALL MOUNTED FAN C/W TWO SPEED CONTROLLER. |
| E-3,5 | 616 | .10 | HIGH SPEED | — | 75 WATTS | XPELAIR | GX 9 | WINDOW MTD. FAN C/W ELECTRICAL SHUTTER OPERATION |
| E-7. | 190. | .10 | HIGH SPEED | — | 80 WATTS | XPELAIR | GX 6. | " |

## (TRANE) UNIT HEATER SCHEDULE

| UNIT No. | MODEL | MOTOR H.P. | MOTOR R.P.M. | CAPACITY @ 5# STEAM PRESS. @ 70°F ENT. AIR BTU/HR | EDR | CFM. | OUTLET VELOCITY | REMARKS |
|---|---|---|---|---|---|---|---|---|
| UH-1. | 71H | 1/30 | 1000 | 15,000 | 71.3 | 292 | 392. | C/W LOUVRE FAN DIFFUSER |
| UH-2. | 71H | 1/30 | 1000 | 17,000 | 71.3 | 292 | 392 | " |
| UH-3. | 71H | 1/30 | 1000 | 14,500 | 71.3 | 292 | 392 | " |
| UH-4. | 71H | 1/30 | 1000 | 15,500 | 71.3 | 292 | 392 | " |

NOTE: ROOM T'STAT FOR EACH UNIT C/W OFF-MANUAL-ON AUTOMATIC SWITCH.

REFER TO P-123 2001


THE ECE GROUP Consulting Engineers


REVISIONS

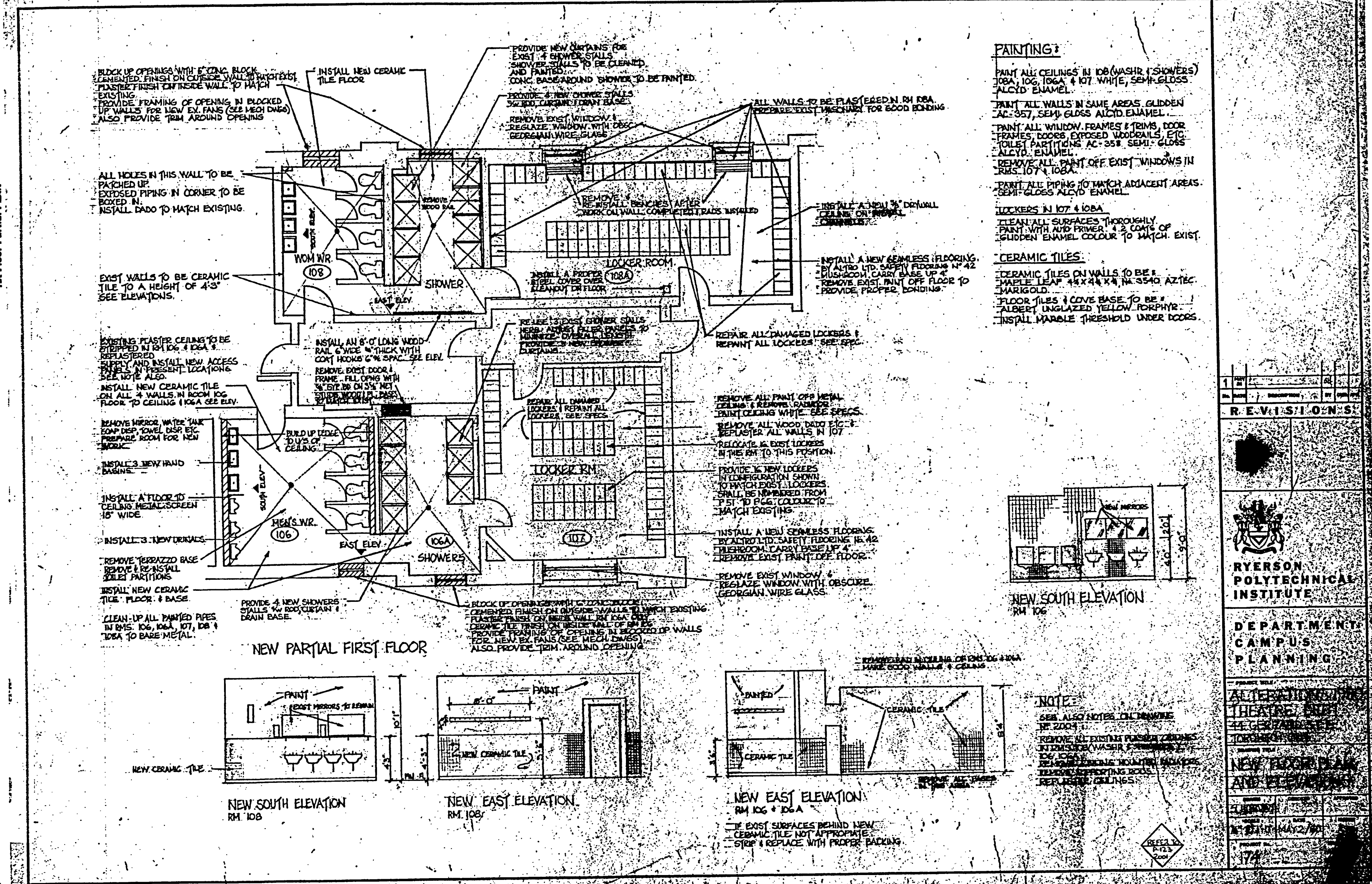
RYERSON POLYTECHNICAL INSTITUTE

DEPARTMENT CAMPUS PLANNING

PROJECT TITLE: ALTERATIONS 1980. 44 GERRARD ST. EAST TORONTO ONTARIO.

DRAWING TITLE: FIRST FLOOR PLAN MECHANICAL

| DRAWN | CHECKED | APPROVED |
|---|---|---|
| SB | T.L.M. | |
| SCALE | DATE | ISSUED |
| 1/8"=1'-0" | MAY 2/80 | |
| PROJECT No. | | DRAWING No. |
| 174 | | M-1 |


NEW PARTIAL FIRST FLOOR
WOM.WR. 108
SHOWER
LOCKER ROOM 108A
MEN'S WR. 106
SHOWERS 106A
LOCKER RM 107
SOUTH ELEV.
EAST ELEV.
INSTALL NEW CERAMIC TILE FLOOR
ALL HOLES IN THIS WALL TO BE PATCHED UP. EXPOSED PIPING IN CORNER TO BE BOXED IN. INSTALL DADO TO MATCH EXISTING.
EXIST WALLS TO BE CERAMIC TILE TO A HEIGHT OF 4'3" SEE ELEVATIONS.
INSTALL AN 8'-0" LONG WOOD RAIL 6" WIDE 3/4" THICK WITH COAT HOOKS 6" SPAC. SEE ELEV.
INSTALL NEW CERAMIC TILE ON ALL 4 WALLS IN ROOM 106 FLOOR TO CEILING & 106A SEE ELEV.
INSTALL 3 NEW HAND BASINS.
INSTALL A FLOOR TO CEILING METAL SCREEN 18" WIDE.
INSTALL 3 NEW URINALS.
REMOVE TERRAZZO BASE REMOVE & RE-INSTALL TOILET PARTITIONS
INSTALL NEW CERAMIC TILE FLOOR & BASE.
CLEAN-UP ALL PAINTED PIPES IN RMS. 106, 106A, 107, 108 & 108A TO BARE METAL.
PROVIDE 4 NEW SHOWERS STALLS W/ ROD, CURTAIN & DRAIN BASE.
BUILD UP LEDGE TO U/S OF CEILING.
ALL WALLS TO BE PLASTERED IN RM 108A. PREPARE EXIST MASONRY FOR GOOD BONDING
REPAIR ALL DAMAGED LOCKERS & REPAINT ALL LOCKERS. SEE SPEC.
RELOCATE 16 EXIST LOCKERS IN THIS RM TO THIS POSITION.
PROVIDE 16 NEW LOCKERS IN CONFIGURATION SHOWN TO MATCH EXIST. LOCKERS SHALL BE NUMBERED FROM P51 TO P66. COLOUR TO MATCH EXISTING.
REMOVE EXIST. WINDOW & REGLAZE WINDOW WITH OBSCURE GEORGIAN WIRE GLASS.
PAINTING:
PAINT ALL CEILINGS IN 108 (WASHR. & SHOWERS) 108A, 106, 106A & 107 WHITE, SEMI-GLOSS ALCYD ENAMEL.
PAINT ALL WALLS IN SAME AREAS GLIDDEN AC-357, SEMI GLOSS ALCYD ENAMEL.
PAINT ALL PIPING TO MATCH ADJACENT AREAS. SEMI-GLOSS ALCYD ENAMEL.
LOCKERS IN 107 & 108A
CERAMIC TILES:
INSTALL MARBLE THRESHOLD UNDER DOORS.
NEW SOUTH ELEVATION RM 106
NEW SOUTH ELEVATION RM 108
NEW EAST ELEVATION RM 108
NEW EAST ELEVATION RM 106 & 106A
PAINT
CERAMIC TILE
NEW CERAMIC TILE
IF EXIST SURFACES BEHIND NEW CERAMIC TILE NOT APPROPRIATE STRIP & REPLACE WITH PROPER BACKING.
NOTE:
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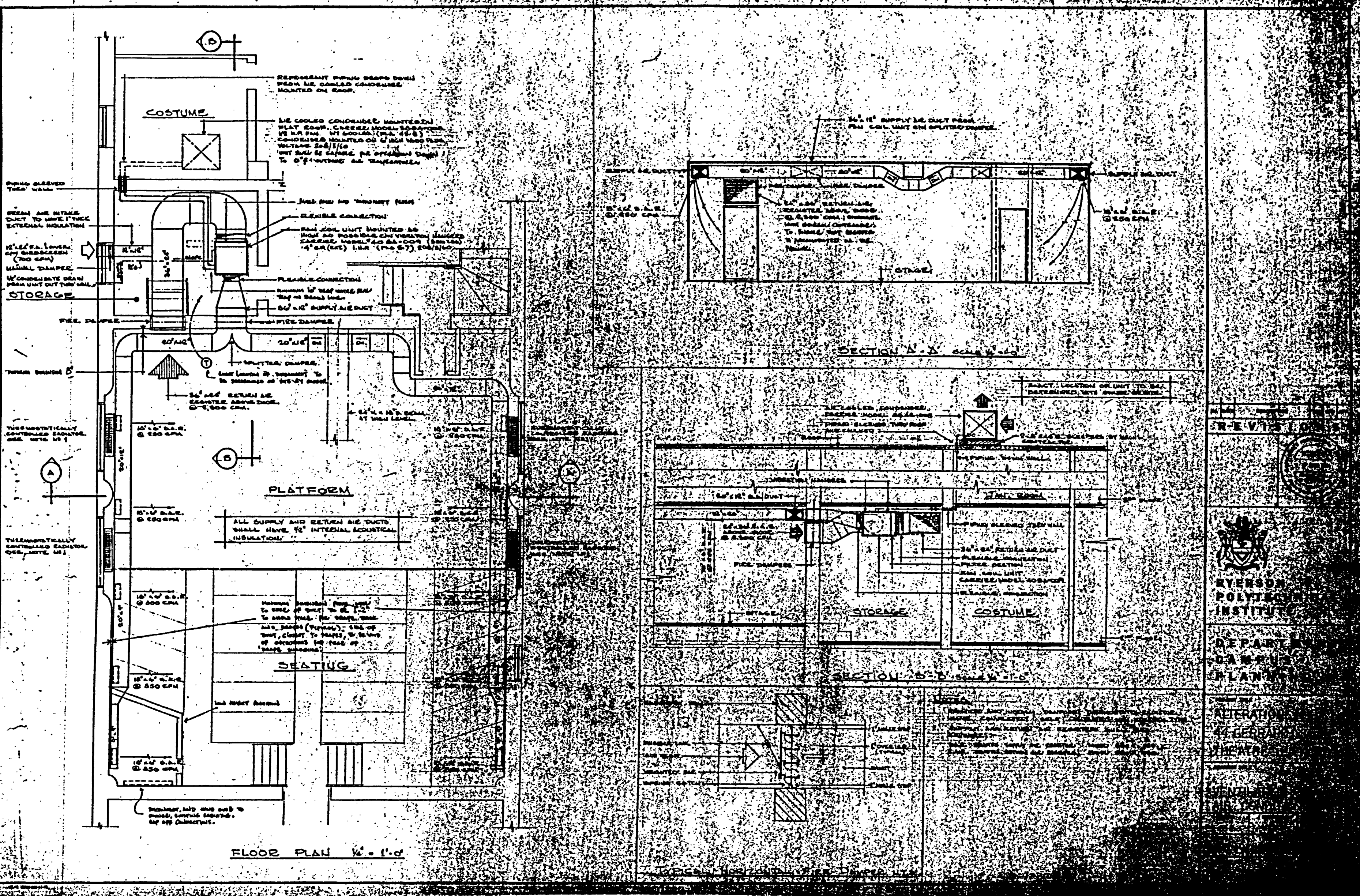
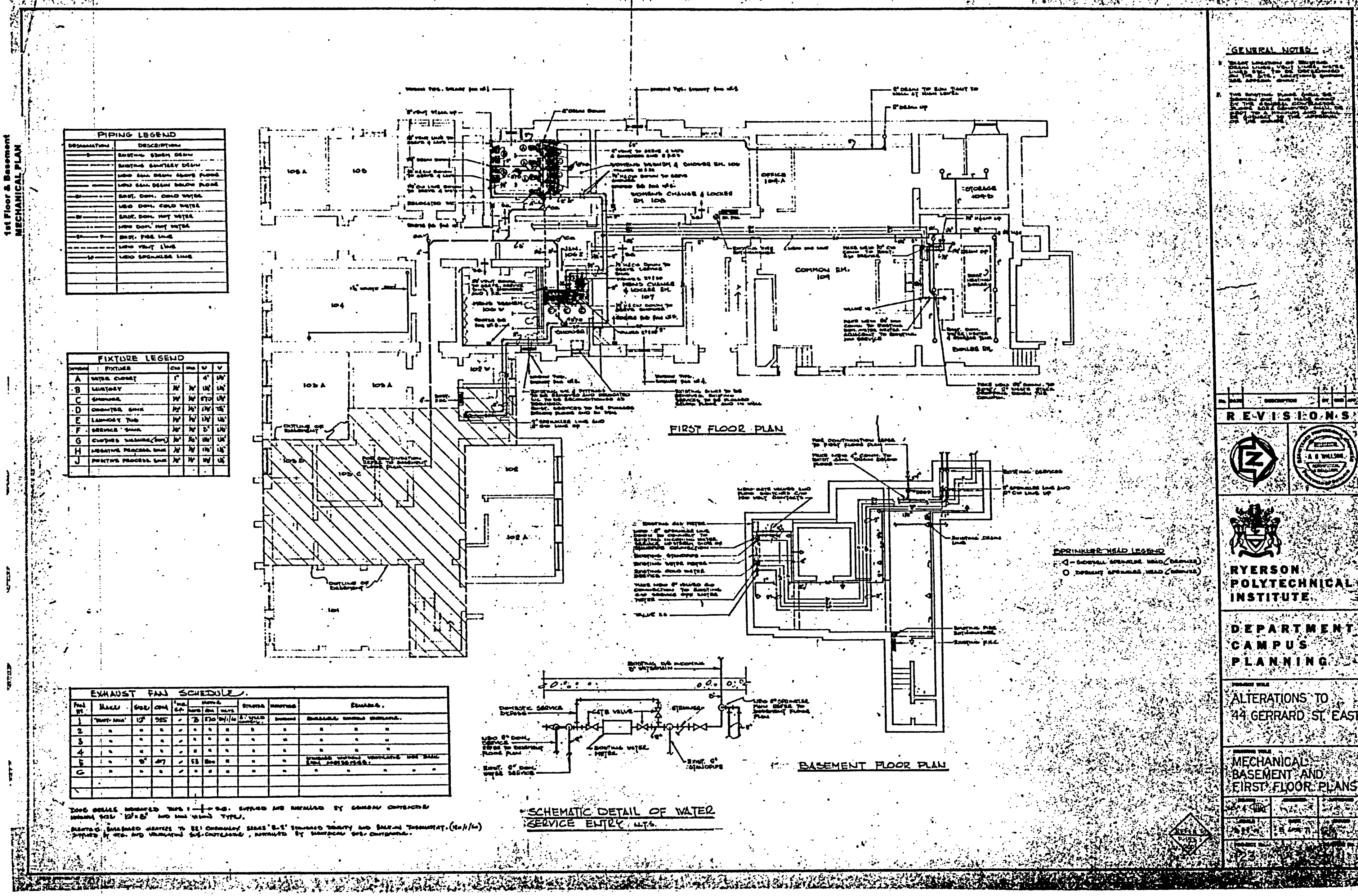
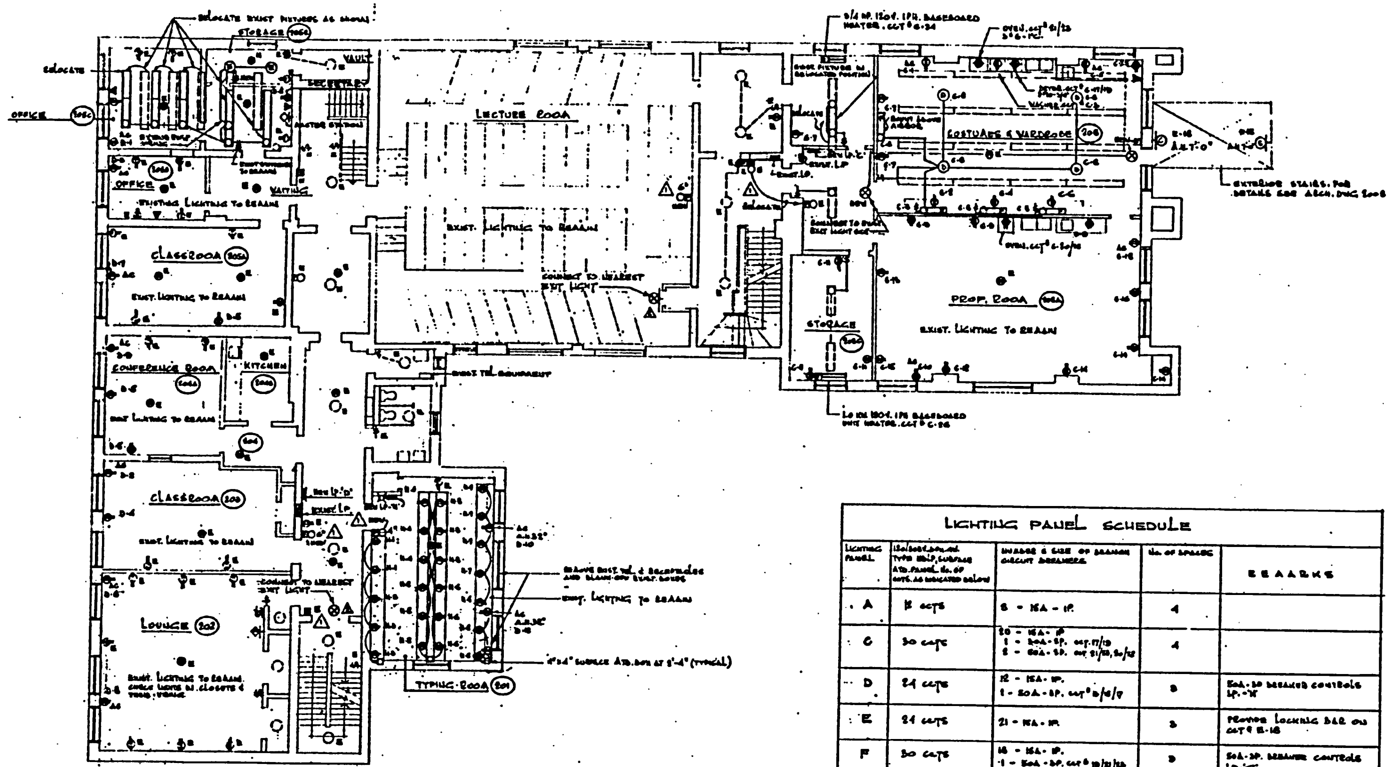
1st Floor VENTILATION & AIR CONDITIONING




GENERAL NOTES
PIPING LEGEND
DESIGNATION
DESCRIPTION
FIXTURE LEGEND
FIXTURE
A
B
C
D
E
F
G
H
J
EXHAUST FAN SCHEDULE
FAN NO.
MAKE
SIZE
CFM
STATUS
REMARKS
1
2
3
4
5
6
OFFICE 104-A
STORAGE 104-B
COMMON RM. 109
BOILER RM.
WOMENS CHANGE & LOCKER RM. 108
MENS CHANGE & LOCKER RM. 107
106
106 A
105 A
104
103 A
102
102 A
101
OUTLINE OF BASEMENT
FIRST FLOOR PLAN
BASEMENT FLOOR PLAN
GATE VALVE
STRAINER
SCHEMATIC DETAIL OF WATER SERVICE ENTRY N.T.S.
SPRINKLER HEAD LEGEND
REVISIONS
RYERSON POLYTECHNICAL INSTITUTE
DEPARTMENT CAMPUS PLANNING
ALTERATIONS TO 44 GERRARD ST. EAST
MECHANICAL BASEMENT AND FIRST FLOOR PLANS




| LIGHTING PANEL | 120/208V 3PH 4W TYPE NBLP, SURFACE MTD. PANEL No. OF CCTS. AS INDICATED BELOW | NUMBER & SIZE OF BRANCH CIRCUIT BREAKERS | No. OF SPACES | REMARKS |
|---|---|---|---|---|
| A | 12 CCTS | 8 - 15A - 1P. | 4 | |
| C | 30 CCTS | 20 - 15A - 1P<br>1 - 20A - 2P. CCT. 17/19<br>2 - 60A - 2P. CCT 21/23, 20/22 | 4 | |
| D | 24 CCTS | 12 - 15A - 1P.<br>1 - 20A - 3P. CCT# 3/5/7 | 9 | 20A-3P BREAKER CONTROLS LP-'H' |
| E | 24 CCTS | 21 - 15A - 1P. | 3 | PROVIDE LOCKING BAR ON CCT# E-18 |
| F | 30 CCTS | 18 - 15A - 1P.<br>1 - 50A - 3P. CCT# 19/21/23 | 9 | 50A-3P. BREAKER CONTROLS LP-'G' |
| G | 12 CCTS | 12 - 15A - 1P. | – | MAIN BREAKER & PILOT LIGHT |
| H | 12 CCTS | 8 - 15A - 1P. | 4 | MAIN BREAKER & PILOT LIGHT |

REFER TO P-123 2002

| No. | DATE | DESCRIPTION | BY | CHD | APP. |
|---|---|---|---|---|---|
| 1 | | EXIT LIGHTS ADDED | J.P. | | |
| 2 | | REVISED FIRE ALARM AS PER ADDENDUM # | J.P. | | |

REVISIONS

PAUL C. ELLARD

RYERSON POLYTECHNICAL INSTITUTE

DEPARTMENT CAMPUS PLANNING

PROJECT TITLE
ALTERATIONS
44 GERRARD ST. E.

DRAWING TITLE
ELECTRICAL
SECOND FLOOR PLAN

| DRAWN | CHECKED | APPROVED |
|---|---|---|
| J.P. | L.B. | – |
| SCALE | DATE | ISSUED |
| 1/8" = 1'-0" | 13 APR. 71 | |
| PROJECT No. | | DRAWING No. |
| 123 | | E-2 |