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ENERGY PERFORMANCE ANALYSIS OF REGION OF PEEL HEADQUARTERS
BUILDING AS A SUSTAINABLE BUILDING USING THE "CARRIER HAP", "eQUEST"
SIMULATION PROGRAM AND "RETScreen" COST ANALYSIS PROGRAM

by

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Abstract

The principles of building energy simulation and its relationship with heating and cooling energy calculation help to make an integrated evaluation of building energy consumption. This is used to achieve a better and more energy efficient building. The sensitivity analysis of energy efficient HVAC design was used to create an energy efficient Peel Region Headquarters Building.

An energy audit was conducted on the existing building to establish the Base Case Model "Peel Region Headquarters Building" to determine its annual energy consumption across all current usage. To reduce the total energy cost of the Base Case Model, different HVAC Systems were investigated to analyze their energy-based performance and impact on the Greenhouse Gas Emission (GHG). The sensitivity analysis was conducted using two whole building simulation programs, "Carrier HAP" and "eQUEST", with three different air systems, namely, "2-Fan Dual Duct Variable Air Volume System", "1-Fan Dual Duct Variable Air Volume System" and "1-Fan Dual Duct Variable Air Volume System with two Rooftop Packaged HVAC System". Three different types of heat pumps, namely, Open Loop Water Source Heat Pump, Closed Loop Water Source Heat Pump, and Ground Source Heat Pump, were used to determine the efficiency and viability of the three proposed HVAC System with the existing infrastructure. RETScreen International Clean Energy Project Analysis Software (Version 4) was used to evaluate the energy production and savings, life-cycle costs, emission reductions and financial viability. MNECB/CBIP and ASHRAE 90.1 (2004) Building Compliance Program was used for determining the key elements for analyzing the building components and for providing recommendations for an energy efficient building.

The improvement from the conventional HVAC System to implementation of an Open Loop Water Source Heat Pump resulted in 75% energy cost savings for the Peel Region Headquarters Building. The percentage contribution of CO₂ was reduced by 78%.

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List of Abbreviations

ACH–Air Change per Hour
Adeline–Advanced Day and Electric Lighting Integrated New Environment
ARI–Air Conditioning and Refrigeration Institute
AST–Apparent Solar Time
ASHRAE–American Society of Heating, Refrigerating and Air-conditioning Engineers
BLAST–Building Loads Analysis and System Thermodynamics
B.H.P–Brake Horse Power
BTU–British Thermal Units
CBIP–Commercial Building Incentive Program
CAD–Computer - Aided Design
CAV–Constant Air Volume
C-factor–Thermal Conductance ($\text{Btu/h-ft}^2\text{-}^{\circ}\text{F}$)
CL–Closed Loop
COP–Coefficient of Performance
CLTD–Cooling Load Temperature Difference Method
CO₂–Carbon Dioxide
COMBINE–Computer Models for the Building Industry in Europe
COMIS–Conjunction of Multi Zone Infiltration Specialists
CSA–Canadian Standards Association
CTF–Conduction Transfer Method
CWEC–Canadian Weather for Energy Calculations
DB–Dry Bulb
DD Wizard–Design Development Wizard
DOE–Department of Energy
DWG–CAD Drawings
DX System–Direct Expansion HVAC System
ECWT–Entering Chilled or Cooling Water Temperature
EEM Wizard–Energy Efficiency Measure Wizard

EER–Energy Efficiency Ratio
ESP-r–Environmental System Performance
EWT–Entering Water Temperature
F-factor–the Perimeter Heat Loss Factor for Slab-On-Grade Floors (Btu/h-ft²-°F)
GLHE–Ground Loop Heat Exchanger
GHG–Greenhouse Gas
GCHPs–Ground Coupled Heat Pumps
GSHP–Ground Source Heat Pump
HAP–Hourly Analysis Programs
HDPE–High Density Polyethylene
HSPF–Heating Seasonal Performance Factor
HVAC–Heating Ventilation and Air Conditioning
IGSHPA–International Ground Source Heat Pump Association
JJH DOE-2–Weather File Format
LEED–Leadership in Energy and Environmental Design
MNECB–Model National Energy Code of Canada for Buildings
MNECH–Model National Energy Code of Canada for Houses
N/A–Not Available
NBSLD–U.S. National Bureau of Standards
NRCan–Natural Resources Canada
OA–Outside Airflow Rate
OL–Open Loop
U Value–Overall Heat Transfer Coefficient (Btu/ h-ft²-°F)
R-values–Thermal Resistance of the Insulation (h-ft²-°F/Btu)
RH–Relative Humidity
RETScreen–International Clean Energy Project Analysis Software
RTS–Radiant Time Series
SkyCalc–Sky Calculation
SD–Systematic Design
SEER–Seasonal Energy Efficiency Ratio
SHGC–Solar Heat Gain Coefficient

SWHPs—Surface Water Heat Pumps

TFM—Transfer Function Method

TMY and TRY—Typical Meteorological Year

TRNSYS—Transient Systems Simulation

T-S diagram—Temperature Entropy Diagram

U-factor—Thermal Transmittance

VENT—Duct Design Program

VAV—Variable Air Volume

WB—Wet Bulb

WF—Weighting Factors

WSHP—Water Source Heat Pump

List of Symbols

CFM–Volume Flow Rate

Cubic m–Unit of Fossil Fuel (Gas) in Cubic Meter

Ft WG–Pressure Head Measured in Feet of Water Gauge

GPM–Gallon per Minute

H–Height of the Floor to Floor

kPa–kilopascal

kW–Kilo-Watts

kWh–kilowatt-hour

L/s–Liter per Second

m³/s–Volumetric Water Flow

MWh–Megawatt hour

MBH–Mega British Thermal Unit

Tons–Refrigeration Capacity Measured in Tons (1ton=12000Btuh)

psi–Pounds per Square Inch

Z, X, Y–Three Dimension Space Coordinates

1. Introduction

1.1. Building Energy Simulation

Building energy simulations are typically used to estimate and then compare energy use and energy cost for alternate building or equipment designs. The topic of building energy simulation contains a wealth of information on integrated building. Buildings account for 31% direct contribution and 52% indirect contribution of greenhouse gas (GHG) emissions making them a primary contributor to global warming and ozone depletion (NRCan, 2008). Better energy efficiency in buildings has become one of the world's major challenges. Simulation plays an important role in the energy-efficient design process. From operating costs, to energy efficiency, to environmental impacts, simulation provides the performance information critical to the "whole-systems" energy-efficient building design process. As heating, ventilating and air conditioning and lighting account for the major part of a building's energy use, it is vital that the performance of essential building services and systems be well understood and optimized to facilitate conservation measures .

Figure 1 shows the percentage contribution of greenhouse gas emission in the building sector in Canada.

Figure 1: Government of Canada GHG Emissions (NRCan, 2008)

The energy requirements of a building depend on the individual performance of the building envelope, HVAC efficient design and lighting systems. It also depends on their overall performance as an integrated system within the unique building. Dynamic heat flow in the building determines cooling and heating demands for the conditioned spaces

in the building. Air handling systems are used to determine the cooling and heating coils loads (Henninger et al, 2004).

Simulation can and has played a significant role in reducing the energy consumption of buildings. During the design phase of a building, many decisions are made that affect the energy consumption and cost over the lifecycle of the facility. If changes in the facility design can be made early, a more cost-effective, energy-conservative building can result. Building thermal simulation allows one to model a building before it is built or before renovations are started. Simulation allows various energy alternatives to be investigated and options compared to one another (Ibm et al, 2004).

With the use of computer simulation method for analyzing energy efficiency and building loads, the costs associated with installation of actual equipment has virtually nullified. Computer aided building designing offers functions such as energy assessment, comfort appraisal, movement simulation, light simulation, and life cycle cost prediction within a single defined environment.

Integrated in every country, building energy consumption is an order of magnitude of 10-50 % of the total delivered energy (Henninger et al, 2004).

Simulation programs such as Carrier HAP and eQUEST consist of a detailed description of the building being analyzed, including hourly scheduling of occupants, lighting, equipment, and thermostat settings. Both simulation programs provide very accurate simulation results of such building parameters as shading, infiltration, fenestration, interior building mass, building envelope, and dynamic response of different heating and air conditioning system types and their controls.

The building description is based on building plans and specifications. A base line building model that assumes a minimum level of efficiency (e.g., minimally compliance with ASHRAE 90.1 (2004) is then developed to establish the base from which energy savings are estimated (ASHRAE, 2004).

1.2. Building Simulation Programs

Building Simulation Programs of the energy processes within a building are used for the energy calculation and intended to provide a thermally comfortable environment for the occupants (or contents) of a building. According to the function, building energy simulation programs may be classified into three major categories (Clarke, 1988).

- Lighting and day lighting simulation
- Component based simulation
- Whole building simulation

1.2.1. Lighting and Day Lighting Simulation

Lighting and day lighting simulation softwares such as Adeline and Radiance, focus on the design of lighting and day lighting systems; they estimate the lighting effect and provide related information and images to visualize the design.

Advanced Day and Electric Lighting Integrated New Environment (Adeline) is used for large commercial building applications. It provides 3-D CAD modeling of a space and displays analysis results in graphical format.

Radiance is a GUI based C++ Programming language. It is an excellent public domain lighting simulation tool. It is freely downloadable software but not easy to use. High-level computer literacy is required to run Radiance.

1.2.2. Component-Based Simulation

Component-based simulation is usually designed for a specific system, such as solar architecture. It is an excellent public domain thermal performance simulation tool. It includes a thermal performance calculator, a design element checklist, and excel spreadsheets database with useful Solar Architecture parameters (e.g., thermal properties) (Arizona Solar Center, 2008).

1.2.3. Whole Building Simulation

Whole building simulation programs are classified according to their characteristics and use. Some programs are user-friendly and some are research based.

User-friendly simulation programs include:

- Carrier HAP
- DOE-2.2
- Visual DOE
- eQUEST
- TRACE 700
- HOT 2000/3000
- Power DOE
- ENERGY-10

Research based programs include:

- ESP-r
- COMBINE
- TRNSYS
- BLAST
- EnergyPlus
- ENERGYBASE

Carrier HAP

Carrier HAP is not a public domain program. Carrier HAP provides two powerful tools in one software package. HAP sizes HVAC systems for commercial buildings. It also simulates 8760-hour building energy performance to derive annual energy use and energy costs (Carrier, 2006).

HAP complies with simulation tool requirements outlined in ASHRAE Standard 90.1 (2001) section 11.2. Data generated with HAP is accepted for LEED project submissions. HAP has been tested using ASHRAE Standard 140-2001 procedures (Carrier, 2006).

DOE-2.2

DOE-2 is a public domain program that performs hourly simulation of a building's energy consumption and energy cost given a description of the building's climate, architecture, materials, operating schedule, and HVAC equipment. DOE-2.2 is widely used in the U.S. and more than forty countries to design energy-efficient buildings, analyze the impact of new technologies, to develop energy conservation standards. DOE-2.2 uses a room weighting factor approach. It provides 20 input verification reports and 50 monthly/annual summary reports. DOE-2.2 also gives full life-cycle cost analysis. All reports are in the graphical and tabular format (Hirsch, 2008).

Visual DOE

Visual DOE utilizes the DOE-2 simulation engine and provides graphical user interface for input and output processing (Hirsch, 2008).

Power DOE

Power DOE is a window graphical user interface version of DOE 2.2. Power DOE is very easy to use and has the same characteristics as Visual DOE (Hirsch, 2008).

eQUEST

eQUEST is a public domain program. eQUEST plays a great simulation role in the energy efficient design process. It is an easy to use building energy use analysis tool. The program consists of a detailed description of the building being analyzed. eQUEST calculates hour-by-hour building energy consumption over an entire year using hourly weather data for the location under consideration. The simulation engine within eQUEST is derived from the latest version of DOE-2.2. The simulation processes are accomplished by combining a Schematic Design Wizard, Design Development Wizard, and Energy Efficiency Measure Wizard. The results are in the graphical and tabular format (Hirsch, 2008).

TRACE 700

TRACE 700 is not a public domain program. TRACE 700 programs developed by the Trane company, is divided into four distinct calculation phases: Design, System, Equipment and Economics.

During the Design phase the program calculates building heat gains for each month based on the building geometry, during the System phase the building is simulated for 8760 hours, and during the Equipment phase it uses the hourly coil loads from the System phase to determine how the cooling, heating, and air moving equipment will consume energy (Trane, 2008).

ENERGY-10

ENERGY-10 is not a public domain program. ENERGY-10 simulation program is a powerful tool that analyzes the energy and cost savings by using more than a dozen sustainable design alternatives. An hourly base simulation program calculates the energy consumption of different building parameters. It also assesses and depicts the benefits of day lighting, passive solar heating, natural ventilation, well-insulated envelopes, better windows, lighting systems, mechanical equipment (NREL, 2008).

ENERGY-10 version 1.8 offers many new features:

- Photovoltaic module that provides the ability to model and simulate the performance of PV system that is either stand-alone or integrated with the building.
- Solar domestic hot water module provides a new solar domestic/service hot water modeling capability.
- All default values of building components are based on ASHRAE 90.1 (2004).

BLAST

The University of Illinois developed the BLAST (Building Loads Analysis and System Thermodynamics) system. It is a set of computer programs for predicting heating and cooling energy consumption in buildings, and analyzing energy costs. BLAST can be used to investigate the energy performance of new or retrofit building design options of almost any type and size. In addition to performing peak load (design day) calculations necessary for mechanical equipment design, BLAST also estimates the annual energy performance of the facility, which is essential for the design of solar and total energy systems (ERDC, 2007).

The BLAST analysis program encompasses three major subprograms, which compute hourly requirements of the space loads, calculates demands (hot water,

steam, gas, electrical, chilled water) of the building and air-handling systems, and computes the hourly and annual fuel and electrical power consumptions. The heart of the space loads prediction is the room heat balance method. For each hour simulated, BLAST performs a complete radiant, convective, and conductive heat balance for each surface of each zone described and a heat balance on the room air. This heat balance includes transmission loads, solar loads, internal heat gains, infiltration loads, and the temperature control strategy used to maintain the space temperature (ERDC, 2007).

TRNSYS

The Solar Energy Laboratory, University of Wisconsin, developed TRNSYS (Transient systems simulation). It was first released in 1975. The latest version is 16!

TRNSYS is used primarily to simulate thermal energy systems. Each physical component in the system, such as a pump or solar collector, is represented by a different FORTRAN subroutine. The subroutines are combined into an executable file controlled with an input file, which describes what physical components are involved in the system and how they are connected. TRNSYS has been used for simulating solar thermal systems as well as general HVAC systems (Klein et al, 2006).

ESP-r

The Energy Systems Research Unit at the University of Strathclyde developed ESP-r (Environmental System Performance) during 1977 to 1984. The ESP-r is the European reference building simulation program, which allows engineers to assess how actual weather patterns, occupant interactions, design parameters changes and control systems affect energy requirements and environmental states. ESP-r is a public domain transient energy simulation system capable of modeling the energy and mass flows within combined building and plant systems (ESRU, 2008).

COMBINE

COMBINE (Computer Models for the Building Industry in Europe) began in 1990 and ended in 1995 resulting in two integrated systems. The first system is for architectural practice, which integrates more than ten design tools into an Intergraph-based architectural CAD system. The second system, dedicated to HVAC design, is an AutoCAD-based computer-aided HVAC drafting system which integrates Super link for

lighting design; ESP-r and DOE-2 for detailed thermal simulation; VENT for duct sizing; a HVAC components database; and DocLinks for document management. COMBINE was a major research project within the JOULE program. The project sought to develop an operational computer-based integrated building design system (Kenny, 2007).

DOE-2+BLAST = ENERGYBASE (From 1994-1996)

The U.S. government has supported two building energy simulation programs, DOE-2 and BLAST, DOE-2 supported by DOE, has its origins in the Post Office program written in the late 1960s for the U.S. Post Office. BLAST supported by DOE, has its origins in National Bureau of Standards programs developed at the U.S. in the early 1970s. The primary difference between the programs is load calculation method—DOE-2 uses a room weighting factor approach while BLAST uses a heat balance approach. In April 1994, a merger project has begun. This new program, Energy-Base combined the best capabilities of DOE-2 and BLAST (Ibm et al, 2004).

DOE-2+BLAST+COMIS = EnergyPlus (From 1999-April, 2007)

DOE-2, BLAST, and COMIS are being combined into a new program called EnergyPlus. EnergyPlus, as a Simulation tool, imitative the representation of the functioning of one system or process by means of the functioning of another. EnergyPlus is a fully integrated building & HVAC simulation program based on best features of BLAST and DOE-2 plus new capabilities. EnergyPlus is used on Windows 95/98/NT/2000/XP and Linux. EnergyPlus is a simulation engine only. Interfaces are available from private software developers. The major concept behind the merger is to combine the heat balance engine of the IBLAST program (a version of BLAST with integrated building, system and plant simulation) with a generalized HVAC engine that includes system types from BLAST and DOE-2. One of the main goals of EnergyPlus is to allow easy additions of features and links to the other programs. EnergyPlus is a heat balance-based zone simulation, and input and output data structures tailored to facilitate third party interface development (U.S. DOE, 2008; Ibm et al, 2004).

1.3. Comparison of the Simulation Programs

Comparison of the features and capabilities of a wide variety of building energy simulation programs are based on zone loads; building envelope; day lighting and solar; infiltration, ventilation and multi-zone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; environmental emissions; climate data availability, and user interfaces. The comparison of the different simulation programs features are summarized in Table 1.

Table 1: Comparison of the Simulation Programs (Crawley et al, 2005)

Comparison of the Simulation Programs Features	BLAST	DOE-2.2	EnergyPlus	eQUEST	HAP	ESP-r	TRANSYS	TRACE
Coupled loads, systems, plant calculations			x	x		x	x	
Space temperature based on loads-system feedback	x	x	x	x		x	x	x
Variable time intervals for zone air/HVAC system interaction	x		x	x		x		
Multi-sized polygons		x	x	x		x		
Import building geometry from CAD programs			x	x		x	x	x
Number of surfaces, zones, systems, and equipment unlimited			x		x	x	x	x
Import calculated or measured loads			x	x		x	x	x
Heat balance calculation(Transfer functions method)	x	x	x	x	x		x	x
Automatic design day sizing calculations (Dry bulb, Dew point temperature or relative humidity)	x	x	x	x	x			x
Shading surface transmittance	x		x	x				
Shading device scheduling	x		x	x			x	x
Shading of sky IR by obstructions		x	x	x			x	

Controllable window blinds (fenestration)		x	x	x		x	x	
Electro chromic glazing			x	x		x	x	
Window blind model			x	x		x	x	
Day lighting illumination and control		x	x	x		x	x	
Surface conduction 1-dimension only	x	x	x	x	x	x	x	x
Surface conduction 2- and 3- dimension			x					
Ground heat transfer 1- dimension	x	x	x	x	x	x	x	
Ground heat transfer 2- and 3- dimension (slabs and basements)			x					
Single zone infiltration	x	x	x	x	x	x	x	x
Renewable Energy System(photovoltaic power)			x	x		x	x	
Ventilation air flow schedule			x	x		x	x	
CO ₂ zone concentration, mechanical and natural					x	x		
CO ₂ based demand-controlled ventilation								
Automatic sizing of HVAC components		x	x	x	x			x
Automatic sizing of air loop flow, outside air, zone airflow			x		x			x
DX system(air-to-air , water-to-air , ground source and open source heat pump)	x	x	x	x	x	x	x	x
Heat exchangers(Plate frame type)				x		x	x	x
Heat exchangers(Immersed coil type)							x	
Heat exchangers(Shell and tube type)						x	x	
Domestic service water heater		x	x	x			x	x
Major greenhouse gases	x	x	x	x	x	x		x
Weather data processing and editing	x	x	x	x		x	x	
Separately downloadable weather data			x	x	x	x	x	x
DOE-2 text format		x	x	x				x
User selectable billing dates		x	x	x				x

1.4. Methodology Used For Modeling the Peel Region Headquarters Building

Figure 3 depicts the methodology used by Carrier HAP and eQUEST, energy simulation softwares for complying with MNECB and ASHRAE 90.1 (2004) Codes.

Figure 3: Flow Chart of Modeling the Peel Region Headquarters Building

1.5. The Objective of the Study

The main objectives and goals of the study are energy conservation of building energy as well as gaining specific information for sustainable building types and HVAC systems. Specific details are:

- Implement the MNECB / CBIP, and ASHRAE 90.1 (2004) energy code compliance to the Peel Region Headquarters Building.
- Utilize whole building simulation and design principles to achieve the goals of energy efficient buildings.
- Determine and analyze the key elements of the building components and provide recommendations for long-term goals of energy efficiency.
- Determine and evaluate the energy and cost of Peel Region Headquarters Building using two different types of whole building energy simulation programs such as Carrier HAP and eQUEST.
- Study high efficiency clean energy HVAC system such as Heat Pump and develop recommendations for energy cost analysis and energy impact of heat pump on utility load characteristics.
- Analyze the feasibility of the Heat Pump system using the RETScreen software.

2. Energy Performance Analysis Simulation Program “Carrier HAP”

2.1. Overview of “Carrier HAP” Program

The purpose of this project is to understand and interpret building energy simulation software HAP, Hourly Analysis Program, by Carrier Corporation. Carrier HAP is a computer tool, which helps engineers in designing and sizing HVAC systems for commercial buildings. It consists of two tools. The first tool is used to estimate the load and design system. The Second tool is used to simulate energy use and to calculate energy cost. This combination of two tools in single package saves time and effort. It also simulates 8760-hour building energy performance to determine annual energy use and cost of energy. Results from one system can be used in other systems (Carrier, 2006).

HAP uses combination of six different calculation engines:

The loads engine uses The ASHRAE Transfer Function Method to analyze dynamic heat transfer in the building, producing space cooling and heating loads.

- The systems engine simulates the thermo-mechanical operation of the airside system.
- The sizing engines integrate with both systems and loads engines and helps to estimate the proper size for diffusers, air terminal, fans, coils and humidifiers.
- The plant engine simulates the operation of chilled water and hot water plants.
- The building engine collects energy and fuel consumptions data from the system and plant calculations and combines it with utility rate specifications to produce energy consumption and energy costs.
- A life cycle engine combines energy costs from HAP with purchase, installation and maintenance costs to derive life cycle costs.

2.2. Carrier HAP Structure (Project Navigator)

Carrier HAP Project Navigator uses an explorer type of graphical user interface to provide quick and efficient access to the project data. The user-friendly graphical interface of Carrier HAP makes the entry of data quick and easy. Figure 4 represents the methodology that the software undergoes to create an input data file for the base case building.

Figure 4: Carrier HAP Structure "Project Navigator"

2.3 Carrier HAP (Limitation /Strength)

2.3.1. Carrier HAP Limitation

1. HAP has limitation for its use for research work.
2. Access to source code is not available which is sometimes required for research purposes.
3. Air system has a limit of spaces (i.e., total number of spaces for one air system up to 100 spaces).
4. Spaces up to 2500 per project
5. Systems up to 250 per project
6. Plants up to 100 per project
7. Buildings up to 100 per project

2.3.2. Carrier HAP Strength

- Carrier HAP offers project sharing for collaboration and archival features.
Carrier HAP is equally good for small, medium and large building.
- Systems include Packaged Roof Top, Packaged and Built-up Central Air Handlers, Terminal unit and Heat Pump.
- HAP is suitable for a wide range of new design and retrofit applications.
- Many different types of CAV and VAV system controls are available.
- More than 50 design, and energy analysis reports and graphs are presented.
- Design reports provide system sizing information, component loads, and building temperatures.
- Simulation reports provide hourly, daily, monthly and annual energy and cost performance data.
- Reports can be exported to word processors and spreadsheets for further use.
- HAP takes a complex utility rate schedule to calculate the energy cost.
- Technical features are comparable to DOE -2.
- Graphical output reports and tables of both detailed and summary reports provide comprehensive information about building, system and equipment.

- Weighting Factors are a type of transfer functions. Carrier HAP is using Weighting Factors, which is based on the DOE-2 program (Carrier, 2006).

2.4. Carrier HAP Weather Data

Weather data has a significant effect on the building heating and cooling loads and the operation and performance of HVAC equipment. Therefore, it plays a key role in the calculation of heating and cooling loads and system performance. HVAC systems of the building and portion of the building exposed to external environment are greatly influenced by temperature, humidity, solar radiation etc. The geographical location, soil properties, local time, atmospheric clearance number, ground reflection are used under the term "Weather". HAP uses only one set of weather data at a time for one project. The Weather Screen is used to define design weather data for a project. The weather form consists of three main parts (Carrier, 2006).

- It provides a database of design weather data for more than 800 cities worldwide.
- It uses TMY and TRY type hourly weather data for energy simulation.
- It provides a library of simulation weather data for more than 500 cities worldwide.

Design Weather Data is used to estimate cooling and heating design load as per industry standards. Cooling and heating design data consists of 24-hour profiles of temperature and humidity representing maximum condition for summer and winter design-day condition. Simulation Weather Data is used to perform hourly energy simulations. It refers to 8760 hours sequence of actual weather data to simulate building loads. These results can be used to estimate annual energy use and costs. Design Weather Data Source is obtained from Chapter 27 of the 2001 ASHRAE Handbook of Fundamentals (Carrier, 2006).

All calculations in Carrier HAP are performed according to local time. This is the most accurate approach for building occupancy, heat gains and equipment operation that are specified in terms of local time. To calculate solar fluxes and heat gains for a specific local time, the corresponding Apparent Solar Time (AST) is computed to determine the position of the sun in the sky. When calculating loads for a certain hour according to local time, the corresponding AST must be determined, so that solar loads

can be calculated. This is because AST is not the same as local time. All cities in the same time zone always have the same local time. However, only cities at the same longitude have the same Apparent Solar Time (Carrier, 2006).

Weather Properties - [Toronto]	
Design Parameters Design Temperatures Design Solar Simulation	
Region:	Canada
Location:	Ontario
City:	Toronto
Latitude:	43.7 deg
Longitude:	79.6 deg
Elevation:	568.0 ft
Summer Design DB	87.0 °F
Summer Coincident WB	71.0 °F
Summer Daily Range	20.2 °F
Winter Design DB	-4.0 °F
Winter Coincident WB	-5.3 °F
Atmospheric Clearness Number	1.00
Average Ground Reflectance	0.20
Soil Conductivity	0.800 BTU/hr/ft/F
Design Clg Calculation Months	Jan to Dec
Time Zone (GMT +/-)	5.0 hours
Daylight Savings Time	☒ Yes ☐ No
DST Begins	Apr 1
DST Ends	Oct 31
Data Source: 2001 ASHRAE Handbook	
OK Cancel Help	

Figure 5: Weather Data Screen (Carrier, 2006)

2.5. Heat Balance Method Used by the Carrier HAP

Generally, the heat balance method is used for sizing equipment such as fans, chillers, boilers, etc. Based on design criteria and thermal properties of the building, the cooling, heating, latent and fresh air loads of the building will be estimated to determine the design flow rate and capacity of the air-conditioning system and its equipment (Chen & Wang, 2001).

There are many methods for the determination of building thermal energy and load, for example, the room response method, equivalent temperature difference method, harmonized wave decomposition method and finite difference method. Nowadays, the "Transfer Function Method" pioneered by Mitalas and Stephenson (Lau & Ayres, 1979) and well known simplified methods such as the degree-day method and the bin method are used to predict the energy consumption of buildings or total cooling and heating load (Chen & Wang, 2001).

2.5.1. Building Energy Analysis

There are many methods for estimating building energy consumption and, in general, they can be divided into two categories (Chen & Wang, 2001; Hui et al, 1998):

1. Steady-State Method
2. Dynamic Method

Steady-state methods, such as the effective heat transfer method, degree day method, bin method, temperature frequency method and full load coefficient method, are simple to use, but they cannot provide information about the variation of energy consumption with the time and do not consider the effect of thermal storage in the building structure. Dynamic methods are more detailed and usually require hourly calculations over the whole year for the analysis of annual load and energy consumption. Conversion from the heat gains to cooling load can be carried out by the heat balance method (Chen & Wang, 2001).

The heat balance method uses more detailed physical thermal models and to solve the balanced condition of heat transfer and inside surface temperature. After the hourly load calculations of the rooms, the energy consumption of the air-conditioning system will be determined. The “space heat extraction” is the cause of the main cooling load consumption and it is affected by the characteristics of the control system and the cooling equipment.

2.5.2. CTF – Conduction Transfer Method

The detailed calculation of space cooling and heating loads is a complex process, which determines of each type of heat gain entering the space (e.g. solar, conduction through the exterior surfaces, or that from people, lights, and equipment), the radiation and convection interaction between each type of heat gain, and the storage and release of energy in thermal mass. In fact, heat conduction through building walls and roofs is a heat transfer problem through a composite medium consisting of several layers of different physical properties in contact (McQuiston et al, 2005; Chen & Wang, 2001).

The most accurate method is the Transfer Function Method (TFM). The TFM is based on two important concepts:

- Conduction Transfer Function (CTF).
- Weighting Factors (WF).

Conduction Transfer Functions are used by the TFM to describe the heat flux at the inside of a wall, roof, partition, ceiling, or floor as a function of previous values of the heat flux and previous values of inside and outside temperatures. Conduction Transfer Function Coefficients depend only on the physical properties of the wall or roof and not on the construction of the rest of the zone. Conduction Transfer Function Coefficients for walls, roofs, partition, floors, and ceilings, can be determined using the CTF Routines (Chen & Wang, 2001).

A Frequency Domain Regression Method is used to estimate CTF models of building multilayer constructions. This method is based on the principle that the frequency characteristics of dynamic models for a system should be equivalent. First, it is simply calculated by numerical matrix multiplication within the frequency range concerned. The CTF coefficients are then obtained by simply solving a set of linear equations. The Frequency Domain Regression method avoids any iterative computation and its computational process is simple, efficient and straightforward.

Weighting Factors are a type of transfer functions and are sometimes referred to as room transfer functions. Both CTF and WF are time series that relate a current variable to past values of it and other variables, at discrete time intervals. The discrete time intervals are usually 1-hour periods for transfer functions used in building analysis. The Weighting Factors is used in the DOE-2 program. The methodology is described by DOE-2 Engineer's Manual (Chen & Wang, 2001).

Different software uses different transfer function method such as Design Master HVAC uses the Cooling Load Temperature Difference (CLTD) Method. Loadsoft uses the new Radiant Time Series (RTS) Method. Trane Trace and Carrier HAP use the Transfer Function Method (TFM). The Conduction Transfer Function is based upon Table 34 in 1997 ASHRAE Handbook-Fundamentals. The CLTD is based upon a table generated by software included with Cooling and Heating Load Calculation Manual Second edition, McQuiston and Spitler, 1992 (Carrier, 2006).

2.6. Methodology for using “Thermal Energy Simulation” Program

- Creation of Building Model (Input Definition)
- Utilizing a Simulation Program (Running/Debugging Input).
- Analysis of Simulation Results (Output)

Every building is different in many ways:

- Location and Exterior Thermal Environment
- Construction / Building Envelope
- Space Usage / Interior Environment
- HVAC System

Location and exterior thermal environment are the driving forces that determine how a building will respond. Energy efficient design requires an understanding of and a response to the exterior thermal environment. Thermal simulation requires information on the exterior thermal environment properly analyze the building from an energy perspective.

Building envelope/construction determines how a building will respond to the exterior environment. Thermal simulation requires information about the physical make-up of the building, where various constructions are located and how they are oriented, how the building is subdivided into zones, etc.

Thermal simulation requires information on the building envelope to analyze the building from an energy perspective. Building construction is defined as an entire collection of interior and exterior features of the structure. Building may consist of one or more zones. A zone is defined a group of surfaces that can interact with each other thermally and have a common air mass at roughly the same temperature. Surfaces are walls, roofs, ceilings, floors, partitions, windows, shading devices. Surfaces consist of a series of materials called “construction”. Construction is a group of homogeneous one-dimensional material layers. Each surface must have a single construction definition, and each construction is made up of one or more materials.

Figure 6 depicts the thermal construction structure of building envelope in the base case building.

Figure 6: Flow Chart of Construction of Building Envelope

Thermal Zone

Zone definition considerably influences the results of energy analysis. In this study, each space is considered to be a zone to ensure accurate temperature control. When modeling existing buildings, zoning is done according to HVAC plans. The most accurate approach is to model one zone per thermostat in the system. This accurately models the system since the program calculates the cooling and heating demands sensed by each thermostat in the system. The danger in simplifying the model by combining zones is that accuracy will suffer. If there is an air temperature difference between adjacent spaces, separate thermal zones are needed.

Figure 7 shows the different types of thermal surfaces (i.e., heat storage surfaces and heat transfer surfaces) of the building envelope.

Figure 7: Types of Thermal Zone Surfaces

Space Usage / Interior Environment

Differences in internal gains may result in different conditioning requirements or distribution, such as office versus gymnasium. Space usage differences may alter the ventilation or exhaust requirements of a space, such as office versus kitchen versus chemistry laboratory.

Thermal simulation requires information about the functions taking place inside the building and how, these might add or subtract heat from the zones. Thermal simulation requires information on air leakage to and from the building to determine its effect on the building heating and cooling needs. Nothing is constant inside a building—people come and go, lights and equipment get turned on and off, etc.—and the thermal simulation needs details on what is happening through the day and year within a building.

Schedules are a way of specifying how much of a particular quantity is present, or at what level something should be set, including:

- Occupancy density
- Occupancy activity
- Lighting
- Thermostatic controls
- Shading element density

Types of Internal Gains:

- People
- Lights
- Equipment
- Infiltration

Heat Additions from Internal Gains:

- Sensible and Latent
- Sensible—energy addition associated with (dry-bulb) temperature change in zone
- Latent—energy addition associated with moisture/humidity change in zone
- Sensible Heat Gains
- Convection
- Thermal (Long Wavelength) Radiation
- Visible (Short Wavelength) Radiation (generally lights only)

HVAC System:

After calculating heating and cooling load for a particular thermal environment inside a building, the next step is to find something that must meet these heating and cooling loads in order for the thermal comfort goals to be met by the HVAC system.

There are two systems:

- Secondary System meets thermal loads of the zones.
- Primary System (central plant) produces or converts energy for use by the secondary system.

Zone Sizing:

- Calculates required supply air volume to maintain zone set points
- Computes maximum cooling load, heating load and airflow for systems sizing and sizing zone components
- Determine outside airflow rate per person based on the total number of people for all people statements in zone.

2.7. Methodology for Simulation of the Peel Region Headquarters Building using “Carrier HAP” Program

The study is divided into two parts; in the first part, the design weather and simulation weather file for Brampton, Ontario locations of Peel Region Headquarters Building are selected. Three air systems are considered for the simulation. The first system is the 2-Fan Variable Air Volume (VAV) “Dual Duct” Systems, the second system is the 1-Fan Variable Air Volume (VAV) Systems and the last system is the 1-Fan Variable Air Volume (VAV) Systems with two Rooftop Packaged HVAC System.

In the second part, a Heat Pump is used in the Peel Region Headquarters Building to find the influence of each component’s characteristic on the overall building performance.

Three base case models are used for analyzing the three-air system:

- The base case building Model #1 consists of 203 zones and uses 2-Fan Variable Air Volume (VAV) “Dual Duct” System.
- The base case building Model #2 consists of 82 zones and uses 1-Fan Variable Air Volume (VAV) System.
- The base case building Model #3 consists of 82 zones and uses 1-Fan Variable Air Volume (VAV) Systems with two Rooftop Packaged HVAC Systems.

Figure 8 presents the methodology used by “Carrier HAP” program in the simulation of Peel Region Headquarters Building.

Figure 8: Methodology of “Carrier HAP” Program for Simulation of Peel Region Building

2.7.1. Information Gathering Input Data

Location and design climate:

The Peel Region Headquarters Building is located at 10 Peel Centre Drive, Brampton, Ontario. The Peel Region Headquarters Building consists of one below grade level, one on grade level and six above grade levels with a total area of approximately 212,078 ft² (13,260 m²). The sub lower level or on grade P1, level consists of a maintenance department, a printing room and store spaces. Below grade P2, level consists of parking and storage room spaces. The 1st, 2nd, and 4th floors consist of office spaces. The 3rd floor consists of computer rooms and office spaces. The 5th floor has the council chamber as well as office spaces. The 1st, 2nd, and 4th and top floors are conditioned by the central air HVAC system. The 3rd and 5th floors are conditioned by the rooftop package units and the central air HVAC system. The top floor consists of the mechanical room and offices spaces. Design climate information is obtained from Carrier HAP weather file and the environment of Canada weather information centre.

Building description:

- Wall, floor, roof constructions
- Wall, floor, roof sizes and locations (shading)
- Window, door, construction and overhang details

Five types of wall constructions are used:

1. Wall 1 (Exterior Wall) Exposed to External Environment (Sun Exposed and Wind Exposed) (Floor 1 to 4)
2. Wall 2 (Exterior Wall) Exposed to External Environment (Sun Exposed and Wind Exposed) (Floor 5 to 6)
3. Wall 3 (Exterior Wall) Exposed to External Environment (Sun Exposed and Wind Exposed) (P1-Level)
4. Wall 4 (Interior Wall) Exposed to Other Zone Surface or Interior Environment (No Sun, No Wind Exposed) (P2-Level)
5. Wall 5 (Interior Wall) Exposed to Other Zone Surface or Interior Environment (No Sun, No Wind Exposed) (Partition Wall b/w Core & Zone Area)

Figure 9 presents different wall types used in the base case building.

Figure 9: Types of Walls Construction

Four types of windows construction materials are used in base case building:

- Window 1 (W 1) is used on Floor 2 to 4 and 6
- Window 2 (W 2) is used on Floor 5
- Window 3 (W 3) is used on Floor 1
- Window 4 (W 4) is used on P1, Level

Figure 10 shows the construction of Window (W 1) being used on Floors # 2, 3, 4 and 6.

Figure 10: Windows Construction (W 1)

Figure 11 shows the construction of Window (W 3) being used on Floor # 1.

Figure 11: Windows Construction (W 3)

Figure 12 shows the construction of Window (W 2) being used on Floor #5.

Figure 12: Windows Construction (W 2)

Figure 13 shows the construction of Window (W 4) used on the P1, Level.

Figure 13: Windows Construction (W 4)

Figure 14 shows the construction of door and roof being used in the base case building.

Figure 14: Construction Material of Doors and Roof

The important thermal properties of walls, windows, doors, floor and roof are summarized in Table # 72 to Table # 78 in Appendix 1:

- Overall Heat Transfer Coefficient Wall-1 = U Value= 0.099 BTU / hr/ ft²/ °F
- Overall Heat Transfer Coefficient Wall-2 = U Value= 0.092 BTU / hr/ ft²/ °F
- Overall Heat Transfer Coefficient Wall-3 = U Value= 0.469 BTU / hr/ ft²/ °F
- Overall Heat Transfer Coefficient Wall-4 = U Value= 0.594 BTU / hr/ ft²/ °F
- Overall Heat Transfer Coefficient Wall-5 = U Value= 0.073 BTU / hr/ ft²/ °F
- Overall Heat Transfer Coefficient of Roof = U Value= 0.04 BTU / hr/ ft²/ °F
- Overall Heat Transfer Coefficient W1 = U Value= 0.542 BTU / hr / ft²/ °F
- Overall Heat Transfer Coefficient W2 = U Value= 0.432 BTU / hr / ft²/ °F
- Overall Heat Transfer Coefficient W3 = U Value= 0.541 BTU / hr / ft²/ °F
- Overall Heat Transfer Coefficient W4 = U Value= 0.823 BTU / hr / ft²/ °F

2.7.2. Zoning of the Building and Create Building Model

The building is oriented due North:

Zone Descriptions:

- Sub-Lower Level (P1) Plan View with Z= -19'- 9", X=0, Y=0, H= 9'-4"
- Lower Level (P2) Plan View with Z= -10'- 5", X=0, Y=0, H=10'- 5"
- 1st Floor Plan View with Z= 0.0, X=0, Y=0, H= 12' (Datum at Z=0.0)
- 2nd Floor Plan View with Z= 12'-10.5", X=0, Y=0, H=12'
- 3rd Floor Plan View with Z= 24'- 10.5", X=0, Y=0, H= 12'
- 4th Floor Plan View with Z= 36'- 10.5", X= 0, Y=0, H= 12'
- 5th Floor Plan View with Z= 48'- 10.5", X=0, Y= 0, H= 12'
- 6th Floor Plan View with Z= 60'- 10.5", X= 0, Y= 0, H= 15'- 1.5"

Scenario #1 is modeled according to the HVAC plan view. Each space is considered a thermal zone being controlled by a single thermostat. Zoning of Scenario #1 is summarized in Table # 81 to Table # 88 in Appendix 2.

Table 2: Scenario #1 Zoning

Scenario #1 Zoning							
Floor Level	Total Floor Area ft ²	Conditioned Floor Area ft ²	Unconditioned Floor Area ft ²	Area Types in Percent (%)ft ²			# No. of Zone
				Office	Corridor	Others	
P2	42483.5	1198.5	41106	-	3.248	96.76	3
P1	38069.0	6514.6	31554.4	39.46	30.25	24.45	8
FL1	19698.6	19698.6	-	75.70	22.40	1.90	40
FL2	23973.3	23973.3	-	86.20	13.90	-	33
FL3	23973.3	23973.3	-	76.10	13.90	10.00	37
FL4	23973.3	23973.3	-	86.10	13.90	-	31
FL5	23973.3	23973.3	-	70.80	13.90	15.30	34
FL6	23973.3	18057.0	5917.0	66.24	9.08	24.67	21

Figure 15 shows a space (zone) input data form of Scenario #1.

Figure 15: Space (Zone) Input Data Form of Scenario #1

Scenario #2 is modeled according to perimeter and core zoning pattern. Zoning of Scenario #2 is summarized in Table # 89 to Table # 96 in Appendix 2.

Table 3: Scenario #2 Zoning

Scenario #2 Zoning							
Floor Level	Total Floor Area ft ²	Conditioned Floor Area ft ²	Unconditioned Floor Area ft ²	Area Types in Percent (%)ft ²			# No. of Zone
				Office	Corridor	Others	
P2	42483.5	1198.5	41106.0	-	3.25	96.76	3
P1	38069.0	6514.6	31554.4	39.46	30.25	24.45	8
FL1	19698.6	19698.6	-	75.70	22.40	1.90	12
FL2	23973.3	23973.3	-	86.20	13.90	-	9
FL3	23973.3	23973.3	-	76.10	13.90	10.00	13
FL4	23973.3	23973.3	-	86.10	13.90	-	9
FL5	23973.3	23973.3	-	70.80	13.90	15.30	12
FL6	23973.3	18057.0	5917.0	66.24	9.08	24.67	21

Figure 16 shows the space (zone) input data form of Scenario #2

Figure 16: Space (Zone) Input Data Form of Scenario #2

The value of the office equipment power density is obtained from the Energy and Building Research Paper (Fung et al, 2003). Table 4 depicts the information of lighting and equipment power density and number of occupant level in each floor used in the base case Peel Region Headquarters Building model.

Table 4: Activity Area Allocation Chart

Activity Area Allocation Chart							
Floor Level	# No of People		Total light power		Total Office equipment power		Miscellaneous Load(Power)
	Occupant per floor	ft ² per Person	Total Watts	Watts per ft ²	Total Watts	Watts per ft ²	Watts per ft ²
P2	-	-	-	-	-	-	0.182
P1	11	297.0	6697	1.028	-	-	0.182
FL1	53	371.6	20073	1.019	15483	0.786	0.182
FL2	163	147.0	26131	1.090	46747	1.950	0.182
FL3	119	201.5	26131	1.090	34281	1.430	0.182
FL4	175	137.0	26131	1.090	63816	2.662	0.182
FL5	87	275.5	22055	0.920	25891	1.080	0.182
FL6	72	250.8	20856	0.870	21336	0.890	0.182

P2, level has three zones:

1. Unconditioned Space: Total lighting load= 22197.24 Watts (0.54 Watts/ft²)
2. Conditioned Space: Total lighting load = 826.9 Watts (0.6 Watts/ft²)

P1, level has eight zones and only office space is used for office equipment:

1. Office Space Total Area (2571 ft²):
2. Total Office Equipment Load= 19025.4 Watts (7.4 Watts/ft²).

Table 5 depicts the information of exposed walls and windows area along the four axes used in the base case building.

Table 5: Exposed Walls, Windows and Roof

Exposed Walls, Windows, And Roof													
Floor Level	Exposed Walls ft ²				Quantity of Exposed Windows (Types)				Windows Area Ft ²				Roof ft ²
	N	S	E	W	N	S	E	W	N	S	E	W	H FLAT
P2	-	-	-	-	-	-	-	-	-	-	-	-	-
P1	441.8	513	300	1375	3(W4)	4(W4)	-	-	30	40	-	-	
FL1	1115	907	1426	1217	28(W3)	24(W3)	28(W3)	24(W3)	1190	1020	1190	1020	
FL2	1395	1395	1395	1395	20(W1)	20(W1)	24(W1)	24(W1)	550	550	660	660	
FL3	1395	1395	1395	1395	20(W1)	20(W1)	24(W1)	24(W1)	550	550	660	660	
FL4	1395	1395	1395	1395	20(W1)	20(W1)	24(W1)	24(W1)	550	550	660	660	
FL5	1395	1395	1395	1395	17(W1) & 11(W2)	20(W2)	29(W2)	28(W2)	467.5 & 302.5	550	797.5	770	
FL6	1395	1395	1395	1395	-	14(W1)	7(W1)	7(W1)	-	385	192.5	192.5	23975

2.7.3. Air Distribution Systems

The primary objective of the analysis of the system is to determine the amount of air to be supplied to the space, its state, and the capacity and operating conditions for the coil. These results then can be used in designing the complete air distribution system.

Air distribution systems:

- Provides all sensible and latent cooling, preheating, and humidification required by the zone(s)
- Additional cooling or humidification at the zone are exceptional (used for industrial systems)
- Heating is either provided by the main air stream by the central system or locally at a specific zone
- Conditioning depends on air mass flow rate and temperature (enthalpy) difference between supply and room air

Air movement may result in energy transfer from one area to another and thus has an energy impact on the zone and or building. The energy impact of air movement is critical to know of how much energy is required to maintain thermally comfortable conditions within a space. The air loop simulates air transport, conditioning, and mixing and includes supply and return fans, central heating and cooling coils, heat recovery, and controls for supply air temperature and outside air economizer. The air loop connects to the zone through the zone equipment. Zone equipment includes diffusers, reheat coils, and supply air control (mixing dampers, fan-powered VAV box, induction unit, VAV dampers). Thermostat input allows control of the air temperature within individual zones—control set point can change on an hourly basis.

Air Distribution Systems is classified into single and dual duct categories as well as constant and variable volume categories.

Single-Duct Systems:

- Main heating and cooling coils in series arrangement
- Ducts supply air to all terminals at a common temperature
- Capacity varied by varying temperature or flow rate

Types of single-duct systems:

1. Constant Air Volume(CAV)
  - Single zone
  - Multiple-zone reheat
2. Variable Air Volume (VAV)
  - Throttling
  - Fan-powered
  - Reheat
  - Induction
  - Variable diffusers

Dual-Duct Systems:

- Main heating and cooling coils in parallel
- May use separate warm and cold air duct distribution systems, blending air at the terminal device
- May blend air near the main unit and have separate duct for each zone
- Most vary supply temperature, limited number (around 1% of all installed systems) vary flow rate

Types of dual-duct systems:

1. Single Zone ("dual duct")
  - Constant volume
  - Variable air volume
2. Multi Zone
  - Constant volume
  - Variable air volume
  - Three-deck multi zone

In the Peel Region Headquarters Building thermal model, we used three different air systems in the simulations. The first system is the 2-Fan Variable Air volume (VAV) "Dual Duct" systems, the second system is the 1-Fan Variable Air volume (VAV) systems, and the last system is the 1-Fan Variable Air volume (VAV) systems with two Rooftop Packaged HVAC systems. The 2-Fan (Variable Air Volume diffusers) (VAV) Dual Duct system uses a central supply fan to provide a variable volume of conditioned

air to zone terminals. Zone thermostat controls supply terminal equipment to regulate the flow of air into each zone and maintain zone comfort conditions. Cooling operation varies in the occupied and unoccupied periods as described in the fan/thermostat schedule.

Figure 17 presents a flow diagram of 1-fan single duct central air system variable air volume (diffuser) with baseboard heating system used in the base case building.

Figure 17: Air System Flow Diagram (Carrier, 2006)

Figure 18 presents flow diagram of 1-fan single duct central air system variable air volume (diffuser) with reheat coils used in the base case building.

Figure 18: Air System Flow Diagram with Reheat Coils (U.S. DOE, 2008)

Table 6 presents design data of the central air system used in the base case building.

Table 6: Design Data of AHU #1 & AHU #2

Design Air Handling System									
					Entering Air		Leaving Air		
Equipment Name	CFM	Face Area ft²	B.H.P	Motor H.P.	°F DB	°F WB	°F DB	°F WB	
Supply Fan #1	53,000	107.88	67.8	15	79	65	55	54.7	
Supply Fan #2	53,000	107.88	67.8	15	79	65	55	54.7	
Return Fan #1	50,000		13.9	15					
Return Fan #2	50,000		13.9	15					
Air System Type	Terminal Box(VAV)								
Cooling Coil	Capacity US GPM				Max. Pressure Drop PSI				
COIL #1	240				2				
COIL # 2	240				2				
VAV Box Actuator/ Thermostat Controller					2.0W / 12.0W				

Table 7 presents seasonal thermostat set points used in the base case building.

Table 7: Seasonal Thermostat Set Points

Seasonal Thermostat Set points	
Occupied (°F)	Unoccupied (°F)
COOL: 75.2	COOL: 84
HEAT: 71.2	HEAT: 64

2.7.4. HVAC SYSTEM

HVAC Equipment Information:

- Equipment types
- Operating schedules
- Control information

There are two water loops for HVAC plant equipment. Primary loops include temperature, flow, and operational controls. Secondary loops include for heat rejection equipments such as cooling towers and condensers. Primary systems of the Peel Region Headquarters Building is provided with Bryan boilers and Multistack chiller to provide heating for the baseboard-heating units for each zone and chilled water to the cooling coils of the air-handling units.

Table 8 presents design data of the central cooling system (electric water-cooled centrifugal multistage chiller) used in the base case building.

Table 8: Chiller Specification

Chiller Plant: Electric		
Field	Units	Object
Chiller Name: Multistack	9 Compressors	Design Chiller
Condenser Type	-	Water Cooled
Full load Capacity	kW or MBH	236.7 tons=4260.6 MBH
COP	-	(Maximum=10) Actual = 5.2
Fuel or Energy Type	-	Electric
Electrical Efficiency	%	Power in = 155.3 kW
Mechanical Efficiency	%	EER= 15.1 at 30 ton & 17.1 at 50 tons
Theoretical Chiller Efficiency	%	80%
Minimum Part Load Ratio	-	11%
Maximum Part Load Ratio	-	100%
Opt Part Load Ratio	-	(Standard) or 65%
Energy Efficiency Rating (at Full Load) EER		18.3
Temp Design Evaporator Outlet	F	42
Temp Design Evaporator Inlet	F	56
Temp Design Condenser Inlet	F	80
Temp Design Condenser Outlet	F	90
Temp Lower Limit Evaporator Outlet	F	41
Design Evaporator Volumetric Water Flow Rate	m ³ /s or GPM	406 GPM
Design Condenser Volumetric Water Flow Rate	m ³ /s or GPM	660 GPM
Chiller Flow Mode		Variable Flow
Coil Delta –T at Design Load	F	55°C - 45°C = 10°C or 18°F
Evaporator / Condenser Pressure Drop	ft WG	6.6 / 5.0
PUMP SPECIFICATION		
Chilled Water Pump Flow Head	m or ft WG	50 ft WG
Condenser Water Pump Flow Head	m or ft WG	50 ft WG
Chilled Water Pump Armstrong(4300TC)	HP or kW	7.5 HP / 5.61 kW
Condenser Water Pump Armstrong(4300TC)	HP or kW	15 HP / 11.22 kW

Figure 19 presents a flow diagram of the central cooling system (electric water-cooled centrifugal multistage chiller) used in the base case building.

Figure 19: Electric Chiller (U.S. DOE, 2008)

Cooling tower is used when the chiller air-cooled condenser is replaced with the water-cooled condenser. Figure 20 presents a flow diagram of the cooling tower (it is coupled with the water-cooled chiller) used in the base case building.

Figure 20: Cooling Tower (U.S. DOE, 2008)

Table 9 presents design data of the cooling tower used in the base case building.

Table 9: Cooling Tower Specification

Cooling Tower		
Field	Units	Object
Fluid Type		Fresh City Water
Condenser Water Flow Rate	m ³ /s or GPM	660.0 GPM
Condenser Pump Head	m or ft WG	50 ft WG
Condenser Pump Mechanical Efficiency	%	80
Condenser pumps Electrical Efficiency	%	94
Design Wet Bulb Temperature	F	71
Range at Design Temperature	F	10
Design Approach	F	10
Full Load Fan	kW / Ton	0.055
Condenser Water Pump (Armstrong)	kW / HP	11.22 / 15
Air Flow Rate At Set Point Control	-	Not available
Set Point Control		• Constant Speed Fan • Variable Speed Fan

Heating Distribution System:

In the Peel Region Headquarters Building, instead of using a central air heating system, baseboard hot water space heating units have been used. The baseboard hot water heating system works on the principle of natural convection. Hot water baseboards are situated in the perimeter zones in the form of a hot water loop. The hot water is provided via pumps from a boiler.

Figure 21 presents a flow diagram of the hot water boiler used in the base case building.

Figure 21: Hot Water Boiler (U.S. DOE, 2008)

Table 10 presents design data of the hot water boiler (natural draft gas fired multistage boiler) used in the base case building.

Table 10: Hot Water Boiler Plant

Hot Water Boiler Plant		
Field	Units	Object
Boiler Name: Bryan Model # L20W-FDG	2	Generic Boiler
Fuel or Energy Type		Natural Gas
Full load Capacity	KW or MBH	Input: 1,500.000 MBH Output: 1,305.000 MBH
Electrical Efficiency	%	94
Mechanical Efficiency	%	87%
Theoretical Boiler Efficiency	%	(standard) or 80%
Design Boiler Water Outlet Temp	F	177.8 or (standard)
Max Design Boiler Water Flow Rate	m ³ /s or GPM	50.0 GPM
Minimum Part Load Ratio		25%
Maximum Part Load Ratio		100%
Hot Water Flow Head	psi	60psi
Coil Delta –T at Design Load	F	18°F
Temp Upper Limit Water Outlet	F	212
Boiler Flow Mode		Variable Flow
PUMP SPECIFICATION		
Max Design Water Flow Rate	m ³ /s or GPM	270 US GPM
Hot Water Pump Flow Head	m or ft WG	
Hot Water Pump Motor Capacity	KW or MBH	3 kW
Hot Water Pump Motor Efficiency		87.5%
Hot Water Pump Motor Horse power	HP	5 HP

The equipment list of other types of HVAC systems and exhaust fans operating information are summarized in Tables # 79 to Table # 80 in Appendix 1.

2.7.5. Building Use Information

The Heating and cooling load of the air system of the base case building model depends on the actual schedules of all types of functions.

1. Occupancy activity schedule
2. Lighting schedule
3. Equipment schedule
4. Fan/thermostat
5. Ventilation

According to MNECB/CBIP, the default values of building operation schedules have to be assigned to both the baseline and reference buildings.

Carrier HAP uses two types of schedule, fractional and fan/thermostat. Fractional schedules are used to describe the variation of internal heat load (i.e., lighting, equipment, control of outside ventilation in an HVAC system and hot water in a domestic water heating system, all these are the fractional schedules).

Fan/thermostat schedules are used to define the hours in HVAC equipment. The occupied and unoccupied thermostat set points are assigned to each hour in HVAC system (Carrier, 2006).

The schedules for lighting, occupancy activity, office equipment, ventilation and exhaust fan, heating and cooling are summarized in Table #11. These are the actual schedules used by the Peel Region Headquarters Building.

Table 11: Operating Schedule of Peel Region Headquarters Building

Occupants, Lighting, Equipment , and Fan Thermostat Operating Schedule of office building					
Schedule	Typical Functions	Operating Hrs/Day	Mon-Fri On-time	Saturday On-time	Sunday On-time
A	Occupancy Activity	9	8am-5pm	off	off
B	Lighting	9	8am-5pm	5%	5%
C	Equipment	9	8am-5pm	5%	5%
D	Variable Air Volume thermostat control	6am-6pm Occupied	6am-6pm Occupied	6am-6pm Unoccupied	6am-6pm Unoccupied
E	Exhaust fan	24/7	24/7	24/7	24/7

Table 12 presents MNECB/CBIP default operating schedules used in the office type building.

Table 12: MNECB/CBIP Default Operating Schedules (Schedule A) (NRCan, 2008)

Occupants, Lighting, Equipment , and Fan Thermostat Operating Schedule of office building											
Schedule In hour →		11pm To 5am	6am	7am	8am	9am To 11am	12pm To 1pm	2pm To 4pm	5pm	6pm	7pm To 10pm
Typical Functions↓											
Occupancy Activity	Mon-Fri	0%	0%	10%	70%	90%	50%	90%	70%	30%	10%
	Saturday	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Sunday	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lighting	Mon-Fri	5%	5%	30%	80%	90%	90%	90%	80%	50%	30%(7pm-8pm) 10%(9pm-0pm)
	Saturday	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
	Sunday	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Equipment	Mon-Fri	20%	20%	30%	80%	90%	90%	90%	90%	50%	30%(7pm-8pm) 20%(9pm-0pm)
	Saturday	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
	Sunday	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
VAV thermostat control (Cooling)	Mon-Fri	off	24h	24h	24h	24h	24h	24h	24h	24h	24 h(7pm-8pm) Off(9pm-10pm)
	Saturday	off	off	off	off	off	off	off	off	off	off
	Sunday	off	off	off	off	off	off	off	off	off	off
VAV thermostat control (Heating)	Mon-Fri	18h	22h	22h	22h	22h	22h	22h	22h	22h	22h(7pm-8pm) 18h(9pm-0pm)
	Saturday	18h	18h	18h	18h	18h	18h	18h	18h	18h	18h
	Sunday	18h	18h	18h	18h	18h	18h	18h	18h	18h	18h
Exhaust fan	Mon-Fri	off	on	on	on	on	on	on	on	on	on(7pm-8pm) off(9pm-10pm)
	Saturday	off	off	off	off	off	off	off	off	off	off
	Sunday	off	off	off	off	off	off	off	off	off	off

2.7.6. Create Input File for the Simulation Programs

The input file reflects the geometry of the building and its characteristics having an impact on thermal loads as well as the description of HVAC systems. An accurate input file has a significant impact on the building energy use.

Followings are the input parameters to create input data file (IDF):

- Weather Year
- Materials and Constructions
- Building Geometry
- Internal Loads
- Design CFM
- Size Systems and Plants
- Utility Rates
- Examine Performance of Various System and Plant Configurations
- Determine More Efficient Operational Schemes
- Calculate Annual Energy Consumption

2.8. Design and Simulation Result

System design of the Base Building includes the following design reports:

- System Sizing Summary
- Zone Sizing Summary
- Ventilation Sizing Summary
- System Load Summary
- Zone Load Summary
- Hourly Air System Loads
- Hourly Zone Loads

2.8.1. System Design of System Sizing Summary and System Load Summary of the Base Case Building Model #1 (Two Fan Variable Air Volume Central Air Systems)

Building Model #1 is the actual building model with 203 thermal zones. Two Fan Variable Air Volume Central Air Systems are used for space cooling. Space heating is provided by a baseboard type heating system. A VAV (Variable Air Volume) system is used in this building.

Table 13 presents Model #1 air system design data of Air Handling Unit #1 used in the base case building.

Table 13: System Sizing Summary Model #1 of Air Handling Unit #1

Air System Sizing Summary for Air Handling Unit #1			
Number of Zones			Max: 100
Floor Area			63501.7 ft ²
Total coil load	130.7 Tons	Load occurs at	Aug 1600
Total coil load	1568.3 MBH	OA DB/ WB	87.0 / 71.0 °F
Sensible coil load	1339.9 MBH	Entering DB / WB	76.7 / 61.6 °F
Coil CFM at Aug 1600	50086 CFM	Leaving DB / WB	51.4 / 50.0 °F
Max block CFM	51509 CFM	Resulting RH	44 %
Sum of peak zone CFM	56579 CFM	Design supply temp	55.0 °F
ft ² / Ton	485.9	Actual max CFM at Aug 1600	51509 CFM
BTU / (hr- ft ²)	24.7	Standard CFM	50460 CFM
Water flow @ 10.0 °F rise	313.83 GPM	Actual max CFM / ft ²	0.81 CFM / ft ²
Unconditioned Floor Area			78248.5 ft ²

Table 14 presents Model #1 design cooling and heating load of Air Handling Unit #1 used in the base case building.

Table 14: System Load Summary for Air Handling Unit #1

	Design Cooling Cooling OA DB / WB 87 °F / 71 °F	Design Heating Heating OA DB / WB -4.0 °F / -5.3 °F
Total zone loads	824189 BTU / hr	468671 BTU / hr
Total system loads	1463144 BTU / hr	755630 BTU / hr
Total conditioning	1463157 BTU / hr	755630 BTU / hr

Table 15 presents Model #1 air design data of Air Handling Unit # 2 used in the base case building.

Table 15: System Sizing Summary Model #1 of Air Handling Unit #2

Air System Sizing Summary for Air Handling Unit # 2				
Number of Zones			max:100	
Floor Area			78834.0 ft ²	
Total coil load	171.7 Tons		Load occurs at	Aug 1600
Total coil load	2060.9 MBH		OA DB/ WB	87.0 / 71.0 °F
Sensible coil load	1720.5 MBH		Entering DB / WB	76.9 / 61.9 °F
Coil CFM at Aug 1600	63379 CFM		Leaving DB / WB	51.3 / 50.0 °F
Max block CFM	63379 CFM		Resulting RH	44 %
Sum of peak zone CFM	68671 CFM		Design supply temp	55.0 °F
ft ² / Ton	459.0		Actual max CFM	63379 CFM
BTU / (hr- ft ²)	26.1		Standard CFM	62089 CFM
Water flow @ 10.0 °F rise	412.41 GPM		Actual max CFM / ft ²	0.80 CFM / ft ²

Table 16 presents Model #1 design cooling and heating load of Air Handling Unit # 2 used in the base case building.

Table 16: System Load Summary for Air Handling Unit #2

	Design Cooling Cooling OA DB / WB 87 °F / 71 °F	Design Heating Heating OA DB / WB -4.0 °F / -5.3 °F
Total zone loads	974933 BTU / hr	488301 BTU / hr
Total system loads	1891271 BTU / hr	1048378 BTU / hr
Total conditioning	1891301 BTU / hr	1048379 BTU / hr

2.8.2. System Design of System Sizing Summary and System Load Summary of Model #2 (with One HVAC System)

Building Model #2 is based on the core and perimeter zone pattern design concept. Model #2 contains 82 thermal zones. One air handling system is used for space cooling with VAV air terminal equipment. Space heating is provided by a baseboard type heating system.

Table 17 presents Model #2 air system design data of air handling unit used in the base case building.

Table 17: System Sizing Summary of Air Handling Unit for Model #2

Air System Sizing Summary for Air Handling Unit				
Number of Zones			82	
Floor Area			142729.7 ft ²	
Total coil load	316.7 Tons		Load occurs at	Aug 1600
Total coil load	3800.4 MBH		OA DB/ WB	87.0 / 71.0 °F
Sensible coil load	3080.3 MBH		Entering DB / WB	77.3 / 62.5 °F
Coil CFM at Aug 1600	113168 CFM		Leaving DB / WB	51.5 / 50.3 °F
Max block CFM	113168CFM		Resulting RH	45 %
Sum of peak zone CFM	126265 CFM		Design supply temp	55.0 °F
ft ² / Ton	450.7		Actual max CFM	113168 CFM
BTU / (hr- ft ²)	26.6		Standard CFM	110864 CFM
Water flow @ 10.0 °F rise	760.48 GPM		Actual max CFM / ft ²	0.79 CFM / ft ²

Table 18 presents Model #2 design cooling and heating load of air handling unit used in the base case building.

Table 18: System Load Summary of Air Handling Unit for Model #2

	Design Cooling Cooling OA DB / WB 87 °F / 71 °F	Design Heating Heating OA DB / WB -4.0 °F / -5.3 °F
Total zone loads	1920691 BTU / hr	1032893 BTU / hr
Total system loads	3624753 BTU / hr	2349475 BTU / hr
Total conditioning	3600014 BTU / hr	2349475 BTU / hr

2.8.3. System Design of System Sizing Summary and System Load Summary of Model #3 (with Three HVAC Systems: One Central Air Handling System and Two Packaged Rooftop HVAC System)

Building Model #3 contains 82 thermal zones. One air handling system is serving space cooling of 80 thermal zones. Two rooftop HVAC systems are serving of Council Chamber and Computer Room respectively. Space heating is provided by a baseboard type heating system.

Table 19 presents Model #3 air system design data of air handling unit used in the base case building.

Table 19: System Sizing Summary of Air Handling Unit for Model #3

Air System Sizing Summary for Air Handling Unit				
Number of Zones			80	
Floor Area			136658.3 ft ²	
Total coil load	290.4 Tons		Load occurs at	Aug 1600
Total coil load	3485.1MBH		OA DB/ WB	87.0 / 70.8 °F
Sensible coil load	2914.8 MBH		Entering DB / WB	76.8 / 62.0 °F
Coil CFM at Aug 1600	109430 CFM		Leaving DB / WB	51.6 / 50.3 °F
Max block CFM	110495 CFM		Resulting RH	45 %
Sum of peak zone CFM	121080 CFM		Design supply temp	55.0 °F
ft ² / Ton	470.6		Actual max CFM	110495CFM
BTU / (hr- ft ²)	25.5		Standard CFM	108245 CFM
Water flow @ 10.0 °F rise	697.38 GPM		Actual max CFM / ft ²	0.81 CFM / ft ²

Table 20 presents Model #3 design cooling and heating load of air handling unit used in the base case building.

Table 20: System Load Summary of Air Handling Unit for Model #3

	Design Cooling Cooling OA DB / WB 87 °F / 71 °F	Design Heating Heating OA DB / WB -4.0 °F / -5.3 °F
Total zone loads	1854931 BTU / hr	896802 BTU / hr
Total system loads	3291082 BTU / hr	1836641 BTU / hr
Total conditioning	3291083 BTU / hr	1836641 BTU / hr

Table 21 presents Model #3 design data of Packaged Rooftop Unit #1 used in the base case building.

Table 21: System Sizing Summary for Model #3 of Packaged Rooftop Unit #1

Air System Sizing Summary for Packaged Rooftop Unit #1				
Number of Zones (Council Chamber)				1
Floor Area				3661.7 ft²
Total coil load	12.5 Tons		Load occurs at	Aug 1600
Total coil load	150.2MBH		OA DB/ WB	87.0 / 71.0 °F
Sensible coil load	108.2MBH		Entering DB / WB	74.4 / 59.9 °F
Coil CFM at Aug 1600	2944 CFM		Leaving DB / WB	39.7 / 38.8 °F
Max block CFM	2944 CFM		Resulting RH	38 %
Sum of peak zone CFM	0.720CFM		Design supply temp	55.0 °F
ft ² / Ton	292.5		Actual max CFM	2944 CFM
BTU / (hr- ft ²)	41		Standard CFM	2885 CFM
Water flow @ 10.0 °F rise	N/A GPM		Actual max CFM / ft ²	0.80 CFM / ft ²

Table 22 presents Model #3 design cooling and heating load of Packaged Rooftop Unit #1 used in the base case building.

Table 22: System Load Summary for Model #3 of Packaged Rooftop Unit #1

Core zone	Design Cooling Cooling OA DB / WB 87 °F / 71 °F	Design Heating Heating OA DB / WB -4.0 °F / -5.3 °F
Total zone loads	45582 BTU / hr	0.0 BTU / hr (No heat transmitted from outside to inside the core zone)
Total system loads	142752 BTU / hr	10934 BTU / hr
Total conditioning	142756 BTU / hr	10934 BTU / hr

Table 23 presents Model #3 design data of Packaged Rooftop Unit #2 used in the base case building.

Table 23: System Sizing Summary for Model #3 of Packaged Rooftop Unit #2

Air System Sizing Summary for Packaged Rooftop Unit #2				
Number of Zones (Computer Room)				1
Floor Area				2411.7 ft ²
Total coil load	8.6 Tons		Load occurs at	Aug 1600
Total coil load	103 MBH		OA DB/ WB	86.4 / 70.8 °F
Sensible coil load	87.7 MBH		Entering DB / WB	73.9 / 54.6 °F
Coil CFM at Aug 1600	1939 CFM		Leaving DB / WB	31.1 / 29.7 °F
Max block CFM	1939 CFM		Resulting RH	20 %
Sum of peak zone CFM	1939 CFM		Design supply temp	55.0 °F
ft ² / Ton	281		Actual max CFM	1939 CFM
BTU / (hr- ft ²)	42		Standard CFM	1900 CFM
Water flow @ 10.0 °F rise	N/A GPM		Actual max CFM / ft ²	0.80 CFM / ft ²

Table 24 presents Model #3 design cooling and heating load of Packaged Rooftop Unit #2 used in the base case building.

Table 24: System Load Summary for Model #3 of Packaged Rooftop Unit #2

	Design Cooling Cooling OA DB / WB 87 °F / 71 °F	Design Heating Heating OA DB / WB -4.0 °F / -5.3 °F
Total zone loads	28487 BTU / hr	9751 BTU / hr
Total system loads	102992 BTU / hr	18013 BTU / hr
Total conditioning	102995 BTU / hr	18013 BTU / hr

2.9. Simulation Results

Building simulation reports contain energy consumption and energy cost data produced by the building energy simulation. Carrier HAP offers thirteen different building simulation reports.

The most important simulation reports consist of the followings:

1. Comparative reports contain cost and energy results for groups of buildings.
2. Summary reports contain annual cost and energy use data for individual building cases.
3. Detailed reports contain tables of monthly energy and cost data for a single building case.
4. Use profiles contain the hour-by-hour energy use profile for a building for one energy source or fuel type.
  - Annual components and energy costs
  - HVAC and non-HVAC cost totals
  - Monthly components and energy costs
  - Monthly, daily and hourly air system simulation reports

The current cost analysis of the base case building is based on the specifications of the systems and building envelope that are summarized in the tables. The actual total annual cost of fuel energy of both types of fuel (electric and natural gas) is summarized in Table 25.

Table 25: Actual Annual Cost of Electric and Natural Gas of the Base Case Building

Types of fuel	Total GST	Fuel Charges	Total Gross Cost	Total Energy Cost with GST
Electric	\$ 15,670.00	\$ 263,619.00	\$ 279,287.00	\$ 345,351.00
Natural Gas	\$ 3,957.76	\$ 62,106.24	\$ 66,064.00	
Total Energy Cost without GST = \$ 325,725.00				

2.9.1. Simulation Results of the Building Model #1

The annual energy costs of building Model #1 of HVAC and non-HVAC components are summarized in Table 26.

Table 26: The Annual Cost Summary of the Carrier HAP Building Model #1

Components	Cost (\$)	Cost (\$ / ft ²)	(%)	Total Energy
Air System Fans	48,876	0.343	16.0	477,722 kWh
Cooling	56,738	0.399	18.5	554,576 kWh
Pumps	8,472	0.060	2.8	82,809 kWh
Cooling Tower Fans	4,555	0.032	1.5	44,522 kWh
Heating	43,423	0.305	14.2	3283.1074 MBTU
Domestic Hot Water	-	-		-
HVAC Sub-Total	162,064	1.139	52.9	-
Lights	44,119	0.310	14.4	431,225 kWh
Electric Equipment	78,660	0.553	25.7	768,842 kWh
Misc. Electric	21,282	0.150	7.0	208,015 kWh
NON-HVAC Sub-Total	144,060	1.012	47.1	
Grand Total	306,124	2.151	100.0	
Conditioned Floor Area(ft²) = 142729.7 ft²				

Figure 22 shows the incurred cost (percentage) of HVAC and non-HVAC components for the base case building Model #1 on the annual basis.

Figure 22: Annual Component Costs of the Carrier HAP Building Model #1

Figure 23 presents monthly energy costs of HVAC electric, HVAC natural gas and non-HVAC electric used in the base case building Model #1.

Figure 23: Monthly Energy Costs of the Carrier HAP Building Model #1

Figure 24 shows the incurred monthly cost of HVAC and non-HVAC components for the base case building Model #1.

Figure 24: Monthly Component Costs of the Carrier HAP Building Model #1

2.9.2. Simulation Results of the Building Model #2

The annual energy and costs of Model #2 of HVAC and non-HVAC components are summarized in Table 27.

Table 27: The Annual Cost Summary of the Carrier HAP Building Model #2

Components	Cost (\$)	Cost (\$ / ft ²)	(%)	Total Energy
Air System Fans	49,547	0.347	15.7	483,934 kWh
Cooling	60,175	0.422	19.0	587,509 kWh
Pumps	11,466	0.080	3.6	111,991 kWh
Cooling Tower Fans	5,451	0.038	1.7	53,220 kWh
Heating	48,958	0.343	15.5	3684.3151 MBTU
Domestic Hot Water	-	-	-	-
HVAC Sub-Total	175,598	1.230	55.6	-
Lights	43,887	0.308	13.9	428,690 kWh
Electric Equipment	76,619	0.537	24.2	748,410 kWh
Misc. Electric	19,979	0.140	6.3	195,156 kWh
NON-HVAC Sub-Total	140,485	0.984	44.4	
Grand Total	316,083	2.215	100.0	

Figure 25 shows the incurred cost (percentage) of HVAC and non-HVAC components for the base case building Model #2 on the annual basis.

Figure 25: Annual Component Costs of the Carrier HAP Building Model #2

2.9.3. Simulation Results of the Building Model #3

The annual energy costs of Model #3 of HVAC and non-HVAC components are summarized in Table 28.

Table 28: The Annual Cost Summary of the Carrier HAP Building Model #3

Components	Cost (\$)	Cost (\$ / ft ²)	(%)	Total Energy
Air System Fans	54,916	0.385	17.1	536,451 kWh
Cooling	62,033	0.435	19.3	605,714 kWh
Pumps	8,376	0.059	2.6	81,822 kWh
Cooling Tower Fans	5,624	0.039	1.8	54,905 kWh
Gas Heating	45,352	0.318	14.1	3194.4424 MBTU
Electric Heating	3409.3	-	-	34,093 kWh
Domestic Hot Water	-	-	-	-
HVAC Sub-Total	179,710	1.235	54.9	-
Lights	44,987	0.315	14.0	439,498 kWh
Electric Equipment	79,298	0.556	24.7	774,690 kWh
Misc. Electric	20,295	0.142	6.3	198,266 kWh
NON-HVAC Sub-Total	144,580	1.013	45.1	-
Grand Total	324,290	2.248	100.0	-

Figure 26 shows the incurred cost (percentage) of HVAC and non-HVAC components for the base case building Model #3 on the annual basis.

Figure 26: Annual Component Costs of the Carrier HAP Building Model #3

2.9.4. Energy and Cost Analysis of Three Models Using Carrier HAP Programs

Comparison between three models of HVAC and non-HVAC costs and energy are summarized in Table 29 for the base case building. From this table, it can be observed that the HVAC costs associated with Model #1 are the lowest. Thus, this Model #1, which comprises of 2-Fan Variable Air Volume System, can be considered the most energy efficient of the three.

Table 29: Comparisons between Three Models Using Carrier HAP Programs

Model Types	HVAC Costs (\$)	Non-HVAC Costs (\$)	HVAC Electric kWh	HVAC Natural Gas MBTU	Non-HVAC Electric (kWh)
Model # 1	162,064	144,060	1,159,629	3283.1074	1,408,082
Model # 2	175,598	140,485	1,236,654	3684.3151	1,372,256
Model # 3	179,710	144,580	1,312,985	3194.4424	1,412,454

Figure 27 shows comparisons of annual energy costs analysis of three models of both HVAC and non-HVAC costs for the base case building Model #1, Model #2 and Model #3 used in the Carrier HAP simulations program.

Figure 27: Comparisons of HVAC and Non-HVAC Annual Energy Costs of Three Models used in the Carrier HAP Simulation Program

Figure 28 shows comparisons of the HVAC electric energy costs analysis of three models used in the Carrier HAP simulation program for the base case building on the annual basis.

Figure 28: Comparisons of HVAC Electric Energy (kWh) of Three Models used in the Carrier HAP Simulation Program

Figure 29 shows comparisons of the HVAC natural gas energy costs analysis of three models used in Carrier HAP simulation program for the base case building on the annual basis.

Figure 29: Comparisons of Fuel Energy (Natural Gas) of Three Models used in the Carrier HAP Simulation Program

3. Overview of “eQUEST” Program

3.1. Introduction

eQUEST is an easy to use building energy use analysis tool that provides professional level results with an affordable level of effort. DOE-2 derived simulation engine is used in eQUEST. DOE-2 is a public domain program that is the most widely used building energy analysis program in the USA and more than forty countries. It is funded by ASHRAE, NASA, the U.S. Postal Service, and the electric and gas utility industries. DOE-2 uses a room weighting factor approach. Other types of DOE-2 are Visual DOE, and Power DOE. The Visual DOE, which utilizes the DOE-2 simulation engine and provides graphical user interface for input and output processing. The windows-based version, Power DOE is based on the new simulation engine DOE-2.2 (Hirsch, 2008).

eQUEST calculates hourly building energy consumption over an entire year. eQUEST also contains a dynamic day lighting model to assess the effect of natural lighting on thermal and lighting demands. eQUEST DOE-2 derived engine is combined with a building creation wizard, an energy efficiency measure wizard, industry standard input defaults (California Title 24 and ASHRAE 90.1, (2004)), and a graphical results display module.

eQUEST provides very accurate simulation results of the following features:

- Shading fenestration
- Interior building mass and envelope building mass
- Dynamic response of different HVAC system types and controls

eQUEST also analyzed hourly scheduling of:

- Occupants
- Lighting and Equipment
- Thermostat settings
- Domestic Hot Water
- Space Cooling and Heating

The latest version of eQUEST 3.62 provides two building creation wizards and energy efficiency wizard along with new wizard for the creation of weather file.

1. The Weather File Creation Wizard or Weather File Generator
2. The Schematic Design Wizard (the “Schematic Wizard”)
3. The Design Development Wizard (“DD Wizard”)
4. The Energy Efficiency Measure Wizard (“EEM Wizard”)

Figure 30: Building Creation Wizard

Figure 31: Energy Efficiency Measure Wizard

Both wizards describe all principal energy-related features of the given model. At each step of describing building design, the wizards provide easy to understand choices of component and system options.

The Schematic Design Wizard is used in the earliest design phase when information is limited. It is best suited for small and simpler structure.

Other features include the followings:

- Building geometry can be predefined generic shapes, or custom user input.
- eQUEST provides users to import DWG files for building footprint and zoning patterns.
- It is limited to one building shell and one footprint.
- Only two different types of HVAC systems can be used in any project. There are 60+ HVAC system types available for the simulation.
- Simple building schedule information uses occupied / unoccupied times and allows up to two seasons per year.
- Most important is the default input values according to California Title 24 and ASHRAE 90.1 (2004) are categorized by building type.

Design Development Wizard is designed for the building when it is under development phase or when detailed design information is available. It is used for larger, more complicated structures, more detailed internal loads, schedules, and HVAC system assignment requirements.

Other features include the followings:

- Multiple building shell components, shell properties and HVAC zoning and system can be described.
- It provides hour-by-hour building occupancy, lighting, and equipment schedule information.

The greatest value that energy simulation can provide to the building design is the reliable guidance in “weighting” the energy performance of design alternatives. Energy Efficiency Measure Wizard is used for easy, quick and reliable preferred design alternatives to “base” building description and then present the simulation results as either individual or comparative graphs. After creating a new building description, EEM Wizard can be used up to ten design alternatives.

The Parametric Runs capability of eQUEST provides multiple, alternative simulation cases, where each new case is a parametric variation of the base case. The Parametric Run differs from the EEM Wizard in that the EEM Wizard operates to modify the base building as defined in the SD or DD Wizard (i.e., as contained in the PD2 file). The Parametric Run operates to modify the base building as defined in the Detailed Interface (i.e., the INP file). In general, Parametric Runs is more detailed and flexible than the EEM Wizard.

3.2. eQUEST Limitation

- For number of floors above grade greater than three eQUEST models only three floors and uses a multiplier on the middle (typical) floor.
- For number of floors below grade greater than two eQUEST models only two floors and uses a multiplier on the lowest most below grade floor as a typical underground floor.
- Maximum number of vertices is up to 120 for any one polygon.
- Any edit made directly to the detailed project input will not be reflected in the Schematic Design Wizard
- User Selected allows the user to browse only DOE-2 weather files.
- The Selected Footprint shape applies to all floors in the project
- The only changes that can be made to a base case model, using Parametric Runs, are changes to the attributes of existing building components.
- HVAC zone ventilation type is available only for buildings located in the state of Washington and only for system types that do not specify “no zone ventilation”.
- All roof constructions are “delayed” (i.e., use Layers command) as opposed to “quick” (i.e., use U-Value keyword in the Construction command).

3.3. eQUEST Strength

- Automatic daylight-sensing/dimming light controls can be used in the base case model
- There are three choices for heat pump source:
  - Air source heat pump
  - Ground loop or ground source heat pump
  - Closed loop water source heat pump
- The Parametric Runs of eQUEST provides multiple, alternative simulation cases
- Weather file generator generates DOE-2 weather file
- Result produce in the tabular and graphical format.
- All windows and door types can be modeled using “quick” (i.e., use U-Value keyword in the Construction command) as opposed to “delayed” (i.e., use Layers command)
- In the activity areas, allocation screen up to eight activity areas can be input. When usage details are set to “Simplified Schedule”, the default values are based on the calculation methods approved by the California Title 24. When a usage detail is set to “Hourly End-use Profile”, the defaults are based on ASHRAE 62.
- DWG plan files of building geometry can be imported or custom user input via a drawing tablet.
- Simple building schedule information uses occupied versus unoccupied times same as MNECB default schedule pattern.

3.4. eQUEST Weather Data

There are three choices for weather file coverage:

1. California Title 24 (limits the choices to the 16 California climate zones)
2. All eQUEST Locations (U.S and Canada wide coverage)
3. User Selected (allows the user to browse for any DOE-2 weather files).

eQUEST comes with an additional 650+ weather files available for North American locations. Some international locations are also available. Any DOE-2 weather file with a JH DOE-2 based program can be used with eQUEST.

eQUEST 3.62 has provided a new wizard of weather file generator. Energy codes are either 2005 California Title 24 or ASHRAE 90.1 (2004). Climate zone is the user selected and any user selected weather file can be generated with the use of this weather file generator. Weather file generator is used for generating user defined weather file.

Figure 32 shows the weather file generator screen is used to create the weather file in eQUEST version 3.62. This screen can be called from the start up menu to eQUEST, by selecting the Generate SkyCalc Weather File option. On the weather file generation screen, pressing the Generate Weather File button, creates a weather file with a .wea3 extension, which can then be imported into SkyCalc. The default location and name of this weather file can be changed in the SkyCalc Weather File to be Generated field. The input screen allows selecting a location, specifying either a custom or default roof U-factor based on climate zone, energy code, and roof type, and then generating a SkyCalc weather file (Hirsch, 2008).

The screenshot shows the 'SkyCalc Weather File Generator' window. It features a series of dropdown menus and text input fields for configuring weather file generation. The settings shown are: Coverage: California (Title 24); Region: Los Angeles Area (CZ06); City: Los Angeles AP; Latitude: 33.90; Longitude: 118.24; Energy Code: 2005 California Title 24; Default CZ: CZ6 (Los Angeles); Climate Zone: CZ6 (Los Angeles); Roof U-factor: 0.076 (with a note that T-24 max allowed is 0.076); and the output file path: D:\Program Files\eQUEST 3-62\SkyCalcWthr\Weat. The window includes a 'Help' button and a 'Generate Weather File' button with a gear icon.

Figure 32: eQUEST Weather Files Generator

3.5. eQUEST Structure (Project Navigator)

The Project Navigator is incorporated with the Schematic Wizard and the Development Wizard, as well as an Energy Efficiency Measure Wizard. The two Creation Wizards guide the user through a series of steps and fully describe the principle of energy-related features of the base-line design. The Simulation Wizard then creates a detailed description of the proposed design as required by the DOE-2 simulation program.

Figure 33 depicts the eQUEST simulation structure used in the base case building.

Figure 33: eQUEST Project Navigator

3.6. Methodology for using “eQUEST” Program

The same methodology used in Section 2, has been applied here. Three models are used with two different air system to simulate the base case building. Model #1 is modeled with one central HVAC system with the above grade and below grade floors. Model #2 is divided into two parts such that Model #2 Part 1 is only for the above grade floor and Model #2 Part 2 is for above and below grade floors with one central HVAC system. Model #3 is same as Model #2 except it has three HVAC systems i.e., one central HVAC and two rooftop packaged units (Note: due to the limitation of the HVAC system, only one rooftop packaged unit was used).

Figure 34 shows the eQUEST model #1 of the Peel Region Headquarters Building with one central HVAC system with the above grade and below grade floors.

Figure 34: eQUEST Building Model #1 of Peel Region Headquarters Building

3.7. Simulation Results

3.7.1. Simulation Results of eQUEST Building Model #1 with One HVAC System

The annual energy and costs of Model #1 of HVAC and non-HVAC components are summarized in Table 30.

Table 30: Annual Cost and Energy Summary of the eQUEST Building Model #1

Components	Total Energy (kWh x 000)	Cost (\$)	Total Electric (kWh x 000)	Total Natural Gas (MBTU)
Air System Fans	716.5 kWh		716.5 kWh	
Cooling	450.8 kWh		450.8 kWh	
Pumps and Aux	125.6 kWh		125.6 kWh	
Lights	488.0 kWh		488.0 kWh	
Electric Equipment	843.3 kWh		843.3 kWh	
Gas Heating	3,274.6 MBTU			3,274.6 MBTU
Domestic Hot Water	627.5 MBTU			627.5 MBTU
Grand Total of Electric and Gas Energy			2,627.500 kWh	3,902.1 MBTU
Total Electric Energy Costs (\$)		\$ 253,500.00	Total Annual Bill across all rates	\$ 302,489.00
Total Gas Energy Costs (\$)		\$ 48,989.00		

Figure 35 shows the percentage contribution of electric use and fuel use of HVAC and non-HVAC components for the base case building Model #1 on the annual basis.

Figure 35: Annual Percentage Energy Consumption of HVAC and Non-HVAC Components of eQUEST Model #1

3.7.2. Simulation Results of Building Model #2 Part 1 with One HVAC System

Figure 36: eQUEST Building Model #2 Part 1 With Above Grade Floor Only

Model #2 Part 1 is modeled in eQUEST with the above grade floor only.

1. In order to model the building in eQUEST, the third floor has been considered as the first floor.
2. Similarly, the fourth floor of the building has been considered as the typical floor (multiplier is equal to 3).
3. The sixth floor of the building has been considered as the top floor.

The annual energy and costs of Model #2 Part 1 of HVAC and non-HVAC components are summarized in Table 31.

Table 31: Annual Cost and Energy Summary of the eQUEST Building Model #2 Part 1

Components	Total Energy (kWh x 000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	602.5 kWh		602.5 kWh	
Cooling	327.9 kWh		327.9 kWh	
Pumps and Aux	126.9 kWh		126.9 kWh	
Lights	359.5 kWh		359.5 kWh	
Electric Equipment	733.9 kWh		733.9 kWh	
Gas Heating	2,335.1 MBTU			2,335.1 MBTU
Domestic Hot Water	652.2 MBTU			652.2 MBTU
Grand Total of Electric and Gas Energy			2,153.800 kWh	2, 987.3 MBTU
Total Electric Energy Costs (\$)		\$ 208, 024.00	Total Annual Bill across all rates	\$ 245, 817.00
Total Gas Energy Costs (\$)		\$ 37, 793.00		

Figure 37 shows the percentage contribution of electric use and fuel use of HVAC and non-HVAC components for the base case building Model #2 Part 1 on the annual basis.

Figure 37: Annual Percentage Energy Consumption of HVAC and Non-HVAC Components of eQUEST Model #2 Part 1

3.7.3. Simulation Results of Building Model #2 Part 2 with One HVAC System

Figure 38: eQUEST Building Model #2 Part 2

Model #2 Part 2 is modeled in eQUEST with the above and below grade floor taken into consideration. The building is presented in figure 38.

- P2, level (below grade floor) of the building has been considered as the first floor below grade when modeled in eQUEST.
- P1, level (on grade floor) of the building has been considered as the first floor above grade when modeled in eQUEST.
- Main floor (above grade floor) of the building has been taken as the top floor when modeled in eQUEST.

The annual energy and costs of Model #2 Part 2 HVAC and non-HVAC components are summarized in Table # 32.

Table 32: Annual Cost and Energy Summary of the eQUEST Building Model #2 Part 2

Components	Total Energy (kWh x 000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	133.68 kWh		133.68 kWh	
Cooling	112.52 kWh		112.52 kWh	
Pumps and Aux	38.64 kWh		38.64 kWh	
Lights	146.95 kWh		146.95 kWh	
Electric Equipment	157.68kWh		157.68kWh	
Gas Heating	1,377.7 MBTU			1,377.7 MBTU
Domestic Hot Water	62.6 MBTU			62.6 MBTU
Grand Total of Electric and Gas Energy			589.990 kWh	1,440.3 MBTU
Total Electric Energy Costs (\$)		\$ 57,899.00	Total Annual Bill across all rates	\$ 76,660.00
Total Gas Energy Costs (\$)		\$ 18, 761.00		

3.7.4. Simulation Results of Building Model #2 (With Part 1 and Part 2)

The annual energy and costs of Model #2 (with Part 1 and Part 2) of HVAC and non-HVAC components are summarized in Table # 33.

*Table 33: Annual Cost and Energy Summary of the eQUEST Building Model #2
(With Part 1 and Part 2)*

Components	Total Energy (kWh x 000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	736.18 kWh		736.18 kWh	
Cooling	440.42 kWh		440.42 kWh	
Pumps and Aux	165.54 kWh		165.54 kWh	
Lights	506.45 kWh		506.45 kWh	
Electric Equipment	891.58 kWh		891.58 kWh	
Gas Heating	3712.8 MBTU	47,619.00		3712.8 MBTU
Domestic Hot Water	714.80 MBTU	8,935.00		714.80 MBTU
Grand Total of Electric and Gas Energy			2,743.790 kWh	4427.7 MBTU
Total Electric Energy Costs (\$)		\$ 265,923.00	Total Annual Bill across all rates	\$ 322,477.00
Total Gas Energy Costs (\$)		\$ 56,554.00		

Figure 39 shows electric and natural gas energy consumption by the HVAC and non-HVAC components of Model #2 for the base case building on the annual basis.

Figure 39: Annual Energy Consumption by End-Use of eQUEST Model #2

3.7.5. Simulation Results of Building Model #3 Part 1 with Two HVAC Systems

Model #3 Part 1 is modeled in eQUEST with the above grade floor only. One HVAC system is serving space cooling of all thermal zones except the computer room on the third floor. It is conditioned by the Rooftop Packaged HVAC systems. A baseboard type heating system for all thermal zones provides space heating and the electric resistance heating coils heat the computer room. Model #3 Part 2 is same as of Model #2 Part 2.

The annual energy and costs of HVAC and non-HVAC components of Model #3 Part 1 are summarized in Table 34 and Figure 40.

Table 34: Annual Cost and Energy Summary of the eQUEST Building Model #3 Part 1

Components	Total Energy (kWh x 000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	575.9 kWh		575.9 kWh	
Cooling	326.9 kWh		326.9 kWh	
Pumps and Aux	126.2 kWh		126.2 kWh	
Lights	359.50 kWh		359.50 kWh	
Electric Equipment	733.90 kWh		733.90 kWh	
Gas Heating	2,476.7MBTU			2,476.7MBTU
Electric Heating	12.3 kWh		12.3 kWh	-
Domestic Hot Water	651.8 MBTU			651.8 MBTU
Grand Total of Electric and Gas Energy			2,137.800 kWh	3,128.5 MBTU
Total Electric Energy Costs (\$)		\$ 206,490.00	Total Annual Bill across all rates	\$ 246,013.00
Total Gas Energy Costs (\$)		\$ 39,523.00		

Figure 40 shows the annual energy consumption by end-use of Model #3 Part 1

Figure 40: Annual Percentage Energy Consumption of HVAC and Non-HVAC Components of eQUEST Model #3 Part 1

3.7.6. Simulation Results of Building Model #3 (With Part 1 and Part 2)

The annual energy costs of Model #3 of HVAC and non-HVAC components are summarized in Table # 35.

*Table 35: Annual Cost and Energy Summary of the eQUEST Building Model #3
(With Part 1 and Part 2)*

Components	Total Energy (kWh x 000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	709.58 kWh		709.58 kWh	
Cooling	439.42 kWh		439.42 kWh	
Pumps and Aux	164.84 kWh		164.84 kWh	
Lights	506.45 kWh		506.45 kWh	
Electric Equipment	891.58 kWh		891.58 kWh	
Gas Heating	3854.4 MBTU			3854.4 MBTU
Electric Heating	12.3 kWh		12.3 kWh	-
Domestic Hot Water	714.4 MBTU			714.4 MBTU
Grand Total of Electric and Gas Energy			2,727.790 kWh	4568.8 MBTU
Total Electric Energy Costs (\$)		\$ 264,389.00	Total Annual Bill across all rates	\$ 322,673.00
Total Gas Energy Costs (\$)		\$ 58,284.00		

Figure 41 shows the percentage contribution of electric use and fuel use of HVAC and non-HVAC components for the base case building Model #3 on the annual basis.

Figure 41: Annual Energy Consumption by End-Use of eQUEST Model #3

3.7.7. Energy and Cost Analysis of Three Models using eQUEST Programs

The energy and cost analysis of the building was conducted based on the types of models used in the eQUEST simulation. Table 36 presents the comparative results of the annual usage of energy and costs of the three models used in eQUEST simulation. Even though it can be seen from the table that Model #1 is the most cost effective of the three models, however, this is not entirely true. The limitation of a maximum of 3 above grade floors, as well as the ignorance of the varying floor areas, limits this model and thus does not show an accurate cost comparison picture.

Table 36: Comparisons between Three Models used in eQUEST Simulation Programs

Model Types	Electric Costs (\$)	Fuel (Gas) Costs (\$)	Total Annual Bill across all rates	Electric Energy kWh	Gas Energy MBTU
Model # 1	253,500.00	48,989.00	302,489.00	2,627,500	3,902.1
Model # 2	265,923.00	56,554.00	322,477.00	2,743,790	4427.7
Model # 3	264,389.00	58,284.00	322,673.00	2,727,790	4568.8

Figure 42 shows the comparisons of electric energy costs of three models of HVAC and non-HVAC components for the base case building on the annual basis.

Figure 42: Comparisons of Annual Electric Energy Costs of Three Models used in eQUEST Simulation

Figure 43 shows the comparisons of natural gas energy costs of three models of HVAC and non-HVAC components for the base case building on the annual basis.

Figure 43: Comparisons of Annual Natural Gas Energy Costs of Three Models Used In eQUEST Simulation

Figure 44 shows the comparisons of annual energy costs of three models of HVAC and non-HVACs components for the base case building on the annual basis.

Figure 44: Comparisons of Annual Energy Costs of Three Models Used In eQUEST Simulation

3.8. Energy and Cost Analysis of the Base Case Model #2 using Carrier HAP and eQUEST

The energy and cost comparison between Carrier HAP and eQUEST software is based on the Model #2 type when using the same HVAC system (i.e., 1-Fan Variable Air Volume System).

Table 37 shows the comparisons of energy and cost analysis of the Peel Region Headquarters Building based on the types of model (Model #2 i.e., with one HVAC system) used in two simulation programs. The results show that the total annual costs based on eQUEST software is least of the two.

Table 37: Comparisons of Energy Costs using Carrier HAP and eQUEST Simulation Programs

Types of Software	Electric Costs (\$)	Fuel (Gas) Costs (\$)	Total Annual Bill across all rates
Carrier HAP	267,125	48,958	316,083
eQUEST	265,923	47,619	313,542
Percentage Difference (%)	0.40 %	2.74 %	0.80 %

Figure 45 shows the comparisons of total annual electric costs between Carrier HAP and eQUEST simulation programs for the base case Model #2.

Figure 45: Comparisons of Total Annual Electric Energy Costs between Carrier HAP and eQUEST Simulation Programs of the Base Case Model #2

Figure 46 shows the comparisons of annual natural gas costs between Carrier HAP and eQUEST simulation programs for the base case Model #2.

Figure 46: Comparisons of Total Natural Gas Energy Costs between Carrier HAP and eQUEST Simulation Programs of the Base Case Model #2

Figure 47 shows the comparisons of total annual energy costs across all rates between Carrier HAP and eQUEST simulation programs for the base case Model #2.

Figure 47: Comparisons of Annual Energy Costs across All Rates between Carrier HAP and eQUEST of the Base Case Model #2

4. Heat Pump

4.1. Introduction of Heat Pump

A considerable literature has begun on the subject of the heat pump since 1966. Currently Carrier HAP, eQUEST, EnergyPlus, and EE4 simulation programs are capable of modeling almost all types of heat pump.

Refrigeration systems are heat pumps; they absorb thermal energy at a low temperature and reject it at a higher temperature. The reverse cycle of a refrigeration system is designated as a heat pump, where the heat rejected at the condenser is used instead of being rejected to the atmosphere. Thus, the main difference between the heat pump and refrigeration cycles depends upon the use, cooling by the refrigerator and heating by the heat pump. The heat pump cycle is fully reversible, and can provide year-round climate control for houses and small commercial buildings for heating in winter and cooling in summer.

The heat pump is a device that makes a significant contribution to energy conservation. Therefore, potential use of the heat pump vastly increases as energy conservation equipment increases all over the world. Nearly half a million heat pumps have been installed in the U.S.A (Lund, 2008).

Figure 48 shows the flow diagram of a simple vapor compression heat pump.

Figure 48: Simple Vapor Compression Heat Pump (<http://www.heatpumpcentre.org>, 2008)

There are different types of heat pumps used today depends upon the types of heat source. The most common types of the heat pumps are the following:

- Air- to - Air Heat Pumps
- Air- to - Water Heat Pumps
- Ground Source Heat Pumps:
  1. Ground Source Heat Pumps (Closed Loop)
  2. Ground Source Heat Pumps (Open Loop) or Ground Water Heat Pumps
- Water Source Heat Pumps:
  1. Water Source Heat Pumps (Closed Loop)
  2. Water Source Heat Pumps (Open Loop)

4.2. Evaluation of Heat Pump Efficiency by the ARI Rating & CSA Rating

For selecting a heat pump, it is highly recommended to use the ARI rating or CSA rating. These ratings enable someone to choose an efficient heat pump. The heat pump efficiency rating information from the Air Conditioning and Refrigeration Institute (ARI) is given in EnerGuide Manual and Heat Pumps (Heap, 1979). The Canadian Standards Association (CSA) provides the performance standard, at which the heat pump cooling and heating capacities and efficiency are determined. The performance standards for air-source heat pumps are CSA C273.3 and C656, and for ground source heat pumps, the corresponding standards are CSA C13256-1-01 and C448 Series-02 (NRCan, 2008).

Different terminologies are used to describe heat pump efficiency ratings. If the primary use of the heat pump is heating then we look for HSPF or COP. The Heating Seasonal Performance Factor (HSPF) is a measure of the total heat output in Btu of a heat pump over the entire heating season divided by the total energy in watt-hours it uses during that time. The Coefficient of Performance (COP) is a measure of a heat pump's efficiency at a specific temperature. For an efficient heat pump, we look for higher COP. The COP is the ratio of total heating capacity provided by the heat pump and the electrical energy input (NRCan, 2008).

If the primary use of the heat pump is cooling then we look for SEER or EER. Energy Efficiency Ratio (EER) measures the efficiency for cooling equipment. It is used when unit size exceeds 65,000 Btu/hr or approximately 5.5 tons. The Energy Efficiency Ratio is the ratio of net cooling capacity (Btu/hr) to total rate of electrical energy (Watts). For most efficient cooling systems, we choose higher EER (Hirsch, 2008).

The Seasonal Energy Efficiency Ratio (SEER) measures the season-long efficiency for cooling equipment whose unit size is less than 65,000 Btu/hr. It is the ratio of net cooling capacity (Btu/hr) to total rate of electrical energy input (Watts) (Hirsch, 2008). This efficiency ratio is based on a climate with an average summer temperature of 28°C (NRCan, 2008).

The minimum level annual cooling efficiency (SEER) and heating efficiency (HSPF) of an air source heat pump are 13 and 6.7 for region V (region V has a climate similar to that of Ottawa). The maximum level is 17 and 8.6, respectively (NRCan, 2008).

Similarly, the minimum and maximum level of coefficient of performance and energy efficiency ratio of an open loop ground source heat pump at 10°C are 3.6/16.2 and 5.2/31.1, respectively. The minimum and maximum level of COP and EER of a closed loop ground heat pump at 0°C are 3.2/13.4 and 4.9/25.8, respectively (NRCan, 2008). Detailed information about the efficiency of the others Canadian cities are given in EnerGuide manual (NRCan, 2008).

4.3. Carrier HAP Programs with Heat Pump Systems

Carrier HAP supports three types of high-efficiency HVAC systems to support US LEED certification. Each of the three WSHP/GSHP systems can be modeled with Carrier's Hourly Analysis Program (HAP) as described below.

- Conventional Closed Loop Water Source Heat Pump System
- Open Loop Water Source Heat Pump System
- Ground-Coupled Water Source or Ground Source Heat Pump

Figure 49 shows the conventional (closed loop) water source heat pump.

Figure 49: Closed Loop of Water Source Heat Pump (Carrier, 2006)

Figure 50 shows the ground coupled water source heat pump.

Figure 50: Ground Coupled Water Source Heat Pump (Carrier, 2006)

4.3.1. Open Loop Water Source Heat Pump for the Base Case Model

In this study, we designed the Open Loop Water Source Heat Pump for the Peel Region Headquarters Building. The Water Source Heat Pump System consists of WSHP units connected in parallel to an open water source. The water source is a well, river, pond or municipal water supply. If the heat pump is used in a closed loop WSHP system in the Carrier HAP simulation program, auxiliary heating is provided by the auxiliary boiler attached to the water loop. When the heat pump is used in an open loop WSHP system in the Carrier HAP simulation program, it is assumed the WSHP contains an electric auxiliary heating coil at the zone(s). To model a WSHP system in Carrier HAP, each zone represents a separate WSHP unit. Therefore, the number of zones must equal the number of heat pumps in the system. For the Open Loop Water Source Heat Pump System, an average water temperature for each month must be entered for the “Cooling Tower Properties” (See Table 39). Heat pump design parameters of the flow rate, temperature range, and pump head are given in Table 9 (Carrier, 2006).

Figure 51 shows the open loop water source heat pump.

Figure 51: Open Loop Water Source Heat Pump (Carrier, 2006)

Figure 52 shows flow diagram of the open loop water source heat pump with auxiliary electric resistance heater and heat source as a city water reservoir. Plate heat exchanger is used in between heat pump and heat source.

Figure 52: Open Loop Water Source Heat Pump with Auxiliary Electric Resistance Heater

4.3.2. Heat Source

Heat pump performance is closely dependent upon the temperature of the heat source. An efficient heat pump is one that has a high and stable source temperature during the heating season. Another important factor for the heat source is the availability and thermodynamics properties. For small heat pump systems ambient and exhaust air, soil and ground water are heat sources. While for large heat pump systems seawater, lake/ river water, wastewater and city water reservoirs are the main heat sources.

Table 38 presents different types of heat sources with the temperature range used for the heat pump.

Table 38: Commonly Used Heat Sources (<http://www.heatpumpcentre.org>, 2008)

Commonly used heat sources	
Heat source	Temperature Range ($^{\circ}\text{C}$)
Ambient air	-10 to 15
Exhaust air	15 to 25
Ground water	4 to 10
Lake water	0 to 10
River water	0 to 10
Sea water	3 to 8
Ground	0 to 10
Waste water	> 10

Figure 53 shows the Great Lakes average surface water temperature for the year 2007 obtained from the Great Lakes surface environmental analysis.

Figure 53: Great Lakes Average Surface Water Temperature for the Year 2007 (Schwab, 2008)

Table 39 depicts the Lake Ontario's monthly average surface water temperature for the calendar year 2007. The Lake Ontario's daily average surface water temperature can be found from Table 98 (Schwab, 2008).

Table 39: Lake Ontario's Monthly Surface Water Temperature (Schwab, 2008)

Lake Ontario's Monthly Average Surface Temperature 2007			
Name of Month	Temperature °C	Name of Month	Temperature °C
January	4.51	July	20.42
February	2.56	August	21.34
March	1.61	September	19.21
April	2.68	October	15.50
May	8.37	November	8.51
June	15.4	December	4.71

4.3.3. Heat Pump Performance

Heat pump performance commonly known as the coefficient of performance is the ratio of heat output by the heat pump and the electric energy used by the system component (compressor). The coefficient of performance of an ideal heat pump is determined solely by the condensation temperature and the temperature difference of the two heat exchangers (condenser and evaporator), which is also known as the temperature lift. The ratio of the actual COP of a heat pump and the ideal COP is defined as the Carnot efficiency. It varies from 0.30 to 0.50 for small electric heat pumps and 0.50 to 0.70 for large, very efficient electric heat pump systems. These values are shown in Figure 54 (<http://www.heatpumpcentre.org>, 2008).

Figure 54 shows the coefficient of performance for an ideal heat pump as a function of Condensation temperature, where the temperature of the heat source is 0°C.

Figure 54: Coefficient of Performance versus Condensation Temperature
(<http://www.heatpumpcentre.org>, 2008)

4.3.4. Methodology of Heat Pump using Carrier HAP

The methodology for designing an Open Loop Water Source Heat Pump for the base case model is as follows:

1. Create a cooling tower and choose the water source such as “River, Sea or Well Water” for modeling the cooling tower properties. The average source water temperature (Ave. ECWT) for each month of the year is required for Heat Pump System design calculation.
2. Create a new air system and equipment type (e.g. terminal units and system type such as water source heat pumps).
3. Enter performance data from the manufacturer’s catalog data for each heat pump either for terminal cooling units or for terminal heating units.

The following are the performance data required for system design:

1. Design EWT is the entering water temperature at which the gross heating capacity and input power are defined. The design EWT is a function of the water loop temperature controls.
2. Gross Heating Capacity is the total heating output of the WSHP at design EWT. This value is obtained from equipment selection software or product catalogs.
3. Compressor Power is the total input power for the compressor at design EWT.

Equipments are selected from the manufacturer catalogue at the design cooling and heating load and at the desired dry bulb and wet bulb temperature. (See Table 99 in Appendix 3).

Figure 55 shows the Carrier HAP input data screen of monthly average water temperature for open loop water source heat pump of the selected heat source (city water reservoir or lake water) of the location specified for the Peel Region Headquarters Building.

Cooling Tower Properties - [Evapco Cooling Tower]

Name:

Modeling Method:

☐ Cooling Tower Model

☒ River, Sea or Well Water

Condenser Water Flow Rate: L/s

Condenser Pump Head: kPa

Condenser Pump Mech. Efficiency: %

Condenser Pump Elec. Efficiency: %

River or Sea Water

Month	Avg. ECWT(°C)
Jan	7.2
Feb	7.2
Mar	7.2
Apr	7.2
May	8.3
Jun	15.2
Jul	20.4
Aug	21.3
Sep	19.2
Oct	15.5
Nov	8.5
Dec	7.2

OK Cancel Help

Avg. ECWT Min: = 7.2 (°C) Max: = 35.0 (°C)

Figure 55: Carrier HAP Input Data Form of Monthly Average Water Temperature used for Open Loop Water Source Heat Pump (Carrier, 2006)

Table 40 shows the terminal cooling and heating design load (These values are obtained from the simulation design data in Carrier HAP simulation program). Energy efficiency ratio (EER) or coefficient of performance (COP) of the open loop water source heat pump are obtained from the heat pump manufacturer catalog for the terminal cooling and heating design loads for the base case Model #2 of the Peel Region Headquarters Building used in the Carrier HAP simulation program.

Table 40: Terminal Cooling and Heating Design Load, Compressor Power, and COP of Open Loop Water Source Heat Pump of Base Case Model #2

Terminal Cooling and Heating Design Load, Compressor Power, and Coefficient of Performance of the Open Loop Water Source Heat Pump of the Base Case Model #2 (Design Entering Water Temperature = 85°F /70°F)						
Zone #	Terminal Design Cooling Load (MBH) / (kW) (Output)	EER /COP	Compressor Power (kW) = Output/COP	Terminal Design Heating Load (MBH) / (kW) (Output)	COP	Compressor Power (kW) = Output/COP
1	13.6/4.0	13.2/3.9	1.02	10.9/3.2	4.6	0.695
2	40.9/12	13.2/3.9	3.07	29.3/8.6	4.6	1.87
3	17.1/5.0	13.2/3.9	1.28	14.3/4.2	4.6	0.91
4	64.8/19	13.2/3.9	4.87	43.3/12.7	4.6	2.76
5	17.1/5.0	13.2/3.9	1.28	13/3.8	4.6	0.82
6	17.1/5.0	13.2/3.9	1.28	11.6/3.4	4.6	0.74
7	64.8/19	13.2/3.9	4.87	60.4/17.7	4.6	3.84
8	13.6/4.0	13.2/3.9	1.02	11.7/3.4	4.6	0.74
9	23.9/7.0	13.2/3.9	1.79	17.1/5.0	4.6	1.08
10	44.4/13	13.2/3.9	3.33	34.1/10	4.6	2.17
11	133.1/39	13.5/4.0	9.75	69.8/20.4	4.6	4.43
12	23.9/7.0	13.2/3.9	1.79	22.7/6.7	4.6	1.45
13	17.1/5.0	13.2/3.9	1.28	12.2/3.6	4.6	0.78
14	68.2/20	13.2/3.9	5.10	51.3/15	4.6	3.26
15	17.1/5.0	13.2/3.9	1.28	13.5/4.0	4.6	0.87
16	61.4/18	13.2/3.9	4.61	53.5/15.7	4.6	3.41
17	13.6/4.0	13.2/3.9	1.02	11.0/3.2	4.6	0.69
18	66.5/19.5	13.2/3.9	5.0	53.2/15.6	4.6	3.39
19	20.5/6.0	13.2/3.9	1.54	15.0/4.4	4.6	0.95
20	68.2/20	13.2/3.9	5.12	53.1/15.6	4.6	3.39
21	256/75	11.8/3.5	21.42	169.6/49.7	4.5	11.04

22	20.5/6.0	13.2/3.9	1.54	15.7/4.6	4.6	1
23	51.2/15	13.2/3.9	3.84	38.1/11.2	4.6	2.43
24	17.1/5	13.2/3.9	1.28	13.6/4.0	4.6	0.86
25	13.6/4.0	13.2/3.9	1.02	8.2/2.4	4.6	0.52
26	40.9/12	13.2/3.9	3.07	32.3/9.5	4.6	2.06
27	27.3/8.0	13.2/3.9	2.05	19.4/5.7	4.6	1.23
28	13.6/4.0	13.2/3.9	1.02	9.9/2.9	4.6	0.63
29	64.8/19	13.2/3.9	4.87	45.8/13.4	4.6	2.91
30	17.1/5.0	13.2/3.9	1.28	11.1/3.3	4.6	0.72
31	27.3/8.0	13.2/3.9	2.05	21.2/6.2	4.6	1.35
32	13.6/4.0	13.2/3.9	1.02	9.6/2.8	4.6	0.61
33	27.3/7.0	13.2/3.9	1.79	18.5/5.4	4.6	1.2
34	201.3/59	12.5/3.7	15.94	118.1/34.6	4.5	7.5
35	17.1/5.0	13.2/3.9	1.28	11.1/3.3	4.6	0.72
36	64.8/19	13.2/3.9	4.87	55/16.0	4.6	3.5
37	17.1/5.0	13.2/3.9	1.28	11.3/3.3	4.6	0.72
38	68.2/20	13.2/3.9	5.13	55.1/16.1	4.6	3.5
39	20.5/6.0	13.2/3.9	1.54	13.6/4.0	4.6	0.86
40	64.8/19	13.2/3.9	4.87	50.7/14.9	4.6	3.23
41	17.1/5.0	13.2/3.9	1.28	11.3/3.3	4.6	0.72
42	71.7/21	13.2/3.9	5.38	54.8/16.1	4.6	3.5
43	293.4/86	11.8/3.5	24.6	195.5/57.3	4.5	12.5
44	13.6/4.0	13.2/3.9	1.02	10/2.9	4.6	0.61
45	54.6/16	13.2/3.9	4.10	37.1/10.9	4.6	2.36
46	10.2/3.0	13.2/3.9	0.76	6.1/1.8	4.6	0.39
47	37.5/11	13.2/3.9	2.82	22.1/6.5	4.6	1.41
48	6.8/2.0	13.2/3.9	0.51	3.1/0.9	4.6	0.19
49	6.8/2.0	13.2/3.9	0.51	3.8/1.1	4.6	0.23
50	37.5/11.0	13.2/3.9	2.82	20.8/6.1	4.6	1.33
51	64.8/19	13.2/3.9	4.87	46.0/13.5	4.6	2.9
52	17.1/5.0	13.2/3.9	1.28	10.6/3.1	4.6	0.67
53	68.2/20	13.2/3.9	5.12	38.2/11.2	4.6	2.43
54	122.8/36	13.5/4	9.0	71.8/21.1	4.6	4.58
55	68.2/21	13.2/3.9	5.38	64.2/18.8	4.6	4.08
56	17.1/5.0	13.2/3.9	1.28	10.8/3.2	4.6	0.69
57	34.1/10	13.2/3.9	2.56	28.4/8.3	4.6	1.80
58	13.6/4.0	13.2/3.9	1.02	7.9/2.3	4.6	0.50
59	23.9/7	13.2/3.9	1.79	18.9/5.5	4.6	1.19
60	13.6/4.0	13.2/3.9	1.02	9.7/2.8	4.6	0.61
61	17.1/5.0	13.2/3.9	1.28	10.8/3.2	4.6	0.69

62	34.1/10	13.2/3.9	2.56	26.4/7.7	4.6	1.67
63	34.1/10	13.2/3.9	2.56	26.4/7.7	4.6	1.67
64	23.9/7.1	13.2/3.9	1.79	19.2/5.6	4.6	1.21
65	20.5/6.0	13.2/3.9	1.54	15.5/4.5	4.6	0.97
66	27.3/8.0	13.2/3.9	2.05	21.5/6.3	4.6	1.36
67	30.7/9.0	13.2/3.9	2.3	23.5/6.9	4.6	1.5
68	23.9/7.0	13.2/3.9	1.79	18.7/5.5	4.6	1.19
69	40.9/12	13.2/3.9	3.07	30.7/9.0	4.6	1.95
70	17.1/5.0	13.2/3.9	1.28	11.4/3.3	4.6	0.72
71	51.2/15	13.2/3.9	3.85	40.4/11.8	4.6	2.56
72	40.9/12	13.2/3.9	3.07	28.1/8.2	4.6	1.78
73	51.2/15	13.2/3.9	3.85	46.5/13.6	4.6	2.95
74	27.3/8	13.2/3.9	2.05	22.2/6.5	4.6	1.41
75	64.8/19	13.2/3.9	4.87	76.7/22.5	4.6	4.89
76	221.8/65	12.5/3.7	16.6	300/90	4.0	19.56
77	27.3/8.0	13.2/3.9	2.05	23.7/6.9	4.6	1.5
78	27.3/8.0	13.2/3.9	2.05	25.6/7.5	4.6	1.63
79	17.1/5.0	13.2/3.9	1.28	12.3/3.6	4.6	0.78

Table 41 depicts the product selection of the open loop water source heat pump based on design cooling load from the manufacturer catalog.

Table 41: Product (Heat Pump) Selection from the Manufacturer Catalogs

Product Selection From the Manufacturer Catalog.(Selection Criteria Based on Design Cooling Load and Entering Water Temperature (See Table 99 in Appendix 3)					
With Four Different Model Types			With One Model Type		
Zones Design Cooling Load (kW)	Model Number	Total Number of Heat Pump	Zones Design Cooling Load (kW)	Model Number GLH072 Maximum Cooling Capacity = 20kW	Total Number of Heat Pump
20	GLH072	32	20	GLH072	32
40	GLH160	2	20 * 2 = 40	GLH072	4
60	GLH200	2	20 * 3 = 60	GLH072	6
80	GLH300	3	20 * 4 = 80	GLH072	12
Total number of Heat Pump		39	Total number of Heat Pump		54

The design cooling load determines the number of heat pumps needed for meeting design cooling requirements for each of the zones and their respective floors. Table 42 shows the summary of the distribution of the open loop water source heat pump associated to the zones with Model # GLH072, with 20kW maximum heat pump cooling capacity for the base case Model #2 used in Peel Region Headquarters Building.

Table 42: Summary of the Distribution of Heat Pump with respect to the Zones Design Cooling Load for the Model # GLH072

Summary of the Distribution of Heat Pump Associated to the Zones of Each Floors (With Model Number GLH072) (Heat Pump Maximum Cooling Capacity = 20kW)				
Floor number	Number of Zones Associated with HP	Terminal Cooling Design Load (kW)	Quantity of Heat Pump	Compressor Power (kW)
1	Zone # 1, 2, 3	21	1	5.37
1	Zone # 4	19	1	4.87
1	Zone # 5, 6, 8, 9	21	1	5.37
1	Zone # 7	19	1	4.87
1	Zone # 10, 12	20	1	5.12
1	Zone # 11	39	2	9.75
2	Zone # 13,15,17,19	20	1	5.12
2	Zone # 14	20	1	5.12
2	Zone # 16	18	1	4.61
2	Zone # 18	19.5	1	5.0
2	Zone # 20	20	1	5.12
2	Zone # 21	75	4	21.42
3	Zone # 22,23	21	1	5.37
3	Zone # 24, 25, 26	21	1	5.37
3	Zone # 27, 28, 30	17	1	4.35
3	Zone # 29	19	1	4.87
3	Zone # 31, 32, 33	19	1	4.87
3	Zone # 34	59	3	15.94
4	Zone # 35, 37,39, 41	21	1	5.38
4	Zone # 36	19	1	4.87
4	Zone # 38	20	1	5.13
4	Zone # 40	19	1	4.87
4	Zone # 42	21	1	5.38
4	Zone # 43	86	4	24.60
5	Zone # 44, 45	20	1	5.12
5	Zone # 46, 47, 48, 49	18	1	4.60
5	Zone # 50, 52	16	1	4.10
5	Zone # 51	19	1	4.87
5	Zone # 53	20	1	5.12
5	Zone # 54	36	2	9.0
5	Zone # 55	21	1	5.38
6	Zone # 56, 57, 58	19	1	4.86
6	Zone # 59, 60, 61	16	1	4.09
6	Zone # 62, 63	20	1	5.12
6	Zone # 64, 65, 66	21	1	5.38
6	Zone # 67, 68, 69, 70, 71, 72, 73, 74	83	4	21.26
6	Zone # 75	19	1	4.87
P1	Zone # 76	65	3	16.60
P1 & P2	Zone # 77, 78, 79	21	1	5.38

Figure 56 shows the open loop water source heat pump distribution system of base case Model #2 used in Carrier HAP simulation. For the Heat pump Model # GLH072, total 54 heat pumps are required for the 79 number of zones (See Table 41 for the heat pump selection and Table 42 for the summary of heat pump distribution with respect to the zones design cooling load).

Figure 56: Open Loop Water Source Heat Pump Distribution System

4.4. Simulation Results of Carrier HAP Base Case Model #2 with Open Loop Water Source Heat Pumps

Table 43 depicts the annual cost summary of HVAC and non-HVAC components of the base case Model #2 with open loop water source heat pump used in the Carrier HAP simulation.

Table 43 : The Annual Cost Summary of the Base Case Model #2 with Open Loop Water Source Heat Pump

Components	Cost (\$)	Cost (\$/ft ²)	(%)
Air System Fans	1,113	0.008	0.6
Cooling	16,312	0.114	8.6
Heating	15,577	0.109	8.2
Pumps	9,927	0.070	5.2
HVAC Sub-Total	42,929	0.301	22.7
Lights	45,764	0.321	24.2
Electric Equipment	79,896	0.560	42.2
Misc. Electric	20,762	0.146	11.0
NON-HVAC Sub-Total	146,422	1.026	77.3
Grand Total	189,352	1.327	100.0

Figure 57 shows the percentage cost distribution of HVAC and non-HVAC components for the base case Model #2 on the annual basis.

Figure 57: Annual Percentage Costs of HVAC and Non-HVAC Component of Base Case Model #2 with Open Loop Water Source Heat Pump

Table 44 shows the monthly energy cost of HVAC and non-HVAC components for the base case Model #2 with open loop water source heat pump used in Carrier HAP simulation.

Table 44: Monthly Energy and Costs of HVAC and Non HVAC of Base Case Model #2 with Open Loop Water Source Heat Pump

Month	HVAC Costs				Non-HVAC Costs	
	Electric (\$)	Natural Gas (\$)	Electric (kWh)	Natural Gas (Cubic m)	Electric (\$)	Electric (kWh)
January	5,152	0	48,305	0	12,771	119,731
February	4,448	0	41,661	0	11,224	105,132
March	3,552	0	33,273	0	11,952	111,950
April	2,595	0	24,300	0	12,267	114,864
May	2,266	0	21,219	0	12,373	115,840
June	3,314	0	31,032	0	11,850	110,974
July	4,475	0	41,942	0	12,774	119,731
August	3,904	0	36,572	0	11,951	111,950
September	2,971	0	27,821	0	12,265	114,864
October	2,681	0	25,114	0	12,784	119,731
November	2,991	0	27,998	0	11,439	107,084
December	4,580	0	42,931	0	12,773	119,731
Total	42,929	0	402,168	0	146,423	1,371,581

Figure 58 shows the monthly HVAC and non-HVAC electric costs for the base case Model #2 with open loop water source heat pump used in the Carrier HAP simulation.

Figure 58: Monthly HVAC and Non-HVAC Electric Cost (\$) of Base Case Model #2 with Open Loop Water Source Heat Pump

4.5. Unmet Load Statistics of Terminal Cooling and Heating Units of Open Loop Water Source Heat Pump (WSHP) used in Carrier HAP Simulation Programs

The Unmet Loads Report provides information about the operating hours per month for equipment components and hours during which equipment capacity was insufficient to meet the system load. This report is useful for identifying operating problems in the simulation.

Each table shows the total number of hours during which the heat pump has sufficient capacity to meet the cooling or heating coil load. The unmet loads occur when the gross capacity specified for the equipment is lower than the maximum loads imposed on the equipment or the equipment capacity is less than the coil load. Examine an hourly coil loads graph can identify the maximum coil load. Then compare this coil load against the equipment load specified for the equipment. The total number of unmet load hours for the base case building and proposed design building accepted by the ASHRAE 90.1 (2004), shall not exceed 300 hours (of the 8760 hours simulated) (ASHRAE, 2004).

Table 45 gives the total load hours during which the terminal cooling units of open loop water source heat pump has sufficient and insufficient capacity.

Table 45: Unmet Load Statistics Terminal Cooling Units of Open Loop Water Source Heat Pump

Month	Equipment Capacity is Sufficient (hrs)	Capacity Insufficient by 0%-5% (hrs)	Capacity Insufficient by 5%-10% (hrs)	Capacity Insufficient by >10% (hrs)	Total Hours with Unmet Loads	Total Hours with Equipment Loads
January	2275	0	0	0	0	2275
February	1887	0	0	0	0	1887
March	2496	0	0	0	0	2496
April	7132	0	0	0	0	7132
May	16181	0	0	0	0	16181
June	21717	0	0	0	0	21717
July	27016	5	4	11	20	27036
August	23945	15	11	13	39	23984
September	18141	0	0	0	0	18141
October	8849	0	0	0	0	8849
November	2587	0	0	0	0	2587
December	2376	0	0	0	0	2376
Total	134602	20	15	24	59	134661

Table 46 gives the total load hours during which the terminal heating units of open loop water source heat pump has sufficient and insufficient capacity.

Table 46: Unmet Load Statistics Terminal Heating Units of Open Loop Water Source Heat Pump

Month	Equipment Capacity is Sufficient (hrs)	Capacity Insufficient by 0%-5% (hrs)	Capacity Insufficient by 5%-10% (hrs)	Capacity Insufficient by >10% (hrs)	Total Hours with Unmet Loads	Total Hours with Equipment Loads
January	42607	0	0	0	0	42607
February	33613	0	0	0	0	33613
March	29561	0	0	0	0	29561
April	16714	0	0	0	0	16714
May	5329	0	0	0	0	5329
June	566	0	0	0	0	566
July	353	0	0	0	0	353
August	311	0	0	0	0	311
September	3846	0	0	0	0	3846
October	15571	0	0	0	0	15571
November	27046	0	0	0	0	27046
December	36450	0	0	0	0	36450
Total	211967	0	0	0	0	211967

4.6. Ground Source Heat Pump

The ground source heat pump is a special form of the water source heat pump application. Ground source heat pumps are connected to a common condenser water loop (cold side i.e., evaporator) that uses a ground loop heat exchanger to maintain the loop temperature within the specified range.

The design parameters are:

- Pump loop configuration,
- Flow and operation control, and pump size and efficiency,
- Ground loop heat exchanger type (horizontal or vertical),
- Fluid properties,
- Undisturbed ground temperature,
- Ground description,
- Ground conductivity,
- Grout description,
- Grout conductivity, etc.

4.6.1. Ground Soil Thermal Properties

Ground description and related thermal properties are important parameters of the ground formation at the site where ground loop heat exchanger is installed. The soil and rock that most closely represents the ground formation, the thermal conductivity and diffusivity of the ground are specified. The table of ground thermal properties lists the name of various kinds of rock and soil and associated values of thermal conductivity and diffusivity (Details can be found in Table 100 in Appendix 3).

Grouting of the entire vertical borehole is required to provide better thermal contact between the pipe and ground. The thermal conductivity of the grout material significantly affects the heat transfer performance of the vertical ground loop heat exchanger. The table of grout thermal properties lists the thermal properties of the various grout material (Details can be found in Table 101 in Appendix 3).

4.6.2. Simulation of Base Case Model #2 using Carrier HAP with Ground Source Heat Pump

HAP does not provide a performance model for the ground heat exchanger, so the system configuration cannot be directly modeled. However, using an “Open Loop WSHP” system can approximate performance of this system (Carrier, 2006). An average water temperature for each month must be entered for the “Cooling Tower Properties”. Carrier HAP does not consider design parameters of the ground source heat pump but eQUEST, EnergyPlus, and RETScreen used all necessary design parameters of both ground loop heat exchanger and heat pump.

Figure 59 shows the Carrier HAP input data screen of monthly average soil temperature for ground source heat pump of the selected heat source (ground) of the Toronto location for the Peel Region Headquarters Building.

The image shows a software dialog box titled "Cooling Tower Properties - [Evapco Cooling Tower]". It contains several input fields and a table. The "Name" field is "Evapco Cooling Tower". The "Modeling Method" section has two radio buttons: "Cooling Tower Model" (unselected) and "River, Sea or Well Water" (selected). Below this are four input fields for condenser parameters: "Condenser Water Flow Rate" (41.6 L/s), "Condenser Pump Head" (214.8 kPa), "Condenser Pump Mech. Efficiency" (80.0 %), and "Condenser Pump Elec. Efficiency" (94.0 %). To the right, under the heading "River or Sea Water", is a table with monthly average water temperatures. The table has two columns: "Month" and "Avg. ECWT(°C)". The data is as follows:

Month	Avg. ECWT(°C)
Jan	7.2
Feb	7.2
Mar	7.2
Apr	7.2
May	8.1
Jun	11.8
Jul	14.6
Aug	16.5
Sep	16.3
Oct	14.3
Nov	11.9
Dec	9.2

At the bottom of the dialog are "OK", "Cancel", and "Help" buttons. Below the dialog box, there is a summary bar showing "Avg. ECWT", "Min: = 7.2 (°C)", and "Max: = 35.0 (°C)".

Figure 59: Soil Average Monthly Temperature for Toronto Location (NRCan, 2008)

Table 47 depicts the annual cost summary of HVAC and non-HVAC components of the base case Model #2 with ground source heat pump used in the Carrier HAP simulation.

Table 47: The Annual Cost Summary of the Base Case Model #2 with Ground Source Heat Pump used in the Carrier HAP Simulation

Components	Cost (\$)	Cost (\$/ft ²)	(%)
Air System Fans	962	0.007	0.5
Cooling	12,327	0.086	6.8
Heating	18,309	0.128	10.1
Pumps	9,262	0.065	5.1
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	40,860	0.286	22.5
Lights	43,948	0.308	24.2
Electric Equipment	76,725	0.538	42.3
Misc. Electric	19,938	0.140	11.0
NON-HVAC Sub-Total	140,521	0.985	77.5
Grand Total	181,471	1.272	100.0

Figure 60 shows the percentage energy costs of HVAC and non-HVAC components of ground source heat pump in Carrier HAP simulation programs on the annual basis.

Figure 60: Annual Percentage Component Costs of Base Case Model #2 of Ground Source Heat Pump in Carrier HAP Simulation Programs

4.7. Simulation of Base Case Model #2 using Carrier HAP with Closed Loop Water Source Heat Pump

Closed loop water source heat pumps are connected to a “common condenser” (evaporator) water loop that uses both cooling tower and boiler to maintain the loop temperature within the specified range.

Table 48 provides the annual cost summary of the base case Model #2 with (closed loop) water source heat pump used in the Carrier HAP simulation.

Table 48: The Annual Cost Summary of the Base Case Model #2 used Closed Loop Water Source Heat Pump in Carrier HAP Simulation Program

Components	Cost (\$)	Cost (\$/ft ²)	(%)
Air System Fans	999	0.007	0.5
Cooling	27,296	0.191	12.7
Heating	31,020	0.217	14.4
Pumps	8,499	0.060	3.9
Cooling Tower Fans	6,952	0.049	3.2
HVAC Sub-Total	74,765	0.524	34.7
Lights	43,948	0.308	20.4
Electric Equipment	76,725	0.538	35.6
Misc. Electric	19,938	0.140	9.3
NON-HVAC Sub-Total	140,521	0.985	65.3
Grand Total	215,286	1.508	100.0

Figure 61 shows the annual percentage component costs of base case Model #2 of (closed loop) water source heat pump in the Carrier HAP simulation program.

Figure 61: Annual Percentage Component Costs of Base Case Model #2 of Closed Loop Water Source Heat Pump in Carrier HAP Simulation Programs

4.8. eQUEST Program with Heat Pump Systems

There are three choices for Heat Pump Sources:

- Air Source Heat Pumps
- Ground Source Heat Pump
- Water Source Heat Pump

The water source heat pumps are connected to a “common condenser” (evaporator) water loop that uses both cooling tower and boiler to maintain the loop temperature within the specified range.

Figure 62 : Closed Loop Water Source Heat Pump (Hirsch, 2008)

4.8.1. Simulation of Base Case Model #2 using eQUEST with (Closed Loop) Water Source Heat Pump

Base case Model # 2 in eQUEST is modeled as Model #2 Part 1 and Model #2 Part 2. Model #2 Part 1 is modeled in eQUEST with the above grade floor only and Model #2 Part 2 is modeled with the above and below grade floor.

Table 49 provides the annual electric and natural gas energy and cost summary of HVAC and non HVAC components of the base case Model #2 Part 1 with (closed loop) water source heat pump used in the eQUEST simulation program.

Table 49: The Annual Energy and Cost Summary of the Base Case Model #2 Part 1 Used (Closed Loop) Water Source Heat Pump In eQUEST Simulation Programs

Components	Total Energy (kWh x000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	128.5 kWh		128.5 kWh	
Cooling	230.0 kWh		230.0 kWh	
Pumps and Aux	91.7 kWh		91.7 kWh	
Space Heating	40.8 kWh		40.8 kWh	
Lights	359.5 kWh		359.5 kWh	
Electric Equipment	733.9 kWh		733.9 kWh	
Domestic Hot Water	650.1 MBTU			650.1 MBTU
Space Heating	723.7 MBTU			723.7 MBTU
Grand Total of Electric and Gas Energy			1,597.700 kWh	1,373.8MBTU
Total Electric Energy Costs (\$)		\$ 154,636.00	Total Annual Bill across all rates	\$ 172,579.00
Total Gas Energy Costs (\$)		\$ 17,943.00		

Figure 63 provides the percentage contribution of the annual energy consumption of all HVAC and non-HVAC components of the base case Model #2 Part 1 used (closed loop) water source heat pump.

Figure 63 : Annual Energy Consumption by HVAC and Non-HVAC Components of the Base Case Model #2 Part 1 used (Closed Loop) Water Source Heat Pump in eQUEST

Table 50 provides the annual energy and cost summary across all rates of the base case Model #2 Part 2 with (closed loop) water source heat pump used in the eQUEST simulation program.

Table 50: The Annual Cost Summary of the Base Case Model #2 Part 2 Used (Closed Loop) Water Source Heat Pump In eQUEST Simulation Programs

Components	Total Energy (kWh x 000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	45.41 kWh		45.41 kWh	
Cooling	40.09 kWh		40.09 kWh	
Pumps and Aux	28.66 kWh		28.66 kWh	
Space Heating	30.06 kWh		30.06 kWh	
Lights	146.95 kWh		146.95 kWh	
Electric Equipment	157.68 kWh		157.68 kWh	
Domestic Hot Water	62.65 MBTU			62.65 MBTU
Space Heating	473.66 MBTU			473.66 MBTU
Grand Total of Electric and Gas Energy			450.050 kWh	536.31 MBTU
Total Electric Energy Costs (\$)		\$ 44,465.00	Total Annual Bill across all rates	\$ 51,754.00
Total Gas Energy Costs (\$)		\$ 7,289		

Table 51 provides the annual energy and cost summary of the base case Model #2 (Part 1 and Part 2) with (closed loop) water source heat pump used in the eQUEST simulation program.

Table 51: The Annual Cost Summary of Base Case Model #2 (With Part 1 and Part 2) Used (Closed Loop) Water Source Heat Pump In eQUEST Simulation Programs

Components	Total Energy (kWh x000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	173.91 kWh	\$ 63,522.00	173.91 kWh	
Cooling	270.09 kWh		270.09 kWh	
Pumps and Aux	120.36 kWh		120.36 kWh	
Space Heating	70.86 kWh		70.86 kWh	
Lights	508.45 kWh	\$ 135,579.00	508.45 kWh	
Electric Equipment	891.58 kWh		891.58 kWh	
Domestic Hot Water	712.75 MBTU	\$ 9999.00		712.75 MBTU
Space Heating	1197.36 MBTU	\$ 15,233.00		1197.36 MBTU
Grand Total of Electric and Gas Energy			2,047.750 kWh	1910.11MBTU
Total Electric Energy Costs (\$)		\$199,101.00	Total Annual Bill across all rates	\$ 224,333.00
Total Gas Energy Costs (\$)		\$ 25,232.00		

Figure 64 shows the annual electric and natural gas costs consumption by HVAC and non-HVAC components of Model #2 with (closed loop) water source heat pump used in the eQUEST simulation program.

Figure 64: Annual Electric and Natural Gas Costs Consumption by HVAC and Non-HVAC Components of the Base Case Model #2 used (Closed Loop) Water Source Heat Pump in eQUEST Simulation Program

Figure 65 shows the annual electric and natural gas energy consumption by HVAC and non-HVAC components of base case Model #2 with (closed loop) water source heat pump used in the eQUEST simulation program.

Figure 65: Annual Electric and Natural Gas Energy Consumption by HVAC and Non-HVAC Components of the Base Case Model #2 used (Closed Loop) Water Source Heat Pump in eQUEST Simulation Program

4.8.2. Simulation of Base Case Model #2 using eQUEST Simulation Programs with Ground Source Heat Pump

The ground source heat pumps have some limitations when using the Design Development Wizard:

- Depth bore diameter up to 200 ft, but by using Detailed Interface bore diameter can be changed.
- Only vertical type ground loop heat exchanger is used in the DD Wizard, but in the Detailed Interface user can select different types of heat exchanger.
- User cannot use monthly mean temperature for the entire year; instead, one undisturbed average temperature can be used.

The design parameters are:

1. Pump loop configuration; rectangle (default value 3ft by 5ft)
2. Depth : 200ft
3. Spacing: 20ft
4. Borehole diameter: 6.0in
5. Ground loop heat exchanger type: vertical well field

6. Number of vertical well field: 3 unit (2 unit for Model #2 Part 1 and 1 unit for Model #2 Part 2). {In eQUEST simulation program, one vertical well field has many boreholes placed closely. For more than one identical vertical well field DOE-2 assumes that the identical well fields do not interact with each other. This assumption is only valid when the identical well fields are apart from each other with enough distance. A minimum spacing of 20 ft is recommended (ASHRAE handbook – HVAC Application - 1999) (Hirsch, 2008).
7. Pipe material: there are two pre-defined GLHX pipe material:
  - Polyethylene (thermal conductivity = 0.23 Btu/hr-ft-F)
  - Polybutylene (thermal conductivity = 0.13 Btu/hr-ft-F) or specify; However, the most commonly installed U-tube is made of high density Polyethylene (HDPE).
8. Pipe size: 0.75in.
9. Fluid properties: ethylene glycol (7% solution)
10. Ground temperature adjustment factor: 5°F (calculate via weather data); the sum of ground temperature adjustment factor and the average annual air temperature is used to represent the mean undisturbed ground temperature.
11. GSHP soil thermal properties : (See Table 101 in Appendix 3)
12. Ground description; (Amphibolite, gravel dry, silt, moist/wet, etc)
13. Ground conductivity; (See Table 100 in Appendix 3)
14. Grout description; (See Table 101 in Appendix 3)
15. Grout-conductivity; (See Table 101 in Appendix 3)
16. EER (energy efficiency ratio for cooling): 10.5
17. COP (Coefficient of Performance for heating): 3.8
18. Heat pump unit size: 135 kBTU or 11 tons
19. Cooling design temperature: 75°F (indoor), 55°F (supply)
20. Heating design temperature: 72°F (indoor), 110°F (supply)
21. Loop temperature: MIN = 30°F , MAX = 110°F

Figure 66 shows the ground source heat pump with vertical ground loop heat exchanger.

Figure 66: Ground Source Heat Pump (Vertical Ground Loop Heat Exchanger) (NRCan, 2008)

Figure 67 shows vertical well field with few boreholes placed closely.

Figure 67: Vertical Well Field with Boreholes (NRCan, 2008)

Table 52 provides the annual energy and cost summary of the base case Model #2 Part 1 with ground source heat pump used in the eQUEST simulation program.

Table 52: The Annual Cost Summary of the Base Case Model #2 Part 1 Used Ground Source Heat Pump In eQUEST Simulation Programs

Components	Total Energy (kWh x000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	247.4 kWh		247.4 kWh	
Cooling	185.8 kWh		185.8 kWh	
Pumps and Aux	145.8 kWh		145.8 kWh	
Space Heating	110.8 kWh		110.8 kWh	
Lights	359.5 kWh		359.5 kWh	
Electric Equipment	733.9 kWh		733.9 kWh	
Domestic Hot Water	650.52 MBTU	\$ 8,880.00		650.52 MBTU
Space Heating	0.0 MBTU			0.0 MBTU
Grand Total of Electric and Natural Gas Energy			1,783.2 kWh	650.52 MBTU
Total Electric Energy Costs (\$)		\$ 172,448.00	Total Annual Bill across all rates	\$ 181,341
Total Natural Gas Energy Costs (\$)		\$ 8,880.00		

Figure 68 provides the percentage contribution of the annual energy consumption of all HVAC and non-HVAC components of the base case Model #2 Part 1 used ground source heat pump.

Figure 68 : Annual Energy Consumption by HVAC and Non-HVAC Components of the Base Case Model #2 Part 1 used Ground Source Heat Pump in eQUEST

Table 53 provides the annual energy and cost summary of the base case Model #2 Part 2 with ground source heat pump used in the eQUEST simulation program.

Table 53: The Annual Cost Summary of the Base Case Model #2 Part 2 Used Ground Source Heat Pump In eQUEST Simulation Programs

Components	Total Energy (kWh x000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	45.41 kWh		45.41 kWh	
Cooling	40.30 kWh		40.30 kWh	
Pumps and Aux	33.30 kWh		33.30 kWh	
Space Heating	34.31 kWh		34.31 kWh	
Lights	146.95kWh		146.95kWh	
Electric Equipment	157.68 kWh		157.68 kWh	
Domestic Hot Water	62,653 MBTU	\$ 1,119.00		62,653 MBTU
Grand Total of Electric and Gas Energy			457.960 kWh	62.653 MBTU
Total Electric Energy Costs (\$)		\$ 45,224.00	Total Annual Bill across all rates	\$ 46,343.00
Total Gas Energy Costs (\$)		\$ 1,119.00		

Table 54 provides the annual energy and cost summary of the base case Model #2 (Part 1 and Part 2) with ground source heat pump used in the eQUEST simulation program.

Table 54: The Annual Energy and Cost Summary of Base Case Model #2 (With Part 1 and Part 2) Used Ground Source Heat Pump In eQUEST Simulation Programs

Components	Total Energy (kWh x000)	Cost (\$)	Total Electric Energy (kWh x 000)	Total Gas Energy (MBTU)
Air System Fans	292.81kWh	\$82,105.00	292.81kWh	
Cooling	226.1 kWh		226.1 kWh	
Pumps and Aux	179.1 kWh		179.1 kWh	
Space Heating	145.11 kWh		145.11 kWh	
Lights	508.45 kWh	\$ 135,579.00	508.45 kWh	
Electric Equipment	891.58 kWh		891.58 kWh	
Domestic Hot Water	712.75 MBTU	\$ 9999.00		712.75 MBTU
Grand Total of Electric and Gas Energy			2,243.15kWh	712.75 MBTU
Total Electric Energy Costs (\$)		\$217,672.00	Total Annual Bill across all rates	\$ 227,684.00
Total Gas Energy Costs (\$)		\$ 9999.00		

Figure 69 shows the annual electric and natural gas energy consumption by HVAC and non-HVAC components of base case Model #2 with ground source heat pump used in the eQUEST simulation program.

Figure 69 : Annual Electric and Natural Gas Energy Consumption by HVAC and Non-HVAC Components of the Base Case Model #2 used Ground Source Heat Pump in eQUEST

Figure 70 shows the annual electric and natural gas costs consumption by HVAC and non-HVAC components of base case Model #2 with ground source heat pump used in the eQUEST simulation program.

Figure 70: Annual Electric and Natural Gas Costs Consumption by HVAC and Non-HVAC Components of the Base Case Model #2 used Ground Source Heat Pump in eQUEST

4.9. Energy and Cost Analysis of the Base Case Model #2 using Three Types of Heat Pumps

The energy and cost comparison of Open Loop Water Source Heat Pump, Closed Loop Water Source Heat Pump and Ground Source Heat Pump is based on base case Model #2 (i.e., 1-Fan Variable Air Volume System) using the Carrier HAP and eQUEST simulation programs.

Table 55 shows the comparisons of energy and cost analysis of the Peel Region Headquarters Building based on the base case Model #2 used in the two simulation programs with three types of heat pump, namely, open loop water source heat pump, closed loop water source heat pump, and ground source heat pump. The results show that the total annual cost of the open loop water source heat pump is the least of the three. Thus, the open loop water source heat pump is an energy efficient HVAC system.

Table 55: Comparisons between three Types of Heat Pumps

Types of Heat Pump	HVAC Electric Costs (\$)	HVAC Natural Gas Costs (\$)	Total HVAC Costs (\$)
Open Loop Water Source Heat Pump (Carrier HAP)	42,929	0	42,929
Closed Loop Water Source Heat Pump (Carrier HAP)	58,606	16,159	74,765
Closed Loop Water Source Heat Pump (eQUEST)	63,522	15,233	78,754
Ground Source Heat Pump (eQUEST)	82,105	0	82,105

Figure 71 shows the comparisons of annual HVAC energy costs between the three types of heat pump (open loop water source heat pump, closed loop water source heat pump and ground source heat pump) based on base case Model #2 using Carrier HAP and eQUEST simulation programs.

Figure 71: Comparisons of Annual Energy Costs of Different Types of Heat Pumps Using Carrier HAP and eQUEST Simulation Programs

Figure 72 shows the comparisons of the annual electric and natural gas energy costs of the three types of heat pump used in eQUEST and Carrier HAP simulation programs.

Figure 72: Comparisons of Annual Energy Costs of Three Types of Heat Pump used in eQUEST and Carrier HAP Simulation Programs

4.10. Overview of “RETScreen” Program

The renewable energy technology “RETScreen” is public domain software. The RETScreen software main tools are:

- The Energy Model (the user defined parameters describing the type of system used in the base case).
- Greenhouse Gas (GHG) Emission Reduction Analysis (helps to determine the annual reduction in the emission of greenhouse gases).
- The Financial analysis (the user specifies financial parameters then RETScreen evaluate the viability of the project).
- The Sensitivity and Risk Analysis (assists the user to determine the various key parameters which may affect the financial viability of the project).

RETScreen International’s main renewable energy heating and cooling technologies include the following:

1. Ground Source Heat Pump
2. Solar Water Heating
3. Solar Air Heating
4. Passive Solar Heating

The main feature of the RETScreen is the comparison between a “Base Case” using the conventional technology with a “Proposed Case” using the clean energy technology. RETScreen includes a system that extracts heat from the ground or provides cooling by rejecting heat to the ground. This software is using a clean energy technology i.e., heat pump in place of a conventional HVAC system and estimates the reduction in greenhouse gas emissions and energy cost analysis.

Despite the higher initial costs of the heat pump, it is the most cost effective system compared with conventional HVAC System on a lifecycles cost analysis basis.

Ground source heat pumps (GSHP) system consists of:

- earth connection
- heat pump
- and the heating or cooling distribution system

Due to the stable, moderate temperature of the ground, GSHP systems are more efficient than air source heat pumps. Heat pump capacity ranges from 1 to 20 tons. For house or small building, this range is enough for cooling requirement, but for large commercial building multiple heat pumps, i.e., one heat pump for each zone, is required. Worldwide, 800,000 heat pumps have been installed with approximate 10,000 MW of thermal capacity or 843,000 tons of cooling (Lund, 2008; NRCan, 2008). RETScreen International Weather Database includes ground-based meteorological data and NASA's satellite-derived meteorological data sets for over 4700 sites around the world. Over 20 different sources were used to compile the database.

RETScreen

Country

Canada

Province / State

Ontario

Climate data location

Toronto Int'l Airport

Latitude

°N

43.7

Source

Longitude

°E

-79.6

Source

Elevation

m

173.0

Ground

Heating design temperature

°C

-16.7

Ground

Cooling design temperature

°C

28.9

Ground

Earth temperature amplitude

°C

21.4

NASA

	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
Jan	-5.8	77.0%	1.88	98.7	5.0	-7.7	738	0
Feb	-5.0	74.9%	2.28	98.8	4.6	-5.9	644	0
Mar	-0.2	71.8%	3.60	98.7	4.8	-0.3	564	0
Apr	6.4	66.3%	4.90	98.5	4.8	7.4	348	0
May	13.2	66.3%	5.36	98.6	4.0	13.8	149	99
Jun	18.2	68.4%	5.82	98.6	3.7	18.8	0	246
Jul	21.1	68.0%	6.18	98.6	3.5	20.9	0	344
Aug	20.1	72.2%	5.28	98.8	3.2	19.5	0	313
Sep	15.5	74.9%	3.90	98.8	3.5	15.1	75	165
Oct	9.0	76.0%	2.50	98.8	3.8	8.8	279	0
Nov	3.4	78.3%	1.28	98.7	4.4	2.8	438	0
Dec	-2.5	78.9%	1.18	98.7	4.5	-4.2	636	0
Annual	7.9	72.7%	3.67	98.7	4.1	7.5	3,870	1,167
Source	Ground	Ground	Ground	NASA	Ground	NASA	Ground	Ground
Measured at				m	10	0		

Figure 73: The Integrated Weather Database (NRCan, 2008)

The most significant sources were:

1. Environment Canada, Canadian Climate Normal, Ministry of Supply and Services Canada;
2. Environment Canada, Canadian Renewable Energy Wind and Solar Resource, Ministry of Supply and Services Canada;
3. National Climatic Data Center and National Renewable Energy laboratory;
4. World Meteorological Organization;

Earth energy is available in massive quantities because the earth absorbs 46% of the sun's energy. This huge energy can be used to heat and cool buildings with a comfortable temperature (24°C for cooling and 22°C for heating) over the entire year.

Ground temperature changes slowly depending on the depth and, due to low thermal conductivity of the soil, some heat can transfer from the cooling season to the heating season. Overall temperature variation in soil is negligible in comparison with the air temperature.

Figure 74 shows the typical average monthly temperature and typical soil temperature variation in Canada (NRCan, 2008).

Figure 74: Typical Average Monthly Temperature and Typical Soil Temperature Variation in Canada (NRCan, 2008)

A flowchart of the GSHP systems in RETScreen describes the different processes. The model initially establishes the building load equation, which describes how building loads vary as a function of outside temperature. It then calculates the load for each temperature bin. Balance point temperatures are calculated using the building load equation to determine whether or not heating or cooling is required for each bin. The

required heat pump capacity is estimated using both the weather data and the building load. It will enable the sizing of the ground loop or the ground water flow. Then actual heat pump performance and capacity can be calculated for each bin. The final results from the model consists of the annual electrical energy use of the heat pump system, the heating and cooling energy delivered, the system efficiencies and any auxiliary heating energy requirements.

Figure 75 depicts the different processes of the ground source heat pump (GSHP) used in RETScreen.

Figure 75: Ground Source Heat Pump Energy Model Flow Chart (NRCan, 2008)

Limitation of GSHP Project Model in RETScreen:

1. The model cannot capture heating and cooling demands.
2. The model cannot capture complex buildings usage profiles.
3. The long-term thermal imbalances are not included in the ground heat exchanger calculations.
4. The building heating and cooling energy consumption and peak loads are evaluated using a simplified version of ASHRAE's modified bin method (ASHRAE, 1985). The interior set point temperature is considered constant at 23°C and remains the same for both heating and cooling (NRCAN, 2008).

Despite these limitations, the pre-feasibility and feasibility analysis are sufficiently accurate.

The building's calculation in the RETScreen GSHP Project Model is using modified bin method, because International Ground Source Heat Pump Association's (IGSHPA) also uses this method (NRCAN, 2008).

The RETScreen GSHP Project Model includes an hourly weather data generator. This generator is based on correlations between measured hourly weather data and their design temperatures and latitude (ASHRAE, 1997; NRCAN, 2008).

The RETScreen GSHP Project Model uses two building load calculation method:

- The descriptive data method for new building
- The energy use method for old building.

The descriptive data method works on the assumption that the building is still under construction and no heating and cooling load has been defined. For this application, RETScreen uses the input area of the building as a reference, determines the heating and cooling load and thus calculates the building energy consumption accordingly. The software behaves differently if the building is existing. In this case, it uses the energy use method and calculates the energy consumption based on the prevalent heating and cooling loads.

For Peel Region Headquarters Building, the energy use method is used for load calculation of the heat pump.

4.10.1. Ground Source Heat Pump (Closed Loop Systems)

Table 56 shows the Peel Region Headquarters Building usage data and design temperature of the heating and cooling load used for the base case model in RETScreen software. The weather database is obtained from the ground-based meteorological data and NASA's satellite-derived meteorological data sets (Detailed can be seen in Figure 73).

Table 56: Building and Design Values used in RETScreen Software

Building and design values				
Building type:	Commercial Office Building			
Location:	10 Peel Centre Drive, Brampton, ON			
Year of Construction:	1978			
Number of Storey:	7 + one below grade			
Heated floor area (m ²)	13260			
% of total floor area (%):	100			
Design outdoor temperature(°C)	Heating:	-16.7	Cooling:	28.9
Design indoor temperature (°C)	Heating:	20	Cooling:	24
Degree days	Heating:	3870	Cooling:	1167
Annual earth temperature	7.5°C			

Table 57 shows the design heating and cooling load of the base case Model #1 of the Peel Region Headquarters Building used in RETScreen software to create user defined base model. Design heating and cooling load data are obtained from the base case Model # 1 (Detailed can be seen in Table 14 and 16).

Table 57: Heating and Cooling Load of the Base Case Model # 2 used in RETScreen Software

Heating and Cooling	
Application:	Space Heating and Cooling
Space heating supply and return temperature	Heating: 60°C /45°C
Space cooling supply and return temperature	Cooling: 7°C /12°C
Fuel Consumption Annual (Gas)	Gas (for base case building) = 139,836m ³ = 1456 MWh
Fuel Consumption Annual (Electric)	Electric (for base case building) 526 MWh
Design Load: Heating load for building	Total = 635.2 kW or 49.7 W/m ²
Design Load: Cooling load for building	Total = 986.5 kW or 74.4 W/m ²

Table 58 shows the heating and cooling load of the proposed model with the ground source heat pump system calculated by RETScreen software.

Table 58: Heating and Cooling Load of the Proposed Model Calculated by RETScreen Software

Heating and Cooling Load		
Application:	Space Heating and Cooling	
Heat pump types	Ground Source Heat Pump	
Auxiliary system	Electric resistance heater	
Distribution system	VAV diffuser or terminal unit	
Fuel:	Electric (for proposed case building)	
Heat pump design criteria	100% cooling load	80% heating load
Input : Fuel Consumption Annual	For Heating, Electric (for proposed case building) = 560 MWh	
Input: Fuel Consumption Annual	For Cooling, Electric (for proposed case building) = 385 MWh	
Heating energy delivered	Output: 1456 MWh	
Cooling energy delivered	Output: 1579 MWh	

Table 59 shows the greenhouse gas emission for the base case model and proposed models calculated by RETScreen software.

Table 59: Analysis of Greenhouse Gas Emission for the Base and Proposed Models

Greenhouse Gas Emission for the Base and Proposed Models	
Natural Gas	GHG Emission Factor = 0.174 tCO ₂ / MWh
Electricity	GHG Emission Factor = 0.223 tCO ₂ / MWh
GHG emission for the base case system	253.34 + 117.29 = 370.63 tCO ₂
GHG emission for the proposed case system	210.735 tCO ₂
Net annual GHG emission reduction	370.63– 210.735 = 159.9 tCO ₂
Net GHG Emission Reduction – 25 years	159.9* 25 = 3997.37 tCO ₂
GHG reduction cost	\$15 / tCO ₂
Net annual GHG emission reduction is equivalent to 30 cars and light trucks not used	

Figure 76 shows heating and cooling load characteristics of the ground source heat pump of the base case model defined in RETScreen software.

Figure 76: Base Case System Load Characteristics Graph defined in RETScreen Software

Table 60 shows the energy and cost of the ground source heat pump of the proposed model used in RETScreen software.

Table 60: Performance of the Ground Source Heat Pump of the Proposed Model in RETScreen

Performance of the Heat Pump			
System	Energy input	Energy output	Cost
Cooling and Heating Load	945 MWh	3035 MWh	\$ 80,345

Figure 77 shows cumulative cash flows of the ground source heat pump of the proposed model used in RETScreen. The equity payback period is 9.6 years.

Figure 77: Cumulative Cash Flows Graph of Ground Source Heat Pump

Table 61 shows the financial feasibility report of the ground source heat pump of the proposed model used in RETScreen.

Table 61: Financial Feasibility Report of the Ground Source Heat Pump

Financial Feasibility Report Project costs and savings / income summary	
Heating System	\$ 31,758
Cooling System	\$ 49,350
Ground Loop Heat Exchanger	\$ 249,602
Total initial costs	\$ 330,710
Heat Pump (Compressor) 20 years	\$ 20,000
Fuel cost proposed case	\$ 80,345
Fuel cost-base case	\$ 111,166
Net Present Value(NPV)	\$ 38,743
Equity Payback	9.6 years

5. Energy Code Compliance Analysis

The Energy-efficient buildings improve the lives of Canadians by saving consumers money, lessening our demand for fossil fuels, decreasing the need for new power generation, and reducing environmental emissions. Energy Codes Compliance Program is an information resource work with other national code organizations to promote stronger building energy codes. Building energy codes increases the energy and cost savings in new construction and renovations to existing buildings.

Energy Code Compliance ASHRAE 90.1 (2004), and MNECB/CBIP, are used for the Peel Region Headquarters Building.

5.1. ASHRAE 90.1 (2004)

ASHRAE Standard 90.1 (2004) is used to provide minimum requirements for the energy-efficiency design of only Middle and High-Rise Building.

ASHRAE Standard provides the following minimum energy efficiency requirements for the design and construction:

- New buildings and their systems
- New systems and equipment in existing buildings

ASHRAE Standard is applied to:

Building Envelope:

- Spaces that are heated by a heating system whose output capacity is greater than or equal to 3.4 Btu/hr-ft² or
- Cooled by a cooling system whose sensible output capacity is greater than or equal to 5 Btu/hr-ft²

Systems and Equipments:

1. Heating, ventilating and air conditioning system
2. Domestic water system
3. Lightings etc

This standard does not apply:

- Single-family houses, multi-family structures of three stories or few above grade
- Buildings that do not use either electricity or fossil fuel

5.1.1. Types of Compliance Path

For the appropriate climate, space conditioning category, and class of construction, the building envelope shall comply with three types of compliance path.

1. Mandatory Path
2. Prescriptive Path
3. Performance or Building Envelope Trade-Off Option

The Energy Cost Budget Method must comply with the mandatory compliance path.

The mandatory provisions are the followings:

- Insulation
- Fenestration and Doors
- Air Leakage
- Vestibules

5.1.2. Prescriptive Path

The exterior building envelope shall comply with the either “nonresidential” or “residential” requirements.

Building Envelope:

1. Climate Zone: Table 103 (B-2) in Appendix 4 is used to determine the required climate zone location and number in Canada and Table 103 (B-4) in Appendix 4 is used to determine the climate zone letter. For Toronto location, the climate zone is 6A (ASHRAE, 2004).

All opaque surfaces except door:

Compliance is using two methods:

2. Minimum rated R-values of insulations for the thermal resistance of the added insulation in framing cavities and continuous insulation only.
3. Maximum U-factor, C-factor, or F-factor for the entire assembly:
  - a. Roof Insulation Above Grade Wall Insulation
  - b. Below Grade Wall Insulation
  - c. Floor Insulation
  - d. Slab on Grade Floor Insulation (heated or unheated)
  - e. All opaque doors shall have a U-factor no greater than the values specified in Table 104 in Appendix 4.

Fenestration:

Compliance with U-factors and solar heat gain coefficient (SHGC) is used for overall fenestration product. (All insulation values are specified in Table 104 in Appendix 4). The total vertical fenestration area shall be less than 50% of the gross wall area and total skylight area shall be less than 5% of the gross roof area.

Lightings:

There are two compliance paths:

- Building Area Method
- Space-by-Space Method

The space-by-space method is a more flexible compliance approach than building area method. To determine the total lighting power of the specified space, use the lighting power densities of the designated space from the Table 107 in Appendix 4, and multiply the total area of the space to give the total lighting power of the space.

HVAC System:

There are three compliance paths:

- Simplified Approach Option for HVAC Systems
- Mandatory Provisions
- Prescriptive Path

The simplified approach is used when gross floor area is less than 25,000 ft². Mandatory compliance path is used when any new systems or equipment is installed in

the existing or new building. Prescriptive path is used for economizers, heat pumps, dehumidification, and humidification systems. It also includes the air system design and control. All values are listed in the Table 105 and 106 in Appendix 4.

Service Water:

Existing service water heating systems and equipment is not required to comply with this standard. However, any new system or equipment installed must comply with the standard. All values are listed in the Table 106 in Appendix 4.

5.1.3. Performance Rating Method for Calculating Proposed and Baseline Building Performance

The performance rating method requires that conformance with all above stated requirements is met. The improved performance of the proposed building design is calculated by the following formula:

$$100 \times \frac{(\text{Baseline building performance} - \text{Proposed building performance})}{\text{Baseline building performance}} \quad (\text{Equation 1})$$

The proposed building performance and the baseline building performance are calculated using the:

- Same simulation programs
- Same weather data, and
- Same energy rates

Following are the modeling requirements for calculating proposed and baseline building performance.

- **Equipment Capacities:** The equipment capacities for the baseline building design shall be oversized by 15% for cooling and 25% for heating.
- **Unmet Load Hours:** Unmet load hours for the proposed design or baseline building design shall not be exceed 300 hours (of the 8760 hours simulated), and unmet load hours for the proposed design shall not exceed the number of unmet load hours for the baseline building design by more than 50 hours.

- Sizing Runs: Weather condition used in sizing runs to determine baseline equipment capacities is based on 99.6% heating design temperatures and 1% wet bulb temperature for cooling.

Fan System Operation: Supply and return fans shall operate continuously either space is occupied or unoccupied.

Baseline HVAC System: Compliance is used System #7 (VAV-With Reheat) for nonresidential and more than 5 floors or greater than 150,000 ft². (Fuel types are Fossil Fuel, Electric and Purchased Heat). The HVAC system types are chilled water and hot water fossil fuel boiler. (See Table 105 for System #7 in Appendix 4)

Economizers: Outdoor air economizers shall be included in baseline HVAC System #7.

Economizer High-Limit Shutoff: System #7 Economizer high-limit shutoff is set at 70°F.

Baseline Fan Brake Horsepower: Baseline fan brake horsepower for system #7 is based on supply air volume. If it is greater than or equal to 20,000 CFM, then baseline fan brake horsepower is calculated by the following formula;

$$\text{BHP} = 24 + (\text{CFM} - 20000) \times 0.001125 \quad (\text{Equation 2})$$

In addition, the electrical power to fan motor (watts) is calculated by the following formula:

$$P_{\text{fan}} = \frac{746}{(1 - e^{[-0.2437839 \times \ln(\text{bhp}) - 1.685541]})} (\text{bhp}) \quad (\text{Equation 3})$$

Type and number of boilers: If the baseline building conditioned floor area is more than 15,000 ft², then two equally sized boilers is used for the System #7.

Hot Water Supply Temperature: Supply Temperature = 180°F and Return Temperature = 130°F.

Hot Water Pumps: Hot water pump power = 19 W/GPM.

Types and Number of Chillers: The building conditioned floor area is greater than 120,000 ft² and less than 240,000 ft² shall be used two screw chillers sized equally.

Chilled Water Design Supply Temperature: Supply Temperature = 44°F and Return Temperature = 56°F.

Chilled Water Pumps: Chilled water pump power = 22 W/GPM.

Heat Rejection (Cooling Tower): Condenser water pump power = 19 W/GPM, an axial fan cooling tower with two-speed fan, and condenser water design Supply Temperature = 85°F or 10°F approach to design wet-bulb temperature.

Supply Air Temperature Reset: Design airflow rates shall be sized for the reset supply air temperature.

Temperature difference for the minimum load conditions = 10°F.

Fan Power (VAV Fan Power Boxes): Design flow rate = 0.35W/CFM

Minimum volume set points is equal to 30% of peak design flow rate required to meet the minimum outdoor air ventilation requirement.

5.2. MNECB / CBIP Energy Code Compliance Analysis

The Model National Energy Code for building (MNECB) is used to provide minimum requirements for the energy-efficiency design of only middle and high-rise buildings. Energy efficiency in small residential buildings and houses used Model National Energy Code for Houses (MNECH) (NRCan, 2008).

The MNECB is mainly concerned environmental protection and resource conservation issues and it takes into account climate, fuel types and costs, and construction costs. It does not take into consideration of secondary effects such as the reduction of the size of heating and cooling equipment due to improvements in the building envelope.

The MNECB standard provides the minimum energy efficiency requirements for the design and construction of new buildings and their systems. It may be suitable for application to the alteration or renovation of new systems and equipment in existing (old) buildings (NRCan, 2008).

Simulations are performed for comparing the proposed and reference building to determine the percentage deviations from the MNECB prescriptive requirements.

5.2.1. Compliance Paths

There are two compliance paths:

- Prescriptive Path:
- Performance Path:

The first step in the compliance path is the MNECB Mandatory requirement that cover the following parameters:

- Building envelope (cover the thermal resistance and air tightness of the building structure)
- Lighting (minimum energy requirement)
- HVAC systems (cover the control system and characteristics of the heating and cooling system)
- Service water heating systems (cover the control system and characteristics of the heating and cooling system)
- Electrical components

As per MNECB minimum requirements, the energy consumption of the proposed building (new building) must be at least 25% more energy efficient than a MNECB reference building and the existing building (means old building) must be 10% more energy efficient than a MNECB reference building (NRCan, 2008).

Figure 78 shows rules and compliance procedure requirements used in the MNECB compliance path.

Figure 78: MNECB / CBIP Compliance Paths

5.2.2. MNECB Prescriptive Path

The MNECB reference building will be insulated to the MNECB prescriptive levels as mentioned in Table 111 in Appendix 4) and applicable to the climatic region and fuel type.

Administrative Region and Climate Data: The climate zone and design data required by the code for the location in which the building (proposed design) to be constructed as given in Figure 79. For Toronto, the climate zone is A with less than 5000 heating degree-days. Canadian Weather Energy Calculations (CWECC) provides this climate data. The climate data is used for the performance analysis of both the reference and proposed case. MNECB shall not permit any other climate data to be used for compliance analysis (NRCAN, 2008)

Figure 79: MNECB Administrative Regions (NRCAN, 2008)

Table 62 shows MNECB administrative regions such that Province/Territory and representative weather station.

Table 62: MNECB Administrative Regions

Province/ Territory	Administrative Region	Identification	Representative Weather Station
Newfoundland	A	Island, except Northern Peninsula	A & B: St John's C & D: Goose Bay
	B	Northern Peninsula & Labrador Coast	
	C	Goose Bay/Happy Valley	
	D	Western Labrador	
Prince Edward Island	A	Prince Edward Island	Charlottetown
Nova Scotia	A	Nova Scotia	Halifax
New Brunswick	A	New Brunswick	Fredoncton
Quebec	A	Existing Zone A*	A: Montréal (Dorval)
	B	Existing Zones B*, C* and D*	B: Bagotville
	C	Existing Zone E* and F*	C: Schefferville
Ontario	A	< 5000 Degree-days	A: Toronto
	B	≥ 5000 Degree-days	B: Thunder Bay
Manitoba	A	South of the 53 rd Parallel (< 6500 Degree-days approximately)	A: Winnipeg
	B	At or North of the 53 rd Parallel	B: Thompson
Saskatchewan	A	Saskatchewan	Saskatoon
Alberta	A	Calgary, Lethbridge	A: Calgary
	B	Red Deer, Edmonton, Grand Prairie	B: Edmonton Int'l
	C	Fort McMurray	C: Fort McMurray

Building Assemblies in Contact with the Ground and Above Ground: The orientation must be greater than 60° from horizontal (no default input). The thickness and material of the layers for the walls, roof, and floor can be selected from Table 111 in Appendix 4. When a wall, roof, floor is “existing,” then compliance restrict the input to prevent use of thermal transmittance greater than 167% of that permitted in compliance code.

Return Air Plenum: The compliance can accept an optional input to indicate that the space beneath the roof is a return air plenum. The default is to consider the heat transfer through the roof to be to the room space.

When input for a return air plenum is provided then compliance performs the energy analysis as follows:

- All return air from the space (thermal block) passes through the plenum;
- The heat from the light that does not go to the space is added to the air in the plenum;
- Roof transmission gain/loss is to the plenum;

Heat transfer between the space and the plenum is through a surface having an area equal to the roof area and a thermal transmittance of 1.8 W/m-K (NRCAN, 2008).

The absorptance of exterior surface of the floor is fixed at a value of zero, no input shall be permitted. The MNECB default Absorptivity value for walls and roof is fixed at 0.90 (NRCAN, 2008).

The following are the input required by the compliance: the area of the window; the overall thermal coefficient (U); and the solar heat gain coefficient (SHGC). The window type and related U and SHGC values are obtained from the Table 111 (Table 3.3.1.2.B) in Appendix 4. Window solar heat gain coefficient is fixed at a reference value of 0.65. A credit is offered if the proposed building glazing has a SHGC less than 0.65 and the comparison check box is checked.

Air Leakage (Infiltration) (No credit): For exterior walls, compliance use air leakage with a constant value of 0.25 litre/s-m² of the gross wall area.

Thermal mass (thermal response characteristics) for each thermal block is either defined or taken a default value as “medium weight” (See Tables 25 and 26 of Chapter 26 of the ASHRAE 1993 Handbook-Fundamentals).

If the proposed skylight to roof ratio is less than 2%, both buildings have the same ratio. If the proposed skylight to roof ratio is greater than 2% and the window to wall ratio is greater than 40%, then the reference building is fixed at 2% and the resultant increased reference roof area will be insulated to MNECB RSI-values for that roof type.

Space Use Classification: The compliance shall permit the user to choose space according to building type or space functions. If the thermal block is directly conditioned, input for space, use is according to the basis for space use classification and if it is indirectly conditioned, then the compliance will not accept input for space use classification.

If the classification is "Building Type" then input is selected from the list of building type categories given in Table 63.

Table 63: Building Type Categories and their Minimum Compliance Data

Building Type	Occupant Density (m ² /person)	Receptacle Power (W/m ²)	Service Water Heating (W-person)	Minimum O.A. (L/s/m ²)	Operating Schedule (Table 4.3.2.C.)	Lighting Power Density (W/m ²)
	(1)	(2)	(3)	(4)	(5)	(6)
Office	25	7.5	90	0.4	A	18
Restaurant	10	1	115	1.25	B	15
Retail	30	2.5	40	1.0	C	30
Mall/Concourse/Atria	30	2.5	40	1.0	C	16
School	8	5	60	1.0	D	19
Service Establishment	30	2.5	80	1.0	C	22
Warehouse	1 500	1	300	0.25	E	6
Hotel/motel	25	2.5	500	0.60	F	15
Multifamily Residential	60	5	500	0.30	G	9

If the classification is "Space function type" then input is selected from the list of "Space function" categories given in Table 110 in Appendix 4.

If the space use classification for a thermal block is selected as "Combined," then compliance allows choosing up to four selections from the list of Space Functions categories given in Tables 110 in Appendix 4. Any portions of the building containing unconditioned spaces that have no or little impact on building energy use can be ignored.

Heat Gain Due to Occupants: A uniform value of 75 watts per occupant for sensible heat gain and 55 watts per occupant for latent heat gain are used for all building types and all space function types.

Minimum Outdoor Air: This is an optional input. The default value is obtained from the space use classification tables (See Table 110 in Appendix 4).

HVAC Equipment Efficiency: A Credit is available for HVAC equipment with higher efficiency than stipulated in the MNECB.

Table 64 gives reference HVAC equipment used in the MNECB compliance path.

Table 64 : Reference HVAC Equipment (Chiller)

Reference HVAC Equipment (chiller)		
Cooling Capacity	Reference Chiller Type	Reference Chiller COP
Less than 700 kW	Reciprocating	3.8
700-2100 kW	Centrifugal	5.2
Greater than 2100kW	Centrifugal (2 chillers)	5.2

Boilers, heaters and burners will have reference thermal efficiency of 80%; therefore, a credit is given for specifying a higher thermal efficiency. The proposed building design oversize boilers and chillers to a limit of 130% of the calculated reference building load. Ventilation equipment air handling capacities are allowed to be oversized by 20% overall for the heated air space. All reference building systems use enthalpy controlled economizers. If proposed building does not have economizer on air handling equipment then there may a potential penalty.

Multi-stage Burners, Chillers: A credit is given to the smaller multistage firing boilers of equal capacity with the same thermal efficiency. Similarly, if the chiller capacity is broken up into smaller virtual chillers up to a maximum of 10 per physical chiller and chillers are sequenced a 90% sequencing ratio. A credit is given for variable speed drives on pumps and cooling tower fans, because the reference systems have constant speed pumps and fans. However, there is no credit for multi-speed pumps/fans. The MNECB default value for the cooling tower pump head is equal to 180kPa and efficiency of 70%. A Credit is given if the total connected lighting power density is lower than MNECB levels. A Credit is given for domestic hot water heat recovery systems. Pump default value is used to a heated water supply temperature of 60°C and a chilled water supply temperature of 7.3°C. If the air handling system is based on outdoor air reset, then thermal efficiency of the heating device can be increased by 1.5% for locations of less than 5000 heating degree-days and 2.0% for locations of 5000 and greater heating degree-days.

5.2.3. System Air Flow Rates and Fans

MNECB/CBIP assumes balanced air flows in each zone and for each system. Total system supply airflow is equal to the sum of system return airflow and Zone exhaust flow.

Total exhaust fan flow rate cannot be greater than the total outdoor airflow rate to the building. For most buildings, the required ventilation rate is determined in accordance with ASHRAE 62-1999. If the total building ventilation rate for the design exceeds the 20% tolerance on a space-by-space basis, the reference-building rate must be adjusted. The ventilation rate for reference building is set to the MNECB Code, whereas the proposed building ventilation rate must be equal to the design outdoor airflows on the system level and the occupancy level.

Figure 80 shows air handling system and exhaust fan flow diagram.

Figure 80: MNECB System Air Flow Rates and Fans (NRCAN, 2008)

Outdoor air will be calculated by:

$$OA = \frac{(ACH \times 1000 \times V)}{3600} \quad (\text{Equation 4})$$

Where

OA = outdoor air flow rate (L/s)

V = heated volume of the specific space (m³)

ACH = air change per hour

Supply Airflow Rate: MNECB supply airflow rate for the reference building under both heating and cooling load must be equal to 2 L/ s-m².

Supply Fans (VAV system only): MNECB supply fan must have VAV system. It must have pressure value of 1000Pa static, and 55% combined motor/impeller efficiency. The return fan must have pressure value of 250Pa static and 30% combined motor/impeller efficiency. The supply and return fan must be draw-thru type.

Thermostat-Set-Points: The MNECB thermostats set points are used for both the proposed and reference building. The temperature set point throttling set points must be equal to 1°C.

Each space of the proposed building that contains exterior walls is modeled with air leakage (infiltration) set to a constant value of 0.25 L/(s-m²) or 0.05 cfm/ft² of gross wall area.

Terminal Fan Systems: The compliance shell shall provide a means of indicating the presence of terminal fans for each thermal block. The default is no terminal fans.

Building Schedules: The MNECB/CBIP building schedule for office building is used for proposed and reference building. The default schedule is listed in Table 112 in Appendix 4.

5.2.4. MNECB Minimum Requirements for Reference Building with Principal Heating Source (Gas Boiler) of Region A (Toronto)

Tables 65 to 70 present the comparison between MNECB minimum requirement for the reference building with principle heating source (gas boiler) with the proposed (base case) building. Table 65 shows MNECB minimum requirements for “construction type” used in the MNECB reference building (Region A: Toronto).

Table 65: MNECB Minimum Requirements for Construction Type of Reference Building

MNECB Minimum Requirements for Construction Type with Principal Heating Source (Gas Boiler)	
Construction Type	U-Value W / m ² -°C
Exposed Walls	0.550
Exposed Roof	0.470
Exposed Floor	0.470
Windows	2.40
Overall Shading Coefficient of Windows	1.15SHGC , where SHGC= 0.65
Absorptivity(walls and roof)	0.90

Table 66 shows MNECB minimum requirements for “building use data” used in the MNECB reference building (Region A: Toronto).

Table 66: MNECB Minimum Requirements for Building Use Data of Reference Building

MNECB Minimum Requirements for Building use Data	
Occupancy (m ² /person)	25
Lighting (W / m ²)	18 W / m ² and Ballast Multiplier = 1.08
Equipments (W / m ²)	7.50
Cooling (occupied) = 24 °C	Cooling (unoccupied) = 35°C
Heating (occupied) = 22°C	Heating (unoccupied) = 18°C

Table 67 shows MNECB minimum requirements for “HVAC system” used in the MNECB reference building (Region A: Toronto).

Table 67: MNECB Minimum Requirements for HVAC System of Reference Building

MNECB Minimum Requirements for HVAC System	
Heating Equipment	Gas Boiler Efficiency 80%
Cooling Equipment	Electric Chiller COP = 5.2
Cooling Tower	Pump Constant Speed, Head= 180 KPa, Efficiency = 70%
Supply Fan	Forward Curved Draw through, 1000Pa, 55% combined motor impeller efficiency
Return Fan	Forward Curved Draw through, 250Pa, 30% combined motor impeller efficiency
Heating Supply Temperature	43°C
Cooling Supply Temperature	13°C
Minimum OA	0.40 L / s-m ²
Supply Airflow Rate	2.0 L / s-m ²
Summer Design Day Temperature	29 °C
Winter Design Day Temperature	-17 °C
Economizer	Integrated Enthalpy Economizer Operational at all times
Air System	VAV Air Handling Unit with Terminal VAV Box

Table 68 show data requirements for “construction type” used in the MNECB proposed (base case) building.

Table 68: Data Requirements for Construction Type of Proposed (Base Case) Building

Data Requirements for Construction Type	
Construction Type	U-Value W / m ² -°C
Exposed Walls	0.520 and 0.562
Exposed Roof	0.227
Exposed Floor	0.227
Windows	2.452 and 3.072
Overall Shading Coefficient of Windows	0.311 and 0.344
Absorptivity(walls and roof)	0.90

Table 69 shows data requirements for “building use data” used in the MNECB proposed (base case) building.

Table 69: Data Requirements for Building Use Data of Proposed (Base Case) Building

Data Requirements for Building use Data	
Occupancy(m ² /person)	See Table #4
Lighting (W / m ²)	See Table #4
Equipments (W / m ²)	See Table #4
Cooling (occupied) = 24 °C	Cooling (unoccupied) = 35°C
Heating (occupied) = 22°C	Heating (unoccupied) = 18°C
Ballast Multiplier	1.08

Table 70 shows data requirements for “HVAC system” used in the MNECB proposed (base case) building.

Table 70: Data Requirements for HVAC System of Proposed (Base Case) Building

Data Requirements for HVAC System	
Heating Equipment	Gas Boiler Efficiency 80%
Cooling Equipment	Electric Chiller COP = 5.2
Cooling Tower	Pump Constant Speed, Head= 180 KPa, Efficiency = 70%
Supply Fan	Forward Curved Draw through, 1000Pa, 55% combined motor impeller efficiency
Return Fan	Forward Curved Draw through, 250Pa, 30% combined motor impeller efficiency
Heating Supply Temperature	43 ⁰ C
Cooling Supply Temperature	13 ⁰ C
Minimum OA	0.40 L / s-m ²
Supply Airflow Rate	2.0 L / s-m ²
Summer Design Day Temperature	29 ⁰ C
Winter Design Day Temperature	-17 ⁰ C
Economizer	-
Heat Recovery	-
Air System	Two VAV Air Handling Unit with Terminal VAV Box (Diffuser)

6. Conclusions

It is important to understand the relationship between building energy simulation and heating and cooling load calculations for the Peel Region Headquarters building. The building components that helps in determining the extent to which a building is energy efficient, is mentioned below.

The comparisons of MNECB minimum requirements of the proposed building and the reference building show that the Peel Region Headquarters Building has a better insulating building material. This can be seen by comparing the thermal resistance “R” of the proposed building with that of the reference building. The thermal resistance “R” for the base case building’s components, namely, roof, walls and floor has a higher value (i.e. $R_{\text{roof}} = 0.227$, $R_{\text{walls}} = 0.520$, $R_{\text{floor}} = 0.227$) than what is prescribed by MNECB for reference building. This can be seen from Tables 66 to 70.

This report conducted an energy analysis between three different air systems, namely, 2-Fan Variable Air Volume System, 1-Fan Variable Air Volume System and 1-Fan with 2-Rooftop Packaged Units. The results can be graphically seen in Figure 28 showing that the 2-Fan Variable Air Volume System has the least HVAC energy costs of the three (7.7 % less than the other two systems). This can also be seen in Table 71.

The Energy Efficiency Rating (EER) of the heat pump determines which heat pump system is the most economical and efficient and would bear very low capital cost. Based on this EER rating, the comparative result of the three types of heat pumps (Closed and Open Loop Water Source Pump and the Ground Source Heat Pump) based on cost and energy, indicates that the Open Loop Water Source Heat Pump is deemed to be the most economical having greater environmental benefits. Based on these results, which can be seen in Figures 71 and 72 and Tables 55 and 71, the Open Loop Water Source Heat Pump is 32.3 % more efficient than the Closed Loop Water Source Heat Pump used in the eQUEST simulation program and 42 % more efficient when used in the Carrier HAP program. In addition, the Open Loop Water Source Heat Pump is 24 % more efficient than the Ground Source Heat Pump.

According to the results obtained from the comparison analysis of using the two simulation programs, eQUEST and Carrier HAP, a compromise design or renovation solution was determined. The comparison of energy analysis of conventional HVAC and heat pump system indicates that the heat pump energy consumption is significantly less. This is determined by comparing the energy cost per square foot of conventional HVAC system with that of the open loop water source heat pump system for base case Model #2 (i.e. \$1.23 / ft² versus \$0.302 / ft²). This can also be seen in Figures 25, 57, and Tables 27, 43 and 71.

The comparison between Carrier HAP and eQUEST simulation software shows an approximate difference in electric energy costs, natural gas costs and total annual bill across all rates are 0.40 %, 2.74 %, 0.80 %, respectively. The percentage difference of consumption of HVAC energy is 4.68 %. This can also be seen in Tables 37 and 71.

RETScreen is used to predict the payback period and greenhouse gas (GHG) emission rate of the ground source heat pump. The comparison of base case model and proposed case model has been conducted using RETScreen software. This software shows that the greenhouse gas emissions (GHG) are reduced when going with the proposed case HVAC model (i.e., heat pump). Based on this software and the application of a ground source heat pump, the GHG emissions for the Peel Region Headquarter Building would result in an annual reduction of 142 tCO₂. This can also be seen in Tables 59. The percentage differences of GHG emission of different types of HVAC system is presented in Table 71.

Table 71 presents the comprehensive comparative sensitivity analysis between the following features:

- Comparisons between Carrier HAP and eQUEST software;
- Comparisons between conventional HVAC systems;
- Comparisons between different types of heat pumps;
- Comparisons between conventional HVAC systems with heat pumps;
- Comparisons of GHG emission rate of the base case model with conventional HVAC systems and heat pumps;

Table 71 : Comprehensive Comparative Sensitivity Analysis across All Features

Comparisons Between Three HVAC Air Systems with Conventional HVAC System using Carrier HAP and eQUEST Simulation Programs and Three Types of Heat Pumps only for Model #2 and Greenhouse Gas Emission Percentage Contribution of each HVAC Systems										
HVAC System Types	2-Fan VAV Carrier HAP Model 1 (Base Case Model)	1-Fan VAV Carrier HAP Model 2	1-Fan VAV eQUEST Model 1 (Type 1)	1-Fan VAV eQUEST Model 2 (Type 2)	1-Fan VAV With 1-Rooftop Packaged Units eQUEST Model 3	1-Fan VAV with 2-Rooftop Packaged Units Carrier HAP Model 3	Open Loop Water Source Heat Pump Model 2	Closed Loop Water Source Heat Pump Carrier HAP Model 2	Closed Loop Water Source Heat Pump eQUEST Model 2	Ground Source Heat Pump Model 2
HVAC Electric Costs (\$)	115963	123665	129290	134214	132614	131298	42,929	58,606	63522	82,105
HVAC Natural Gas Costs (\$)	43423	48729	43319	49106	50979	42250	0.00	16,159	15,232	0.00
HVAC Electric MWh	1159.629	1236.654	1292.9	1342.14	1326.14	1312.985	402,168	572.115	635.22	843.11
HVAC Natural Gas MBTU	3283.107 MBTU = 962.184* MWh	3684.315 MBTU = 1079.50 * MWh	3274.6 MBTU = 959.5* MWh	3712.8 MBTU = 1087.8* MWh	3854.4 MBTU = 1129.3* MWh	3194.4424 MBTU = 935.97* MWh	-	1208.7 MBTU = 354.2* MWh	1197.36 MBTU = 350.83* MWh	-
GHG Emission	424.8 tco ₂	-	-	-	-	-	-	-	-	-
GHG Emission Of Proposed Case Model	-	462.37 tco ₂	453.97 tco ₂	487.23 tco ₂	490.90 tco ₂	454.34 tco ₂	89.529 tco ₂	188.64 tco ₂	202.06 tco ₂	187.17 tco ₂
Percentage Increase or Decrease % tco ₂	-	8.12 % tco ₂ Increase	6.42 % tco ₂ Increase	12.81 % tco ₂ Increase	13.46 % tco ₂ Increase	6.50 % tco ₂ Increase	78.9 % tco ₂ Decrease	55.6 % tco ₂ Decrease	52.43 % tco ₂ Decrease	55.94 % tco ₂ Decrease
% Percentage Energy Difference b/w Software	-	4.68 % Less Power	-	4.68 % More Power	-	-	-	6.05 % Less Power	6.05 % More Power	-
% Percentage Energy Difference b/w System	-	8.39 % More Power	5.79 % More Power	12.68 % More Power	13.58 % More Power	5.53 % More Power	81 % Less Power	56.3 % Less Power	53.52 % Less Power	27.29% Less Power

* . HVAC Natural Gas Energy (MWh) Costs is Calculated Based on Block Charges of Natural Gas Fuel.

7. Recommendations

By undertaking a series of analyses using building simulation tools to determine energy performance, it has been found that many steps can be taken to help in the reduction of building energy consumption and improving performance. These can have huge energy saving potential especially in the long run. Recommendations on how to achieve efficient use of energy in the Peel Region Headquarters Building are discussed below.

From an energy conservation point of view, the design temperatures should be higher in summer and lower in winter. As per MNECB standards, a maximum of 22°C should be set for the winter season and a wider range for summer time (minimum 24°C). This is dependent on the difference between the design temperature and the external air temperature.

Based on the location of the Peel Region Headquarters building and proximity and availability of an open water source, it is recommended that an Open Loop Water Source Heat Pump be installed in the Peel Regional Headquarters Building. This recommendation is based on the results obtained by the energy analysis of the different energy systems given in this report.

The existing HVAC system in the Peel Region Headquarters Building does not have any energy recovery equipment installed. The furnace boiler is using outside air and the chiller and cooling tower does not have any economizer. In order to conserve fuel, it is recommended that energy recovery equipment such as economizers coupled with the cooling tower and air pre-heaters as well as reclaim ventilation systems be used.

A general opinion among the employees working at Peel Region Headquarters Building is in the form of excessive lighting. At present, the building is equipped with excessive electrical power density (lights per square feet and power density) resulting in excessive energy consumption. The power density needs to be reviewed to at least match the MNECB compliance and changed accordingly. Also, using compact fluorescent bulbs would facilitate savings. Not only do incandescent lights use more energy, but they also generate heat that results in additional air conditioning for cooling workspaces.

Direct sunlight pouring into offices puts additional demand on the air conditioning system. Screening out the sunlight by installing solar films on windows exposed to direct sunlight would not only reduce the air conditioning load but also reduce the cost by as much as 30% (www.powerwise.ca, 2007).

Seemingly, inconsequential computers and other office equipment consume a lot of energy. Many of these equipments are consuming electricity even when they are not in use, thus wasting energy and money. As a best practice, the Peel Region Headquarters Building should make electricity consumption a priority of the decision process in upgrading or purchasing new office equipment. For example, laptops use less energy than a desktop computer with a typical desktop consuming approximately 10 times more electricity than a typical laptop (www.powerwise.ca, 2007). Also, when purchasing new computers, it should be ensured that they have energy-saving features such as automatic power-down, or/and replacing CRT monitors with LCDs as they are more energy efficient than their older counterparts.

In addition, adopting work practices such as turning off computers and other office equipment at the end of the day contributes to energy savings. 60% of energy consumption is via computer monitors (www.powerwise.ca, 2007). Hence, turning them off when not in use would result in substantial energy and cost savings. Similarly, using power management on printers and faxes during periods of inactivity would result in 50% - 65% reduction of electricity.

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Appendix 1: Construction Materials

Table 72: Wall #1 Construction Materials

CONSTRUCTION MATERIAL						
EXTERIOR WALL(WALL#1) : SUN & WIND EXPOSED (FLOOR 1 to 4)						
Layers in order from inside to outside	Layers 1	Layers 2	Layers 3	Layers 4	Layers 5	Total
Materials	0.5 -in Drywall	2-in Insulation	0.5 -in Parging	4-in HW Concrete	4-in face brick	
Roughness	Smooth	Light Rough	Smooth	Medium Smooth	Medium Smooth	
Thickness: Inch	0.50	2.00	0.50	4.00	4.00	11.0
Conductivity:						
Density: Ib /ft ³	50.0	0.5	45.0	38.0	125.0	
Specific Heat: BTU / Ib-°F	0.26	0.20	0.32	0.20	0.22	
Thermal Resistance: R= hr-ft ² -°F /BTU	0.44803	6.41026	0.32051	1.51515	0.4329	10.15
Weight: Ib / ft ²	2.1	0.1	1.9	12.7	41.7	58.40
Absorptance:Thermal						
Absorptance:Solar						0.900
Gas type	Air					
OVERALL HEAT TRANSFER COEFFICIENT OR U- VALUE : 0.099 BTU / hr- ft ² - °F						

Table 73: Wall #2 Construction Materials

CONSTRUCTION MATERIAL						
EXTERIOR WALL(WALL#2) : SUN & WIND EXPOSED (FLOOR 5 to 6)						
Layers in order from inside to outside	Layers 1	Layers 2	Layers 3	Layers 4	Layers 5	Total
Materials	0.5 -in Drywall	2-in Insulation	0.5 –in Parging	6-in HW Concrete	4-in face brick	
Roughness	Smooth	Light Rough	Smooth	Medium Smooth	Medium Smooth	
Thickness: Inch	0.50	2.00	0.50	6.00	4.00	13.0
Conductivity:						
Density: Ib /ft ³	50.0	0.5	45.0	38.0	125.0	
Specific Heat: BTU / Ib- ⁰ F	0.26	0.20	0.32	0.20	0.22	
Thermal Resistance: R= hr-ft ² - ⁰ F /BTU	0.44803	6.41026	0.32051	2.27273	0.4329	10.90
Weight: Ib / ft ²	2.1	0.1	1.9	19.0	41.7	64.70
Absorptance:Thermal						
Absorptance:Solar						0.900
Absorptance:Visible						
Gas type	Air					
OVERALL HEAT TRANSFER COEFFICIENT OR U- VALUE : 0.092 BTU / hr- ft ² - ⁰ F						

Table 74: Wall #3, 4, 5 Construction Materials

CONSTRUCTION MATERIAL						
	Sun Exposed Exterior Wall #3		No Sun Exposed Interior Wall #4	No Sun Exposed Interior Wall #5		
Layers in order from inside to outside	Layers 1	Layers 2	Layers 1	Layers 1	Layers 2	Layers 3
Materials	0.5 -in Drywall	8-in HW Concrete	8-in HW Concrete	0.5 -in Drywall	Steel framing membrane	0.5 -in Drywall
Roughness	Smooth	Medium Smooth	Medium Smooth	Smooth	Medium Smooth	Smooth
Thickness: Inch	0.50	8.00	8.00	0.50	3.500	0.50
Conductivity:						
Density: Ib /ft³	50.0	140.0	140.0	50.0	489.0	50.0
Specific Heat: BTU / Ib-°F	0.26	0.20	0.20	0.26		0.26
Thermal Resistance: R= hr-ft²-°F /BTU	0.44803	0.66667	0.66667	0.44803	0.68139	0.44803
Weight: Ib / ft²	2.10	93.30	93.30	2.10		
Absorptance:Therm al						
Absorptance:Solar						
U- VALUE	0.4690		0.594	.073		

Table 75: Door Construction Materials

DOOR PROPERTIES				
Types	Gross Area ft ²	U-Value <i>BTU / hr-ft²- °F</i>	Glass Area ft ²	U-Value <i>BTU / hr-ft²- °F</i>
Stile and Rail Door	550.0	0.634	325.0	0.634
Vestibules	135.0	0.300	135.0	0.580

WINDOW MATERIAL - W1 (for Floor 2-4 & 6)

Table 76: Window Construction Materials (W 1)

Construction Name	Double Glazed Clear Glass 1/8"(3mm) / 1/4"(6mm) Air Space		
Layers Name in order	Layers 1(outside)	Layers 2	Layers 3
Material: Windows Glass/ Gas	CLEAR 3MM	AIR 6MM	CLEAR 3MM
Thickness (m)	0.003	0.006	0.003
Solar Transmittance at normal incidence	0.837		0.837
Solar Reflectance at normal incidence : Front side	0.075	-	0.075
Solar Reflectance at normal incidence: Back side	0.075	-	0.075
Visible Transmittance at normal incidence	0.898	-	0.898
Visible Reflectance at normal incidence : Front side	0.081	-	0.081
Visible Reflectance at normal incidence : Back side	0.081	-	0.081
Absorptivity	0.081		0.081
IR Hemispherical Emissivity : Front Side	0.84	-	0.84
IR Hemispherical Emissivity: Back Side	0.84	-	0.84
Conductivity	0.9	-	0.9
Gas Type	-	Air	-

Overall Heat Transfer Coefficient *W1* = U Value= 0.542 BTU/hr/ft²/F or 3.080 W/ m²-K

WINDOW MATERIAL – W2 (only for Floor 5)

Table 77: Window Construction Materials (W 2)

Construction Name	Triple Glazed Clear Glass 1/8"(3mm) / 1/4"(6mm) Air Space		
Layers Name in order	Layers 1(outside)	Layers 2	Layers 3
Material: Windows Glass/ Gas	CLEAR 3MM	AIR 6MM	CLEAR 3MM
Thickness (m)	0.003	0.006	0.003
Solar Transmittance at normal incidence	0.837		0.837
Solar Reflectance at normal incidence : Front side	0.075	-	0.075
Solar Reflectance at normal incidence: Back side	0.075	-	0.075
Visible Transmittance at normal incidence	0.898	-	0.898
Visible Reflectance at normal incidence : Front side	0.081	-	0.081
Visible Reflectance at normal incidence : Back side	0.081	-	0.081
Absorptivity	0.081		0.081
IR Hemispherical Emissivity : Front Side	0.84	-	0.84
IR Hemispherical Emissivity: Back Side	0.84	-	0.84
Conductivity	0.9	-	0.9
Gas Type	-	Air	-

Table 78: Roof Construction Materials

CONSTRUCTION MATERIAL						
ROOF (6 th FLOOR) : SUN & WIND EXPOSED						
Layers in order from inside to outside	Layers 1	Layers 2	Layers 3	Layers 4	Layers 5	Layers 6
Materials	0.5-in gypsum board	Air Space	11-in HW Concrete	R-19 batt insulation	0.375-in felt & Membrane	0.5-in Slag or stone
Roughness	Smooth	-	Smooth	Smooth	Medium Smooth	Medium Smooth
Thickness: inch	0.500	-	11.00	6.0	0.375	0.5
Conductivity:		-	-		1.32	9.96
Density: Ib /ft ³	50.0	-	140.0	0.50	70.0	55.0
Specific Heat: BTU / Ib-°F	0.26	-	0.2	0.20	0.4	0.40
Thermal Resistance: R= hr-ft ² -°F /BTU	0.44803	0.97	0.91667	19.23	1.29	0.05
Weight: Ib / ft ²						
Absorptance:Thermal						
Absorptance:Solar						
Absorptance:Visible						
Gas type	Air					
OVERALL HEAT TRANSFER COEFFICIENT OR U- VALUE : 0.04 BTU / hr- ft ² - °F						

Table 79: Equipment List of Other Types of HVAC System

EQUIPMENT LIST OF OTHER TYPES OF HVAC				
Field	Units	Object	Quantity	Location
Council Chambers Rooftop unit#1 Lennox (Model #LGA088SH1J)	MBH or Ton	180 10	1	Roof(6 th Floor)
Council Chambers Rooftop unit#2 Lennox (Model #LGA088SH1J)	MBH or Ton	180 10	1	Roof(6 th Floor)
Council Chambers Rooftop unit#3 Lennox (Model#GCS16-036-90-2J)	MBH or Ton	90 5	1	Roof(6 th Floor)
UPS Condenser York (Model#H1DB060S58B)	MBH or Ton		1	<u>P2 Garage</u>
<u>UPS Fan Coil York (Model#K2EU060A06A)</u>	MBH or Ton		1	<u>P2 UPS Room</u>
Telephone Room Condenser Carrier (Model # 38HDL036)	MBH or Ton		1	P2 Garage
<u>Telephone Room Fan Coil Carrier</u> <u>(Model # FA4BNF036000)</u>	MBH or Ton	36 or 3	1	<u>P1 Telephone Room</u>
SCADA Room Condenser Mitsubishi (Model# PUH30EK)	MBH or Ton	30 or 1.66	1	P2 Garage
<u>SCADA Room Fan Coil Mitsubishi</u> <u>(Model# PLH30AK)(Heat)</u>	MBH	20.8	1	<u>3rd SCADA Room</u>
Dispatch Room Condenser Mitsubishi (Model #PUH18EK)	MBH or Ton	17.3 or 0.96	1	P2 Garage
<u>Dispatch Room Fan Coil Mitsubishi</u> <u>(Model #PLH18AK) (Heat)</u>	MBH	11.5	1	<u>3rd Dispatch Room</u>
<u>Computer Room Fan Coil Liebert</u> <u>(Model #)</u>	MBH or Ton	270 or 15	2	<u>3rd Floor Computer Room</u>
Computer Room Condenser Liebert (Model #)	MBH or Ton	270 or 15	2	Roof 6 th Floor

Table 80: Equipment List of Exhaust Fan / Humidifier

EQUIPMENT LIST FOR EXHAUST FAN / Humidifier				
Field	Units	Object	C.F.M	Location
Rooftop Exhaust Fan –Greenheck(1) (Model#CBE-18-4)	hp or KW	0.5 or 0.35	3112	
Rooftop Exhaust Fan –Greenheck(1) (Model# CE-7.5D)	hp or KW	0.03 or 0.021	200	
Rooftop Exhaust Fan –Greenheck(1) (Model# CBE-36-10)	hp or KW	1 or 0.748	4000	
Rooftop Exhaust Fan –Greenheck(1) (Model# CBE-18-4)	hp or KW	0.5 or 0.35	3112	
Rooftop Exhaust Fan –Greenheck(1) (Model# CBE-18-4)	hp or KW	0.5 or 0.35	3112	
Garage Exhaust Fan–Greenheck(2) (Model# SBCE-3H42-50	hp or KW	5 or 3.74	20,000	
Steam Humidifiers- Nortec (Model # NHMC 020)				Mechanical Room
Steam Humidifiers- Nortec (Model # NHMC 010)				6th Floor
Steam Humidifiers- Nortec (Model # NHMC 030)				Floor 1 through 6

Appendix 2: Simulation Models of the Base Case Building

Figure 81: 1st Floor Zone Layout Scenario #1 Building Model

Table 81: Scenario #1 Building Model (Floor-1, Zone Input Data Sheet)

Building Model # 1 <u>ZONE INPUT DATA SHEET</u> FLOOR-1: Foot print Area = 19698.68 ft ² , Perimeter = 563'-9" Occupancy: 371.6 ft ² / Person, Overhead Lighting: 1.019 W / ft ² , Electric Equipment : 0.786 W / ft ²								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person "Standard"	Occupancy ft ² / Person "Standard"	Overhead Lighting W / ft ² "Standard"	Electric Equipment W / ft ² "Standard"
1 st FL_Z-1	OFFICE	160.11	51'- 2"	75	20.00	275.0	2.00	0.75
1 st FL_Z-2	OFFICE	253.54	64'- 11"	520	20.00	275.0	2.00	0.75
1 st FL_Z-3	OFFICE	594.58	114'- 3"	780	20.00	275.0	2.00	0.75
1 st FL_Z-4	OFFICE	388.28	95'- 4"	650	20.00	275.0	2.00	0.75
1 st FL_Z-5	OFFICE	266.43	65'- 4"	500	20.00	275.0	2.00	0.75
1 st FL_Z-6	OFFICE	662.82	113'- 7"	970	20.00	275.0	2.00	0.75
1 st FL_Z-7	OFFICE	409.00	82'- 8"	360	20.00	275.0	2.00	0.75
1 st FL_Z-8	OFFICE	329.58	73'- 0"	500	20.00	275.0	2.00	0.75
1 st FL_Z-9	OFFICE	188.57	55'- 11"	300	20.00	275.0	2.00	0.75
1 st FL_Z-10	OFFICE	580.93	103'- 3"	910	20.00	275.0	2.00	0.75
1 st FL_Z-11	OFFICE	497.34	96'-2"	780	20.00	275.0	2.00	0.75
1 st FL_Z-12	OFFICE	580.13	103'- 2"	850	20.00	275.0	2.00	0.75
1 st FL_Z-13	OFFICE	331.50	73'- 2"	400	20.00	275.0	2.00	0.75
1 st FL_Z-14	OFFICE	189.43	56'- 0"	330	20.00	275.0	2.00	0.75

1 st FL_Z-15	OFFICE	407.53	112'- 6"	500	20.00	275.0	2.00	0.75
1 st FL_Z-16	OFFICE	246.21	62'- 10"	500	20.00	275.0	2.00	0.75
1 st FL_Z-17	OFFICE	539.47	93'- 9"	700	20.00	275.0	2.00	0.75
1 st FL_Z-18	OFFICE	257.49	72'- 7"	200	20.00	275.0	2.00	0.75
1 st FL_Z-19	OFFICE	4428.8	302'- 9"	1200	15.00	-	2.00	0.75
1 st FL_Z-20	CORRIDOR	294.22	74'- 8"	480	20.00	275.0	2.00	0.75
1 st FL_Z-21	OFFICE	375.25	88'- 4"	520	20.00	275.0	2.00	0.75
1 st FL_Z-22	OFFICE	227.81	60'- 4"	390	20.00	275.0	2.00	0.75
1 st FL_Z-23	OFFICE	150.00	50'- 0"	180	20.00	275.0	2.00	0.75
1 st FL_Z-24	OFFICE	150.00	50'- 0"	180	20.00	275.0	2.00	0.75
1 st FL_Z-25	OFFICE	885.31	150'- 9"	1170	20.00	275.0	2.00	0.75
1 st FL_Z-26	OFFICE	364.34	97'- 0"	450	20.00	275.0	2.00	0.75
1 st FL_Z-27	OFFICE	607.09	110'- 7"	630	20.00	275.0	2.00	0.75
1 st FL_Z-28	OFFICE	514.01	117'- 8"	225	20.00	275.0	2.00	0.75
1 st FL_Z-29	OFFICE	292.75	77'- 2"	225	20.00	275.0	2.00	0.75
1 st FL_Z-30	OFFICE	436.95	88'-10"	300	20.00	275.0	2.00	0.75
1 st FL_Z-31	OFFICE	393.71	99'- 1"	460	20.00	275.0	2.00	0.75
1 st FL_Z-32	OFFICE	401.72	102'- 0"	460	20.00	275.0	2.00	0.75
1 st FL_Z-33	OFFICE	453.61	114'- 10"	575	20.00	275.0	2.00	0.75
1 st FL_Z-34	OFFICE	492.27	90'- 2"	420	20.00	275.0	2.00	0.75
1 st FL_Z-35	OFFICE	218.58	67'- 11"	140	20.00	275.0	2.00	0.75

1 st FL_Z-36	OFFICE	218.09	59'- 1"	150	20.00	275.0	2.00	0.75
1 st FL_Z-37	OFFICE	309.13	71'-2"	255	20.00	275.0	2.00	0.75
1 st FL_Z-38	OFFICE	572.87	109' - 7"	600	20.00	275.0	2.00	0.75
1 st FL_Z-39	OFFICE	360.51	85'- 1"	250	15.00	275.0	2.00	0.75
1 st FL_Z-40	VESTIBULE S	360.51	85'- 1"	250	15.00	275.0	2.00	0.75

Figure 82: 2nd Floor Zone Layout Scenario #1 Building Model

Table 82: Scenario #1 Building Model (Floor-2, Zone Input Data Sheet)

Building Model # 1 <u>ZONE INPUT DATA SHEET</u> FLOOR-2: Foot print Area = 23973.36 ft², Perimeter = 619' - 4" Occupancy : 147.0 ft² / Person, Overhead Lighting 1.09 W / ft², Electric Equipment 1.95 W / ft²								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person "Standard"	Occupancy ft ² / Person "Standard"	Overhead Lighting W / ft ² "Standard"	Electric Equipment W / ft ² "Standard"
2 nd FL_Z-1	OFFICE	303.34	69'- 8"	600	20.00	275.0	2.00	0.75
2 nd FL_Z-2	OFFICE	174.17	54'- 10"	450	20.00	275.0	2.00	0.75
2 nd FL_Z-3	OFFICE	870.83	134'- 10"	1120	20.00	275.0	2.00	0.75
2 nd FL_Z-4	OFFICE	696.67	114'- 10"	800	20.00	275.0	2.00	0.75
2 nd FL_Z-5	OFFICE	261.55	64'- 10"	280	20.00	275.0	2.00	0.75
2 nd FL_Z-6	OFFICE	390.42	79'- 8"	480	20.00	275.0	2.00	0.75
2 nd FL_Z-7	OFFICE	348.33	74'- 10"	450	20.00	275.0	2.00	0.75
2 nd FL_Z-8	OFFICE	261.25	64'- 10"	240	20.00	275.0	2.00	0.75
2 nd FL_Z-9	OFFICE	435.42	84'- 10"	400	20.00	275.0	2.00	0.75
2 nd FL_Z-10	OFFICE	1020.0	154'- 10"	1200	20.00	275.0	2.00	0.75
2 nd FL_Z-11	OFFICE	328.32	79'- 8"	610	20.00	275.0	2.00	0.75
2 nd FL_Z-12	OFFICE	957.92	144'- 10"	1100	20.00	275.0	2.00	0.75
2 nd FL_Z-13	OFFICE	1157.9	184'- 10"	1190	20.00	275.0	2.00	0.75
2 nd FL_Z-14	OFFICE	477.51	89'- 8"	610	20.00	275.0	2.00	0.75
2 nd FL_Z-15	OFFICE	522.50	94'- 10"	660	20.00	275.0	2.00	0.75
2 nd FL_Z-16	OFFICE	435.42	84'- 10"	550	20.00	275.0	2.00	0.75
2 nd FL_Z-17	OFFICE	267.42	65'- 6"	300	20.00	275.0	2.00	0.75

2 nd FL_Z-18	OFFICE	342.17	74'- 2"	450	20.00	275.0	2.00	0.75
2 nd FL_Z-19	OFFICE	261.25	64'- 10"	450	20.00	275.0	2.00	0.75
2 nd FL_Z-20	OFFICE	261.25	64'- 10"	600	20.00	275.0	2.00	0.75
2 nd FL_Z-21	CORRIDOR	3321.8	230'- 0"	900	20.00	-	2.00	-
2 nd FL_Z-22	OFFICE	378.98	80'- 6"	600	20.00	275.0	2.00	0.75
2 nd FL_Z-23	OFFICE	500.00	98'- 3"	375	20.00	275.0	2.00	0.75
2 nd FL_Z-24	OFFICE	221.02	59'- 6"	375	20.00	275.0	2.00	0.75
2 nd FL_Z-25	OFFICE	300.00	70'- 0"	375	20.00	275.0	2.00	0.75
2 nd FL_Z-26	OFFICE	850.00	150'- 0"	780	20.00	275.0	2.00	0.75
2 nd FL_Z-27	OFFICE	525.00	100'- 0"	450	20.00	275.0	2.00	0.75
2 nd FL_Z-28	OFFICE	2044.0	238'- 4"	2050	20.00	275.0	2.00	0.75
2 nd FL_Z-29	OFFICE	2009.3	180'- 5"	2015	20.00	275.0	2.00	0.75
2 nd FL_Z-30	OFFICE	1580.5	170'- 4"	1575	20.00	275.0	2.00	0.75
2 nd FL_Z-31	OFFICE	303.75	70'- 5"	300	20.00	275.0	2.00	0.75
2 nd FL_Z-32	OFFICE	1456.2	199'- 10"	1650	20.00	275.0	2.00	0.75
2 nd FL_Z-33	OFFICE	709.16	104'- 9"	1000	20.00	275.0	2.00	0.75

Figure 83: 3rd Floor Zone Layout Scenario #1 Building Model

Table 83: Scenario #1 Building Model (Floor-3, Zone Input Data Sheet)

Building Model # 1					<u>ZONE INPUT DATA SHEET</u>			
FLOOR-3: Foot print Area = 23973.36 ft ² , Perimeter = 619'- 4" Occupancy : 201.5 ft ² / Person, Overhead Lighting 1.09 W / ft ² , Electric Equipment: 1.43 W / ft ²								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person "Standard"	Occupancy ft ² / Person "Standard"	Overhead Lighting W / ft ² "Standard"	Electric Equipment W / ft ² "Standard"
3 rd FL_Z-1	CAFETERIA	564.59	99'- 8"	610	20.00	323	2.7	0.23
3 rd FL_Z-2	OFFICE	522.50	94'- 10"	1040	20.00	275.0	2.00	0.75
3 rd FL_Z-3	OFFICE	583.75	124'- 10"	1170	20.00	275.0	2.00	0.75
3 rd FL_Z-4	OFFICE	200.00	60'- 0"	280	20.00	275.0	2.00	0.75
3 rd FL_Z-5	OFFICE	522.50	94'- 10"	780	20.00	275.0	2.00	0.75
3 rd FL_Z-6	OFFICE	478.39	89'- 9"	660	20.00	275.0	2.00	0.75
3 rd FL_Z-7	OFFICE	348.33	74'- 10"	390	20.00	275.0	2.00	0.75
3 rd FL_Z-8	COMPUTER ROOM	2411.7	213'- 1"		20.00	275.0	2.00	0.75
3 rd FL_Z-9	OFFICE	870.83	134'- 10"	720	20.00	275.0	2.00	0.75
3 rd FL_Z-10	OFFICE	302.80	69'- 7"	440	20.00	275.0	2.00	0.75
3 rd FL_Z-11	OFFICE	671.79	179'- 7"	600	20.00	275.0	2.00	0.75
3 rd FL_Z-12	OFFICE	185.90	54'- 9"	230	20.00	275.0	2.00	0.75
3 rd FL_Z-13	OFFICE	185.90	54'- 9"	280	20.00	275.0	2.00	0.75
3 rd FL_Z-14	OFFICE	1043.6	154'- 9"	1200	20.00	275.0	2.00	0.75
3 rd FL_Z-15	OFFICE	302.93	69'-7"	520	20.00	275.0	2.00	0.75
3 rd FL_Z-16	OFFICE	697.17	114'- 11"	700	20.00	275.0	2.00	0.75
3 rd FL_Z-17	OFFICE	262.50	65'- 0"	300	20.00	275.0	2.00	0.75

3 rd FL_Z-18	OFFICE	496.01	104'- 8"	945	20.00	275.0	2.00	0.75
3 rd FL_Z-19	OFFICE	435.42	84'-10"	440	20.00	275.0	2.00	0.75
3 rd FL_Z-20	CAFETERIA	348.33	74'- 10"	340	20.00	323	2.7	0.23
3 rd FL_Z-21	CORRIDOR	3608.4	289'- 2"	900	20.00	-	2.00	-
3 rd FL_Z-22	CAFETERIA	489.06	120'- 0"	570	20.00	323	2.7	0.23
3 rd FL_Z-23	CAFETERIA	939.43	122'- 6"	1000	20.00	323	2.7	0.23
3 rd FL_Z-24	OFFICE	768.27	132'- 5"	720	20.00	275.0	2.00	0.75
3 rd FL_Z-25	OFFICE	375	80'- 0"	330	20.00	275.0	2.00	0.75
3 rd FL_Z-26	OFFICE	475.16	120'- 1"	440	20.00	275.0	2.00	0.75
3 rd FL_Z-27	OFFICE	808.84	148'- 9"	910	20.00	275.0	2.00	0.75
3 rd FL_Z-28	OFFICE	939.67	131'- 6"	1160	20.00	275.0	2.00	0.75
3 rd FL_Z-29	OFFICE	1525.0	160'- 0"	1560	20.00	275.0	2.00	0.75
3 rd FL_Z-30	OFFICE	400.00	80'- 0"	650	20.00	275.0	2.00	0.75
3 rd FL_Z-31	OFFICE	808.84	148'- 9"	910	20.00	275.0	2.00	0.75
3 rd FL_Z-32	OFFICE	939.67	131'- 6"	1160	20.00	275.0	2.00	0.75
3 rd FL_Z-33	LAB	600.57	110'- 0"	775	20.00	275.0	2.00	0.75
3 rd FL_Z-34	LIBRARY	157.48	51'- 6"	130	20.00	275.0	2.00	0.75
3 rd FL_Z-35	OFFICE	314.97	71'- 6"	255	20.00	275.0	2.00	0.75
3 rd FL_Z-36	OFFICE	226.07	60'- 2"	300	20.00	275.0	2.00	0.75
3 rd FL_Z-37	OFFICE	150.00	50'- 0"	300	20.00	275.0	2.00	0.75

Figure 84: 4th Floor Zone Layout Scenario #1 Building Model

Table 84: Scenario #1 Building Model (Floor-4, Zone Input Data Sheet)

Building Model # 1 <u>ZONE INPUT DATA SHEET</u> FLOOR- 4: Foot print Area = 23973.36 ft² , Perimeter = 619'- 4" Occupancy : 137.0 ft² / Person, Overhead Lighting :1.09 W / ft², Electric Equipment: 2.062 W / ft²								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person "Standard"	Occupancy ft ² / Person "Standard"	Overhead Lighting W / ft ² "Standard"	Electric Equipment W / ft ² "Standard"
4 th FL_Z-1	OFFICE	303.34	69'- 8"	450	20.00	275.0	2.00	0.75
4 th FL_Z-2	OFFICE	1045	154'- 10"	1440	20.00	275.0	2.00	0.75
4 th FL_Z-3	OFFICE	1045	154'- 10"	1440	20.00	275.0	2.00	0.75
4 th FL_Z-4	OFFICE	303.34	69'- 8"	390	20.00	275.0	2.00	0.75
4 th FL_Z-5	OFFICE	609.58	104'- 10"	750	20.00	275.0	2.00	0.75
4 th FL_Z-6	OFFICE	261.25	64'- 10"	250	20.00	275.0	2.00	0.75
4 th FL_Z-7	OFFICE	348.33	74'- 10"	250	20.00	275.0	2.00	0.75
4 th FL_Z-8	OFFICE	609.58	104'- 10"	875	20.00	275.0	2.00	0.75
4 th FL_Z-9	OFFICE	261.25	64'- 10"	230	20.00	275.0	2.00	0.75
4 th FL_Z-10	OFFICE	390.42	79'- 8"	480	20.00	275.0	2.00	0.75
4 th FL_Z-11	OFFICE	261.25	64'- 10"	250	20.00	275.0	2.00	0.75
4 th FL_Z-12	OFFICE	696.67	114'- 10"	740	20.00	275.0	2.00	0.75
4 th FL_Z-13	OFFICE	1045.0	154'-10"	1100	20.00	275.0	2.00	0.75
4 th FL_Z-14	OFFICE	303.34	69'- 8"	400	20.00	275.0	2.00	0.75
4 th FL_Z-15	OFFICE	957.92	144'-10"	1500	20.00	275.0	2.00	0.75
4 th FL_Z-16	OFFICE	1132.0	164'- 10"	1500	20.00	275.0	2.00	0.75

4 th FL_Z-17	CORRIDOR	3342.1	230'- 4"	900	20.00	-	2.00	-
4 th FL_Z-18	OFFICE	1000.0	150'- 0"	1035	20.00	275.0	2.00	0.75
4 th FL_Z-19	OFFICE	225	60'- 0"	230	20.00	275.0	2.00	0.75
4 th FL_Z-20	OFFICE	215.96	58'- 10"	230	20.00	275.0	2.00	0.75
4 th FL_Z-21	OFFICE	236.86	61'- 7"	230	20.00	275.0	2.00	0.75
4 th FL_Z-22	OFFICE	772.19	129'- 8"	805	20.00	275.0	2.00	0.75
4 th FL_Z-23	OFFICE	507.70	120'- 10"	575	20.00	275.0	2.00	0.75
4 th FL_Z-24	OFFICE	1310.5	216'- 8"	1150	20.00	275.0	2.00	0.75
4 th FL_Z-25	OFFICE	603.75	110'- 5"	805	20.00	275.0	2.00	0.75
4 th FL_Z-26	OFFICE	226.63	60'- 3"	270	20.00	275.0	2.00	0.75
4 th FL_Z-27	OFFICE	191.89	61'- 10"	230	20.00	275.0	2.00	0.75
4 th FL_Z-28	OFFICE	1389.6	227'- 7"	1150	20.00	275.0	2.00	0.75
4 th FL_Z-29	OFFICE	502.63	124'- 8"	460	20.00	275.0	2.00	0.75
4 th FL_Z-30	OFFICE	2150.0	200'- 0"	1495	20.00	275.0	2.00	0.75
4 th FL_Z-31	OFFICE	1725.0	170'- 0"	1430	20.00	275.0	2.00	0.75

Figure 85: 5th Floor Zone Layout Scenario #1 Building Model

Table 85: Scenario #1 Building Model (Floor-5, Zone Input Data Sheet)

Building Model # 1 <u>ZONE INPUT DATA SHEET</u> FLOOR-5: Foot print Area = 23973.36 ft², Perimeter = 619'- 4" Occupancy : 275.5 ft² / Person, Overhead Lighting: 0.92 W / ft², Electric Equipment: 1.08 W / ft²								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person "Standard"	Occupancy ft ² / Person "Standard"	Overhead Lighting W / ft ² "Standard"	Electric Equipment W / ft ² "Standard"
5 th FL_Z-1	OFFICE	390.42	79'- 8"	450	20.00	275.0	2.00	0.75
5 th FL_Z-2	OFFICE	261.25	64'- 10"	600	20.00	275.0	2.00	0.75
5 th FL_Z-3	OFFICE	261.25	64'- 10"	265	20.00	275.0	2.00	0.75
5 th FL_Z-4	OFFICE	522.50	94'- 10"	660	20.00	275.0	2.00	0.75
5 th FL_Z-5	OFFICE	1045.0	154'- 10"	1220	20.00	275.0	2.00	0.75
5 th FL_Z-6	OFFICE	216.26	59'- 8"	300	20.00	275.0	2.00	0.75
5 th FL_Z-7	OFFICE	1094.2	174'- 10"	1125	20.00	275.0	2.00	0.75
5 th FL_Z-8	OFFICE	196.72	63'- 6"	150	20.00	275.0	2.00	0.75
5 th FL_Z-9	OFFICE	726.21	125'- 11"	500	20.00	275.0	2.00	0.75
5 th FL_Z-10	OFFICE	915.77	154'- 2"	600	20.00	275.0	2.00	0.75
5 th FL_Z-11	OFFICE	781.32	123'- 6"	910	20.00	275.0	2.00	0.75
5 th FL_Z-12	OFFICE	522.5	94'- 10"	570	20.00	275.0	2.00	0.75
5 th FL_Z-13	OFFICE	390.42	79'- 8"	480	20.00	275.0	2.00	0.75
5 th FL_Z-14	OFFICE	435.42	84'- 10"	600	20.00	275.0	2.00	0.75
5 th FL_Z-15	OFFICE	348.33	74'- 10"	440	20.00	275.0	2.00	0.75
5 th FL_Z-16	OFFICE	348.33	74'- 10"	350	20.00	275.0	2.00	0.75
5 th FL_Z-17	OFFICE	522.5	94'- 10"	680	20.00	275.0	2.00	0.75
5 th FL_Z-18	OFFICE	261.25	64'- 10"	330	20.00	275.0	2.00	0.75

5 th FL_Z-19	OFFICE	480.25	86'- 4"	600	20.00	275.0	2.00	0.75
5 th FL_Z-20	CORRIDOR	3102.8	226'- 1"	900	20.00	275.0	2.00	0.75
5 th FL_Z-21	CONFERENCE ROOM#1	1264.5	189' – 6"	1200	20.00	-	2.00	-
5 th FL_Z-22	CONFERENCE ROOM#2	3661.7	263' – 7"	-	20.00	215	2.3	0 .23
5 th FL_Z-23	OFFICE	225	60'- 0"	300	20.00	275.0	2.00	0.75
5 th FL_Z-24	OFFICE	450.0	90'- 0"	600	20.00	275.0	2.00	0.75
5 th FL_Z-25	OFFICE	685.66	164'- 3"	925	20.00	275.0	2.00	0.75
5 th FL_Z-26	OFFICE	648.49	109'- 10"	750	20.00	275.0	2.00	0.75
5 th FL_Z-27	OFFICE	842.86	154'- 3"	800	20.00	275.0	2.00	0.75
5 th FL_Z-28	OFFICE	363.93	84'- 1"	390	20.00	275.0	2.00	0.75
5 th FL_Z-29	OFFICE	1588.9	174'- 3"	940	20.00	275.0	2.00	0.75
5 th FL_Z-30	OFFICE	171.33	54'- 3"	120	20.00	275.0	2.00	0.75
5 th FL_Z-31	OFFICE	225.0	60'- 0"	200	20.00	275.0	2.00	0.75
5 th FL_Z-32	OFFICE	225.0	60'-0"	200	20.00	275.0	2.00	0.75
5 th FL_Z-33	OFFICE	225.0	60'- 0"	150	20.00	275.0	2.00	0.75
5 th FL_Z-34	OFFICE	630.21	118'- 10"	375	20.00	275.0	2.00	0.75

Figure 86: 6th Floor Zone Layout Scenario #1 Building Model

Table 86: Scenario #1 Building Model (Floor-6, Zone Input Data Sheet)

Building Model # 1 <u>ZONE INPUT DATA SHEET</u> FLOOR-6: Foot print Area = 23973.36 ft², Perimeter = 619'- 4" Occupancy : 250.8 ft² / Person, Overhead Lighting: 0.87 W / ft², Electric Equipment: 0.890 W / ft²								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person "Standard"	Occupancy ft ² / Person "Standard"	Overhead Lighting W / ft ² "Standard"	Electric Equipment W / ft ² "Standard"
6 th FL_Z-1	OFFICE	303.36	69'- 8"	400	20.00	275.0	2.00	0.75
6 th FL_Z-2	OFFICE	696.72	114'- 10"	785	20.00	275.0	2.00	0.75
6 th FL_Z-3	OFFICE	291.20	80'- 0"	200	20.00	275.0	2.00	0.75
6 th FL_Z-4	OFFICE	700.14	110'- 0"	945	20.00	275.0	2.00	0.75
6 th FL_Z-5	OFFICE	261.23	64'- 10"	270	20.00	275.0	2.00	0.75
6 th FL_Z-6	OFFICE	261.23	64'- 10"	270	20.00	275.0	2.00	0.75
6 th FL_Z-7	OFFICE	569.17	104'- 10"	540	20.00	275.0	2.00	0.75
6 th FL_Z-8	OFFICE	737.00	124'- 10"	630	20.00	275.0	2.00	0.75
6 th FL_Z-9	OFFICE	261.27	64'- 10"	190	20.00	275.0	2.00	0.75
6 th FL_Z-10	OFFICE	390.39	79'- 8"	300	20.00	275.0	2.00	0.75
6 th FL_Z-11	OFFICE	696.61	114'- 10"	560	20.00	275.0	2.00	0.75
6 th FL_Z-12	OFFICE	496.4	91'-10"	460	20.00	275.0	2.00	0.75
6 th FL_Z-13	OFFICE	1192.7	184'- 3"	900	20.00	275.0	2.00	0.75
6 th FL_Z-14	OFFICE	928.39	124'-3"	980	20.00	275.0	2.00	0.75
6 th FL_Z-15	OFFICE	1571.7	165'- 9"	1315	20.00	275.0	2.00	0.75
6 th FL_Z-16	OFFICE	1278.4	141'- 11"	1050	20.00	275.0	2.00	0.75
6 th FL_Z-17	OFFICE	397.54	83'- 0"	370	20.00	275.0	2.00	0.75

6 th FL_Z-18	OFFICE	3608	237'- 8"	1200	20.00	275.0	2.00	0.75
6 th FL_Z-19	CORRIDOR	2177	242'- 5"	900	20.00	-	2.00	-
6 th FL_Z-20	OFFICE	674.98	120'- 00"	840	20.00	275.0	2.00	0.75
6 th FL_Z-21	MECHANICAL ROOM	5916.0	423'- 11"	-	20.00	-	2.00	-

Figure 87: P1 Level Floor Zone Layout Scenario #1 Building Model

Table 87: Scenario #1 Building Model (P1Level, Zone Input Data Sheet)

Building Model # 1 <u>ZONE INPUT DATA SHEET</u> P1 LEVEL: Foot print Area = 38069 ft², Perimeter = 788'-6" Occupancy : 297.0 ft² / Person, Overhead Lighting :1.028 W / ft², Electric Equipment : 2.17 W / ft²								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² Per Person	Overhead Lighting W / ft2	Electric Equipment W / ft ²
P1 FL_Z-1	UNCONDITIONED SPACE	31226	788'- 6"	-	20.00	-	0.09	-
P1 FL_Z-2	HEALTH/STORAGE TELEPHONE ROOM RECYCLING ROOM	1197.3	169'- 4"	935	20.00	-	2.00	-
P1 FL_Z-3	TELEPHONE ROOM	396.44	80'- 2"	-	20.00	-	2.00	-
P1 FL_Z-4	MAINTENANC ROOM WELLNESS CENTER METER ROOM	1175.93	164'- 2"	935	20.00	275.0	2.00	0.75
P1 FL_Z-5	CORRIDOR	1971.82	272'- 4"	200	20.00	-	2.00	-
P1 FL_Z-6	MAILING ROOM	341.18	73'- 6"	500	20.00	275.0	2.00	0.75
P1 FL_Z-7	PRINTING ROOM	1029.42	135'- 2"	1000	20.00	275.0	2.00	0.75
P1 FL_Z-8	COMMUNICATION ROOM	725.19	122'- 9"	800	20.00	275.0	2.00	0.75

Figure 88: P2 Level Floor Zone Layout Scenario #1 Building Model

Table 88: Scenario #1 Building Model (P2 Level, Zone Input Data Sheet)

Building Model # 1 <u>ZONE INPUT DATA SHEET</u> P2 LEVEL: Foot print Area = 42483.5 ft², Perimeter = 899'-3" Occupancy : 0 ft² / Person, Overhead Lighting :0.54,0.60,0.09 W / ft², Miscellaneous load:0.182W/ ft²								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² / Person	Overhead Lighting W / ft2	Electric Equipment W / ft ²
P2 FL_Z-1	CORRIDOR STORAGE ROOM	1170.7	166'- 2"	200	20.00	-	2.00	-
P2 FL_Z-2	STORAGE CAGE	207.49	56'- 7"	-	20.00	-	2.00	-
P2 FL_Z-3	UNCONDITI ONED SPACE	41106	899'- 3"	-	-	-	-	-

Figure 89: 1st Floor Zone Layout Scenario #2 Building Model

Table 89: Scenario #2 Building Model (Floor-1, Zone Input Data Sheet)

Building Model # 2 <u>ZONE INPUT DATA SHEET</u> FLOOR-1: Foot print Area = 19698.68 ft² , Perimeter = 563'-9"								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² / Person	Overhead Lighting W / ft ²	Electric Equipment W / ft ²
1 st FL_Z-1	OFFICE	413.5	86'-8"	595	20.00	275.0	2.00	0.75
1 st FL_Z-2	OFFICE	982.9	157'-0"	1430	20.00	275.0	2.00	0.75
1 st FL_Z-3	OFFICE	266.43	65'- 4"	500	20.00	275.0	2.00	0.75
1 st FL_Z-4	OFFICE	1401.4	203'-7"	1830	20.00	275.0	2.00	0.75
1 st FL_Z-5	OFFICE	660.76	102'- 11"	520	20.00	275.0	2.00	0.75
1 st FL_Z-6	OFFICE	188.6	55'- 11"	300	20.00	275.0	2.00	0.75
1 st FL_Z-7	OFFICE	1989.8	273'-3"	2940	20.00	275.0	2.00	0.75
1 st FL_Z-8	OFFICE	189.43	56'- 0"	330	20.00	275.0	2.00	0.75
1 st FL_Z-9	OFFICE	653.7	112'-6"	1000	20.00	275.0	2.00	0.75
1 st FL_Z-10	OFFICE	797.0	113'-1"	900	20.00	275.0	2.00	0.75
1 st FL_Z-11	CORE SPACE	12154	500'- 4"	7870	15.00	275.0	2.00	0.75
1 st FL_Z-12	VESTIBULES	360.51	85'- 1"	250	15.00	275.0	2.00	0.75

2nd Floor Zone layout

Figure 90: 2nd Floor Zone Layout Scenario #2 Building Model

Table 90: Scenario #2 Building Model (Floor-2, Zone Input Data Sheet)

Building Model # 2 <u>ZONE INPUT DATA SHEET</u> FLOOR-2: Foot print Area = 23973.36 ft² , Perimeter = 619'- 4"								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² / Person	Overhead Lighting W / ft2	Electric Equipment W / ft ²
2 nd FL_Z-1	OFFICE	303.34	69'- 8"	600	20.00	275.0	2.00	0.75
2 nd FL_Z-2	OFFICE	2002.7	264'-10"	2650	20.00	275.0	2.00	0.75
2 nd FL_Z-3	OFFICE	390.42	79'-8"	480	20.00	275.0	2.00	0.75
2 nd FL_Z-4	OFFICE	2065.0	274'-10"	2290	20.00	275.0	2.00	0.75
2 nd FL_Z-5	OFFICE	328.32	79'- 8"	610	20.00	275.0	2.00	0.75
2 nd FL_Z-6	OFFICE	2115.8	294'-10"	2290	20.00	275.0	2.00	0.75
2 nd FL_Z-7	OFFICE	477.51	89'- 8"	610	20.00	275.0	2.00	0.75
2 nd FL_Z-8	OFFICE	2090.1	274'-10"	3010	20.00	275.0	2.00	0.75
2 nd FL_Z-9	CORE SPACE	14400	480'- 0"	12420	20.00	275.0	2.00	0.75

3RD FLOOR ZONE LAYOUT

Figure 91: 3rd Floor Zone Layout Scenario #2 Building Model

Table 91: Scenario #2 Building Model (Floor-3, Zone Input Data Sheet)

Building Model # 2 <u>ZONE INPUT DATA SHEET</u> FLOOR-3: Foot print Area = 23973.36 ft² , Perimeter = 619'- 4"								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² / Person	Overhead Lighting W / ft2	Electric Equipment W / ft ²
3 rd FL_Z-1	CAFETERIA	564.59	99'- 8"	610	20.00			5.00
3 rd FL_Z-2	OFFICE	1828.8	244'-10"	3270	20.00			0.80
3 rd FL_Z-3	OFFICE	478.39	89'- 9"	660	20.00			0.80
3 rd FL_Z-4	OFFICE	348.33	74'- 10"	390	20.00			0.80
3 rd FL_Z-5	COMPUTER ROOM	2411.7	94'- 10"	780	20.00			0.80
3 rd FL_Z-6	OFFICE	870.83	134'- 10"	720	20.00			0.80
3 rd FL_Z-7	OFFICE	302.80	69'- 7"	440	20.00			0.80
3 rd FL_Z-8	OFFICE	2087.2	274'-9"	2310	20.00			0.80
3 rd FL_Z-9	OFFICE	302.93	69'-7"	520	20.00			0.80
3 rd FL_Z-10	OFFICE	959.7	145'-0"	1000	20.00			0.80
3 rd FL_Z-11	OFFICE	496.0	104'-7"	1245	20.00			0.80
3 rd FL_Z-12	OFFICE	783.7	124'-10"	780	20.00			0.80
3 rd FL_Z-13	CORE SPACE	13353	570'- 0"	10610	20.00			0.80

4th FLOOR ZONE LAYOUT

Figure 92: 4th Floor Zone Layout Scenario #2 Building Model

Table 92: Scenario #2 Building Model (Floor-4, Zone Input Data Sheet)

Building Model # 2 <u>ZONE INPUT DATA SHEET</u> FLOOR-4: Foot print Area = 23973.36 ft² , Perimeter = 619'- 4"								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² / Person	Overhead Lighting W / ft2	Electric Equipment W / ft ²
4 th FL_Z-1	OFFICE	303.34	69'- 8"	450	20.00			5.00
4 th FL_Z-2	OFFICE	2090.0	274'-10"	2880	20.00			0.80
4 th FL_Z-3	OFFICE	303.3	69'- 8"	390	20.00			0.80
4 th FL_Z-4	OFFICE	2090	274'-10"	2355	20.00			0.80
4 th FL_Z-5	OFFICE	390.42	79'- 8"	480	20.00			0.80
4 th FL_Z-6	OFFICE	2003.0	264'-10"	2090	20.00			0.80
4 th FL_Z-7	OFFICE	303.3	69'- 8"	390	20.00			0.80
4 th FL_Z-8	OFFICE	2090	274'-10"	2400	20.00			0.80
4 th FL_Z-9	CORE SPACE	14400	480'- 0"	10995	20.00			0.80

Figure 93: 5th Floor Zone Layout Scenario #2 Building Model

Table 93: Scenario #2 Building Model (Floor-5, Zone Input Data Sheet)

Building Model # 2 <u>ZONE INPUT DATA SHEET</u> FLOOR-5: Foot print Area = 23973.36 ft², Perimeter = 619'- 4"								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² / Person	Overhead Lighting W / ft2	Electric Equipment W / ft ²
5 th FL_Z-1	OFFICE	390.42	79'- 8"	450	20.00			5.00
5 th FL_Z-2	OFFICE	2090	274'-10"	2745	20.00			0.80
5 th FL_Z-3	OFFICE	216.26	59'- 8"	300	20.00			0.80
5 th FL_Z-4	OFFICE	1094.2	174'- 10"	1125	20.00			0.80
5 th FL_Z-5	OFFICE	480.25	86'- 4"	600	20.00			0.80
5 th FL_Z-6	OFFICE	196.72	63'- 6"	150				0.80
5 th FL_Z-7	OFFICE	726.21	125'- 11"	500				0.80
5 th FL_Z-8	OFFICE	2219.5	279'-0"	2080				0.80
5 th FL_Z-9	OFFICE	390.42	79'- 8"	480				0.80
5 th FL_Z-10	OFFICE	1915.8	254'-10"	2360				0.80
5 th FL_Z-11	CORE SPACE	10648.7	495'-1"	7850				0.80
5 th FL_Z-12	CONFERENCE ROOM#2	3661.7	263' – 7"	-	20.00	275.0	2.00	0.75

6TH FLOOR ZONE LAYOUT

Figure 94: 6th Floor Zone Layout Scenario #2 Building Model

Table 94: Scenario #2 Building Model (Floor-6, Zone Input Data Sheet)

Building Model # 2 <u>ZONE INPUT DATA SHEET</u> FLOOR-6: Foot print Area = 23973.36 ft² , Perimeter = 619' - 4"								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² / Person	Overhead Lighting W / ft2	Electric Equipment W / ft ²
6 th FL_Z-1	OFFICE	303.36	69'- 8"	400	20.00			5.00
6 th FL_Z-2	OFFICE	696.72	114'- 10"	785	20.00			0.80
6 th FL_Z-3	OFFICE	291.20	80'- 0"	200	20.00			0.80
6 th FL_Z-4	OFFICE	700.14	110'- 0"	945	20.00			0.80
6 th FL_Z-5	OFFICE	261.23	64'- 10"	270	20.00			0.80
6 th FL_Z-6	OFFICE	261.23	64'- 10"	270	20.00			0.80
6 th FL_Z-7	OFFICE	569.17	104'- 10"	540	20.00			0.80
6 th FL_Z-8	OFFICE	737.00	124'- 10"	630	20.00			0.80
6 th FL_Z-9	OFFICE	261.27	64'- 10"	190	20.00			0.80
6 th FL_Z-10	OFFICE	390.39	79'- 8"	300	20.00			0.80
6 th FL_Z-11	OFFICE	696.61	114'- 10"	560	20.00			0.80
6 th FL_Z-12	OFFICE	496.4	91'-10"	460	20.00			0.80
6 th FL_Z-13	OFFICE	1192.7	184'- 3"	900	20.00			0.80
6 th FL_Z-14	OFFICE	928.39	124'-3"	980	20.00			0.80
6 th FL_Z-15	OFFICE	1571.7	165'- 9"	1315	20.00			0.80
6 th FL_Z-16	OFFICE	1278.4	141'- 11"	1050	20.00			0.80
6 th FL_Z-17	OFFICE	397.54	83'- 0"	170	20.00			0.80
6 th FL_Z-18	OFFICE	3608	237'- 8"	1200	20.00	275.0	2.00	0.75

6 th FL_Z-19	CORRIDOR	2177	242'- 5"	900	20.00	275.0	2.00	0.75
6 th FL_Z-20	OFFICE	674.98	120'- 00"	840	20.00	275.0	2.00	0.75
6 th FL_Z-21	MECHANICAL ROOM	5916.0	423'- 11"	-	20.00	275.0	2.00	0.75

Figure 95: P1 Level Floor Zone Layout Scenario #2 Building Model

Table 95: Scenario #2 Building Model (P1 Level, Zone Input Data Sheet)

Building Model # 2 ZONE INPUT DATA SHEET P1 LEVEL: Foot print Area = 23973.36 ft ² , Perimeter = 619'- 4"								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person "Standard"	Occupancy ft ² Per Person	Overhead Lighting W / ft ²	Electric Equipment W / ft ²
P1 FL_Z-1	UNCONDITIONED SPACE	31226	788'- 6"		20.00	-		-
P1 FL_Z-2	HEALTH/STORAGE, TELEPHONE ROOM, RECYCLING ROOM, MAINTENANC ROOM, WELLNESS CENTER, METER ROOM, and CORRIDOR	4741.5	371'- 0"	1400	20.00	1185	1/03	1.76
P1 FL_Z-3	MAILING ROOM and PRINTING ROOM	1370.6	15'-1"	500	20.00	297	1.03	7.1
P1 FL_Z-3	COMMUNICATION ROOM	725.19	122'- 9"		20.00	297	1.03	7.1

P2 LEVEL FOOTPRINT CONDITIONED AND UNCONDITIONED LAYOUT

Figure 96: P2 Level Floor Zone Layout Scenario #2 Building Model

Table 96: Scenario #2 Building Model (P2 Level, Zone Input Data Sheet)

Building Model # 2 <u>ZONE INPUT DATA SHEET</u> P2 LEVEL: Foot print Area = 42483.5 ft², Perimeter = 899'-3"								
Zone Name	Zone	Floor Area ft ²	Perimeter Ft-in	CFM Per Zone	Out Door Air CFM Per Person	Occupancy ft ² / Person	Overhead Lighting W / ft2	Electric Equipment W / ft ²
P2 FL_Z-1	CORRIDOR STORAGE ROOM	1378.2	161'- 1"	200 +	20.00	-	0.55	-
P2 FL_Z-2	UNCONDITIONED SPACE	41106	899'- 3"	-	-	-	0.09	0.182

Table 97: Lighting Controls Strategy

Lighting Controls		
Lighting Control Strategy		% Reduction in Lighting Power
Day Lighting Sensing Control	Continuous Dimming	30%
	Multiple Step Dimming	20%
	On / Off	10%
Occupancy Sensor		30%
Occupancy & Daylight Sensing	Continuous Dimming	40%
	Multiple Step Dimming	40%
	On / Off	40%

Appendix 3: Weather Data, Product Catalogues of Heat Pumps and Ground Properties

Table 98: Ontario Lake Daily Monthly Surface Temperature (Great Lake Surface Environmental Analysis Maps)

Daily Ontario Lake Average Surface Water Temperature From the Great Lake Surface Environmental Analysis Maps (Surface Water Temperature ⁰ C)											
Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp
1-Jan	5.87	3-Mar	0.84	3-May	5.14	3-Jul	18.91	2-Sep	19.43	2-Nov	11.95
2-Jan	5.84	4-Mar	0.84	4-May	4.55	4-Jul	18.34	3-Sep	22.13	3-Nov	10.97
3-Jan	6.07	5-Mar	0.94	5-May	4.96	5-Jul	18.36	4-Sep	22.56	4-Nov	10.68
4-Jan	5.65	6-Mar	1.19	6-May	4.95	6-Jul	20.39	5-Sep	20.47	5-Nov	10.68
5-Jan	5.65	7-Mar	1.21	7-May	7.77	7-Jul	21.43	6-Sep	21.1	6-Nov	9.3
6-Jan	5.66	8-Mar	1.17	8-May	6.58	8-Jul	20.83	7-Sep	21.02	7-Nov	9.78
7-Jan	5.1	9-Mar	1.61	9-May	5.25	9-Jul	18.64	8-Sep	20.94	8-Nov	9.81
8-Jan	5.13	10-Mar	1.61	10-May	5.49	10-Jul	18.68	9-Sep	18.82	9-Nov	9.81
9-Jan	4.98	11-Mar	2.28	11-May	5.73	11-Jul	17.7	10-Sep	19.09	10-Nov	10.09
10-Jan	4.82	12-Mar	1.56	12-May	6.33	12-Jul	17.71	11-Sep	19.39	11-Nov	9.75
11-Jan	4.46	13-Mar	1.64	13-May	6.32	13-Jul	17.74	12-Sep	19.06	12-Nov	9.75
12-Jan	4.47	14-Mar	1.64	14-May	5.57	14-Jul	18.4	13-Sep	17.91	13-Nov	9.2
13-Jan	4.47	15-Mar	1.65	15-May	5.69	15-Jul	21.09	14-Sep	18.14	14-Nov	7.84
14-Jan	4.47	16-Mar	1.63	16-May	6.5	16-Jul	19.91	15-Sep	18.99	15-Nov	9.12
15-Jan	4.47	17-Mar	1.63	17-May	6.24	17-Jul	17.78	16-Sep	19.16	16-Nov	8.53
16-Jan	4.52	18-Mar	1.95	18-May	6.48	18-Jul	19.25	17-Sep	19.39	17-Nov	7.74
17-Jan	3.98	19-Mar	1.25	19-May	6.08	19-Jul	20.91	18-Sep	18.6	18-Nov	7.74
18-Jan	4.04	20-Mar	2.09	20-May	8.29	20-Jul	19.58	19-Sep	18.73	19-Nov	7.75
19-Jan	4.04	21-Mar	1.24	21-May	10.26	21-Jul	19.45	20-Sep	19.01	20-Nov	8.56
20-Jan	4.49	22-Mar	1.24	22-May	11.94	22-Jul	20.82	21-Sep	19.3	21-Nov	7.59
21-Jan	3.9	23-Mar	2.08	23-May	11.69	23-Jul	22.25	22-Sep	18.99	22-Nov	8.04
22-Jan	3.9	24-Mar	1.63	24-May	11.67	24-Jul	21.32	23-Sep	19.01	23-Nov	8.04
23-Jan	3.91	25-Mar	1.63	25-May	8.52	25-Jul	22.01	24-Sep	19.01	24-Nov	8.02
24-Jan	4.14	26-Mar	1.83	26-May	10.45	26-Jul	22.15	25-Sep	18.66	25-Nov	6.67
25-Jan	4.08	27-Mar	1.94	27-May	13.29	27-Jul	24.3	26-Sep	18.76	26-Nov	6.67
26-Jan	4.01	28-Mar	2.4	28-May	14.92	28-Jul	24.1	27-Sep	17.23	27-Nov	6.66
27-Jan	4.01	29-Mar	2.76	29-May	14.91	29-Jul	25.48	28-Sep	15.9	28-Nov	5.5
28-Jan	4.01	30-Mar	2.22	30-May	16.92	30-Jul	25.47	29-Sep	17.54	29-Nov	5.51
29-Jan	3.63	31-Mar	2.13	31-May	14.14	31-Jul	24.15	30-Sep	17.34	30-Nov	5.51
30-Jan	3.57	1-Apr	2.13	1-Jun	14.14	1-Aug	23.78	1-Oct	18.04	1-Dec	5.49
31-Jan	3.57	2-Apr	2.13	2-Jun	12.55	2-Aug	23.44	2-Oct	19.75	2-Dec	5.15
1-Feb	3.57	3-Apr	2.16	3-Jun	9.3	3-Aug	22.4	3-Oct	18.75	3-Dec	5.02
2-Feb	3.57	4-Apr	2.16	4-Jun	8.92	4-Aug	22.62	4-Oct	18.01	4-Dec	5.02

3-Feb	3.53	5-Apr	2.16	5-Jun	13.33	5-Aug	22.67	5-Oct	19.86	5-Dec	5.07
4-Feb	3.49	6-Apr	2.17	6-Jun	9.67	6-Aug	22.61	6-Oct	18.31	6-Dec	5.07
5-Feb	3.49	7-Apr	2.17	7-Jun	11.47	7-Aug	22.61	7-Oct	17.96	7-Dec	5.07
6-Feb	3.49	8-Apr	2.19	8-Jun	14.01	8-Aug	23.62	8-Oct	17.59	8-Dec	5.03
7-Feb	3.47	9-Apr	1.6	9-Jun	14.59	9-Aug	23.47	9-Oct	17.22	9-Dec	5.5
8-Feb	2.91	10-Apr	2.3	10-Jun	15.19	10-Aug	22.9	10-Oct	16.64	10-Dec	4.82
9-Feb	2.95	11-Apr	1.82	11-Jun	13.4	11-Aug	22.17	11-Oct	14.74	11-Dec	4.83
10-Feb	2.88	12-Apr	1.82	12-Jun	16.62	12-Aug	20.81	12-Oct	14.54	12-Dec	4.83
11-Feb	2.81	13-Apr	1.82	13-Jun	16.51	13-Aug	21.1	13-Oct	14.99	13-Dec	4.83
12-Feb	2.81	14-Apr	1.82	14-Jun	15.56	14-Aug	20.86	14-Oct	15.23	14-Dec	4.57
13-Feb	2.81	15-Apr	2.91	15-Jun	17.48	15-Aug	19.51	15-Oct	15.23	15-Dec	4.57
14-Feb	2.81	16-Apr	3.59	16-Jun	17.28	16-Aug	18.93	16-Oct	15.31	16-Dec	4.58
15-Feb	2.06	17-Apr	3.14	17-Jun	15.03	17-Aug	18.95	17-Oct	15.33	17-Dec	4.58
16-Feb	2.15	18-Apr	2.94	18-Jun	14.71	18-Aug	18.79	18-Oct	15.37	18-Dec	4.44
17-Feb	2.12	19-Apr	3.2	19-Jun	14.58	19-Aug	18.87	19-Oct	15.79	19-Dec	4.42
18-Feb	2.17	20-Apr	4.42	20-Jun	15.43	20-Aug	19.32	20-Oct	15.79	20-Dec	4.44
19-Feb	1.49	21-Apr	3.25	21-Jun	17.78	21-Aug	21.42	21-Oct	15.1	21-Dec	4.44
20-Feb	1.49	22-Apr	2.28	22-Jun	18.33	22-Aug	21.39	22-Oct	14.77	22-Dec	4.44
21-Feb	2.15	23-Apr	2.28	23-Jun	21.02	23-Aug	20.29	23-Oct	14.68	23-Dec	4.43
22-Feb	1.79	24-Apr	2.28	24-Jun	19.52	24-Aug	19.73	24-Oct	14.68	24-Dec	4.43
23-Feb	2.24	25-Apr	2.28	25-Jun	17.57	25-Aug	21.31	25-Oct	13.9	25-Dec	4.31
24-Feb	2.14	26-Apr	3.84	26-Jun	17.53	26-Aug	23.37	26-Oct	12.76	26-Dec	4.31
25-Feb	1.75	27-Apr	3.48	27-Jun	18.63	27-Aug	21.05	27-Oct	12.29	27-Dec	4.31
26-Feb	1.75	28-Apr	3.48	28-Jun	17.64	28-Aug	21.12	28-Oct	13.04	28-Dec	4.27
27-Feb	1.75	29-Apr	4.56	29-Jun	17.85	29-Aug	20.92	29-Oct	12.52		
28-Feb	2.01	30-Apr	3.88	30-Jun	17.37	30-Aug	21.05	30-Oct	12.56		
1-Mar	0.84	1-May	4.3	1-Jul	17.39	31-Aug	20.44	31-Oct	12.37		
2-Mar	0.84	2-May	4.42	2-Jul	18.6	1-Sep	20.18	1-Nov	11.5		

Table 99: Product Catalogue of Heat Pumps

THE SMART SOLUTION FOR ENERGY EFFICIENCY

Genesis Large (GL) Series
Rev. 05/23/2020

Performance Data
ARI/ASHRAE/ISO 13256-1

ASHRAE/ARI/ISO 13256-1, English (IP) Units

Model	Water Loop Heat Pump				Ground Water Heat Pump				Ground Loop Heat Pump			
	Cooling 86°F		Heating 68°F		Cooling 59°F		Heating 50°F		Cooling 77°F		Heating 32°F	
	Capacity Btuh	EER Btuh/W	Capacity Btuh	COP	Capacity Btuh	EER Btuh/W	Capacity Btuh	COP	Capacity Btuh	EER Btuh/W	Capacity Btuh	COP
GLH072	58,000	13.2	86,000	4.8	76,000	18.7	69,000	4.1	70,500	14.6	52,500	3.6
GLH096	94,600	12.8	108,700	4.4	101,900	17.4	91,000	4.0	98,700	14.2	72,600	3.4
GLH120	120,000	12.7	137,800	4.2	127,600	17.2	114,000	3.9	122,200	14.1	90,500	3.2
GLV080	71,000	13.5	90,000	4.5	76,500	17.7	72,000	3.9	72,200	14.8	56,800	3.2
GLV100	97,000	12.5	111,000	4.5	106,000	17.0	98,700	4.0	103,000	14.3	79,300	3.3
GLV120	108,000	12.2	124,000	4.2	116,500	16.8	99,500	3.8	111,000	13.4	79,000	3.3
GLV160	142,000	13.5	180,000	4.5	151,000	17.7	144,000	3.9	144,400	14.8	112,800	3.2
GLV200	194,000	12.5	228,000	4.5	216,000	17.0	181,400	4.0	206,000	14.3	146,600	3.3
GLV240	218,000	12.2	248,000	4.2	233,000	16.2	199,000	3.8	222,000	13.4	168,600	3.3
GLV300	273,000	11.8	318,000	4.0	286,000	15.8	250,500	3.4	275,400	12.7	209,200	3.0

Cooling capacities based upon 80.6°F DB, 66.2°F WB entering air temperature
Heating capacities based upon 68°F DB, 59°F WB entering air temperature
All air flow is rated on high speed
All ratings based upon operation at lower voltage of dual voltage rated models

ASHRAE/ARI/ISO 13256-1, Metric (SI) Units

Model	Water Loop Heat Pump				Ground Water Heat Pump				Ground Loop Heat Pump			
	Cooling 30°C		Heating 20°C		Cooling 15°C		Heating 10°C		Cooling 25°C		Heating 0°C	
	Capacity Wats	EER W/W	Capacity Wats	COP	Capacity Wats	EER W/W	Capacity Wats	COP	Capacity Wats	EER W/W	Capacity Wats	COP
GLH072	17,530	3.9	25,205	4.8	22,274	5.9	20,203	4.1	20,562	4.3	15,587	3.6
GLH096	27,726	3.8	31,858	4.4	29,895	5.1	26,671	4.0	28,341	4.2	21,278	3.4
GLH120	35,170	3.7	40,387	4.2	37,397	5.0	33,411	3.9	35,815	4.1	26,524	3.2
GLV080	20,809	4.0	26,377	4.5	22,128	5.2	21,132	3.9	21,161	4.9	16,501	3.2
GLV100	28,429	3.7	32,532	4.5	31,653	5.0	28,563	4.0	30,188	4.2	21,482	3.3
GLV120	31,858	3.6	36,342	4.2	34,144	4.7	29,152	3.8	32,562	3.9	25,154	3.3
GLV160	41,616	4.0	52,755	4.5	44,256	5.2	42,204	3.9	42,321	4.9	33,001	3.2
GLV200	58,858	3.7	66,064	4.5	63,308	5.0	53,159	4.0	60,375	4.2	42,966	3.3
GLV240	63,306	3.6	72,685	4.2	68,288	4.7	58,324	3.8	65,064	3.9	46,307	3.3
GLV300	80,012	3.5	89,200	4.0	83,822	4.6	78,377	3.4	81,504	3.7	61,513	3.0

Cooling capacities based upon 27°C DB, 19°C WB entering air temperature
Heating capacities based upon 20°C DB, 15°C WB entering air temperature
All air flow is rated on high speed
All ratings based upon operation at lower voltage of dual voltage rated models

THE SMART SOLUTION FOR ENERGY EFFICIENCY

Genesis Large (GL) Series
Rev. 1: 05/23/07 D

Performance Data GLH072

2400 CFM Nominal (Rated) Airflow

Performance capacities shown in thousands of Btu/h

EWT °F	GPM	WPD		Cooling - EAT 80/67°F						Heating - EAT 70°F				
		PSI	FT	TC	SC	Refr/Flt Ratio	kW	HR	EER	HC	kW	HE	LAT	COP
20	18	6.0	13.7	Operation Not Recommended						42.7	4.00	29.1	85.5	3.15
	9	1.7	4.0	82.7	64.8	0.66	3.79	95.6	21.8	47.7	4.19	33.4	89.4	3.33
	14	5.1	7.8	83.4	65.3	0.66	3.54	95.5	23.8	49.9	4.28	35.3	90.2	3.41
30	15	6.4	12.5	83.7	65.5	0.66	3.43	95.4	24.4	51.1	4.33	36.3	90.7	3.46
	9	1.6	3.8	80.6	64.3	0.68	4.16	94.8	19.4	55.5	4.50	40.1	91.4	3.51
	14	3.0	6.8	82.0	65.5	0.68	3.80	95.8	21.1	56.2	4.60	42.5	92.4	3.70
40	18	5.1	11.7	82.5	65.6	0.67	3.76	95.4	21.9	59.8	4.66	43.7	93.0	3.75
	9	1.3	3.0	77.8	63.4	0.69	4.55	93.3	17.1	63.4	4.80	47.0	94.4	3.87
	14	2.5	5.8	79.9	64.5	0.68	4.38	94.4	18.7	66.6	4.91	49.8	95.7	3.97
50	18	4.2	9.7	80.7	65.0	0.68	4.14	94.9	19.5	68.3	4.98	51.3	95.3	4.02
	9	1.2	2.8	74.3	61.4	0.69	4.96	91.2	15.0	71.3	5.09	54.0	97.6	4.11
	14	2.4	5.5	76.7	62.8	0.69	4.86	92.7	16.4	75.0	5.22	57.2	98.9	4.21
60	18	4.0	9.2	77.9	63.5	0.69	4.64	93.4	17.2	77.0	5.29	58.9	99.7	4.26
	9	1.2	2.7	70.8	49.2	0.70	5.37	88.7	13.1	79.3	5.37	61.0	100.6	4.39
	14	2.3	5.3	73.0	50.7	0.69	5.10	90.4	14.3	83.4	5.51	64.6	102.2	4.48
70	18	3.8	8.6	74.3	51.4	0.69	4.96	91.2	15.0	85.6	5.59	66.5	103.0	4.48
	9	1.1	2.6	66.2	47.0	0.71	5.78	85.9	11.5	87.2	5.64	67.9	103.5	4.58
	14	2.2	5.1	68.9	48.5	0.70	5.52	87.7	12.5	91.6	5.79	71.9	105.4	4.64
80	18	3.7	8.5	70.3	49.2	0.70	5.66	88.6	13.1	94.0	5.87	74.0	106.3	4.70
	9	1.1	2.6	64.2	46.3	0.72	5.86	84.8	10.7	91.1	5.77	71.4	105.1	4.62
	14	2.2	5.0	66.6	47.5	0.71	5.72	86.3	11.7	95.7	5.92	75.5	106.9	4.74
90	18	3.6	8.4	68.2	48.1	0.71	5.59	87.2	12.2	98.2	6.00	77.7	107.9	4.80
	9	1.1	2.5	62.2	45.5	0.73	6.16	83.8	10.1	94.9	5.89	74.8	106.6	4.72
	14	2.1	4.9	64.7	46.5	0.72	5.96	84.9	10.9	99.7	6.04	79.0	108.4	4.83
100	18	3.6	8.2	66.0	47.1	0.71	5.80	85.8	11.4	102.2	6.12	81.3	109.4	4.89
	9	1.1	2.5	58.5	44.5	0.75	6.56	80.9	8.3	Operation Not Recommended				
	14	2.1	4.8	60.7	45.0	0.74	6.39	82.3	9.6					
	15	3.4	7.9	61.9	45.4	0.73	6.21	83.1	10.0					
110	9	1.0	2.4	55.4	44.3	0.80	6.91	79.0	8.0	Operation Not Recommended				
	14	2.0	4.6	57.2	44.3	0.77	6.70	80.1	8.5					
	18	3.3	7.6	58.2	44.4	0.75	6.59	80.7	8.8					

Interpolation is permissible; extrapolation is not.
 All entering air conditions are 80°F DB and 67°F WB in cooling, and 70°F DB in heating.
 AHRS/CO control conditions are 80°F DB and 66.2°F WB in cooling and 68°F DB in heating.
 Table does not reflect fan or pump power corrections for AHRS/CO conditions.
 All performance is based upon the lower voltage of dual voltage rated units.
 Performance shown is at the rated power supply; performance may vary as the power supply varies from the rated.
 Operation below 40°F EWT is based upon a 15% ammonia solution.
 Operation below 55°F EWT requires optional insulated refrigerant/pipework circuit.
 See Performance Correction Tables for operating conditions other than those listed above.
 See Performance Data Selection Notes for operation in shaded areas.

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GL
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THE SMART SOLUTION FOR ENERGY EFFICIENCY

Genesis Large (GL) Series

REV. 05/23/07 D

Performance Data GLV160

5000 CFM Nominal (Rated) Airflow

Performance capacities shown in thousands of Btu/h

EWT °F	GPM	WPD		Cooling - EAT 80/67°F						Heating - EAT 70°F				
		PSI	FT	TC	SC	Base/Alt Ratio	kW	HR	EER	HC	kW	HE	LAT	COP
20	37	13.3	30.8	Operation Not Recommended						96.6	3.47	64.8	87.2	3.99
30	18	7.5	17.3	156.7	109.3	0.70	7.94	183.8	19.7	106.3	9.79	79.1	89.8	3.20
	27	9.8	22.2	156.6	109.0	0.70	7.56	182.6	20.7	110.7	9.84	77.1	89.7	3.29
	37	12.5	28.9	156.6	108.8	0.70	7.51	182.2	20.9	116.6	10.00	82.4	90.8	3.41
40	18	6.9	16.0	155.6	110.2	0.71	8.48	184.5	19.3	122.1	10.15	87.4	91.7	3.52
	27	8.9	20.5	156.5	109.8	0.70	8.11	184.1	19.3	127.7	10.31	92.5	92.7	3.63
	37	11.5	26.7	156.7	109.3	0.70	7.93	183.7	19.8	130.0	10.39	95.4	93.3	3.69
50	18	5.4	12.4	153.2	109.7	0.72	9.07	184.2	16.9	138.9	10.62	102.6	94.7	3.93
	27	7.5	17.4	154.9	110.1	0.71	8.66	184.5	17.9	145.9	10.81	100.0	96.0	3.95
	37	9.9	22.9	155.6	110.2	0.71	8.47	184.5	18.4	149.8	10.92	112.5	98.7	4.02
60	18	5.2	12.0	149.9	109.3	0.72	9.78	183.1	15.4	156.5	11.12	118.6	97.9	4.13
	27	7.3	16.9	152.3	109.3	0.72	9.27	183.9	16.4	164.9	11.36	126.2	99.4	4.26
	37	9.7	22.3	159.3	109.7	0.72	9.05	184.2	16.9	169.7	11.48	130.5	100.2	4.33
70	18	5.1	11.7	145.6	106.5	0.73	10.49	181.4	13.9	174.8	11.64	135.1	101.1	4.40
	27	7.2	16.5	148.6	107.7	0.73	9.96	182.6	14.9	184.8	11.83	144.1	102.9	4.54
	37	9.4	21.8	149.9	108.3	0.72	9.72	183.1	15.4	190.6	12.10	149.2	103.9	4.61
80	18	5.0	11.5	140.5	104.8	0.74	11.36	176.4	12.4	193.7	12.20	152.1	104.5	4.65
	27	7.0	16.2	144.0	105.8	0.73	10.77	180.7	13.4	205.3	12.54	162.6	106.6	4.80
	37	9.2	21.3	145.6	106.5	0.73	10.48	181.4	13.9	211.9	12.74	168.4	107.7	4.87
85	18	4.9	11.4	137.8	103.7	0.75	11.86	176.3	11.5	203.4	12.48	160.6	106.2	4.77
	27	7.0	16.1	141.4	104.9	0.74	11.22	179.7	12.8	215.8	12.86	172.0	108.4	4.92
	37	9.1	21.1	143.2	105.5	0.74	10.91	180.4	13.1	222.9	13.07	178.3	109.7	5.00
90	18	4.9	11.3	134.8	102.9	0.75	12.43	177.3	10.8	213.2	12.76	169.6	106.9	4.89
	27	6.9	15.9	138.7	104.0	0.75	11.72	178.7	11.8	226.4	13.16	181.6	110.3	5.04
	37	9.1	20.9	140.5	104.5	0.74	11.38	179.4	12.3	233.9	13.40	188.2	111.7	5.11
100	18	4.8	11.1	128.6	101.7	0.79	13.67	175.2	9.4	Operation Not Recommended				
	27	6.8	15.7	132.7	102.4	0.77	12.84	176.5	10.3					
	37	8.9	20.6	134.7	102.9	0.76	12.45	177.9	10.8					
110	18	4.8	11.0	121.9	101.2	0.83	15.19	173.5	8.1	Operation Not Recommended				
	27	6.7	15.5	126.2	101.5	0.80	14.16	174.6	8.9					
110	37	8.8	20.4	128.4	101.7	0.79	13.71	175.2	9.4	Operation Not Recommended				

Interpolation is permissible; extrapolation is not.
 All entering air conditions are 80°F DB and 67°F WB in cooling, and 70°F DB in heating.
 AHRI/ISO certified conditions are 80°F DB and 66.2°F WB in cooling and 58°F DB in heating.
 Table does not reflect fan or pump power corrections for AHRI/ISO conditions.
 All performance is based upon the lower voltage of dual voltage rated units.
 Performance listed is at the rated power supply; performance may vary as the power supply varies from the rated.
 Operation below 60°F EWT is based upon a 12% antifreeze solution.
 Operation below 60°F EWT requires optional insulated water/heating/coolant circuit.
 See performance correction tables for operating conditions other than those listed above.
 See Performance Data Selection Notes for operation in shaded areas.

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GL
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CLIMATEMASTER WATER-SOURCE HEAT PUMPS

Genesis Large (GL) Series
Rev.: 05/23/07D

Performance Data GLV200

7000 GPM Nominal (Rated) Airflow

Performance capacities shown in thousands of btu/h

EWT °F	GPM	WPD		Cooling - EAT 80/67°F						Heating - EAT 70°F				
		PSI	FT	TC	SC	Sens/Tot Ratio	kW	HR	EER	HC	kW	HE	LAT	COP
20	48	15.6	36.1	Operation Not Recommended						157.2	13.01	93.5	98.2	3.11
30	24	7.4	17.2	224.8	157.2	0.70	11.78	265.9	19.1	146.1	13.26	100.8	99.3	3.22
	36	10.3	23.7	225.2	156.0	0.69	11.16	263.3	20.2	150.8	13.41	104.8	99.9	3.25
	48	14.0	32.4	225.4	153.8	0.69	10.85	262.4	20.6	153.1	13.49	107.1	100.2	3.36
40	24	9.8	15.7	222.9	156.7	0.71	12.59	265.8	17.7	162.8	13.76	115.8	91.5	3.47
	36	9.4	21.7	224.6	157.7	0.70	11.99	265.5	18.7	169.1	13.93	121.6	92.4	3.56
	48	12.8	29.7	224.8	156.9	0.70	11.89	264.7	19.2	172.6	14.02	124.9	92.8	3.61
50	24	9.4	14.9	218.1	158.7	0.73	13.41	263.8	16.6	182.2	14.28	133.5	94.1	3.74
	36	8.8	20.4	221.9	158.8	0.72	12.80	265.5	17.3	190.3	14.48	140.9	95.2	3.85
	48	11.9	27.6	223.2	158.8	0.71	12.50	265.9	17.9	194.8	14.60	145.0	95.8	3.91
60	24	9.2	14.3	211.2	157.5	0.75	14.31	260.1	14.8	203.2	14.81	152.7	96.9	4.02
	36	8.5	19.6	216.4	158.4	0.73	13.65	263.0	15.9	212.8	15.05	161.4	98.1	4.14
	48	11.4	26.4	218.7	158.7	0.73	13.33	264.1	16.4	218.0	15.19	166.2	98.8	4.21
70	24	9.0	13.9	203.1	155.4	0.76	15.35	255.5	13.2	224.6	15.35	172.2	99.7	4.29
	36	8.2	19.0	209.1	157.0	0.76	14.69	258.9	14.3	235.2	15.62	181.9	101.1	4.41
	48	11.1	25.7	211.9	157.8	0.74	14.23	260.5	14.9	240.9	15.77	187.1	101.9	4.48
80	24	9.0	13.6	194.4	152.7	0.79	16.58	251.0	11.7	246.4	15.88	191.2	102.5	4.55
	36	8.1	18.7	200.8	154.8	0.77	15.69	254.1	12.8	256.3	16.17	201.1	103.9	4.64
	48	10.9	25.2	203.7	155.5	0.76	15.28	255.8	13.3	261.8	16.32	206.2	104.6	4.70
90	24	8.8	13.6	190.1	151.3	0.80	17.28	249.0	11.0	255.2	16.14	200.1	103.8	4.68
	36	8.0	18.5	198.2	153.3	0.78	16.31	251.9	12.0	265.8	16.48	209.8	105.2	4.74
	48	10.8	25.0	199.3	154.2	0.77	15.87	253.5	12.6	271.1	16.67	214.5	105.9	4.79
100	24	8.8	13.4	185.8	149.8	0.81	18.05	247.4	10.9	264.4	16.40	208.4	105.0	4.72
	36	7.9	18.3	191.8	151.8	0.79	17.00	249.8	11.3	274.4	16.70	217.4	106.3	4.81
	48	10.7	24.8	194.8	152.8	0.78	16.51	251.2	11.8	279.2	16.80	221.9	106.9	4.87
110	24	8.7	13.1	177.9	147.2	0.83	19.67	245.7	9.0	Operation Not Recommended				
	36	7.8	18.0	183.2	149.0	0.81	18.69	248.8	9.9					
	48	10.5	24.3	186.1	149.9	0.81	18.01	247.5	10.8					
120	24	8.5	12.7	171.5	145.5	0.85	22.10	246.9	7.8	Operation Not Recommended				
	36	7.5	17.4	176.7	146.5	0.83	20.52	245.7	8.8					
	48	10.2	23.6	178.1	147.3	0.83	19.82	245.7	9.0					

Interpolation is permissible; extrapolation is not.
All heating air conditions are 80°F DB and 67°F WB in cooling, and 70°F DB in heating.
ARI/ISO certified conditions are 80°F DB and 66.2°F WB in cooling and 68°F DB in heating.
Table does not reflect fan or pump power corrections for ARI/ISO conditions.
All performance is based upon the lower voltage of dual voltage rated units.
Performance stated is at the rated power supply; performance may vary as the power supply varies from the rated.
Operation below 60°F EWT requires optional insulated water-inlet/outlet circuit.
See performance correction tables for operating conditions other than those listed above.
See Performance Data Selection Notes for operation in shaded areas.

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ClimateMaster Water-Source Heating and Cooling Systems

CLIMATEMASTER WATER-SOURCE HEAT PUMPS

Genesis Large (GL) Series

Rev.: 05/23/07D

Performance Data GLV300

9000 CFM Nominal (Fixed) Airflow

Performance capacities shown in thousands of Btu/h

EWT °F	GPM	WPD		Cooling - EAT 80/67°F						Heating - EAT 70°F				
		PSI	FT	TC	SC	Sensitive Fields	KW	HR	EER	HC	kW	HE	LAT	COP
30	75	18.3	43.7	Operation Not Recommended						183.3	19.73	115.7	88.9	2.71
	66	8.6	20.0	282.3	200.2	0.71	16.61	339.3	17.0	203.8	20.36	131.4	90.7	2.69
	56	12.6	29.1	283.0	198.2	0.70	15.68	337.2	17.8	207.3	20.57	137.1	91.3	2.65
40	75	17.5	40.3	283.2	197.1	0.70	15.50	336.1	18.3	210.9	20.65	140.3	91.7	2.65
	66	7.1	16.5	282.3	203.4	0.72	17.88	343.3	15.8	228.3	21.28	155.0	93.5	3.15
	56	10.1	23.4	282.7	201.8	0.71	17.12	341.1	16.5	229.2	21.56	163.4	94.4	3.22
50	75	14.1	32.7	283.0	200.8	0.71	16.74	340.1	16.9	241.6	21.72	167.5	94.9	3.26
	66	6.9	16.0	280.9	205.9	0.78	19.21	346.5	14.6	258.1	22.28	182.1	96.6	3.39
	56	9.8	22.7	281.9	204.5	0.78	18.40	344.7	15.9	268.1	22.62	190.9	97.6	3.47
60	75	13.7	31.7	282.2	203.7	0.72	18.00	343.7	15.7	273.7	22.61	195.9	98.2	3.52
	66	6.7	15.5	279.0	207.2	0.75	20.65	349.5	13.5	288.1	23.30	208.6	99.8	3.62
	56	9.5	22.0	280.0	206.6	0.74	19.78	347.4	14.2	299.4	23.69	219.6	100.8	3.70
70	75	13.3	30.7	280.7	206.0	0.79	19.83	346.7	14.5	305.7	23.90	224.1	101.4	3.75
	66	6.5	15.1	273.0	207.0	0.76	22.34	348.9	12.3	317.4	24.30	234.5	102.7	3.83
	56	9.3	21.4	276.3	207.3	0.75	21.25	348.8	13.0	329.4	24.70	245.1	103.9	3.91
80	75	12.9	29.9	277.7	207.3	0.75	20.77	348.5	13.4	335.9	24.94	250.9	104.8	3.95
	66	6.4	14.7	265.6	204.7	0.77	24.02	347.5	11.1	344.7	25.20	258.7	105.5	4.01
	56	9.1	20.9	270.5	206.3	0.76	22.91	348.5	11.6	355.5	25.58	269.2	106.7	4.06
90	75	12.6	29.1	272.5	206.9	0.76	22.37	348.9	12.2	362.6	25.77	274.7	107.3	4.12
	66	6.3	14.6	260.8	202.7	0.78	24.99	346.0	10.4	367.2	25.90	289.9	108.8	4.09
	56	9.0	20.7	266.5	205.1	0.77	23.82	347.8	11.2	368.5	25.96	279.9	107.9	4.16
100	75	13.5	29.8	269.1	205.9	0.77	23.24	348.4	11.6	374.1	26.12	285.0	108.5	4.20
	66	6.2	14.4	255.2	200.0	0.78	26.02	344.0	9.8	369.7	25.96	280.1	107.9	4.16
	56	8.9	20.6	261.9	203.2	0.78	24.78	346.4	10.6	379.1	26.26	289.5	109.0	4.23
110	75	12.4	28.6	264.9	204.4	0.77	24.17	347.4	11.0	384.1	26.46	294.0	109.5	4.26
	66	6.2	14.2	241.4	192.5	0.80	28.28	337.9	8.5	Operation Not Recommended				
	56	8.7	20.2	259.0	197.3	0.79	26.90	341.8	9.3					
	75	12.2	28.2	254.1	199.5	0.79	26.21	343.5	9.7					
120	66	6.1	14.1	233.9	181.7	0.81	30.82	329.1	7.3	Operation Not Recommended				
	56	8.7	20.0	254.6	188.4	0.80	29.30	334.6	8.0					
	75	12.1	27.9	253.7	191.5	0.80	28.54	337.1	8.4					

Interpolation is permissible; extrapolation is not.
 All entering air conditions are 80°F DB and 67°F WB in cooling, and 70°F DB in heating.
 AHJ/ISO certified conditions are 80.0°F DB and 66.2°F WB in cooling and 68°F DB in heating.
 Table does not reflect fan or pump power corrections for AHJ/ISO conditions.
 All performance is based upon the lower voltage of dual voltage rated units.
 Performance shown is at the rated power supply; performance may vary as the power supply varies from the rated.
 Operation below 40°F EWT is based upon a 15% antifreeze solution.
 Operation below 50°F EWT requires optional insulated water/refrigerant circuit.
 See performance correction tables for operating conditions other than those listed above.
 See Performance Data Selection Notes for operation in shaded areas.

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ClimateMaster Water-Source Heating and Cooling Systems

Table 100: Ground Thermal Properties

Ground Thermal Properties Table

Description	Thermal Conductivity (Recommended)	Thermal Conductivity (Minimum)	Thermal Conductivity (Maximum)	Diffusivity (Recommended)	Diffusivity (Minimum)	Diffusivity (Maximum)
	Btu-ft-RF	Btu-ft-RF	Btu-ft-RF	ft ² /day	ft ² /day	ft ² /day
Amphibolite	1.7	1.1	2.7	1.0		
Andesite	1.3	0.8	2.8	0.9	1.1	1.7
Anhydrite	2.4	0.9	4.5	1.9		
Asite	1.8	1.5	2.3	1.2		
Azores	1.7	1.5	2.2	1.3		
Basalt	1.0	0.8	1.4	0.7	0.5	0.9
Basalts	1.8	1.2	2.4	1.2		
Clay, dry	0.2	0.2	0.5	0.2	0.2	0.5
Clay, moist - wet	0.5	0.5	1.3	0.6	0.5	0.8
Claystone	1.3	0.8	1.7	0.9	0.5	1.2
Coal	0.2	0.2	0.4	0.2		
Concrete	0.9	0.6	1.2	0.8		
Condominate	1.8	0.8	2.1	1.2		
Diorite	1.5	1.1	1.9	0.8	0.7	1.0
Dolomite	1.9	0.9	3.0	1.2	0.8	2.3
Dunite	2.4	2.3	2.7	1.3		
Eckspite	1.7	1.3	2.1	0.9		
Gabbro	1.1	0.9	1.8	0.7	0.7	1.2
Gneiss	1.7	1.0	3.3	1.3	0.9	2.3
Gneiss	2.0	1.1	3.0	1.3	0.9	1.8
Gneissolite	1.9	1.2	2.0	1.2	0.8	1.4
Gravel, dry	0.2	0.2	0.3	0.2	0.3	0.3
Gravel, saturated	1.0			0.7		
Gypsum	0.9	0.7	1.8	0.7		
Gyps (Sagapell)	0.3	0.3	0.5	0.3		
Ignimbrite	1.7	1.4	2.4	1.3	1.2	2.0
Lamprophyre	1.5	1.4	2.0	1.2		
Limestone, marly	1.3	0.8	3.0	0.9	0.8	2.4
Limestone, massive	1.8	1.1	1.8	1.1		
Limestone, calcic	1.4	1.2	1.9	1.0		
Marble	1.6	1.2	3.2	1.2	0.8	2.6
Marl	1.2	1.0	2.0	0.8	0.8	1.3
Marl, clayey/pellaceous	1.2	0.9	1.5	0.8		
Marl, dolomitic	1.3	1.1	2.3	0.9		
Melagranite	3.4	3.4	3.4	2.8	2.8	2.5
Mica schist	1.2	0.9	1.8	0.8		
Peat	0.2	0.1	0.4	0.2	0.4	0.2
Peridotite	1.7	1.7	1.9	1.3		
Peridotite	2.3	2.2	3.0	1.4		
Quartzite	3.6	3.0	4.0	2.7	2.2	3.0
Rhyolite	1.9	1.8	1.9	1.6		
Rock Salt	3.1	3.1	3.7	4.2		
Sand, dry	0.2	0.2	0.4	0.3	0.2	0.4
Sand, dry, compacted	0.7	0.6	0.7	0.7		
Sand, frozen	1.2	0.3	1.0	1.2		
Sand, moist	0.8	1.0	2.9	0.6	1.3	2.1
Sand, saturated	1.4	0.7	1.7	0.9	0.5	1.0
Sandstone	1.3	0.7	2.9	1.1	0.7	1.7
Serpentinite	1.7	1.3	2.5	1.3		
Siltite	1.2	0.8	2.3	0.8	0.5	1.5
Schist	1.8	1.2	2.8			
SM, dry	0.2	0.2	0.8	0.2	0.2	0.8
SM, moist - wet	1.0	0.8	1.3	0.8	0.8	0.8
Siltstone	1.4	0.8	2.0	1.0	0.8	1.4
Slate	1.2	0.9	1.5	0.8	0.6	0.9
Syenite	1.5	1.0	2.0	1.0		
Till (boulder clay, moraine)	1.2	0.8	1.4	0.9	0.8	0.9
Tuffite	1.8	1.3	2.4	1.0		
Tuffite	1.8	1.3	2.1	1.2		
Tuff	0.8	0.8	0.8	0.9		

These data are compiled from following sources:

- Database of EED version 2.0 (Demo) (Hellstrom, et al 2000).
- Kavanaugh, Stephen and K. Rafferty, Ground-Source Heat Pumps, ASHRAE 1997.
- Soil and Rock Classification for the Design of Ground-Coupled Heat Pump Systems, IGSHPA 1989.

Table 101: Grout Thermal Properties

Description	Thermal Conductivity Btu/hr-ft-F
Grouts without Additives	
Dentonite 10%, frozen	0.0
Rentonite 10%, in water	0.4
Bentonite 20%, in water	0.3
Bentonite 40%, frozen	0.5
Rentonite 40%, in water	0.3
Bentonite, dry	0.1
Clay, dry	0.2
Clay, moist - wet	0.9
Concrete	0.9
Gravel, dry	0.2
Gravel, saturated	1.0
Sand, dry	0.2
Sand, dry, compacted	0.7
Sand, frozen	1.2
Sand, moist	0.6
Sand, saturated	1.4
Silt, dry	0.2
Silt, moist - wet	1.0
Fill	1.2
Thermally Enhanced Grouts	
20% Bentonite -40% Quartzite	0.9
30% Bentonite -30% Quartzite	0.8
30% Bentonite -30% Iron Ore	0.5
50% Quartzite -Flowable Fill (Cement + FlyAsh + Sand)	1.1

Table 102 : Ground Loop Heat Exchanger Size and Rating

GLHX Pipe Size & Rating Table

Pipe Size		Pressure Ratings				Pressure Ratings			
		Schedule 40		Schedule 80		SCH 10		SCH 16	
Size	Nom OD	ID	Wall Thick.	ID	Wall Thick.	ID	Wall Thick.	ID	Wall Thick.
(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)
3/4	1.315	0.824	0.113	0.742	0.124	0.653	0.095	0.535	0.032
1	1.315	0.824	0.113	0.742	0.124	0.653	0.095	0.535	0.032
1-1/4	1.660	1.131	0.14	0.991	0.151	0.860	0.101	0.700	0.035
1-1/2	1.9	1.315	0.145	1.15	0.2	0.955	0.123	0.775	0.032
2	2.375	1.657	0.154	1.531	0.215	1.243	0.135	0.975	0.035

Appendix 4: ASHRAE 90.1, (2004) and MNECB/CBIP Compliance Code

Table 103 : B-2 and B-4 Climate Zone Location (ASHRAE 90.1, (2004))

Table B-2

City	Zone	City	Zone	City	Zone	City	Zone
Alberta (AB)		(Manitoba cont.)		Ontario (ON)		(Quebec cont.)	
Calgary International A	7	Winnipeg International A	7	Belleville	6	Granby	6
Edmonton International A	7	New Brunswick (NB)		Comwall	6	Montreal Dorval International A	6
Grande Prairie A	7	Chatham A	7	Hamilton RBG	5	Quebec A	7
Jasper	7	Fredericton A	6	Kapuskasing A	7	Rimouski	7
Lethbridge A	6	Moncton A	6	Kenora A	7	Septles A	7
Medicine Hat A	6	Saint John A	6	Kingston A	6	Shawinigan	7
Red Deer A	7	Newfoundland (NF)		London A	6	Sherbrooke A	7
British Columbia (BC)		Cornier Brook	6	North Bay A	7	St Jean de Cherboung	7
Dawson Creek A	7	Gander International A	7	Oshawa WPCP	6	St Jerome	7
Ft Nelson A	8	Goose A	7	Ottawa International A	6	Thetford Mines	7
Kamloops	5	St John's A	6	Owen Sound MOE	6	Trois Rivières	7
Nanaimo A	5	Stephenville A	6	Peterborough	6	Val d'Or A	7
New Westminster BC Pen	5	Northwest Territories (NW)		St Catharines	5	Valleyfield	6
Penticton A	5	Ft Smith A	8	Sudbury A	7	Saskatchewan (SK)	
Prince George	7	Inuvik A	8	Thunder Bay A	7	Estevan A	7
Prince Rupert A	6	Yellowknife A	8	Timmins A	7	Moose Jaw A	7
Vancouver International A	5	Nova Scotia (NS)		Toronto Downsview A	6	North Battleford A	7
Victoria Gonzales Hts	5	Halifax International A	6	Windsor A	5	Prince Albert A	7
Manitoba (MB)		Kentville CDA	6	Prince Edward Island (PE)		Regina A	7
Brandon CDA	7	Sydney A	6	Charlottetown A	6	Saskatoon A	7
Churchill A	8	Truro	6	Summerside A	6	Swift Current A	7
Dauphin A	7	Yarmouth A	6	Quebec (PQ)		Yorkton A	7
Flin Flon	7	Nunavut		Bagotville A	7	Yukon Territory (YT)	
Portage La Prairie A	7	Resolute A	8	Drummondville	6	Whitehorse A	8
The Pas A	7						

Table B-4

Country	Country	Country	Country
City (Province or Region)	City (Province or Region)	City (Province or Region)	City (Province or Region)
Zone	Zone	Zone	Zone
Singapore	Switzerland	Tunisia	Uruguay
Singapore/Changi	Zurich	Tunis/El Aouina	Montevideo/Carrasco
1	5	3	3
South Africa	Syria	Turkey	Venezuela
Cape Town/D F Malan	Damascus Airport	Adana	Caracas/Maiquetia
4	3	3	1
Johannesburg	Taiwan	Ankara/Erimesgut	Vietnam
4		Istanbul/Yesilkoy	Hanoi/Gialam
Pretoria	Taiman	4	1
3	Taipei	United Kingdom	Saigon (Ho Chi Minh)
Spain	2		1
Barcelona	Tanzania	Birmingham (England)	
4	Dar es Salaam	5	
Madrid	4	Edinburgh (Scotland)	
4	Thailand	Glasgow Apt (Scotland)	
Valencia/Manises	3	London Heathrow (England)	
Sweden	Bangkok	4	
Stockholm/Arlanda	1		
6			

Table 104: Building Envelope Requirement for Climate Zone 6A (Toronto) (ASHRAE 90.1, (2004))

TABLE 5.5-6 Building Envelope Requirements For Climate Zone 6 (A,B)

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.063	R-15.0 ci	U-0.063	R-15.0 ci	U-0.173	R-5.0 ci
Metal Building	U-0.065	R-19.0	U-0.065	R-19.0	U-0.097	R-10.0
Airic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.053	R-19.0
Walls, Above-Grade						
Mass	U-0.104	R-9.5 ci	U-0.090	R-11.4 ci	U-0.380	NR
Metal Building	U-0.113	R-13.0	U-0.057	R-13.0 + R-13.0	U-0.113	R-13.0
Steel-Framed	U-0.084	R-13.0 + R-3.8 ci	U-0.064	R-13.0 + R-7.5 ci	U-0.124	R-13.0
Wood-Framed and Other	U-0.089	R-13.0	U-0.064	R-13.0 + R-3.8 ci	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-1.140	NR	C-0.119	R-7.5 ci	C-1.140	NR
Floors						
Mass	U-0.087	R-8.3 ci	U-0.064	R-12.5 ci	U-0.522	NR
Steel-Joist	U-0.038	R-30.0	U-0.038	R-30.0	U-0.069	R-13.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.066	R-13.0
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.730	NR	F-0.730	NR
Heated	F-0.840	R-10 for 36 in.	F-0.780	R-10 for 48 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.500		U-0.700	
Non-Swinging	U-0.500		U-0.500		U-1.450	
Penetration	Assembly Max. U (Fixed/Operable)	Assembly Max. SHGC (All Orientations/ North-Oriented)	Assembly Max. U (Fixed/Operable)	Assembly Max. SHGC (All Orientations/ North-Oriented)	Assembly Max. U (Fixed/Operable)	Assembly Max. SHGC (All Orientations/ North-Oriented)
Vertical Glazing, % of Wall						
0-10.0%	U _{fixed} -0.57 U _{oper} -0.67	SHGC _{all} -0.49 SHGC _{north} -0.49	U _{fixed} -0.57 U _{oper} -0.67	SHGC _{all} -0.49 SHGC _{north} -0.64	U _{fixed} -1.22 U _{oper} -1.27	SHGC _{all} -NR SHGC _{north} -NR
10.1-20.0%	U _{fixed} -0.57 U _{oper} -0.67	SHGC _{all} -0.39 SHGC _{north} -0.49	U _{fixed} -0.57 U _{oper} -0.67	SHGC _{all} -0.39 SHGC _{north} -0.49	U _{fixed} -1.22 U _{oper} -1.27	SHGC _{all} -NR SHGC _{north} -NR
20.1-30.0%	U _{fixed} -0.57 U _{oper} -0.67	SHGC _{all} -0.39 SHGC _{north} -0.49	U _{fixed} -0.57 U _{oper} -0.67	SHGC _{all} -0.39 SHGC _{north} -0.49	U _{fixed} -1.22 U _{oper} -1.27	SHGC _{all} -NR SHGC _{north} -NR
30.1-40.0%	U _{fixed} -0.57 U _{oper} -0.67	SHGC _{all} -0.39 SHGC _{north} -0.49	U _{fixed} -0.57 U _{oper} -0.67	SHGC _{all} -0.39 SHGC _{north} -0.49	U _{fixed} -1.22 U _{oper} -1.27	SHGC _{all} -NR SHGC _{north} -NR
40.1-50.0%	U _{fixed} -0.46 U _{oper} -0.47	SHGC _{all} -0.25 SHGC _{north} -0.49	U _{fixed} -0.46 U _{oper} -0.47	SHGC _{all} -0.25 SHGC _{north} -0.49	U _{fixed} -0.98 U _{oper} -1.02	SHGC _{all} -NR SHGC _{north} -NR
Skylight with Curb, Glass, % of Roof						
0-2.0%	U _{all} -1.17	SHGC _{all} -0.49	U _{all} -0.98	SHGC _{all} -0.46	U _{all} -1.98	SHGC _{all} -NR
2.1-5.0%	U _{all} -1.17	SHGC _{all} -0.49	U _{all} -0.98	SHGC _{all} -0.36	U _{all} -1.98	SHGC _{all} -NR
Skylight with Curb, Plastic, % of Roof						
0-2.0%	U _{all} -0.87	SHGC _{all} -0.71	U _{all} -0.76	SHGC _{all} -0.63	U _{all} -1.90	SHGC _{all} -NR
2.1-5.0%	U _{all} -0.87	SHGC _{all} -0.58	U _{all} -0.76	SHGC _{all} -0.53	U _{all} -1.90	SHGC _{all} -NR
Skylight without Curb, All, % of Roof						
0-2.0%	U _{all} -0.69	SHGC _{all} -0.44	U _{all} -0.58	SHGC _{all} -0.49	U _{all} -1.36	SHGC _{all} -NR
2.1-5.0%	U _{all} -0.69	SHGC _{all} -0.49	U _{all} -0.58	SHGC _{all} -0.39	U _{all} -1.36	SHGC _{all} -NR

Table 105: Baseline HVAC System Types for ASHRAE 90.1 (2004) Compliance

TABLE G3.1.1A Baseline HVAC System Types

Building Type	Fossil Fuel, Fossil/Electric Hybrid, & Purchased Heat	Electric and Other
Residential	System 1 - PTAC	System 2 - PTHP
Nonresidential & 3 Floors or Less & <75,000 ft ²	System 3 - PSZ-AC	System 4 - PSZ-HP
Nonresidential & 4 or 5 Floors & <75,000 ft ² or 5 Floors or Less & 75,000 ft ² to 150,000 ft ²	System 5 - Packaged VAV w/ Reheat	System 6 - Packaged VAV w/PFP Boxes
Nonresidential & More than 5 Floors or >150,000 ft ²	System 7 - VAV w/Reheat	System 8 - VAV w/PFP Boxes

Notes:

Residential building types include dormitory, hotel, motel, and multifamily. Residential space types include guest rooms, living quarters, private living space, and sleeping quarters.

Other building and space types are considered nonresidential.

Where no heating system is to be provided or no heating energy source is specified, use the "Electric and Other" heating source classification.

Where attributes make a building eligible for more than one baseline system type, use the predominant condition to determine the system type for the entire building.

TABLE G3.1.1B Baseline System Descriptions

System No.	System Type	Fan Control	Cooling Type	Heating Type
1. PTAC	Packaged terminal air conditioner	Constant Volume	Direct Expansion	Hot Water Fossil Fuel Boiler
2. PTHP	Packaged terminal heat pump	Constant Volume	Direct Expansion	Electric Heat Pump
3. PSZ-AC	Packaged rooftop air conditioner	Constant Volume	Direct Expansion	Fossil Fuel Furnace
4. PSZ-HP	Packaged rooftop heat pump	Constant Volume	Direct Expansion	Electric Heat Pump
5. Packaged VAV w/ Reheat	Packaged rooftop variable air volume with reheat	VAV	Direct Expansion	Hot Water Fossil Fuel Boiler
6. Packaged VAV w/PFP Boxes	Packaged rooftop variable air volume with reheat	VAV	Direct Expansion	Electric Resistance
7. VAV w/Reheat	Packaged rooftop variable air volume with reheat	VAV	Chilled Water	Hot Water Fossil Fuel Boiler
8. VAV w/PFP Boxes	Variable air volume with reheat	VAV	Chilled Water	Electric Resistance

Table 106 : HVAC and Service Water Heating Minimum Efficiency Requirement (ASHRAE 90.1, (2004))

**TABLE 6.8.1B Electrically Operated Unitary and Applied Heat Pumps—
Minimum Efficiency Requirements**

Equipment Type	Size Category	Heating Section Type	Sub-Category or Rating Condition	Minimum Efficiency ^a	Test Procedure ^b
Air Cooled (Cooling Mode)	<65,000 Btu/h ^c	All	Split System	10.0 SEER (before 1/23/ 2006) 12.0 SEER (as of 1/23/2006)	ARI 210/240
			Single Package	9.7 SEER (before 1/23/ 2006) 12.0 SEER (as of 1/23/ 2006)	
Through-the-Wall (Air Cooled, Cooling Mode)	<30,000 Btu/h ^c	All	Split System	10.0 SEER (before 1/23/ 2006) 10.9 SEER (as of 1/23/ 2006) 12 SEER (as of 1/23/ 2010)	
			Single Package	9.7 SEER (before 1/23/ 2006) 10.6 SEER (as of 1/23/ 2006) 12.0 SEER (as of 1/23/ 2010)	
Small-Duct High- Velocity (Air Cooled, Cooling Mode)	<65,000 Btu/h ^c	All	Split System	10 SEER	
Air Cooled (Cooling Mode)	≥65,000 Btu/h and <135,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	10.1 EER	ARI 340/360
		All other	Split System and Single Package	9.9 EER	
	≥135,000 Btu/h and <240,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	9.3 EER	
		All other	Split System and Single Package	9.1 EER	
	≥240,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	9.0 EER 9.2 IPLV	
		All other	Split System and Single Package	8.8 EER 9.0 IPLV	
Water-Source (Cooling Mode)	<17,000 Btu/h	All	55°F Entering Water	11.2 EER	ISO-13256-1
	≥17,000 Btu/h and <65,000 Btu/h	All	55°F Entering Water	12.0 EER	ISO-13256-1
	≥65,000 Btu/h and <135,000 Btu/h	All	55°F Entering Water	12.0 EER	ISO-13256-1
Groundwater-Source (Cooling Mode)	<135,000 Btu/h	All	39°F Entering Water	16.2 EER	ISO-13256-1

TABLE 6.8.1A (continued) Air Conditioners and Condensing Units

Equipment Type	Size Category	Heating Section Type	Sub-Category or Rating Condition	Minimum Efficiency ^a	Test Procedure ^b
Air Conditioners, Water and Evaporatively Cooled	<65,000 Btu/h	All	Split System and Single Package	12.1 EER	ARI 210/240
	>65,000 Btu/h and <135,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.5 EER	ARI 340/360
		All other	Split System and Single Package	11.3 EER	
	>135,000 Btu/h and <240,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER	
		All other	Split System and Single Package	10.8 EER	
	>240,000 Btu/h	Electric Resistance (or None)	Split System and Single Package	11.0 EER 10.3 IPLV	
		All other	Split System and Single Package	10.8 EER 10.1 IPLV	
Condensing Units, Air Cooled	>135,000 Btu/h	—		10.1 EER 11.2 IPLV	ARI 365
Condensing Units, Water or Evaporatively Cooled	>135,000 Btu/h	—		13.1 EER 13.1 IPLV	

^a IPLVs and part load rating conditions are only applicable to equipment with capacity modulation.

^b Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.

^c Single-phase, air-cooled air-conditioners < 65,000 Btu/h are regulated by NABCE. SEER values are those set by NABCE.

TABLE 6.8.1C Water Chilling Packages—Minimum Efficiency Requirements

Equipment Type	Size Category	Subcategory or Rating Condition	Minimum Efficiency ^a	Test Procedure ^b
Air Cooled, with Condenser, Electrically Operated	All Capacities		2.80 COP 3.05 IPLV	ARI 550/590
Air Cooled, without Condenser, Electrically Operated	All Capacities		3.10 COP 3.45 IPLV	
Water Cooled, Electrically Operated, Positive Displacement (Reciprocating)	All Capacities		4.20 COP 5.05 IPLV	ARI 550/590
Water Cooled, Electrically Operated, Positive Displacement (Rotary Screw and Scroll)	<150 tons		4.45 COP 5.20 IPLV	ARI 550/590
	>150 tons and <300 tons		4.90 COP 5.60 IPLV	
	>300 tons		5.50 COP 6.15 IPLV	
Water Cooled, Electrically Operated, Centrifugal	<150 tons		5.00 COP 5.25 IPLV	ARI 550/590
	>150 tons and <300 tons		5.55 COP 5.90 IPLV	
	>300 tons		6.10 COP 6.40 IPLV	
Air-Cooled Absorption Single Effect	All Capacities		0.60 COP	ARI 560
Water-Cooled Absorption Single Effect	All Capacities		0.70 COP	
Absorption Double Effect, Indirect-Fired	All Capacities		1.00 COP 1.05 IPLV	
Absorption Double Effect, Direct-Fired	All Capacities		1.00 COP 1.00 IPLV	

^a The chiller equipment requirements do not apply for chillers used in low-temperature applications where the design leaving fluid temperature is <40°F.

^b Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.

7.8 Product Information

TABLE 7.8 Performance Requirements for Water Heating Equipment

Equipment Type	Size Category (Input)	Subcategory or Rating Condition	Performance Required ^a	Test Procedure ^b
Electric Water Heaters	≤12 kW	Resistance ≥20 gal	0.93-0.00132V EF	DOE 10 CFR Part 430
	>12 kW	Resistance≥20 gal	$20 + 35 \sqrt{V}$ SL, Btu/h	ANSI Z21.10.3
	≤24 Amps and ≤250 Volts	Heat Pump	0.93-0.00132V EF	DOE 10 CFR Part 430
Gas Storage Water Heaters	≤75,000 Btu/h	≥20 gal	0.62-0.0019V EF	DOE 10 CFR Part 430
	>75,000 Btu/h	<4000 (Btu/h)/gal	$80\% E_t (Q/800 + 110 \sqrt{V})$ SL, Btu/h	ANSI Z21.10.3
Gas Instantaneous Water Heaters	>50,000 Btu/h and <200,000 Btu/h	≥4000 (Btu/h)/gal and <3 gal	0.62-0.0019V EF	DOE 10 CFR Part 430
	≥200,000 Btu/h ^c	≥4000 (Btu/h)/gal and <10 gal	80% E_t	ANSI Z21.10.3
	>200,000 Btu/h	≥4000 (Btu/h)/gal and ≥10 gal	$80\% E_t (Q/800 + 110 \sqrt{V})$ SL, Btu/h	
Oil Storage Water Heaters	≤105,000 Btu/h	≥20 gal	0.59-0.0019V EF	DOE 10 CFR Part 430
	>105,000 Btu/h	<4000 (Btu/h)/gal	$78\% E_t (Q/800 + 110 \sqrt{V})$ SL, Btu/h	ANSI Z21.10.3
Oil Instantaneous Water Heaters	≤210,000 Btu/h	≥4000 (Btu/h)/gal and <2 gal	0.59-0.0019V EF	DOE 10 CFR Part 430
	>210,000 Btu/h	≥4000 (Btu/h)/gal and <10 gal	80% E_t	ANSI Z21.10.3
	>210,000 Btu/h	≥4000 (Btu/h)/gal and ≥10 gal	$78\% E_t (Q/800 + 110 \sqrt{V})$ SL, Btu/h	
Hot Water Supply Boilers, Gas and Oil	≥300,000 Btu/h and <12,500,000 Btu/h	≥4000 (Btu/h)/gal and <10 gal	80% E_t	ANSI Z21.10.3
Hot Water Supply Boilers, Gas		≥4000 (Btu/h)/gal and ≥10 gal	$80\% E_t (Q/800 + 110 \sqrt{V})$ SL, Btu/h	
Hot Water Supply Boilers, Oil		≥4000 (Btu/h)/gal and ≥10 gal	$78\% E_t (Q/800 + 110 \sqrt{V})$ SL, Btu/h	
Pool Heaters Oil and Gas	All		78% E_t	ASHRAE 146
Heat Pump Pool Heaters	All		4.0 COP	ASHRAE 146
Unfired Storage Tanks	All		R-12.5	(none)

^a Energy factor (EF) and thermal efficiency (E_t) are minimum requirements, while standby loss (SL) is maximum Btu/h based on a 70°F temperature difference between stored water and ambient requirements. In the EF equation, V is the rated volume in gallons. In the SL equation, V is the rated volume in gallons and Q is the nameplate input rate in Btu/h.

^b Section 12 contains a complete specification, including the year version, of the referenced test procedure.

^c Instantaneous water heaters with input rates below 200,000 Btu/h must comply with these requirements if the water heater is designed to heat water to temperatures 180°F or higher.

Table 107: Lighting Power Densities for Building Area Method

TABLE 9.5.1 Lighting Power Densities Using the Building Area Method

Lighting Power Density	
Building Area Type ^a	(W/ft ²)
Automotive Facility	0.9
Convention Center	1.2
Court House	1.2
Dining: Bar Lounge/Leisure	1.3
Dining: Cafeteria/Fast Food	1.4
Dining: Family	1.6
Dormitory	1.0
Exercise Center	1.0
Gymnasium	1.1
Health Care-Clinic	1.0
Hospital	1.2
Hotel	1.0
Library	1.3
Manufacturing Facility	1.3
Motel	1.0
Motion Picture Theater	1.2
Multi-Family	0.7
Museum	1.1
Office	1.0
Parking Garage	0.3
Penitentiary	1.0
Performing Arts Theater	1.6
Police/Fire Station	1.0
Post Office	1.1
Religious Building	1.3
Retail	1.5
School/University	1.2
Sports Arena	1.1
Town Hall	1.1
Transportation	1.0
Warehouse	0.3
Workshop	1.4

^a In cases where both general building area type and a specific building area type are listed, the specific building area type shall apply.

Table 108: Lighting Power Densities for Space-by-Space Method

TABLE 9.6.1 Lighting Power Densities Using the Space-by-Space Method

Common Space Types*	LPD (W/ft ²)	Building Specific Space Types	LPD (W/ft ²)
Office-Enclosed	1.1	Gymnasium/Exercise Center	
Office-Open Plan	1.1	Playing Area	1.4
Conference/Meeting/Multipurpose	1.3	Exercise Area	0.9
Classroom/Lecture/Training	1.4	Courthouse/Police Station/Prison	
For Prison	1.3	Courtroom	1.9
Lobby	1.3	Confinement Cells	0.9
For Hotel	1.1	Judges Chambers	1.3
For Performing Arts Theater	3.3	Fire Stations	
For Motion Picture Theater	1.1	Fire Station Engine Room	0.8
Audience Seating Area	0.9	Sleeping Quarters	0.3
For Gymnasium	0.4	Post Office—Sorting Area	1.2
For Exercise Center	0.3	Convention Center—Exhibit Space	1.3
For Convention Center	0.7	Library	
For Prison	0.7	Card File and Cataloging	1.1
For Religious Buildings	1.7	Stacks	1.7
For Sports Arena	0.4	Reading Area	1.2
For Performing Arts Theater	3.6	Hospital	
For Motion Picture Theater	1.2	Emergency	2.7
For Transportation	0.5	Recovery	0.8
Atrium—First Three Floors	0.6	Nurse Station	1.0
Atrium—Each Additional Floor	0.2	Exam/Treatment	1.5
Lounge/Recreation	1.2	Pharmacy	1.2
For Hospital	0.8	Patient Room	0.7
Dining Area	0.9	Operating Room	2.2
For Prison	1.3	Nursery	0.6
For Hotel	1.3	Medical Supply	1.4
For Motel	1.2	Physical Therapy	0.9
For Bar/Lounge/Leisure Dining	1.4	Radiology	0.4
For Family Dining	2.1	Laundry—Washing	0.6
Food Preparation	1.2	Automotive—Service/Repair	0.7
Laboratory	1.4	Manufacturing	
Restrooms	0.9	Low Bay (<25 ft Floor to Ceiling Height)	1.2
Dressing/Locker/Fitting Room	0.6	High Bay (≥25 ft Floor to Ceiling Height)	1.7
Corridor/Transition	0.5	Detailed Manufacturing	2.1
For Hospital	1.0	Equipment Room	1.2
For Manufacturing Facility	0.5	Control Room	0.5
Stairs—Active	0.6	Hotel/Motel Guest Rooms	1.1
Active Storage	0.8	Dormitory—Living Quarters	1.1
For Hospital	0.9	Museum	
Inactive storage	0.3	General Exhibition	1.0
For Museum	0.8	Restoration	1.7

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Table 109: Building Type Categories (MNECB / CBIP, 1997)

Building Type	Occupant Density (m ² /person)	Receptacle Power (W/m ²)	Service Water Heating (W-person)	Minimum O.A. (L/s/m ²)	Operating Schedule (Table 4.3.2.C.)	Lighting Power Density (W/m ²)
	(1)	(2)	(3)	(4)	(5)	(6)
Office	25	7.5	90	0.4	A	18
Restaurant	10	1	115	1.25	B	15
Retail	30	2.5	40	1.0	C	30
Mall/Concourse/Atria	30	2.5	40	1.0	C	16
School	8	5	60	1.0	D	19
Service Establishment	30	2.5	80	1.0	C	22
Warehouse	1 500	1	300	0.25	E	6
Hotel/motel	25	2.5	500	0.60	F	15
Multifamily Residential	60	5	500	0.30	G	9

Table 110 : Space Function Default Assumption (MNECB / CBIP, 1997)

Space Function	Occupant Density (m ² /person)	Receptacle Power (W/m ²)	Service Water Heating (W-person)	Minimum O.A. (L/s/m ²)	Operating Schedule (Table 4.3.2.C.)	Lighting Power Density (W/m ²)
	(1)	(2)	(3)	(4)	(5)	(6)
Assembly						
Auditorium/Exhibit	5	2.5	30	1.5	C	17.2
Religious Worship	5	1	15	1.5	I	26.9
Theater - Performance	7.5	2.5	30	1.0	I	16.2
Theater - Motion Picture	5	2.5	30	1.5	I	16.2
Lobby	10	1	0	1.0	C	10.8
Atria	10	2.5	0	0.5	C	7.5
Recreation/Lounge	10	1	60	3.0	B	7.5
Conference/Meeting	5	1	45	2.0	C	19.4
Indoor Athletics Seating	5	0	30	1.5	I	10.8
Recreational Sports Area	5	1	90	2.0	I	13.0
Professional Sports Area	5	1.5	60	2.0	I	28.0
Locker Room and Shower	10	2.5	0	2.5	*	8.6
Health/Institutional						
Dental Suite/Exam	20	10	90	0.4	C	22.6
Emergency	20	10	180	0.75	H	24.7
Laboratory	20	10	180	0.75	H	20.4
Medical Supplies	20	1	0	0.75	H	25.8
Nursery	20	10	90	0.6	H	21.5
Nurse Station	20	2.5	45	0.4	H	22.6
Occupational/Physical Therapy	20	10	45	0.6	C	17.2
Patient Rooms	20	10	90	0.6	H	15.1
Pharmacy	20	2.5	45	0.4	C	18.3
Radiology	20	10	90	0.4	H	22.6
Surgical/O.B. Suites	20	10	180	0.75	H	22.6
Operating Room	20	10	300	0.75	H	75.3
Recovery	20	10	180	0.4	H	24.8

Table 4.3.2.B. Space Functions: Default Assumptions (cont.)

Space Function	Occupant Density (m ² /person)	Receptacle Power (W/m ²)	Service Water Heating (W/person)	Minimum O.A. (L/s/m ²)	Operating Schedule (Table 4.3.2.C.)	Lighting Power Density (W/m ²)
	(1)	(2)	(3)	(4)	(5)	(6)
Hotel/Motel						
Banquet Room	10	1	90	0.75	B	25.8
Hotel Prefunction	10	2.5	60	0.75	C	25.8
Guest Rooms	25	2.5	600	0.6	F	15.1
Exhibition Hall	10	2.5	60	0.75	C	28.0
Lobby/Reception Desk	10	2.5	30	0.75	H	21.5
Shop (Non-industrial)						
Machinery	30	1	50	2.5	C	26.9
Electrical/Electronic	30	10	50	1.25	C	26.9
Painting	30	10	90	5.0	C	17.2
Carpentry	30	10	50	1.25	C	24.8
Welding	30	10	90	5.0	C	12.9
Auto Repair	20	5	90	7.5	C	10.8
Office						
Category 1: <i>Enclosed offices, all open plan offices without partitions or with partitions lower than 1.37 m below the ceiling. Offices less than 84 m².</i>	20	7.5	90	0.5	A	19.4
Category 2: <i>Open plan offices 84 m² or larger with partitions 1.07 m to 1.37 m below the ceiling.</i>	20	7.5	90	0.5	A	20.4
Category 3: <i>Open plan offices 84 m² or larger with partitions higher than 1.07 m below the ceiling.</i>	20	7.5	90	0.5	A	23.7
Computer/Office Equipment	20	7.5	90	0.5	A	22.6
Filing, Inactive	50	0	0	0.2	A	10.8
Sorting and Mailing	20	7.5	90	0.5	A	19.4
Bank Business Area	20	7.5	90	0.2	A	30.1
Bank Customer Area	30	2.5	0	0.25	A	11.8

Table 4.3.2.B. Space Functions: Default Assumptions (cont.)

Space Function	Occupant Density (m ² /person)	Receptacle Power (W/m ²)	Service Water Heating (W/person)	Minimum O.A. (L/s/m ²)	Operating Schedule (Table 4.3.2.C.)	Lighting Power Density (W/m ²)
	(1)	(2)	(3)	(4)	(5)	(6)
Food Service						
Bar/Lounge	10	1	90	1.5	B	26.9
Leisure Dining	10	1	90	1.0	B	26.9
Fast Food/Cafeteria	10	1	120	1.0	B	14.0
Kitchen	20	10	120	1.5	B	15.1
Dormitory						
Bedroom	25	2.5	500	0.3	G	11.8
Bedroom/Study	25	2.5	500	0.3	G	15.1
Study Hall	25	2.5	90	0.3	C	19.4
Education						
Classroom	7.5	5	65	1.0	D	21.5
Library						
Audio/Visual	20	5	90	0.4	C	11.8
Stack - Stack Mounted Lighting	20	0	90	0.4	C	16.2
Stack - Ceiling Lighting	20	0	90	0.4	C	32.3
Card File/Cataloguing	20	2.5	90	0.4	C	17.2
Reading	20	1	90	0.4	C	20.4
Laboratories						
Laboratories	20	10	160	0.5	A	24.8
Storage/Warehouse						
Inactive Storage	1750	0	300	0.25	E	3.2
Active Storage, Bulky	100	1	65	0.25	E	3.2
Active Storage, Fine	50	1	65	0.25	E	7.5
Material Handling	20	1	65	0.4	E	10.8

Table 4.3.2.B. Space Functions: Default Assumptions (cont.)

Space Function	Occupant Density (m ² /person)	Receptacle Power (W/m ²)	Service Water Heating (W-person)	Minimum O.A. (L/s/m ²)	Operating Schedule (Table 4.3.2.C)	Lighting Power Density (W/m ²)
(1)	(2)	(3)	(4)	(5)	(6)	
Service and Common						
Mechanical/electrical room	200	1	0	0.25	*	7.5
Corridors	100	0	0	0.25	*	8.6
Toilet and Washrooms	30	1	0	1.0	*	8.7
Active Stairway	100	0	0	0.25	*	6.5
Emergency Stairway Exit	500	0	0	0.25	*	4.3
Air/Bus/Rail Terminals						
Baggage Area	20	2.5	65	0.5	H	10.8
Concourse/Main Thruway	20	0	65	0.5	H	9.7
Ticket Counter	10	2.5	65	1.0	H	28.9
Waiting and Lounge	10	0	65	1.0	H	12.9
Fire/Police						
Fire Engine Room	25	2.5	325	0.4	H	8.6
Jail Cell	25	2.5	325	0.4	H	8.6
Museum/Gallery						
General Exhibition	5	2.5	60	1.5	C	20.4
Inspection/Restoration	20	5	50	0.5	A	42.0
Storage (Artifacts) - Inactive	1000	0	60	0.25	E	6.5
Storage (Artifacts) - Active	100	1	60	0.25	E	7.5
Laundry						
Washing	20	20	60	0.6	C	9.7
Ironing and Sorting	20	20	60	0.5	C	14.0
Multifamily Residential						
Dwelling units	60	5	500	1.7	G	9

Table 111: Default Building Thermal Resistance or Overall Heat Transfer Coefficient (MNECB)

Ontario

Region A – < 5000 Degree-days

Table A-3.2.3.1.
Mandatory Provisions – Building Assemblies in Contact with the Ground
Forming Part of Sentences 3.2.3.1.(1), 3.2.3.2.(1) and 3.2.3.3.(1) and (2)

Assembly Description	Principal Heating Source		
	Electricity, Other	Oil, Propane, Heat Pump	Natural Gas
	Minimum Effective Thermal Resistance (RSI-value), m ² ·°C/W		
Walls and Roofs:			
Type I - finished	2.40	1.70	1.30
Type II - otherwise unfinished	2.40	no insulation required	no insulation required
Floors-on-ground:			
Type I - with imbedded heating cables, ducts or pipes (e.g., radiant heating slabs)	1.08 @ full floor area	1.08 @ full floor area	1.08 @ full floor area
Type II - other floors-on-ground less than 0.6 m below grade (e.g., concrete slab with rigid insulation)	1.08 @ perimeter	no insulation required	no insulation required

Table A-3.3.1.1.(1)
Prescriptive Requirements – Above-ground Building Assemblies
Forming Part of Sentence 3.3.1.1.(1)

Assembly Description	Principal Heating Source		
	Electricity, Other	Oil, Propane, Heat Pump	Natural Gas
	Maximum Overall Thermal Transmittance (U-value), W/m ² ·°C		
Roofs (See Appendix Note A-3.3.1.1.(1)):			
Type I - attic-type roofs	0.140	0.200	0.200
Type II - parallel-chord trusses and joist-type roofs	0.230	0.230	0.230
Type III - all other roofs (e.g., concrete decks with rigid insulation)	0.290	0.410	0.470
Walls	0.330	0.480	0.550
Floors:			
Type I - parallel-chord trusses and joist-type floors	0.220	0.220	0.220
Type II - all other floors (e.g., concrete slabs with rigid insulation)	0.290	0.410	0.470

Table A-3.3.1.1.(3)
Prescriptive Requirements – Solid Masonry Walls
 Forming Part of Sentence 3.3.1.1.(3)

Wall Description	Principal Heating Source		
	Electricity, Other	Oil, Propane, Heat Pump	Natural Gas
Solid masonry walls with no interior or exterior finish that incorporates insulation or creates a space that could accommodate insulation	not exempted	exempted	exempted

Table A-3.3.1.2.
Prescriptive Requirements – Fenestration⁽¹⁾
 Forming Part of Sentence 3.3.1.2.(1)

Assembly Description	Fenestration-to-Wall Ratio	Principal Heating Source		
		Electricity, Other	Oil, Propane, Heat Pump	Natural Gas
		Maximum Overall Thermal Transmittance (U-value), W/m ² .°C		
Fixed Glazing without Sash	up to 0.4	2.10	3.20	3.20
	> 0.4 to 0.5	1.80	2.70	2.80
	> 0.5 to 0.6	1.70	2.40	2.40
	> 0.6 to 0.7	1.60	2.20	2.20
	> 0.7 to 0.8	1.50	2.00	2.00
	> 0.8 to 0.9	1.40	1.80	1.90
	> 0.9	1.30	1.70	1.80
Operable or Fixed Glazing with Sash	up to 0.4	2.80	3.40	3.40
	> 0.4 to 0.5	2.40	2.90	2.90
	> 0.5 to 0.6	2.20	2.50	2.50
	> 0.6 to 0.7	2.00	2.30	2.30
	> 0.7 to 0.8	1.90	2.10	2.10
	> 0.8 to 0.9	1.70	1.90	1.90
	> 0.9	1.70	1.80	1.80

Notes to Table A-3.3.1.2.:

(1) See Appendix Note A-3.3.1.2.(1)

Table A-5.3.4.3.
Prescriptive Requirements – Heat Recovery
 Forming Part of Sentence 5.3.4.3.(1)

Description	Principal Heating Source		
	Electricity, Other	Oil, Propane, Heat Pump	Natural Gas
Heat recovery on principal exhaust component of the mechanical ventilation system in dwelling units	required	-	-

Table 112 : Default Operating Schedule 'A' (Office Building)

	1a	2a	3a	4a	5a	6a	7a	8a	9a	10a	11a	12	1p	2p	3p	4p	5p	6p	7p	8p	9p	10p	11p	12
Occupants																								
Mon-Fri	0	0	0	0	0	0	0.1	0.7	0.9	0.9	0.9	0.5	0.5	0.9	0.9	0.9	0.7	0.3	0.1	0.1	0.1	0.1	0	0
Sat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sun	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lighting																								
Mon-Fri	0.05	0.05	0.05	0.05	0.05	0.05	0.3	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.5	0.3	0.3	0.1	0.1	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Receptacle																								
Mon-Fri	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.5	0.3	0.3	0.2	0.2	0.2	
Sat	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sun	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Fans																								
Mon-Fri	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	Off	Off	Off	Off
Sat	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
Sun	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
Cooling																								
Mon-Fri	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	Off	Off	Off	Off
Sat	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
Sun	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
Heating																								
Mon-Fri	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	18	18	18	18
Sat	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Sun	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Hot Water																								
Mon-Fri	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.5	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.5	0.3	0.2	0.2	0.2	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05