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LEED CANADA ENERGY PERFORMANCE MODELLING OF A MEDICAL OFFICE BUILDING USING CARRIER HAP AND NRCAN EE4

by

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Bachelor of Science in Mechanical Engineering
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A project
presented to Ryerson University

in partial fulfillment of the
requirements for the degree of
Master of Engineering
in the Program of
Mechanical Engineering
Toronto, Ontario, Canada, 2007

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Abstract

The specific goal of this project is to model the energy performance of a medical office building in Carrier HAP and NRCan EE4 simulation software in order to qualify for LEED Canada energy and atmosphere perquisite 2 and credit 1. LEED Canada requires that to be eligible for EAp2 and EAc1, the proposed building must be 25% more energy efficient than a reference building which is designed according to Model National Energy Code for Buildings (MNECB). The demise of EE4 has created a demanding need to look for substitute software. One of the tasks of the project is to analyze HAP for EAp2 and EAc1 compliance process. EE4 generates the MNECB reference building itself but in HAP the reference building has to be modelled manually. The results from HAP and EE4 show that energy savings are 39.10% and 38.31% respectively with respect to MNECB reference building.

Acknowledgements

I would like to thank my advisor Dr. Alan Fung for his valuable guidance and assistance provided during the project and for his role as an editor. He suggested the need for this study and continuously encouraged me with his intellectual advice. His support and direction was essential for exploring the various aspects of this project. I also thank the owner and consultant of the medical office building for providing the opportunity to conduct the analysis on the building. I also would like to thank my family and friends for the encouragement and support they have provided to me.

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List of Abbreviations and Symbols

ACH	Air Changes per Hour
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
CaGBC	Canadian Green Building Council
CAV	Constant Air Volume
CBIP	Commercial Building Incentive Program
CLGSHP	Closed-loop Ground Source Heat Pump
EAc1	LEED Canada Energy and Atmosphere Credit 1
EAc2	LEED Canada Energy and Atmosphere Credit 2
EAp2	LEED Canada Energy and Atmosphere Prerequisite 2
FWR	Fenestration-to-Wall Ratio
IBPSA	International Building Performance Simulation Association
IESNA	The Illuminating Engineering Society of North America
GHG	Greenhouse Gas Emissions
GCHP	Ground-coupled Heat Pump
GLHE	Ground-loop Heat Exchanger
GSHP	Ground Source Heat Pump
GWHP	Ground Water Heat Pump
HGSHP	Hybrid Ground Source Heat Pump
HAP	Carrier Hourly Analysis Program v 4.3
HP	Heat Pump
kWh	Kilowatt Hour
kt	Kiloton
LCRG	LEED Canada Reference Guide-NC 1.0
MJ	Mega Joules
MNECB	Model National Energy Code for Buildings-1997
MOB	Medial Office Building
MWh	Megawatt Hour
NRC	National Research Council of Canada

NRCan	Natural Resources Canada
PCB	Performance Compliance for Buildings Specifications for Calculation Procedures for Demonstrating Compliance to the Model National Energy Code for Buildings Using Whole Building Performance-1999.
SC	Shading Coefficient
SHGC	Solar Heat Gain Coefficient
SWHP	Surface Water Heat Pump
USGBC	US Green Building Council
WSHP	Water Source Heat Pump

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1. Introduction

1.1 Buildings and Environment

Buildings constitute a major portion of Canadian energy demand. Hence, buildings are responsible for enormous amount of emissions in Canada. There is a great potential of energy savings in buildings than any other sector that use energy. The energy that buildings use for heating, lighting and cooling is the major component of their environmental impacts, approximately 85% of total life cycle impacts for typical Canadian office building (CaGBC, 2004). Roughly 38% of Canadian secondary energy use is for commercial, institutional and residential purposes (The term commercial used henceforth includes commercial, institutional and public administration categories excluding transportation-related energy) (CaGBC, 2004). Natural gas and electricity are prominent in the energy source breakdown for the commercial sector, meeting 46% and 42% of the demand (Cuddihy et al., 2005). The breakdown of energy consumption for the commercial sector is shown in Figure 1.

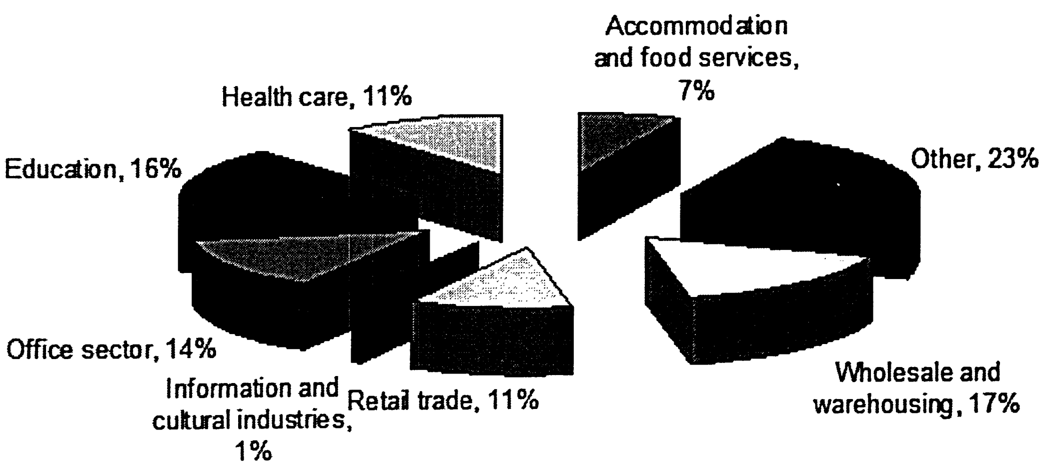

Figure 1: Energy Consumption Break Down in the Commercial Sector (NRCan, 2004)

Commercial and residential buildings account for 30% of total greenhouse gas emissions in Canada (CaGBC, 2004) and guzzle 40% of raw material (3 billions ton annually) across the globe (CaGBC, 2004). In 2004, the commercial sector emitted 37,700 kt of CO_2, 0.8 kt of N_2O, 0.7 kt of CH_4 and the CO_2 eq. were 37,900 kt (Environment Canada, 2004) across Canada. In the same time period, the emissions from residential sector across Canada were 40,700 kt of CO_2, 2 kt of N_2O, 90 kt of CH_4 and the CO_2 eq. were 43,000 kt (Environment Canada, 2004). Note that above figures do not include the indirect emissions from commercial and residential sector. Indirect emissions due to buildings include electricity generation plants, forestry, land use, transportation and construction sector. Hence, buildings are responsible for consuming a huge amount of energy nation wide. On the other hand, buildings are responsible for a large amount of greenhouse gas emissions in Canada. There is a great potential of reducing GHG emissions in commercial and residential buildings. Table 1 illustrates this fact.

Table 1: GHG reduction potential in Canada (CaGBC, 2007)

	2003 Actual	**Target 2012 reduction from 2003**		**Target use in 2012**	**% progress towards Kyoto**
	10^6 Tones	%	10^6 Tones	10^6 Tones	%
Residential	90	50	45	45	26.8
Personal Transport	120				
Commercial/Institutional	84	50	42	42	25.0
Freight Transport	96				
Gen. Manufacturing	36				
Energy Intensive Manufacturing	84				
Oil & Gas Export	90				
Non-Energy Emissions	140				
Total	740				
Kyoto Target	572				51.8

Canadian commercial sector end-use data demonstrate that 53% of energy consumption is for space heating (NRCan, 2003). Electricity, primarily for the operation of auxiliary motors and lighting, meets roughly 42% of the sector's demand. Space cooling as a consumer of electricity is of particular concern throughout the summer months, particularly in Ontario and British Columbia (NRCan, 2005). It can be easily concluded that more than half of total energy requirements of commercial buildings is consumed in space heating and cooling. Therefore, if the heating and cooling systems are more efficient there would be a dramatic decrease in energy consumption and GHG emissions. The improvement in the energy performance efficiency of buildings results in lowering the operational costs, energy consumption and greenhouse gas emissions.

1.2 Green Buildings

Green Buildings have economic, environmental and social benefits for all stakeholders including owners, occupants and general public. They are essential to support sustainable patterns of living (CaGBC, 2004). Over their lifecycles, green buildings use less energy and water, generate less greenhouse gases and other pollutants, use materials wisely, and produce less waste (CaGBC, 2004). They cost less to operate, are more adaptable to new uses and typically have longer economic lives (CaGBC, 2004).

1.3 Benefits of Green Buildings

Green Buildings are much better than non-green buildings. Green Buildings are more energy efficient than other buildings. From an environmental point of view, green buildings produce fewer emissions and are healthier for occupants. The features of green buildings are as follows (CaGBC, 2004);

- Minimize stress on natural systems, either by building on previously contaminated sites or by protecting ecologically-sensitive areas.
- Durable, thermally efficient roofs, walls and windows that reduce heating and cooling and enhance thermal comfort.

- Building form, orientation and thermal mass optimized for solar gains, natural ventilation and day lighting for free heating, cooling, ventilation and lighting.
- Significantly smaller and more efficient HVAC and electrical lighting systems.
- Water efficient supply and waste fixtures.
- Adaptable interior designs, providing visual access to the outdoors and access to daylight.
- Interior finishes and installation methods having lower toxic emissions.
- Landscaping that requires little or no irrigation or application of synthetic chemicals, manages and treats storm water and non-point-source pollution onsite, and replenishes groundwater supplies.
- Supports efficient travel options for building users.

1.4 LEED® Canada-NC Green Building Rating System

Leadership in Energy and Environmental Design Canada is a comprehensive green building rating system which evaluates the environmental performance of commercial and residential buildings (CaGBC, 2004). In the past few years in Canada, there has been increased awareness about environmental damage caused by buildings. People spend most of their time indoors; therefore, the impact of buildings on health of people is also worth considering (CaGBC, 2004). Hence, increased awareness and interest in the environmental and health impacts of buildings in Canada has lead to the widespread demand for a common method of certifying the merits of a given building, a well understood method/procedure to ensure the building has met a rigorous and carefully defined level of environmental performance (CaGBC, 2004).

1.4.1 History of LEED® Canada

LEED® Canada for New Constructions and Major Renovations version 1.0 (LEED-NC 1.0) is an adaptation of the US Green Building Council's (USGBC) Leadership in Energy and Environmental Design Green Building Rating System (LEED®), tailored specifically for Canadian climates, construction practices and regulations (CaGBC, 2004). This first version of LEED Canada has been adapted from the USGBC's LEED-NC 2.1 and influenced by anticipated changes planned for version 2.2 (CaGBC, 2004). LEED-Canada-NC 1.0 version was developed in December 2004 (CaGBC, 2004). CaGBC has all the rights of LEED® in Canada. The CaGBC was formed in 2002 (CaGBC, 2005). This council is a non-profit organization. At that time, it consisted of 5 full-time employees. CaGBC consists of important stakeholders such as, industry, engineers/architects, building owners, governmental departments, energy provider and universities etc. The membership of different stakeholder by percentage is shown in Figure 2.

CaGBC is growing rapidly since its establishment in 2002. The council membership has grown to 1,375 members in 2007 (CaGBC 2007). The CaGBC offices are located in Ottawa and Vancouver. The Chapters of CaGBC are Atlantic region, Quebec region, Ottawa region, Toronto region, Manitoba region, Saskatchewan region, Alberta region and Cascadian region chapters.

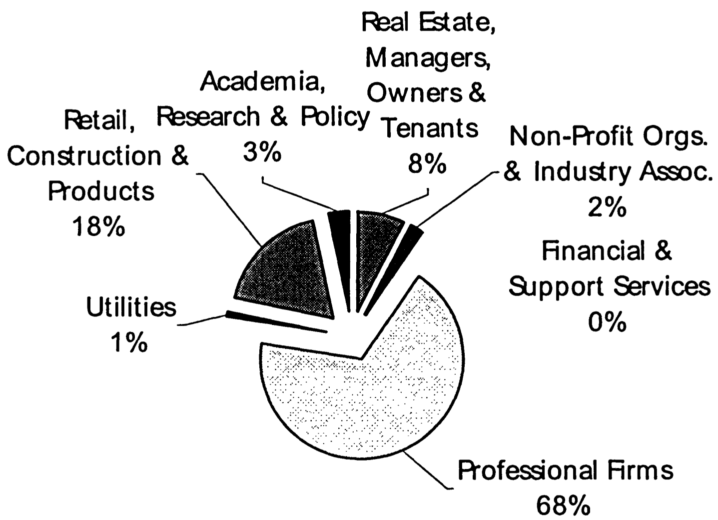

Figure 2: CaGBC membership by Category (%) (CaGBC, 2007)

There are 31 LEED® certified projects by May, 2007 in Canada (CaGBC 2007). The details of registered and certified projects across Canada from 2004 to 2007 are given in Figure 3. The number of LEED® registered projects is 466 (CaGBC, 2007). In Ontario, the number of certified projects is 16 and registered projects are 150 as of May, 2007 (CaGBC, 2007). LEED® certifications as of May 2007 and registrations by owner type as of April 2007 for CaGBC/ USGBC are given in Figure 4 and Figure 5 respectively.

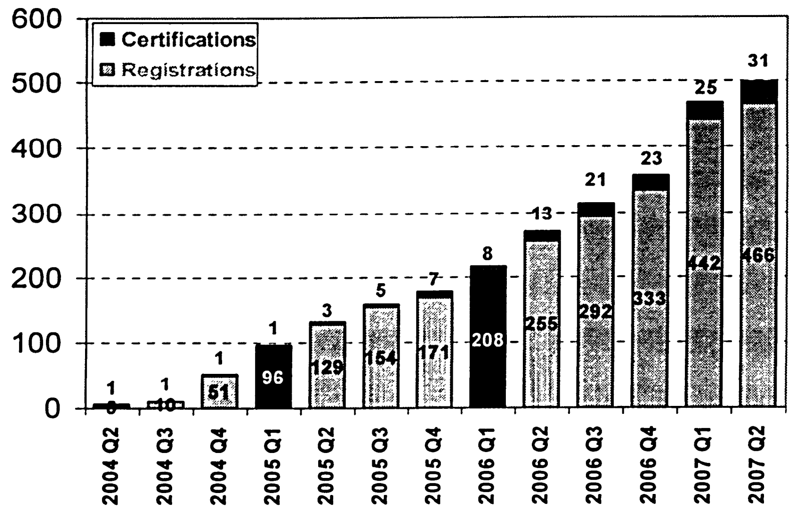

Figure 3: LEED® Canada registrations and certifications 2004-2007 (CaGBC, 2007)

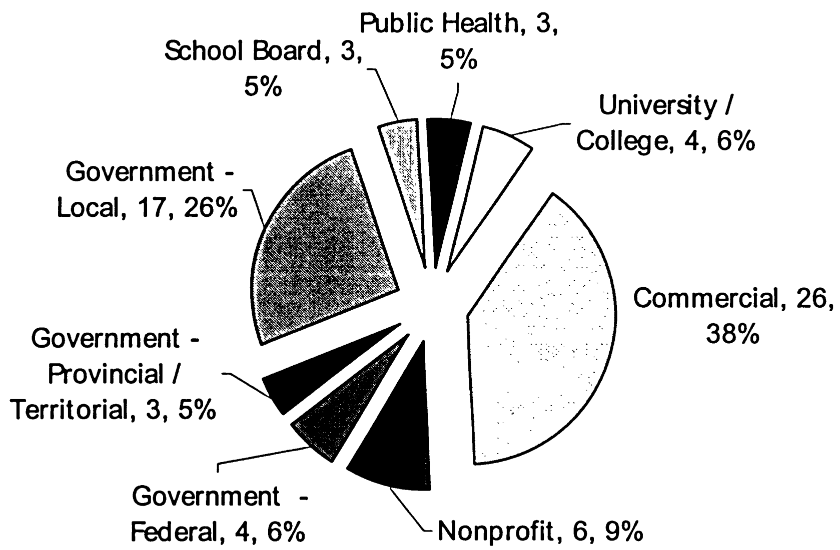

Figure 4: LEED® CaGBC and USGBC certifications by owner type as of May 2007 (CaGBC, 2007)

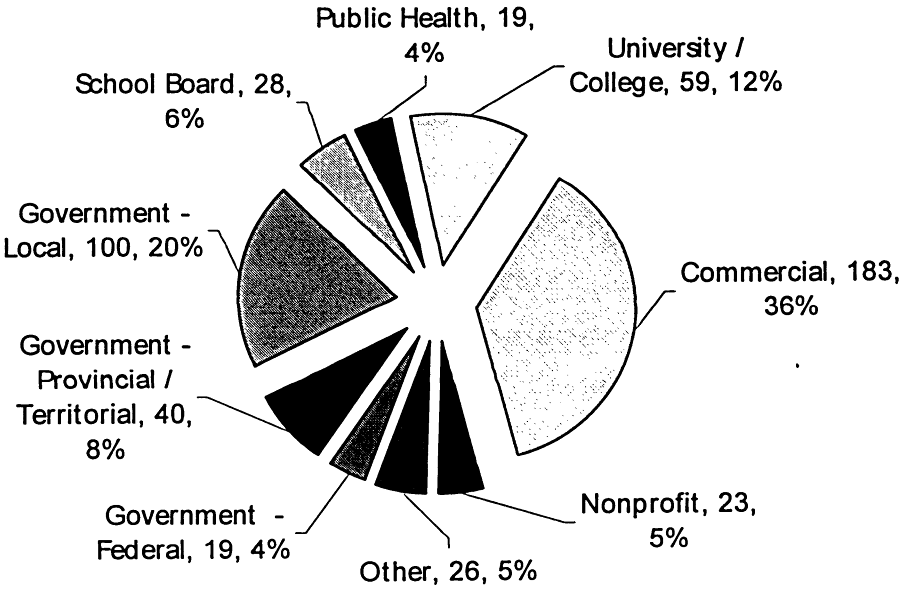

Figure 5: LEED® CaGBC and USGBC registrations by owner type (CaGBC, 2007)

1.5 Structure of LEED® Canada-NC 1.0

LEED® Canada has been adapted from USGBC's LEED® but has been developed keeping Canadian codes and standards in mind. The certification of a building to LEED® Canada is completely voluntarily. However, it is highly encouraged so that energy performance of a building is evaluated precisely. There are 4 certification levels which can be achieved according to points obtained by the building. These certification levels with their points are shown in Table 2.

Table 2: LEED® Canada certification levels and points (CaGBC, 2004)

Certification Level	Points
Certified	26 to 32
Silver	33 to 38
Gold	39 to 51
Platinum	52 or more

The total possible points are 70 and these points are assigned to 6 different categories. Each category has prerequisites and credits. When a building is in process of LEED certification, it is compulsory to meet requirements of prerequisites and there are no exceptions. However, it is not compulsory to fulfill the requirements of credits in each category. The points are only awarded if the building meets the requirements set out in credits and points are not associated with prerequisites. Each category and its possible points are summarized in Table 3. Innovation and design process is the only category which does not contain any prerequisites. This category contains only credit points.

The details of categories, prerequisites and credits are available in "LEED® Canada-NC 1.0 Reference Guide 2004".

Table 3: LEED® Canada categories and points (CaGBC, 2004)

Categories	Points
Sustainable Sites	14
Water Efficiency	5
Energy and Atmosphere	17
Materials and Resources	14
Indoor Environmental Quality	15
Innovation and Design Process	5

The division of points in each category by percentage are show in Figure 6. Energy and atmosphere category accumulates the most percentage of points than any other category.

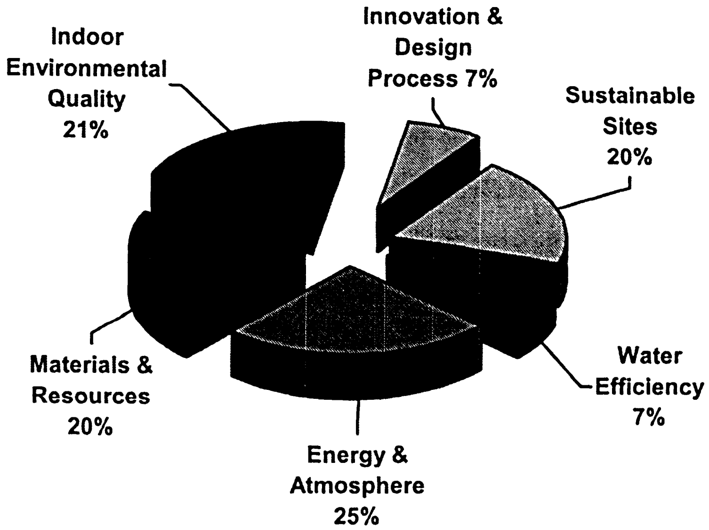

Figure 6: LEED Canada points distribution (CaGBC, 2004)

1.6 Background of Study

A proposed building must be 25% more energy efficient than MNECB reference building in order to qualify for LEED energy performance standard. EE4 simulations have been used for MNECB/CBIP compliance process. The Same procedure is being used for LEED Canada Energy and Atmosphere Prerequisite 2 (EAp2) and Energy and Atmosphere Credit 1 (EAc1) (CaGBC, 2004). The demise of Canadian Commercial Building Incentive Program (CBIP) and EE4 (IBPSA/CaGBC, 2007), initiated a pressing need for CaGBC to look for alternative software. In addition to the fact that EE4 has lots of inherent bugs, its behaviour is unpredictable some of the times (NRCan, 2006). As of now, EE4 simulations are still acceptable for EAp2 and EAc1 until a reliable and cost-effective alternative is established. EE4 generates the reference building itself based on MNECB requirements. Any alternative software to EE4 will require the simulator to define the reference building manually based on MNECB requirements.

2. Literature Review

2.1 LEED® Canada Energy and Atmosphere (EA) Section

EA is the largest section in LEED Canada Green Building Rating System. It contains the most number of possible points i.e. 17 or 25% of total points for all LEED Canada categories. The intention of the LEED Energy and Atmosphere category is to reduce depletion of non-renewable energy resources, reduce related environmental impacts, particularly emissions of local, regional and global air pollutants, and encourage use of renewable energy sources, with low environmental impacts (CaGBC, 2004). The scope of this study is Energy and Atmosphere Prerequisite 2 and Credit 1 (EAp2 and EAc1).

2.1.1 EA Prerequisite 2: Minimum Energy Performance

The intention of EAp2 is to establish the minimum level of energy efficiency for the proposed building (CaGBC, 2004). LEED Canada Reference Guide 1.0 defines the following possible paths to achieve EAp2. Both paths require complete energy simulation of building. Both ASHRAE 90.1-1999 and MNECB/CBIP establish the minimum requirements for the energy efficient design of buildings.

2.1.2 Path A: Energy Savings Relative to MNECB/CBIP

LEED Canada Reference Guide 1.0 describes path A for new and existing buildings as follows (CaGBC, 2004):

New Buildings: The energy consumption of the proposed building (design) must be reduced so that it complies with Canada's Commercial Building Incentive Program (CBIP). That means proposed building must be at least 25% more energy efficient than a reference building which is designed according to Model National Energy Code for Buildings (MNECB).

Existing Buildings: The proposed building must be 10% more energy efficient than MNECB reference building which is compliant with MNECB/CBIP. However CBIP approval is not required for any project (CaGBC, 2004).

2.1.3 Path B: Energy Savings Relative to ASHRAE 90.1-1999

The path B is described as follows by LEED Canada-NC Reference Guide (CaGBC, 2004):

New Buildings: The proposed building must be 18% more energy efficient than a reference building which is designed according to ASHRAE 90.1-1999 without amendments.

Existing Buildings: The proposed building must comply with ASHRAE 90.1-1999 without amendments.

2.1.4 EAp1 and EAc2 Compliance Process

The compliance to MNECB/CBIP or ASHRAE-90.1(1999) must be demonstrated using whole building energy simulation including regulated and non regulated loads (CaGBC, 2004). Regulated loads include HVAC, service hot water, Interior lighting. Non-regulated loads include plug loads, exterior lighting, garage ventilation, elevators and vertical transportation (CaGBC, 2004). However if non-regulated loads are isolated from the proposed building, their energy modeling is not required (CaGBC, 2004).

LEED Canada Reference Guide 1.0 states that EA section is performance based. Performance method is relatively flexible; it is up to the discretion of designer where to save energy in the building. There are mandatory requirements in both ASHRAE and MNECB such as wattage of exit signs. These mandatory requirements must be incorporated in the proposed design and there are no exceptions (CaGBC, 2004).

A reference building is created in simulation software based on prescriptive requirements exactly same as defined in MNECB (NRCan, 2006). Certain requirements remain same in both the reference and proposed buildings (NRCan, 2006). The proposed building must be using less energy than the reference building.

High levels of savings in energy cost are required to achieve EA credit points. Energy cost savings (%) and corresponding points for new and existing buildings are shown in Table 4.

Table 4: Points awarded for % savings in energy cost for new & existing buildings (CaGBC, 2004)

Points	MNECB	ASHRAE/IESNA 90.1-1999	MNECB	ASHRAE/IESNA 90.1-1999
	New Buildings		Existing Buildings	
1	24%	15%	15%	5%
2	29%	20%	20%	10%
3	33%	25%	24%	15%
4	38%	30%	29%	20%
5	42%	35%	33%	25%
6	47%	40%	38%	30%
7	51%	45%	42%	35%
8	55%	50%	47%	40%
9	60%	55%	51%	45%
10	64%	60%	55%	50%

Simulations using the MNECB/CBIP path must be done in accordance with "Performance Compliance for Buildings Specifications for Calculation Procedures for Demonstrating Compliance to the Model National Energy Code for Buildings Using Whole Building Performance May 1999" (CaGBC, 2004). Simulations using ASHRAE 90.1-1999 path must be done in accordance with procedures descried in "ASHRAE/IESNA 90.1-1999" (CaGBC, 2004). All projects *must follow modeling guidelines of Natural Resources Canada's "Modeling Guide* for CBIP/EE4 1.6" (CaGBC, 2004). Energy simulations must be performed using detailed hourly energy analysis program that has the ability to model complicated HVAC systems (CaGBC, 2004). EE4 is one of such software which was developed by Natural Resources Canada for MNECB/CBIP compliance.

2.2 MNECB/CBIP

Model National Energy Code for Buildings (MNECB) was published in 1997 by the National Research Council of Canada. This code contains a set of "prescriptive" energy-efficiency measures that should be included in new commercial buildings (NRCan, 2006). The code also allows for the substitution or trading-off of prescriptive energy-efficiency measures provided that the substitution does not increase building energy consumption. Because the code is voluntary, these measures only apply if the provincial government or local authority having jurisdiction adopts the code (NRCan, 2006). The Part 8 of MNECB is Building Energy Performance Compliance. This part of MNECB let the proposed design to deviate from prescriptive requirements mentioned in Parts 3 to 7. The basic principle of Part 8 is that a design may depart from the prescriptive requirements if it can be shown, that the energy performance of the proposed design is as good or better than a building energy target that is based on the prescriptive requirements (NRC, 1999).

Commercial Building Incentive Program (CBIP) was launched by NRCan in 1997. Because the MNECB is a code, it represents a minimum level of energy efficiency but CBIP required the proposed building to be 25% more energy efficient than a reference building which just meets the MNECB requirements. CBIP provided incentives to building owners who met with the CBIP requirements. This program is no longer offered by NRCan. The Office of Energy Efficiency of NRCan offered CBIP until March 31, 2004 (NRCan, 2000). CBIP provides an incentive to building owners if their "proposed" building design is expected to consume 25% less energy than a standard or "reference" building (NRCan, 2006). Incentives were equivalent to twice the annual energy cost savings versus a similar building designed to just meet the Model National Energy Code for Building (MNECB) requirements (NRCan, 2000). Incentives were capped at $60,000 or total verifiable design costs, whichever is less (NRCan, 2000).

2.3 Performance Compliance for Buildings (PCB)

This document is supplement to MNECB prescriptive requirements as stated in part 8 of MNECB. This document was published by National Research

Council of Canada in 1999. The purpose of PCB is NOT to predict accurate annual energy consumption of buildings instead its purpose is to describe requirements and procedures based on MNECB to model the proposed and reference buildings that are following the performance compliance path so that annual adjusted energies of the proposed and reference buildings can be compared (NRC, 1999). Many simplifying assumptions are used by PCB to rationalize the modelling (NRC, 1999).

2.4 Building Simulation

Simulation represents a possible solution to the complexity dilemma by enabling comprehensive and integrated appraisals of design options under realistic operating conditions; in other words, simulation supports the emulation of future realities at the design stage (Clarke, 2001). Simulation allows users to understand the interaction between design and performance parameters, to identify potential problem areas, and so implement and test appropriate design modifications (Clarke, 2001). The resulting design is more energy conscious with better comfort levels and air quality attained throughout (Clarke, 2001).

Building energy performance simulation is a powerful tool that architects, engineers, and developers use to analyze how the form, size, orientation, and type of building systems affect overall building energy consumption (Energy Design Resources, 2006). This information is vital for making informed design decisions about building systems that impact energy use, including envelope, glazing, lighting, and HVAC (Energy Design Resources, 2006). It is often the case that a few building simulation runs in the early phases of a project can lead to design solutions that, though they appear simple, significantly improve building energy performance (Energy Design Resources, 2006).

It is hard to estimate the annual energy costs associated with operating a building while it is still under design. The answer depends on numerous factors, including the construction details and orientation of walls and windows, occupancy patterns, local climate, operating schedules, the efficiency of lighting and HVAC systems, and the characteristics of other equipment loads within the building (Energy Design Resources, 2006). Accounting for all these variables, as well as their interactions, is a daunting task, especially because some changes by the hour (Energy Design Resources, 2006). Given this complexity, rigorous calculations of annual building energy costs were rarely performed before personal computers became commonplace (Energy Design Resources, 2006). Software packages for building energy performance simulation carry out the numerous and complex equations that, when combined, describe how buildings use energy (Energy Design Resources, 2006). The most sophisticated of these programs are capable of calculating building energy consumption hour by hour for an entire year (Energy Design Resources, 2006).

Albert Einstein once said, "Make things as simple as possible, and no simpler." This is an excellent rule of thumb for building simulationists. There is no need to strive over details that will not have a significant impact on the design questions at hand. For example, EE4 Modelling Guide 2006 states that if there are round corners in the walls, the area of the wall can be measured to the closest approximation of round corner. It does not recommend measuring the curve area very precisely (NRCan, 2006).

2.5 Objectives of the Study

The objective of the study is to model the energy performance of a medical office building located in Toronto. The modelling of energy performance is required to qualify for EAp2 and to achieve credit points of EAc1 as described by LEED Canada-NC 1.0 Reference Guide. Path A has been followed for this project. This path requires the proposed building to be 25% more energy efficient than a MNECB reference building as described earlier. The building selected for this project is a medical office building. This building is selected because it has diverse spaces, e.g., offices, labs and retail areas. Since the medical office building is still under design process, all procedures and requirements for new buildings have been used. Moreover, the purpose of the project is not to design the energy requirements of the building. All design data have been provided by the building design consultant. The objective is to use that data and evaluate the whole building energy performance and savings in energy of the proposed building with respect to the MNECB reference building.

There are various building simulation software packages available in the market. However, EE4 version 1.60 (Natural Resources Canada, 2005) and Carrier HAP version 4.31 (Carrier Corporation, 2006) have been used for this project. As MNECB path has been used for this project, the first step in modelling is to find out different requirements for the proposed and reference building based on MNECB. These requirements are available in Model National Energy Code for Buildings-1997 and Performance Compliance for Buildings Specifications for Calculation Procedures for Demonstrating Compliance to the Model National Energy Code for Buildings Using Whole Building Performance-1999 (PCB). The next step is to model the proposed building in Carrier HAP and EE4 simulation software. EE4 generates the reference building automatically based on MNECB requirements. However, HAP does not have the capability to generate the reference building automatically. One of the tasks is to model the reference building in HAP based on MNECB requirements manually. This project also highlights the limitations of Carrier HAP to model the proposed and reference buildings and describes the comparison between HAP and EE4 in terms of modelling the medical office building from EAp2 and EAc1 points of view.

3. Project Methodology

3.1 Procedure

For detailed requirements for EAp2 and EAp1, LEED Canada Reference Guide has been examined cautiously. Any prerequisite in LEED Canada is mandatory. A project in the process of LEED Canada certification must fulfill all prerequisites in each category and so is the prerequisite, EAp2: Minimum Energy Performance (CaGBC, 2004). EAp2 states that its intent is to establish the minimum level of energy efficiency for proposed building. It requires the proposed building to be 25% more energy efficient than the MNECB reference building. EAp2 and EAc1 also states that compliance with these two can only be demonstrated with whole building energy simulation.

For this purpose, first the reference building is simulated in Carrier HAP based on the requirements provided by MNECB and PCB. In this way, the minimum energy level for the proposed building compliant with MNECB is established. The proposed building is then simulated in Carrier HAP by making changes to the reference building and incorporating energy efficiency measures that will make the proposed building 25% more energy efficient than the reference building. While modelling the proposed building, real building data provided by the consultant is being used. However, Performance Compliance for Buildings (PCB) manual requires certain inputs to be fixed to a specific value, even if the real data is different. For example, the minimum supply flow rate cannot be less than 2 $L/s/m^2$ (NRC, 1999); if actual supply flow rate is less than 2 $L/s/m^2$ then the original value would be ignored and 2 $L/s/m^2$ would be used instead. Certain inputs remain same in both the proposed and reference buildings, for example, building floor area remains same in the both buildings (NRC, 1999).

Once the proposed and reference buildings are simulated, the results are obtained from the output file. The output of HAP is in kWh for electricity usage and natural gas usage is in m^3. All energies from different fuel sources must be converted to mega joules (MJ) (NRCan, 2000). The energy savings (%) are calculated as follows (CaGBC, 2004):

$$\text{Savings (\%)} = (\text{ECR} - \text{ECP}) / \text{ECR} \qquad \text{(Eq: 1)}$$

Where

ECR = Energy consumption of reference building (MJ)

ECP = Energy consumption of proposed building (MJ)

The next step is to model the proposed building in EE4. EE4 is a compliance checking software and generates the reference building automatically. The output of EE4 for different energy types is in MJ. Once the proposed building is simulated, energy savings (%) are calculated.

EAc1: "Optimize energy performance" requires the savings (%) to be calculated in terms of cost (CaGBC, 2004). The whole compliance procedure is same as described above. EAc1 provides 1 credit point if the energy cost of the proposed building is 24% less than the energy cost of reference building (CaGBC, 2004). Hence as the energy cost savings (%) increase, the awarded number of points also increase. The maximum number of awarded points is 10, if the proposed building cost savings are 64% with respect to the reference building. Annual energy costs are determined from the rates for the type of fuel used. In the case of medical office building current fuel rates have been used. HAP and EE4 both automatically calculate annual energy costs based on these rates.

3.2 Simulation Software Requirements

Performance compliance for buildings manual (PCB) requires the building simulation software of having certain capabilities so that it can be used properly for compliance process. The very basic requirement for compliance software is that it must be able to perform a simulation on a time interval no greater than 1 hour over a one year period (8760 hours) (NRC, 1999). The compliance software must be able to take building envelope data (NRC, 1999). Moreover the software must be able to model at least 15 zones and 15 air systems (NRC, 1999). The requirements as stated by PCB are summarized in the following lines (NRC, 1999):

- Calculation of annual consumption of fuel and electricity for:
  - Heating, cooling
  - Fans, pumps and auxiliaries
  - Lights
  - Miscellaneous electric loads
- Climatic data
- Calculates loads due to occupants, lights, solar radiation, Infiltration and transmission through building envelope etc.
- Calculates amount of heating and cooling required to maintain the specified space temperature
- Simulates air systems and terminal systems
- Simulates the primary systems such as boilers and chillers.
- Models the efficiencies of primary systems.

3.3 Carrier Hourly Analysis Program (HAP)

Carrier's Hourly Analysis Program (HAP) is a computer tool which assists engineers in designing HVAC systems for commercial buildings. HAP is two tools in one. First it is a tool for estimating loads and designing systems. Second, it is a tool for simulating energy use and calculating energy costs. HAP uses the transfer function method for load calculations and detailed 8,760 hour-by-hour energy simulation techniques for the energy analysis (Carrier, 2003). The screen shot of HAP is shown in Figure 7. As the name indicates, HAP performs energy analysis on hour by hour basis for 8760 hours of a year. HAP has the ability to fulfill all general software requirements as stated in section 3.2: Simulation software requirements. It is important to note that, HAP has also been already approved for USGBC's LEED projects (Carrier, 2006).

HAP estimates design cooling and heating loads for buildings in order to determine required sizes for HVAC system components. Ultimately, the program provides information needed for selecting and specifying equipment. Specifically, the program performs the following tasks:

- Calculates design cooling and heating loads for spaces, zones, and coils in the HVAC system.
- Calculates annual energy consumptions.
- Calculates annual energy costs.
- Determines required airflow rates for spaces, zones and the system
- Sizes cooling and heating coils.
- Sizes air circulation fans.
- Sizes chillers and boilers

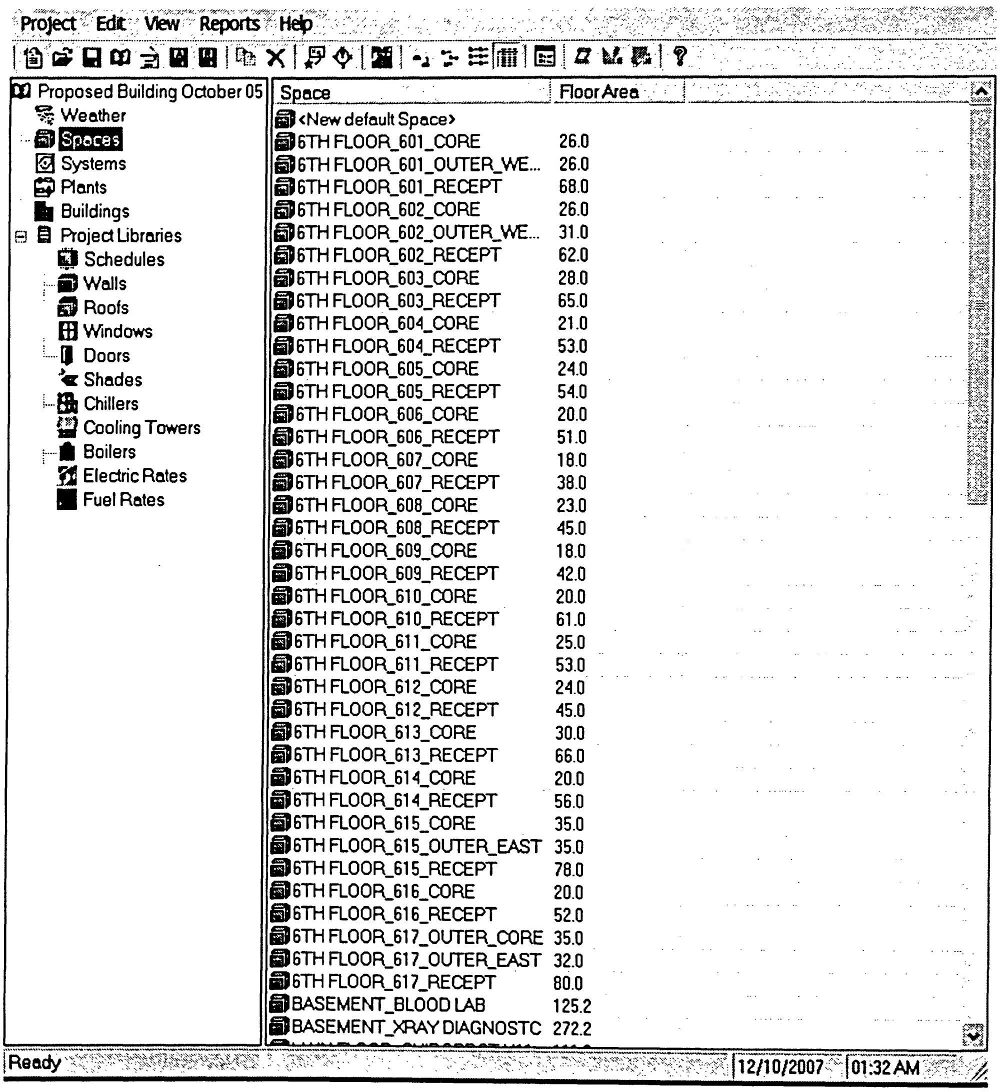

Figure 7: Screenshot of Carrier HAP

HAP estimates the annual energy use and energy costs for HVAC and non-HVAC energy consuming systems in a building by simulating building operation for each of the 8,760 hours in a year using real hourly weather data (Carrier, 2003). Results of the energy analysis are used to compare the energy use and energy costs of alternate HVAC system designs so the best design can be chosen. Specifically, HAP performs the following tasks during an energy analysis (Carrier, 2003):

- Simulates hour-by-hour operation of all heating and air conditioning systems in the building.
- Simulates hour-by-hour operation of all plant equipment in the building.
- Simulates hour-by-hour operation of non-HVAC systems including lighting and appliances.
- Uses results of the hour-by-hour simulations to calculate total annual energy use and energy costs.
- Costs are calculated using actual utility rate features such as time-of-day and demand charges, if specified.

HAP is in its 20th year providing design and simulation solutions to the HVAC engineering community. U.S. Green Building Council has determined that the Carrier Hourly Analysis Program (HAP) is acceptable for use in LEED projects (Carrier, 2006). This acceptance is based on the fact that HAP complies with simulation software requirements set forth in ASHRAE Standard 90.1-1999 for software used in the Energy Cost Budget (ECB) compliance path. Further, HAP has remained compliant with the 2001 and 2004 editions of ASHRAE Standard 90.1 (Carrier, 2006).

3.4 NRCan EE4 Building Simulation Software

EE4 is a compliance checking building simulation software, developed by Natural Resources Canada. The EE4 software was developed to support the CBIP. It performs a detailed energy simulation of the proposed and reference buildings. The software is comprised of three principle components: a graphical user interface, a compliance rules processor, and a simulation engine (Morrison et al, 2001). EE4 calculations are based on an approved version of DOE-2.1E. DOE-2.1E is a comprehensive building energy analysis program developed by Lawrence Berkeley National Laboratory (LBNL) under contract with the United States Department of Energy (NRCan, 2006). EE4 is designed to analyse all buildings covered by the MNECB, primarily non-residential buildings, high-rise or large residential buildings, and hotels/motels (NRCan, 2006). The compliance calculation predicts annual building energy performance as explained in Part 8 of the MNECB and Section 5 of the CBIP technical guide (NRCan, 2006). DOE-2.1E computes estimated annual energy use for all building types covered by the MNECB (NRCan, 2006). A screenshot of EE4 is shown in Figure 8.

It has been stated earlier that EE4 performs annual simulations of the proposed and reference buildings using the extensively validated DOE-2.1E simulation program. To prevent tampering with the simulation results, the user has no opportunity to interfere with this process. The rules processor creates the DOE-2.1E input file immediately prior to invoking the simulation and immediately following completion of the simulation; the rules processor extracts the necessary results from the DOE-2.1E results file (Morrison et al., 2001). It should be noted that the EE4's functions that create the DOE-2.1E input files have been isolated from the incentive programme's rules set, this to facilitate switching to an alternate simulation engine in the future should a better alternative arise (Morrison et al., 2001).

When all building elements are entered, the simulation can be performed. EE4 uses the information entered in the Building Tree and incorporates MNECB rules to construct two input files: one for the proposed building and one for the MNECB reference building. The building energy analysis program DOE-2.1E then analyzes each input file. The results of the DOE-2.1E calculation are then passed back to EE4 for display of the simulation results. It should be noted that EE4 automatically provides results in MJ, so there is no need to convert different type of energies into MJ. The simulation results from the proposed and reference buildings are compared to look at if they meet the 25% savings target.

The purpose of EE4 simulations is NOT to accurately predict the expected energy use of the building. Rather it is to provide a uniform and consistent means of verifying compliance to MNECB and CBIP and comparing the energy efficiency of building designs (NRCan, 2006). MNECB and CBIP simulations assume typical building use patterns and standards of construction (NRCan, 2006). Because use patterns and standards of construction vary from building to building, simulations based on these assumptions may or may not be indicative of the actual building energy consumption (NRCan, 2006).

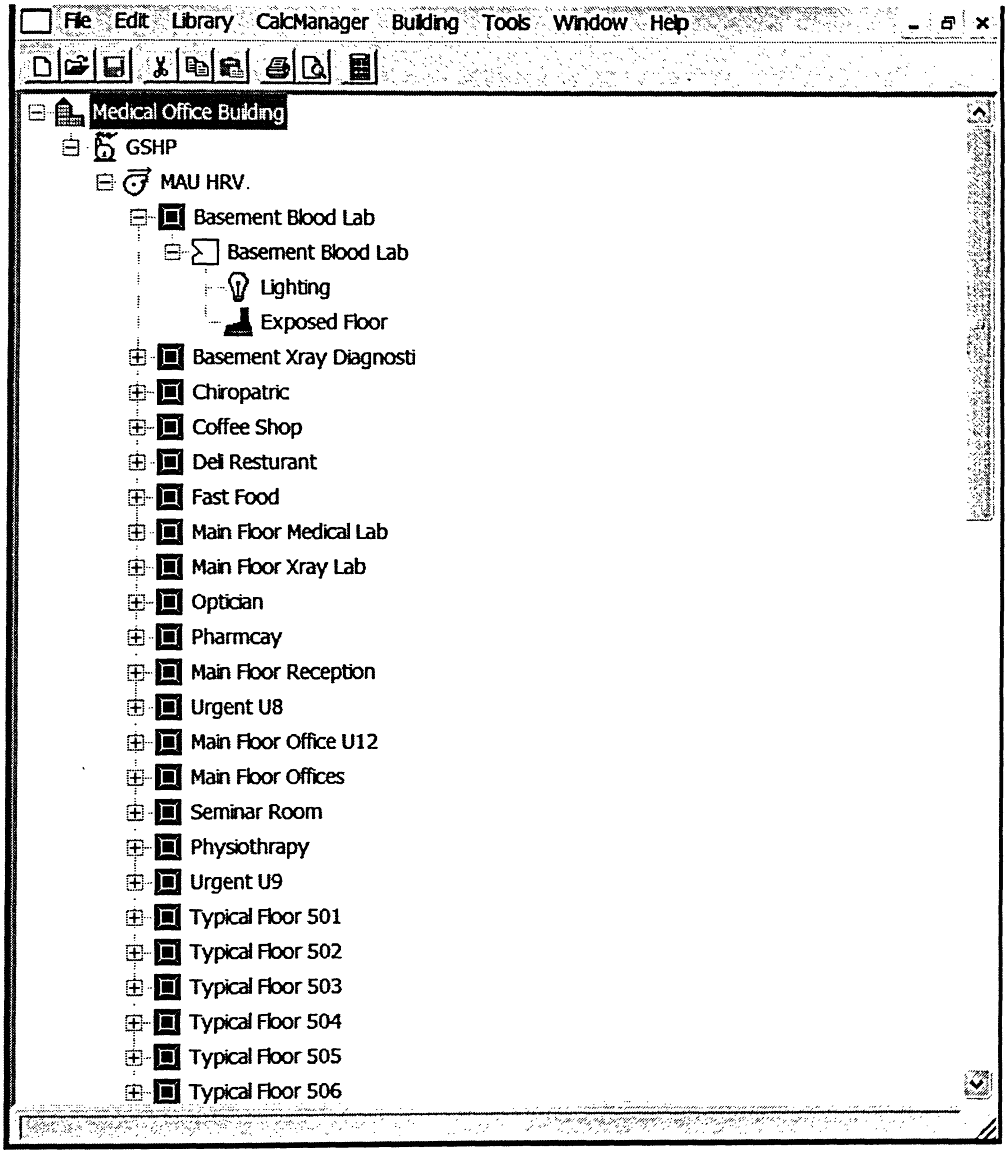

Figure 8: Screenshot of EE4

4. Ground Source Heat Pump

The medical office building is equipped with a network of closed-loop ground source heat pumps (GSHP). Another common name for closed-loop GSHP is ground-coupled heat pumps (GCHP) (ASHRAE, 1999). In the following sections, a general background and history about GSHP is provided. The three types of GSHP as defined by ASHRAE, 1999 are discussed briefly. An overview about hybrid ground source heat pump (HGSHP) has also been provided.

4.1 History and Background

A Swiss patent issued in 1912 to Heinrich Zoelly is the first known reference to ground-source heat pump systems (Spitler, 2005). In the US, some ground-source heat pump systems were installed just prior to World War II and post-war installations began to take off (Spitler, 2005). At the same time, about a dozen research projects involving laboratory investigations and field monitoring were undertaken by US electric utilities. Research began again in the late 1970s after the oil crisis and initially followed much of the same paths as the 1940s research, with an emphasis on experimental testing (Spitler, 2005). There are approximately 1.1 million heat pumps installed world wide (Lund, 2004).

Maintaining a comfortable temperature inside a building can require a significant amount of energy. Separate heating and cooling systems are often used to maintain the desired air temperature, and the energy required to operate these systems generally comes from electricity, fossil fuels, or biomass. In the Ground-Source Heat Pump Chapter (CANMET, 2005), it is stated that 46% of sun's energy is absorbed by the earth as shown in Figure 9. Another option is to use this abundant energy to heat and cool a building. In contrast to many other sources of heating and cooling energy which need to be transported over long distances, Earth Energy is available on-site, and in massive quantities.

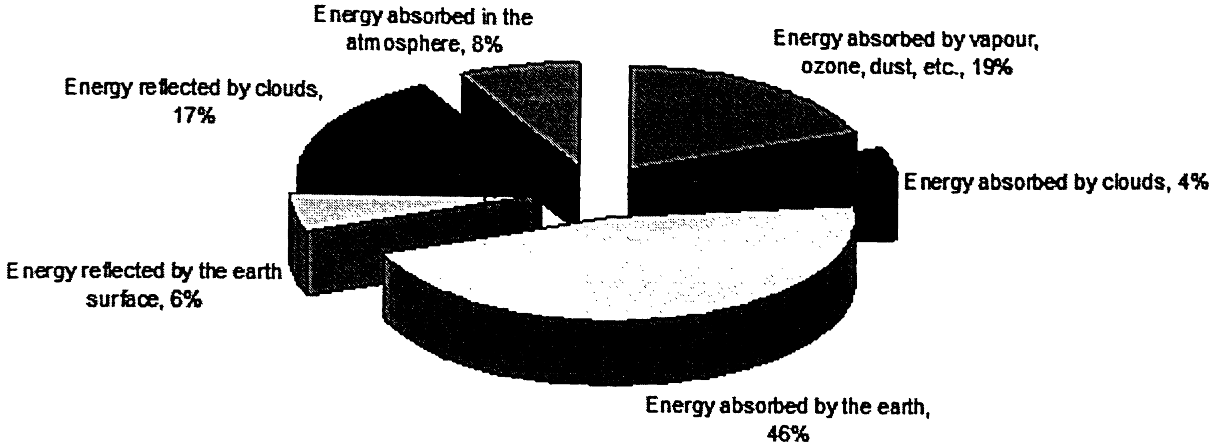

Figure 9: Solar energy distribution (NRCan, 2005)

A ground source heat pump is used to concentrate or upgrade low temperature heat energy from the ground before distributing it in a building through conventional ducts. It operates much as a refrigerator or conventional air conditioning system in that it relies on an external source of energy, typically electricity to concentrate the heat and shift the temperature. Typically, each kilowatt (kW) of electricity used to operate a GSHP system draws more than 3 kW of renewable energy from the ground (CANMET, 2005). Heat pumps typically range from 3.5 to 35 kW in heating and cooling capacities, and a single unit is generally sufficient for a house or a small commercial building (NRCan, 2005). For larger commercial, institutional or industrial buildings, multiple heat pumps units would often be employed; the same situation applies to the case of medical office building.

Currently, ground-source heat pump (GSHP) systems are perhaps one of the most widely used renewable energy resources (Khan, 2004). GSHP systems use the earth's relatively constant temperature as a heat sink for cooling and a heat source for heating. From a thermodynamic perspective, using the ground as a heat source or sink makes more sense than the ambient air because the temperature is usually much closer to room conditions. The use of liquid instead of air as the source/sink fluid for the heat pump also promotes higher efficiency, which can be attributed to the decrease in difference between the source/sink temperature and the refrigerant temperatures. In addition, the specific heat of water is more than four times greater than that of air (Khan, 2004).

Besides providing the advantage of having lower energy costs, GSHP systems have also proved to have lower maintenance costs, presumably due to not requiring outdoor equipment (Cane et al., 1998). Water source heat pumps tend to have a longer service life, as they are not subjected to refrigerant pressures as high or low as those of conventional air source heat pumps. These benefits apparently result in high owner satisfaction, as shown by a survey (DOE, 1997), 95% of GSHP system owners were completely satisfied.

Heat pumps have proved themselves a much better option for heating and cooling of a building than other systems such as gas-fired boilers and direct expansion (DX) cooling systems. In a study performed by Spitler the GSHP and DX cooling system was compared. It was found that that the peak electricity demand for GSHP is much lower than DX cooling. The annual electrical energy consumption for DX cooling system was 23.8 MWh, compared to 15.3 MWh for the ground-source heat pump system (Spitler et al., 2000).

4.2 Types

Depending upon the heat source and sink for heat pump, ASHRAE (1999) has divided ground source heat pump into following three different categories:

1. Ground-Coupled Heat Pump (GCHP)
2. Ground Water Heat Pump (GWHP)
3. Surface Water Heat Pump (SWHP)

The GCHP is a sub-type of the GSHP and is often called a closed-loop ground-source heat pump. A GCHP refers to a system that consists of a reversible vapour compression cycle that is linked to a ground loop heat exchanger (GLHE) buried in soil (ASHRAE, 1999). The most widely used unit is a water-to-air heat pump, which circulates water or a water-antifreeze solution through a ground-loop heat exchanger (ASHRAE, 1999). Closed-loop systems collect heat from the ground by means of a continuous loop GLHE. An antifreeze solution (or refrigerant in the case of a DX earth-energy system), which has been chilled by the heat pump's refrigeration system to several degrees colder than the outside soil, circulates through the GLHE and absorbs heat from the surrounding soil (NRCan, 2004). GCHP arrangements with vertical and horizontal GLHEs are shown in Figure 10 and Figure 11.

The GSHP system used in the medical office building is GCHP type system. It contains multiple water-to-air heat pumps. These heat pumps in a closed loop are connected with horizontal GLHE.

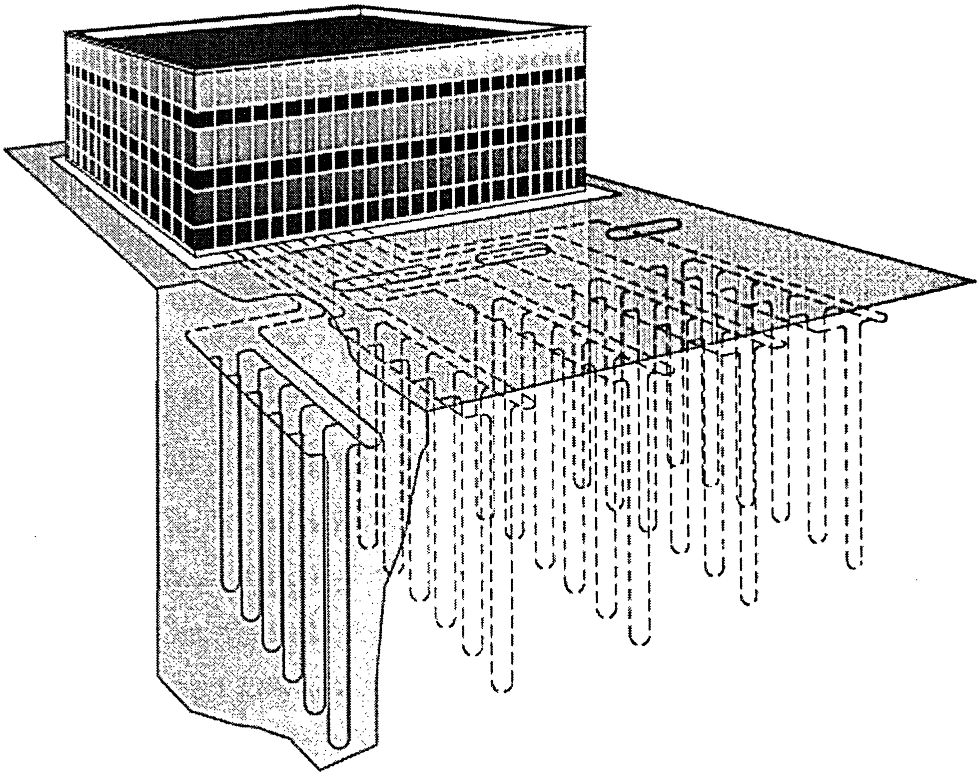

Figure 10: Closed-loop GCHP with vertical heat exchanger (CANMET, 2005)

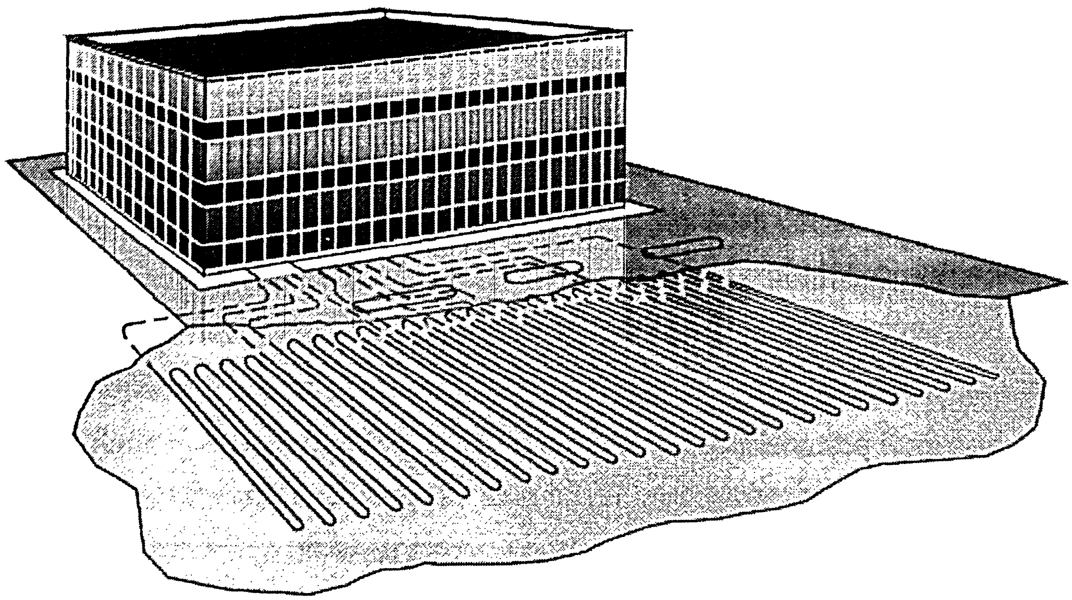

Figure 11: Closed-loop GCHP with horizontal heat exchanger (CANMET, 2005)

The second type of GSHPs is groundwater heat pump (GWHP) which is connected to a central water-to-water heat exchanger. Until the recent development of GCHPs, they were the most widely used type of GSHP (ASHRAE, 1999). GWHPs can be an attractive alternative because large quantities of water can be delivered from and returned to relatively inexpensive wells that require very little ground area. The water from the well is circulated in the water-to-water heat exchanger and the water-to-water heat exchanger isolates the heat pumps from ground water that may cause corrosion and fouling (ASHRAE, 1999). For a large building, GWHP systems are lower in cost as compared to GCHP because a single high volume well can serve an entire building, which might require many GCHP boreholes (Rafferty, 1995). Local environmental regulations and factors may be the deciding factor in choosing GWHP.

Surface water heat pumps (SWHP) can be either closed-loop systems similar to GCHPs or open-loop systems similar to GWHPs (ASHRAE, 1999). However, the thermal characteristics such as monthly temperatures are different for surface water as compared to ground water so, the performance of SWHP varies with that. SWHP can be either open-loop or close loop. In the closed-loop system SWHP is connected to a network of piping that is placed in a lake, river or pond. A pump circulates water or water antifreeze solution through the heat pump heat exchanger and the submerged piping loop. In the open-loop system, lake water can be pumped directly to water-to-air or water-to-water heat pumps or through an intermediate water-to-water heat exchanger that is connected to the units with a closed piping loop. The benefit of using a heat exchanger is that it prevents corrosion in the heat pump (ASHRAE, 1999). The open-loop system has the limitation that it cannot be used in cold climates where temperatures drop below 7 ^{0}C and in this case closed-loop system is a viable option (ASHRAE, 1999).

4.3 Recent Development

There is continuous research in progress on different aspects of ground source heat pumps. One of the recent developments is the hybrid ground source heat pump (HGSHP). This is desired because it replaces the need for long length of loops (Bose et al., 2002). The ground source heat pump systems that incorporate both a ground heat exchanger and an above ground heat rejecter (cooling tower) are commonly referred to as hybrid ground source heat pump (HGSHP) system (Bose et al., 2002). A HGSHP system is shown in Figure 12.

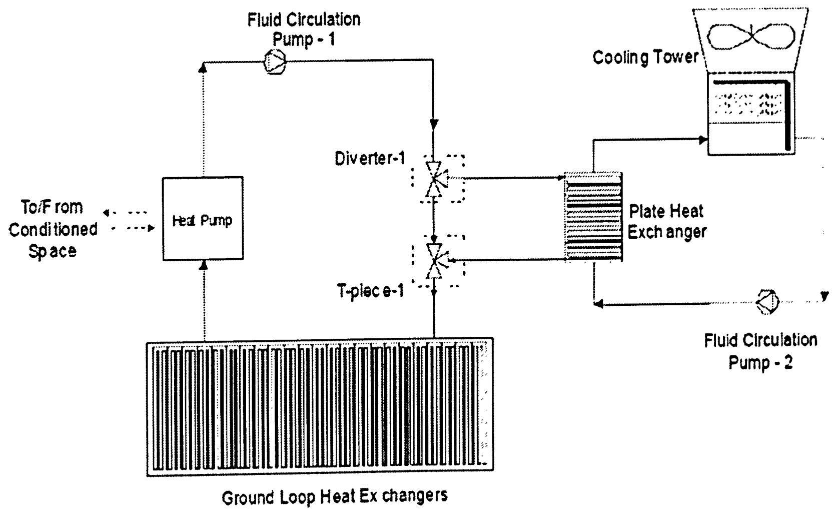

Figure 12: Hybrid Ground Source Heat Pump System with Cooling Tower (Bose et al., 2002)

5. Medical Office Building

5.1 Description

The building selected for this project is a medical office building. There are several positive sides of selecting this kind of building. It has diverse spaces such as labs, doctors' examination rooms, clinics, offices, restaurants and retails areas. These types of spaces widen the scope of the study such that different type of MNECB/PCB requirements can be incorporated in the simulation study and accordingly effects may be analyzed. The other reason to select this building is that it is being designed with the aim of LEED Canada certification. It has a number of energy efficient features such as heat pumps, heat recovery and tight envelope etc.

The medical office building is going to be located in Toronto, Ontario. The building is currently under design phase and has not been constructed yet. The building comprises one six-storey medical arts condominium office building. The combined area of all floors of the building is approximately 10,700 m^2. Moreover, two labs are located in the basement of the building namely; Basement Blood Lab and Basement X-ray Diagnostic Lab.

The main (ground) floor is a little different than rest of the floors. This floor consists of commercial tenancies with floor area of 2038 m^2. Some of the tenancies are coffee shop, restaurant/deli, pharmacy, chiropractic, physiotherapy, labs and seminar room. All floors above the ground floor have similar layout. There are 5 typical floors and each typical floor contains about 17 medical suites with 1506 m^2 floor area. Each suite consists of office and reception area. Typical floors are from storey2 to storey6 with similar HVAC loads except 6^{th} floor whose HVAC load is different due to exposed roof. The medical suites are for general physician doctors and do not constitute any operation theatre or labs.

5.2 Building Zones

The heating and cooling requirements of the building are fulfilled entirely by heat pumps. There is no chiller and boiler for the building. There are 102 heat pumps serving 102 zones. The backup heating is provided by electric resistance heating while there is no backup cooling. It is directly inline with MNECB/PCB requirements. PCB allows the building to have under cooled hours during the year but there must not be any under heated hours (NRC, 1999). But during the simulation it is found that heat pumps are adequately sized. Hence, there is no risk that there would be under heated or cooled hours.

The medical office building is divided into zones keeping the principles of zoning in mind as described by Modeling Guide for EE4-CBIP version 1.6. The spaces are divided into zones according to their exposure, thermostat and the heat pumps serving them. There is one thermostat associated with each heat pump.

There are 85 zones in the 5 typical floors, 15 zones in the main floor and 2 zones in the basement. The spaces on the typical floors (2-6) share heat pumps and spaces with same heat pump constitute one zone. The zones have been assigned heat pumps keeping their floor area and exposure in mind. The spaces on the main (ground) floor have relatively large loads and hence are served by individual heat pump(s); in some cases two heat pumps are assigned for one zone. The summary of zones, associated heat pump, their floor location and floor areas being served is shown in Table 5.

Table 5: Summary of zones, heat pump location and floor areas

Zones	Heat Pump (HP)	Floor	Floor area m^2
Basement Blood Lab	HP 2	Basement	125
Basement X-ray Diagnostic	HP 2 + HP 2	Basement	272.20
Chiropractic	HP 3	Main Floor	111.20

Zones	Heat Pump (HP)	Floor	Floor area m^2
Coffee shop	HP 3	Main Floor	102.70
Deli Restaurant	HP 3	Main Floor	96.30
Fast Food	HP 3	Main Floor	93
Medical Lab	HP 3	Main Floor	130.40
X-ray Lab	HP 3	Main Floor	93
Optician	HP 3	Main Floor	87.50
Pharmacy	HP 2 + HP 2	Main Floor	234
Reception	HP 2	Main Floor	78.80
Urgent U8	HP 2 + HP 2	Main Floor	131.40
Office U12	HP 6	Main Floor	33.10
Offices	HP 5	Main Floor	61.30
Seminar room	HP 1	Main Floor	50.10
Physiotherapy	HP 4 + HP3	Main Floor	218.30
Urgent U9	HP 4	Main Floor	119.90
501	HP 2	Typical Floors 2-5	120
502	HP 2	Typical Floors2-5	119
503	HP 2	Typical Floors 2-5	93
504	HP 2	Typical Floors 2-5	74
505	HP 2	Typical Floors 2-5	78
506	HP 2	Typical Floors 2-5	71
507	HP 2	Typical Floors 2-5	56
508	HP 2	Typical Floors 2-5	68
509	HP 2	Typical Floors 2-5	60
510	HP 2	Typical Floors 2-5	81
511	HP 2	Typical Floors 2-5	78
512	HP 2	Typical Floors 2-5	69
513	HP 2	Typical Floors 2-5	96
514	HP 2	Typical Floors 2-5	76
515	HP 2	Typical Floors 2-5	148

Zones	Heat Pump (HP)	Floor	Floor area m^2
516	HP 2	Typical Floors 2-5	72
517	HP 2	Typical Floors 2-5	147
601	HP 2	6^{th} floor	120
602	HP 2	6^{th} floor	119
603	HP 2	6^{th} floor	93
604	HP 2	6^{th} floor	74
605	HP 2	6^{th} floor	78
606	HP 2	6^{th} floor	71
607	HP 2	6^{th} floor	56
608	HP 2	6^{th} floor	68
609	HP 2	6^{th} floor	60
610	HP 2	6^{th} floor	81
611	HP 2	6^{th} floor	78
612	HP 2	6^{th} floor	69
613	HP 2	6^{th} floor	96
614	HP 2	6^{th} floor	76
615	HP 2	6^{th} floor	148
616	HP 2	6^{th} floor	72
617	HP 2	6^{th} floor	147

It should be noted that typical floors 2-6 layouts are identical both architecturally and HVAC system vice. Each zone on typical floors consists of office and reception area. The heat pumps and terminal units data is given in HVAC system section.

5.3 Building Envelope

The building envelope consists of walls, roof, exposed floors, exposed doors and windows. Heat flows in and out of the building through building envelope. The fundamental principles of thermodynamics states that heat transfer in and out of the building depends upon the envelope material, thickness and the temperature differential. The U-value of envelope plays an important role in energy loss calculations. Heat transfer through the building envelope constitutes a major portion of heating and cooling requirements of the building. Hence building envelope data should be carefully measured and used for simulation purposes. The modelling guide for EE4-CBIP states that the reference building and proposed buildings have identical envelope areas, so moderate differences between modelled envelope areas and "actual" envelope areas may have a negligible impact on building energy results and final incentive determination. The envelope properties are given in Table 6.

Table 6: Building envelope construction and U-values

Envelope Component	Construction	U-value ($W/m^2/^0C$)
Walls	15.875 mm gypsum board, LW concrete block, R-14 board insulation, 101.6 mm face brick	0.302
Roof	12.7 mm gypsum board, R-22 batt insulation, 12.7 mm plywood, concrete deck	0.227
Exposed Floors	Concrete floor with rigid insulation	0.568
Doors	Swinging, HM-Steel, 90 minutes fire rating	1.533
Windows	Double glazing without sash, 6.4 mm air space, fixed aluminium with thermal break	3.521

The overall shading coefficient of windows is 0.60. The absorptivity for walls and roof is 0.90. There are no external shades around any window. For floors and doors, only U-values are provided. Both HAP and EE4 permit to model doors and floors by just entering U-values, and detailed construction is not required. MNECB/PCB requires that a constant value of infiltration at 0.25 L/

(s.m^2) (based on exposed wall area) must be used for all exterior walls of the building.

5.4 Occupancy, Lighting and Equipments

The occupants also increase the energy requirements of the building. The fundamental principles of HVAC state that occupants emit sensible and latent heats. MNECB/PCB requires that default values of sensible and latent heat from occupants be used. These values are:

Sensible heat	75 W/person
Latent heat	55 W/person

The occupant density values should also be default values (NRC, 1999). The values are summarized for medical office building in Table 7.

Table 7: Occupancy, lighting and equipments default values (NRC, 1999)

Medical Office Building Spaces	Occupancy m^2/person	Lighting W/m^2	Equipments W/m^2
Office	20	23.70	7.50
Reception	10	21.50	2.50
Laboratory	20	24.80	10
Seminar Room / Conference / Meeting	5	19.40	1
Physiotherapy	20	17.20	10
Pharmacy	20	18.30	2.50
Restaurants /Deli / Fast food	10	14	1
Kitchen	20	15.1	10
Coffee shop	30	29.10	2.50
Urgent	20	22.60	10

Medical Office Building Spaces	Occupancy m^2/person	Lighting W/m^2	Equipments W/m^2
Optician	20	22.60	10
Chiropractic	20	22.60	10

The lighting inside the building also causes a major portion of cooling load. The lighting in the medical office building is fluorescent type. The detailed drawings for lighting data are not available. In this case MNECB/PCB requires that default lighting values should be used in both the proposed and reference buildings. This could be a potential credit for the building, if the lighting intensity of the proposed building is less than the default values. The default lighting values according to space type are summarized for the medical office building in Table 7.

Equipments inside the building increase the energy requirements of the building. Equipments include computers, microwaves, refrigerators and coffee brewers etc. MNECB/PCB requires that default values of equipment power density be used and are summarized for the medical office building in Table 7.

The detailed tables of occupant density, lighting intensity and equipments density for different spaces are given in Appendix 1 and 2. It should be noted that MNECB/PCB requires the values of occupancy, lighting and equipments to be same in both the proposed and reference buildings.

5.5 Building Schedules

Building schedules include occupancy, lighting, equipments and HVAC operational hours. MNECB/PCB requires that default values of building schedules be used in both the proposed and reference buildings. The default schedules for the medical office building are listed in Appendix 2. Appendix 2 must be read in conjunction with Appendix 1. The schedules type A, B or C etc. are listed in Appendix 1 against different types of spaces. The detailed schedules are available in Appendix 2.

5.6 HVAC System

The medical office building is equipped with unitary heat pumps that provide heating and cooling to individual thermostatically controlled zone. These individual water-to-air heat pumps are connected to a common water loop through a closed loop ground source heat exchanger. As described in Chapter 4, another name for this type of system is ground-coupled heat pump (GCHP). These heat pumps accept energy from the water-loop via heat exchanger and deliver it to the zones when in heating mode. While in the cooling mode the heat pumps accept energy from the zone and deliver it to the water-loop via a heat exchanger. The detailed operation of this type of system has been discussed already in Chapter 4. The input data of the heat pumps is available in Table 8.

Table 8: Heat pumps and terminal data

Heat Pump	Heating Capacity (kW)	Compressor Power Heating (kW)	Cooling Capacity (kW)	Compressor Power Heating (kW)	COP Heating / Cooling	Terminal Fan Air Flow (L/s)	Terminal Fan Power (W)
HP 1	8.45	1.96	7.54	1.89	4.50 / 4.16	379	249.67
HP 2	11.29	2.90	10.62	2.58	4 / 4.25	568	249.67
HP 3	15.33	3.36	13.9	3.39	4.67 / 4.19	767	374
HP 4	20	4.29	17.76	3.99	4.53 / 4.54	946	374
HP 5	9.95	2.16	8.72	1.95	4.78 / 4.66	474	249.67
HP 6	4.46	0.98	3.64	0.71	4.53 / 5.77	249	156
HP 2 + HP 2	22.48	5.70	21.14	4.97	4 / 4.25	1134	498.34
HP 4 + HP3	34.33	7.54	31.5	7.29	4.6 / 4.37s	1711	756

The zonal thermostats set-points have to be default values from MNECB/PCB (NRC, 1999). The thermostat set-points are as follows:

Cooling:

Occupied 24 ^{0}C

Unoccupied 35 ^{0}C

Heating:

Occupied 22 ^{0}C

Unoccupied 18 ^{0}C

Outdoor ventilation air is provided to the terminal units via a centrally located ventilation unit. A heat recovery device is installed in the passage of return air; both sensible and latent heats are recovered. The heat recovery device is based on reverse flow technology with 90% efficiency. The heat reclaim device is operational throughout the year. The central supply and return fans are forward curved types with 18.4 kW motors. MNECB/PCB requires having certain minimum ventilating requirements in different spaces. The minimum outdoor air requirements based on floor area are given in Table 9.

Table 9: Minimum outdoor air requirements (NRC, 1999)

Medical Office Building Spaces	**Min. Outdoor Air L/(s.m^2)**	**Medical Office Building Spaces**	**Min. Outdoor Air L/(s.m^2)**
Office	0.50	Restaurants /Deli / Fast food	1
Reception	0.75	Kitchen	1.5
Laboratory	0.50	Coffee shop	1
Seminar Room / Conference / Meeting	2	Urgent	0.40
Physiotherapy	0.60	Optician	0.40
Pharmacy	0.40	Chiropractic	0.40

6. Utility Rates

According to EE4-CBIP modelling guide, provincial and federal sales taxes must be excluded in the modelling procedure (NRCan, 2006).

6.1 Toronto Electricity Rates

The electricity rates have been taken from Toronto Hydro Electric Systems. The rates are for commercial consumers because the medical office building comes under the commercial category. The rates are up-to-date as of September, 2007. There are demand charges for the use of electricity. The first 750kWh are charged at $0.0530 and the remaining units are charged $0.0620. Per peak kW is defined as maximum kW and is charged in terms of time of day. These rates are applicable only between 7:00 a.m. to 7:00 p.m. Monday to Friday excluding holidays (Toronto Hydro, 2007). The rates structure also includes delivery charges (sub-charges under delivery charges are also included) and regulatory charges. The rate structure is shown in Table 10.

Table 10: Toronto Electricity Rates (Toronto Hydro, 2007)

Monthly Charges	Rates Structure	Rates
Electricity	(per first 750 kWh/30 days)	$0.0530
	(per remaining kWh/30 days)	$0.0620
Delivery Charges		
Network	(per Peak kW/30 days)	$2.40
Connection	(per Max kW/30 days)	$1.77
Distribution Charge	(per Max kVA/30 days)	$4.16
Market Transition Charge	(per Max kVA/30 days)	$0.07
Customer Charge	(per 30 days)	$718.10
Transformer Allowance	(per Max kVA/30 days)	($0.62)
Regulatory Charges		

Monthly Charges	Rates Structure	Rates
Wholesale Market Operations (includes Rural Rate Protection)	(per kWh)	$0.0062
Regulated Price Plan (RPP) Admin Charge (formerly Standard Supply Service (SSS) Charge)	(per 30 days)	$0.25
Debt Retirement Charge		
Debt Retirement Charge	(per kWh)	$0.0070

6.2 Toronto Gas Rates

The gas rates have been taken from Enbridge Gas Distribution and are for commercial consumers. The rates are up-to-date as of September, 2007. The Gas Supply Charge is charged at 33.0229 cents per cubic meter ("¢/m^3"). This price is based on a forecast of market prices for the next twelve months. The forecast price is reviewed every three months and, if necessary, adjusted accordingly to reflect market changes (Enbridge Gas, 2007). If Enbridge forecasts are over or under actual costs, they reimburse or collect the difference from customers through gas cost adjustments (Enbridge Gas, 2007). The rates used for medical office building are shown in Table 11.

Table 11: Toronto Gas Rates (Enbridge Gas, 2007)

Monthly Charges	Monthly Rates
Customer Charge	$23.58
Gas Supply Charge	33.0229 ¢/m^3
Delivery Charge: Amount of gas used per month in cubic metres (m^3)	
Delivery Charge	

Monthly Charges	**Monthly Rates**
Amount of gas used per month in cubic metres	Cost in cents per cubic metre ¢/m³
First 500	13.7195 ¢/m³
Next 1,050	11.5252 ¢/m³
Next 4,500	9.9891 ¢/m³
Next 7,000	9.0017 ¢/m³
Next 15,250	8.5628 ¢/m³
Over 28,300	8.4531 ¢/m³
ADDITIONAL ITEMS	MONTHLY RATES
Gas Cost Adjustment	(6.2723) ¢/m³

7. Building Simulation in HAP and EE4

MNECB requires that, in order to demonstrate the compliance with the performance path, reference building must be modelled such that, it is physically similar to the proposed building and just meets the requirements of MNECB and PCB. HAP does not have the capability to generate the reference building itself. Hence, the reference building must be modelled manually based on the MNECB/PCB requirements. EE4 generates the reference building automatically. When all the building elements are modelled, EE4 uses the information entered and incorporates MNECB and PCB rules to generate the MNECB reference building (NRCan, 2006).

7.1 Modelling the Similar Requirements

The section discusses modelling the MNECB/PCB requirements that are same for both the proposed and reference buildings.

7.1.1 Building Type vs. Space Function Approach

In the process of modelling the medical office building to demonstrate compliance with the MNECB/PCB, a key decision has to be made whether to model the building by the building type approach or the space function approach. This decision affects many requirements such as occupant density, ventilation requirements, schedules and lighting for the reference building. When the building type approach is used, a single set of operating parameters has to be defined for the entire building. For example, the medical office building has diverse spaces such as offices, labs. With the building type approach the whole building must be modelled either using the operating parameters for offices or labs. A single building cannot have two types of operating parameters in the building type approach.

Keeping in view the diverse spaces of the medical office building, The space function approach has been adopted. Modelling the building using the space function approach allows lighting, receptacle loads, ventilation and operating schedules etc., to be defined for each space within a zone (NRCan, 2006). EE4-CBIP modelling guide-1.6 also recommends using the space function approach because of its flexibility in describing the various building functions. The values for different parameters under the space function approach are listed in Appendix 1.

7.1.2 Principle Heating Source

The principle heating source plays a key role in modelling the proposed and reference buildings. The principle heating source defines the insulation levels for the reference building envelope. The higher the cost of heating fuel and the higher are the insulation requirements (NRCan, 2006). The principle heating source is defined at the zone level and there may be different principle heating sources in different zones (NRCan, 2006).

In the medical office building, heating is provided by closed-loop ground source heat pumps. It has been stated earlier that each zone has an individual heat pump connected to a common loop; hence, the principle heating source for all zones is "Heat Pump".

7.1.3 MNECB Administrative Regions

MNECB has divided Canada into 34 climatic regions as shown in Figure 13, and, in Appendix A of MNECB regional requirements for different regions are listed. These requirements are used while modelling the proposed and reference buildings. U-values for the reference building for different types of walls, roofs, floors and windows are listed for each region. The selection of U-value for the reference building depends upon the type of wall, roof, floor and window in the proposed building, principle heating source and the region where it is located. For example; the medical office building is located in Toronto and has a concrete roof. Therefore, the administrative region is Ontario, Region A and the proposed building falls under the roof type III category of MNECB. Hence, a U-value of 0.410 $W/m^2.^0C$ would be used for the roof of the reference building.

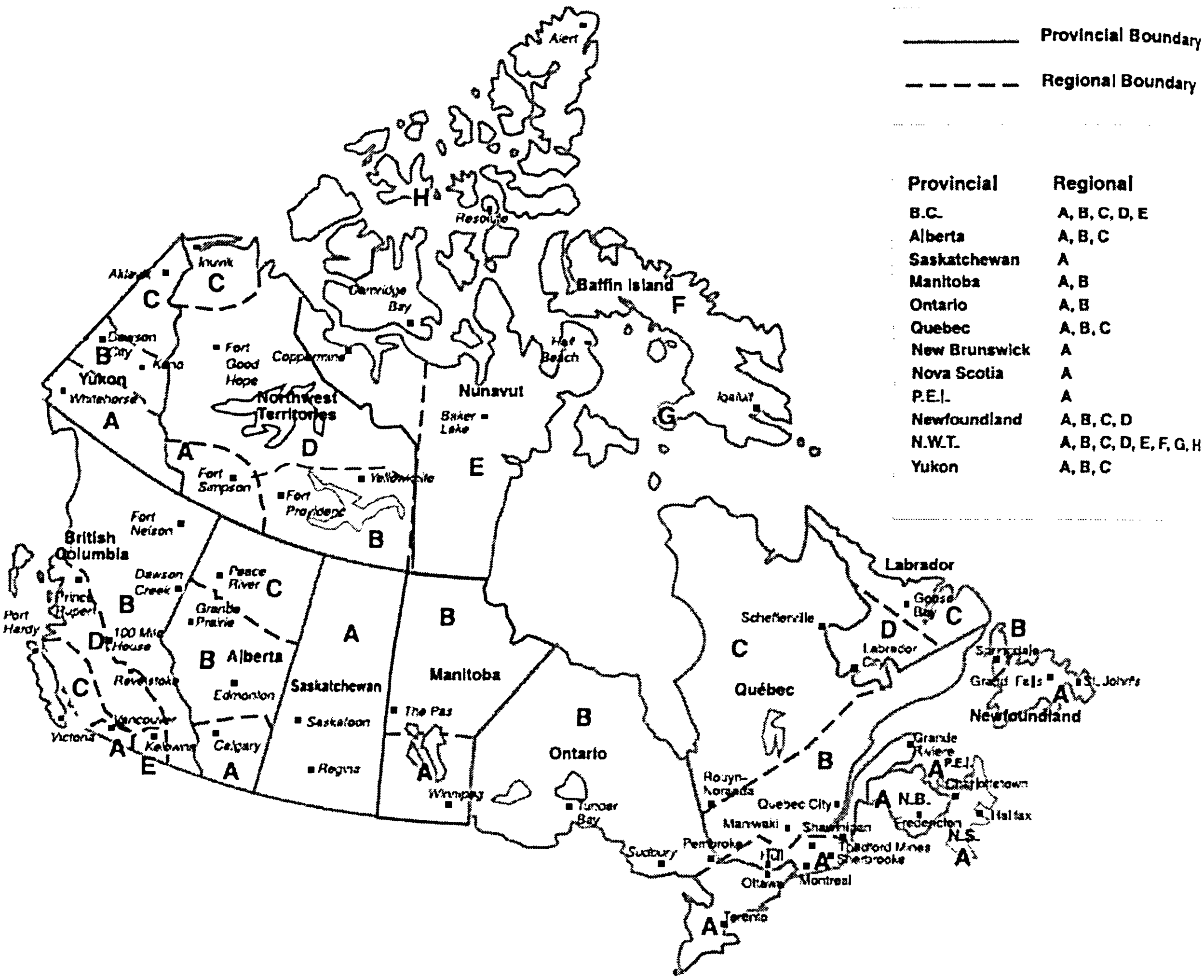

Figure 13: MNECB administrative regions (NRCan, 2000)

7.1.4 Climatic Data and Calendar

The medical office building is located in Toronto; hence, the city of Toronto weather file is used in HAP and EE4. However, summer and winter design day temperatures in HAP are different than the weather file of EE4. Hence, for the purpose of consistency, the summer and winter design day temperatures of EE4 have been used in HAP. These are:

Summer design day temperature: 29 ^{0}C

Winter design day temperature: -17 ^{0}C

Since different provinces across Canada have different holidays, PCB requires that statutory holidays must not be modelled. For this purpose, statutory holiday have not been defined.

7.1.5 Building Schedules

MNECB/PCB requires that the default values of building operation schedules have to be assigned to both the proposed and reference buildings (NRCan, 2006). The operating parameters include occupant density, equipment loads, ventilation rates and heating/cooling thermostats set points (NRCan, 2006). The detailed schedules for all these parameters are listed in Appendix 2. The schedules that are required for the spaces of medical office building are summarized in Table 12.

Table 12: Schedules for medical office building

Medical Office Building Spaces	Schedules from Appendix 2
Offices	A
Reception	A
Laboratories	A
Seminar Room / Conference / Meeting	C
Physiotherapy	C
Pharmacy	C
Restaurants /Deli / Fast food	B
Coffee shop	C
Urgent	C
Optician	C
Chiropractic	C

7.1.6 Space Data

The space data which is same in both the proposed and reference buildings have been modelled using the medical office building envelope input data and Appendix 1. The following space data is same in both the proposed and reference buildings (NRC, 1999):

- Floor, wall, roof and door areas
- Orientation of walls, windows, roofs and doors
- U-value of the doors
- Quantity of windows and doors in each wall
- Absorptance values
- Ceiling Height
- Occupant density (m^2/person)
- Equipment loads (W/m^2)

Doors are the only envelope component of a building whose U-values are same in both the proposed and reference buildings (NRC, 1999). Hence, there is no credit or penalty for having less efficient doors.

7.1.7 Ventilation (Outdoor Air)

The minimum outdoor air values are given in Appendix 1. The outdoor air requirements (L/s/m^2, based on floor area) are same for both the proposed and reference buildings (NRC, 1999).

7.1.8 Heat Gain Due to Occupants

The heat gain from occupants for all space types shall be uniform value in the building (NRC, 1999). PCB requires that following values must be used:

Sensible heat gain	75 W/Occupant
Latent heat gain	55 W/Occupant

7.1.9 Thermostat Set-Points

The zonal thermostats set-points have to be default values from MNECB/PCB and room throttling range must be equal to 1^0C in both the proposed and reference buildings (NRC, 1999). The thermostat set-points are as follows:

Cooling:

Occupied	24 ^0C
Unoccupied	35 ^0C

Heating:

Occupied	22 ^0C
Unoccupied	18 ^0C

7.2 Modelling the Reference Medical Office Building in HAP

Reference building means a generic building design of the same size and shape as the proposed design that complies with the prescriptive requirements of the MNECB and has prescribed assumptions, as given in PCB (NRC, 1999).

The purpose to define the reference building is to set the energy target for the proposed building. The reference building has same area, envelope, occupancy, schedules etc, but all other parameters, for example, insulation levels, window types are modelled according to prescriptive requirements mentioned in MNECB/PCB (NRC, 1999).

The following paragraph has been summarized from MNECB/PCB by looking at different requirements for the reference building:

The reference building is architecturally identical to the proposed building, thus having the same wall orientations, areas, windows, level of air-tightness, number of occupants, indoor set-point temperatures (space heating, cooling), fan operation, appliance, electrical usage and equipment. The reference building must be insulated to the MNECB prescriptive levels. The reference building will have a defined heating and cooling plant (if applicable), a representative air handling system. The type of air handling system selected for the reference building is dependent upon the building's function, and the type of air handling system contemplated in the proposed building. The reference building will be constructed with a certain mass level and will not incorporate any window shading devices.

7.2.1 Lighting

The modelling of lighting systems is relatively straightforward. Recessed type of fluorescent lighting would be used in the medical office building. Most lights (other than incandescent and halogen) require ballasts. Ballasts increase power requirements over the rated bulb power (NRC, 1999). An average value of 1.08 is assumed as ballast multiplier. The lighting power density for the reference medical office building has to be the default values as specified by MNECB/PCB and are given in Appendix 1. The assumption of ballast multiplier does not affect the energy savings calculations because ballast multiplier is same in both the proposed and reference buildings.

7.2.2 Exterior Walls

As described earlier, that orientation, absorptance and area of all the exterior walls are the same in both the proposed and reference buildings. The construction of walls for the medical office reference building as required by MNECB/PCB is given in Table 13. Either detailed construction can be defined or just the U-value may be entered (NRC, 1999).

Table 13: Reference wall construction (NRC, 1999)

Wall Type	Layer material	Thickness (mm)
All types	Face brick	100
	Air space	25
	Insulation	25.30
	Gypsum board	15

The U-value for the walls of the reference medical office building is 0.480 $W/m^2.^0C$, when the principle heating source is a heat pump (NRC, 1997). U-values for different heating sources are listed in Appendix 3.

7.2.3 Roofs

The area, orientation and absorptance for the roof of the reference building are same as the proposed building (NRC, 1999). The construction of the roof for the reference medical office building as required by MNECB/PCB is given in Table 14. Either detailed construction can be defined or just the U-value may be entered (NRC, 1999).

Table 14: Reference roofs construction (NRC, 1999)

Roof Type	Layer material	Thickness (mm)
Concrete decks with rigid insulation	Gravel	50
	Roofing built up	10
	Insulation	83.30
	Metal deck	15

The U-value for the roof of the reference medical office building is 0.410 $W/m^2.^0C$, when principle heating source is a heat pump (NRC, 1997). U-values for different heating sources are listed in Appendix 3.

7.2.4 Exposed Floors

The areas of the exposed floors for the proposed and reference buildings remain same (NRC, 1999). The construction of the exposed floors for the reference medical office building as required by MNECB/PCB is given in Table 15 and the U-value may also be entered directly. The U-value for the exposed floors of the reference medical office building is 0.410 $W/m^2.^0C$, when the principle heating source is a heat pump (NRC, 1997). U-values for different heating sources are listed in Appendix 3. HAP does not have the capability to

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define series of layers for exposed floors. However, HAP permits entering the U-value of exposed floors directly, so this situation is not a hurdle in the modelling process.

Table 15: Reference exposed floors construction (NRC, 1999)

Floor Type	Layer material	Thickness (mm)
Concrete decks with rigid insulation	Gypsum board	12
	Concrete	50
	Insulation	80.4

7.2.5 Windows

The orientation, SHGC or SC and area of each window of the reference building are same as the proposed building and there must be no external shadings in the reference building (NRC, 1999). MNECB/PCB does not require entering the detailed construction of the windows; instead it only requires entering orientation, area and SHGC or SC. In addition to these requirements, HAP also has the capability to define detailed construction of windows. Since all windows in the medical office building are fixed type without sash, the U-value for the reference windows is 2.40 $W/m^2.^0C$ from Appendix 4. HAP does not have the capability to take input of SHGC; instead, SC may be entered. Following is the conversion formula between SHGC and SC (NRC, 1999):

$$SC = (1.15)\ SHGC \qquad \text{(Eq: 2)}$$

7.2.6 Infiltration (Air Leakage)

Each space of the proposed building that contains exterior walls is modelled with air leakage (infiltration) set to a constant value of 0.25 $L/(s.m^2)$ (0.05 cfm/ft^2) of gross wall area (NRC, 1999). HAP provides three options to model infiltration, i.e., L/s or $L/(s.m^2)$ or ACH (Air changes per hour).

7.2.7 Supply Temperatures and Airflow Rates

The supply airflow rate for any zone in the heating or cooling mode must be equal to 2 L/(s.m^2) in the reference building as required by MNECB/PCB and design supply temperatures should be as follows (NRC, 1999):

Heating Supply Temperature	=	43 ^{0}C
Cooling Supply Temperature	=	13 ^{0}C

7.2.8 Supply and Return Fans

The reference medical office building must have VAV system, the supply fan must be 1000 Pa (4.0 inch) static and 55% combined motor/impeller efficiency; the return fan must be 250 Pa (1 inch) static and 30% combined motor/impeller efficiency (NRC, 1999). Both supply and return fans must be draw-thru configuration (NRC, 1999). HAP provides three options to define the fan parameters i.e. static, motor kW and motor hp.

7.2.9 Economizer

The control of outdoor air in the reference building must be achieved by an integrated enthalpy economizer and it must be operational at all times, i.e., economizer operation must not be limited between specific outdoor air temperatures (NRC, 1999). In HAP, when the upper cut-off temperature is 50 ^{0}C and lower cut-off temperature is -50 ^{0}C, the economizer is operational at all times (Carrier, 2006).

7.2.10 Heating and Cooling Equipment

When the heating and cooling equipment in the proposed building is electric heat pump then the reference building must have an electric boiler as heating equipment and an electric chiller as cooling equipment (NRC, 1999). The heating capacity of the boiler must be equal to the sum of the heating capacities of all the heat pumps and the cooling capacity of the chiller must be equal to the sum of cooling capacities of all the heat pumps (NRC, 1999). The boiler efficiency must be 80% with 16 ^{0}C temperature drop for flow through hot water heating coils and the heat circulating pump combined motor impeller efficiency must be 60% (NRC, 1999).

The type of chiller that is required, e.g., reciprocating or centrifugal depends upon the sum of cooling capacities of all the heat pumps and, in the case of medical office building the sum of cooling capacities is about 1150 kW. MNECB/PCB requires that when the cooling capacity is between 700 kW to 2100 kW, then the reference chiller must be centrifugal type with COP of 5.2 (NRC, 1999). The combined motor/impeller efficiency of the chiller cooling circulating pump must be 60% (NRC, 1999).

The cooling tower capacity required for the chiller must be calculated based on water temperature rise from 29 ^{0}C to 35 ^{0}C (NRC, 1999). The cooling tower fan will be a constant speed fan with cycling control for the reference medical building (NRC, 1999). The pump of cooling tower must be a constant speed pump with head equal to 180 kPa and combined motor/impeller efficiency of 70% (NRC, 1999).

HAP has the capability to model all the parameters discussed in above paragraphs; hence, no work around is required.

7.3 Modelling the Proposed Medical Office Building in HAP and EE4

The proposed building means the building, group of buildings or portions of the building for which construction approval is being sought (NRC, 1999). The proposed design includes the building envelope, lighting and electrical systems, and mechanical systems to provide space conditioning (NRC, 1999). The requirements that are same for both the proposed and reference buildings have been defined already. In the following sections, only those requirements will be discussed that are particular to the proposed building.

7.3.1 Exterior Walls

There is an optional requirement by MNECB/PCB to define the wall construction as series of layers. For each layer, material and thickness should be defined. In HAP, wall construction type has to be defined because it does not let the U-value to be entered directly. In this way, the representative U-value is calculated. PCB allows entering the U-value directly. In EE4 either wall construction may be defined or the U-value may be entered directly.

It was mentioned earlier that the orientation and area of walls is same in both the proposed and reference buildings. However, according to MNECB/PCB, for any wall of the proposed building the U-value cannot be greater than 167% of the U-value for the reference building. In the reference building, the U-value for exterior walls is 0.480 $W/m^2.^0C$ and 167% of this value is 0.8016 $W/m^2.^0$ C. For all the walls of medical office building, U-value is 0.302 $W/m^2.^0C$, which is perfectly inline with the above requirement.

7.3.2 Windows

The orientation of the windows is same as the walls of the building. MNECB/PCB requires that area, U-value, window type classification (operable or fixed) and SHGC must be defined. In HAP, SHGC cannot be defined directly; instead, the SC value may be entered. Defining the window type classification is also beyond the capability of HAP. But this incapability does not affect the results because this aspect cannot be defined for both the proposed and reference buildings. EE4 accepts the input for both the SHGC and window type classification. The conversion formula between SHGC and SC is given in Equation 2 of 7.2.5.

7.3.3 Roofs

The roof is located on the 6^{th} floor of the medical office building. The area of roof remains the same in both the proposed and reference buildings. However, according to MNECB/PCB, the U-value for the roof of the proposed building cannot be greater than 167% of the U-value for the reference building. In the reference building, the U-value of the roof is 0.410 $W/m^2.^0C$ and 167% of this value is 0.685 $W/m^2.^0$ C. The U-value for the roof of the medical office building is 0.227 $W/m^2.^0C$ which is perfectly inline with the above requirement.

There is an optional requirement by MNECB/PCB is to define the roof construction as series of layers. For each layer, material and thickness should be defined. Otherwise, the U-value of the roof may be entered directly. In HAP, the roof construction type has to be defined because it does not let the U-value to be entered directly. Thus, the representative U-value is calculated. In EE4 either wall construction may be defined or the U-value may be entered directly.

7.3.4 Exposed Floors

The area of all the exposed floors remains the same in both the proposed and reference buildings. There is an optional requirement by PCB is to define the floor construction as series of layers. For each layer, material and thickness should be defined. In HAP, floor construction type cannot be defined but U-value may be entered and PCB allows entering the U-value directly. In EE4 either floor construction may be defined or U-value may be entered directly.

According to MNECB/PCB, for any exposed floor of the proposed building the U-value cannot be greater than 167% of the U-value for the reference building. In the reference building exposed floor U-value is 0.410 $W/m^2.^0C$ and 167% of this value is 0.685 $W/m^2.^0$ C. For all the exposed floors of medical office building, the U-value is 0.568 $W/m^2.^0C$ which is perfectly inline with the above requirement. As the U-value for the exposed floors of the proposed building is greater than the reference, this is a penalty for the medical office building.

7.3.5 Lighting

For some projects, the lighting layout may not be defined at the early stages of design; for example, speculative office or retail space, where the tenant will be responsible for the lighting design. In these cases, the proposed building must use the same lighting power density as the reference building (NRC, 1999). In other words, there is no credit or penalty given for the lighting design.

In the case of the medical office building, recessed type of fluorescent lighting is intended but lighting architectural drawings are not available; hence, the default lighting power density for different spaces, from Appendix 1 has to be used as per the requirements of PCB. The ballast multiplier is assumed to be 1.08 for both the proposed and reference buildings.

7.3.6 Infiltration (Air Leakage)

For each space of the proposed building that contains exterior walls, is modelled with air leakage (infiltration) set to a constant value of 0.25 L/(s.m^2) (0.05 cfm/ft^2) of gross wall area (NRC, 1999). HAP provides three options to model infiltration, i.e. L/s or L/(s.m^2) or ACH (Air changes per hour) and EE4 takes 0.25 L/ (s.m^2) as a default value when running the compliance mode.

7.3.7 Supply Temperatures and Airflow Rates

The minimum supply airflow rate for any zone in heating or cooling mode cannot be less than 2 L/ (s.m^2) as required by MNECB/PCB. When the supply airflow rate is greater than 2 L/ (s.m^2), then it should be calculated at design supply temperatures (NRC, 1999) which are given below:

Heating Supply Temperature = 43 ^{0}C

Cooling Supply Temperature = 13 ^{0}C

7.3.8 Supply and Return Fans

MNECB/PCB requires that for both the supply and return fans, motor power or static pressure and efficiency or parameters from which efficiency can be determined must be modelled. In the medical office building both supply and return fans are forward curved type and have 18.4 kW motor. HAP and EE4 have the capability to define the fan parameters as discussed above and work around is not required.

7.3.9 Closed-Loop Ground Source Heat Pumps

For closed-loop ground source heat pumps the heating and cooling capacities must be defined and COP or compressor power must also be defined (NRC, 1999). HAP and EE4 take the input of heating and cooling capacities. However, HAP requires compressor power where as EE4 requires COP.

Defining the closed-loop ground source heat pumps (CLGSHP) in EE4 is straight forward. Currently, HAP does not provide a performance model for the ground heat exchanger that is used for the loop heat transfer, so the system configuration of CLGSHP cannot be directly modelled. However, using an “Open

Loop WSHP" system configuration can approximate the performance of this system (Carrier, 2005). This simulates the loop water temperature for the WSHP units as a function of time of year and an average loop water temperature for each month must be entered in the cooling tower properties (Carrier, 2005). In the actual system, the loop water temperature for a ground-coupled system is a function both of time of year and the hourly heat rejection or heat extraction (Carrier, 2005). However, using the "Open Loop WSHP" system model allows a general approximation of system performance (Carrier, 2005). The monthly soil temperatures for Toronto that are recommended by NRCan for heat pump system are given in Table 16. These temperatures are directly defined for closed-loop heat pumps in EE4.

Table 16: Monthly soil temperatures for Toronto to use with heat pump system (NRCan, 2006)

Month	Soil Temperatures ^0C
January	6.6
February	5.4
March	4.5
April	4.9
May	8.1
June	11.8
July	14.6
August	16.5
September	16.3
October	14.3
November	11.9
December	9.2

8. Comparison between HAP and EE4

This section describes the comparison between HAP and EE4 in terms of modelling the medical office building from EAp2 and EAc1 point of view. When different parameters of software are described here, the medical office building specific inputs are kept in view. It has been described earlier that both HAP and EE4 are hourly analysis program and perform analysis for each of the 8760 hours of the year which is the basic requirement for EAp2 and EAc1. An introductory overview about HAP and EE4 has been provided already in Chapter 3. HAP is based on ASHRAE's transfer function method (Carrier, 2006) whereas EE4 is based on DOE 2.1E (NRCan, 2006).

HAP uses a bottom up approach to model a building for example, first spaces are defined and then they are linked to zones and HVAC system serving them. EE4 adopts a top to bottom approach in hierarchal manner just like a tree; first the HVAC system is defined at plant and system level, after that all zones served by the HVAC system are specified at zone level and then space data in each zone is defined at room level. Generally speaking in a building, a space represents a single room but it is dependent upon the simulator how to define spaces. A space consists of a number of elements such as walls, roofs, windows and internal heat gains.

8.1 Weather

HAP: It has well defined weather database for many cities across the world. When the weather file for a specific city is assigned, HAP automatically allocates the parameters such as hourly dry bulb and wet bulb temperatures and monthly solar heat gains. If desired these values may be changed also manually. The default values of latitude, longitude and elevation for a specific city may also be changed thereby making them very specific to a particular building location. Although summer and winter design dry/wet bulb temperatures are default values associated with a weather file, but HAP also provides flexibility in making them user defined. If the desired city is not in HAP's database and therefore does not appear in the city drop-down list, design weather data can be directly specified but this would be very time consuming process.

EE4: The weather database of EE4 consists of 34 MNECB climatic regions and includes different cities across Canada under those climatic regions. The list of cities is not very comprehensive. For example: weather file for city of Mississauga is not available. In this case the weather file for closest city must be used (NRCan, 2006). Once a weather file is selected, its parameters cannot be changed. The only flexibility in weather section is provided by making it possible to change the summer and winter design dry bulb and summer wet bulb temperatures. Hence the weather file of EE4 cannot be made very specific to building location in contrast to HAP.

8.2 Schedules

HAP: Building characteristics and HVAC system behaviour is defined by schedules. Three distinct kinds of schedules may be defined in the central library of HAP. These are fractional, fan/thermostat and utility rate schedules. The hourly and daily variation of lighting, occupancy and equipments etc. is defined by fractional schedules. For example the fraction of lighting in use during each hour of the day may be defined by fractional schedules. Fan/Thermostat schedule defines the hours when HVAC system is in operation. The operational hours are defined as "occupied" or "unoccupied". During the occupied hours, the occupied thermostat setpoints are used and during unoccupied hours unoccupied thermostat setpoints are used. The purpose of utility rates schedules is to define the on-peak and off-peak pricing periods. All schedules are assigned to the building at space level.

EE4: The schedules in EE4 are basically of two types i.e. fractional and temperature schedules. Fractional schedules just like HAP are used to define the hourly and daily variation of lighting, occupancy and equipments. Temperature schedules are used for heating and cooling equipment operation. The temperatures that heating and cooling equipments are required to maintain are defined for each hour for occupied and unoccupied periods of the day. The schedules are defined at zone level.

8.3 Walls

Construction of walls is defined in the central library in both HAP and EE4 and then walls are linked to the relevant spaces. Absorptivity value of the exterior surface of the wall is required to calculate solar heat absorbed by the wall and can be input directly in both HAP and EE4.

HAP: A wall is defined by a series of material layers that are used to construct the wall. For these layers thickness, density, specific heat and R-value may be defined. Hence HAP calculates the overall R-value and U-value for the wall, direct input of the overall U or R-value is not permitted. The area and exposure of walls is specified under spaces.

EE4: Walls may be defined as series of layers, however only thickness value is required for these layers. EE4 allows entering the overall U-value of the wall directly. The area and orientation in degrees for the walls are defined at room level.

8.4 Windows

HAP: Construction and area of windows are defined in the central library and then specific type of window may be linked to the respective walls. HAP has the option to specify the overall U-value and SC (shading coefficient) of the window directly. Alternatively separate glazings in the window may also be defined. In this case, the properties of each glazing such as transmissivity, reflectivity and absorptivity can be indicated. When multi-glazing window assembly is desired, the gap type option allows defining the width of the gap between glazings and also the gas which is used to fill the gap. Window type classification for instance operable or fixed cannot be identified in HAP. The area of windows is specified in the central library. The quantity of windows in each wall is indicated in spaces.

EE4: It does not have the capability to define the detailed window glazings. The overall U-value and SHGC (solar heat gain coefficient) are entered directly in the central library. The area of window and the wall in which window is located is specified at room level.

8.5 Doors

HAP: The quantity of doors and the walls in which they are located, has to be specified in the spaces. U-values and areas of doors are defined in the central library. The detailed construction of the doors cannot be defined instead only the overall U-value of the door is required. If a door contains a glass portion, glass area and U-value may be specified.

EE4: Doors are defined in the central library and only U-value is specified. The doors and areas of doors in each wall are indicated at room level. The glass portion of door cannot be associated with the door; it has to be identified as an operable window in the central library (NRCan, 2006).

8.6 Roofs

Construction of roofs is defined in the central library in both HAP and EE4 and then construction of roofs is linked to the specific spaces. Absorptivity value of the exterior surface of the roof is required to calculate solar heat absorbed by the roof and can be input directly in both HAP and EE4.

HAP: A roof in HAP is defined in the central library by a series of material layers that are used to construct the roof. For these layers thickness, density, specific heat and R-value may be indicated. Hence HAP calculates the overall R-value and U-value for the roof, direct input of the overall U-value or R-value is not permitted. The area and exposure of the roof is defined under spaces.

EE4: The roofs in the central library may be defined as series of layers, only thickness value is required for these layers. However EE4 allows entering the overall U-value of the roof directly. The area and exposure of the roof is specified at room level and the roof construction is linked to the related room from the central library.

8.7 Exposed Floors

HAP: It does not have the capability to define the detailed floor construction as series of layers instead the overall U-value of floor is entered directly. The floor area is defined in the spaces.

EE4: In EE4 detailed floor construction may be indicated or the over U-value may be entered in the central library. Then the construction of floor from the central library can be linked to a specific space. The area of exposed floors is defined under particular spaces at room level.

8.8 Lighting

*HAP: T*he lighting fixture type may be specified as recessed/unvented or recessed/vented or free hanging, lighting intensity may be entered in watts or W/m^2. HAP does not provide any option to define the lighting controls such as sensors. But it can use schedule to allow percentage of the total lighting load to be on at given hour.

EE4: It is possible to specify lighting controls if required and for each space, lighting can only be delineated as total wattage installed in a space. Moreover EE4 does not have the capability to specify the lighting fixtures.

8.9 Occupancy

HAP: For each space occupancy may be entered as number of people or m^2/person. Sensible and latent heat gains in W/person may be user defined or activity level of people can be specified then HAP would automatically take the heat gains based on ASHRAE 62-2001(Carrier, 2006).

EE4: Occupancy can only be defined as m^2/person. The default MNECB values have to be used which are given in Appendix 1. Sensible and latent heat gains from occupants are fixed values at 75 W/person and 55 W/person respectively, when running the MNECB compliance mode (NRCan, 2006).

8.10 Equipments

HAP: Equipments such as computers, copy machines and kitchen equipments may be specified in total watts in a space or W/m^2. The equipments are defined in the spaces.

EE4: Equipments heat gain in W/m^2 are fixed with space type selected and cannot be changed when running the compliance mode (NRCan, 2006).These MNECB default values for different spaces types are available in Appendix 1. Equipments are defined at room level.

8.11 Infiltration

HAP: Infiltration for each space that contains exterior wall is specified separately for design heating and cooling days and for annual energy simulation. Infiltration is defined in the spaces and three units are available for infiltration, either in L/s or $L/s/m^2$ (based on exterior wall area) or ACH. Moreover infiltration load can be indicated as occurring during all hours or during unoccupied hours when the HVAC system fans are off.

EE4: Infiltration is a fixed value for each space at 0.25 $L/s/m^2$, when running the MNECB compliance mode (NRCan, 2006).

8.12 Ventilation

HAP: For each space, ventilation requirements may be defined in L/s or L/ ($s.m^2$) (based on floor area) or L/s/person. Ventilation may be user defined or space usage type can be specified then HAP would automatically take the ventilation requirements based on ASHRAE 62-2001(Carrier, 2006).

EE4: Ventilation is defined at room level in L/($s.m^2$) or L/s/person. The default values for ventilation requirements for each space have to be used (NRCan, 2006). The MNECB ventilation requirements are given in Appendix 1.

8.13 Fans

HAP: The supply and return fans are defined at the system level. For fans, the fan type, airflow rates and configuration such as motor power or static pressure are specified. The terminal fans are defined at zone level, for terminal fan in each zone, the airflow rate and configuration of fan is specified.

EE4: It assumes balanced air flows in each zone and for each system, that is the total system supply airflow equals system return airflow plus zone exhaust air flows (NRCan, 2006). Hence EE4 only allows to model supply fans and return fan cannot be modelled when heat pumps are conditioning equipments. EE4 automatically assumes a return fan equal to supply fan (NRCan, 2006). The supply fan is modelled at system level. For this fan, the airflow rate and motor power or static pressure are specified. The terminal fans are modelled at zone level. For each fan, airflow rate and motor power are specified.

8.14 Air System

HAP: The basic purpose of an air system is to provide heating and cooling to the zones of a building. When performing an energy analysis, the DX cooling, heat pump, electric resistance heating and combustion heating components are considered part of the air system (Carrier, 2006). Heating and cooling units located in each zone such as water source heat pumps are defined as terminal units. The ventilation to these units may be provided directly or a central/common ventilation unit may be used to temper outdoor air and then deliver it to all zonal heat pumps. The operation of terminal units can be demand based (based on schedule) or 24 hour operation.

EE4: When heat pumps are used as the space conditioning equipment, then for the air system in EE4, hydronic heat pump is selected. Hydronic heat pump should be selected as air system whether the heat pump is ground source or water-loop (NRCan, 2006). Heat pumps in the zone are only available if the air handling system selected is a hydronic heat pump system. Zonal heat pumps are not supported in EE4 for VAV, constant volume or other air handling systems (NRCan, 2006).

8.15 Heat Recovery Device

HAP: The heat transfer between outdoor air and exhaust air streams is achieved by the heat recovery device and it is defined at system level. This device reclaims only sensible or both sensible and latent heats. The thermal efficiency is used to specify the fraction of total heat transfer that occurs due to the heat recovery device. The operation of heat recovery device is restricted by schedule that specifies the months during which heat recovery device is operational.

EE4: The heat recovery device is modelled at the system level. The efficiency of heat recovery device has to be specified and schedule cannot be associated with it. Hence EE4 assumes that heat recovery device is operational throughout the year (NRCan, 2006).

8.16 Closed-Loop Ground Source Heat Pumps

HAP: Currently, HAP does not provide a performance model for the ground heat exchanger, so the system configuration of the closed-loop ground source heat pumps cannot be directly modelled. However, using an "Open Loop WSHP" system configuration can approximate the performance of this system (Carrier, 2005). Using the "Open Loop WSHP" system model allows a general approximation of system performance (Carrier, 2005). The modelling method of this system involves creating a cooling tower in HAP with river, sea or well water modelling approach. Average monthly soil temperatures are entered into the cooling tower model. In the air system water source heat pump is selected. Each zone represents a separate WSHP unit, hence the number of zones must equal the number of WSHP units in the system (Carrier, 2005). The heat pump data such as compressor power and cooling or heating capacities are defined at the system level. Separate values for each heat pump must be defined and the cooling tower is linked with the loop of heat pumps.

EE4: The closed-loop, monthly ground temperatures and heat exchanger for the ground source heat pumps is defined at the plant level. When closed-loop is selected at plant level, EE4 assumes that closed-loop is connected to an in-ground heat exchanger (NRCan, 2006). The heat pump data such as COP, heat and cooling capacities are defined at the zone level. When the hydronic heat pump is selected as air system, only then EE4 allows entering the data for heat pumps at the zone level. In the process of defining the closed-loop heat pumps, the principle heating source is selected as heat pump.

9. Simulation Results and Analysis

The medical office building has been modelled in HAP and EE4 based on the requirements of MNECB. EE4 generates the reference building automatically based on the input of the proposed building and then incorporating the requirements of MNECB. In HAP, both the proposed and reference buildings have been modelled manually by analyzing the different requirements of MNECB. The purpose of EE4 simulations is not to accurately predict the expected energy use of the building. Rather it is to provide a uniform and consistent means of verifying compliance to MNECB (NRCan, 2006). EE4 simulations assume typical building use patterns and standards of construction (NRCan, 2006). Because use patterns and standards of construction vary from building to building, simulations based on these assumptions may not be indicative of the actual building energy consumption (NRCan, 2006). The simulation results generated by HAP in terms of annual energy requirements for the proposed and reference buildings are shown in Table 17.

Table 17: Annual energy requirements for the proposed and reference buildings (HAP)

	Reference Building	Proposed Building
Component	**Energy (kWh)**	**Energy (kWh)**
Air System Fans	242,448	143,577
Heating and Cooling	248,276	147,744
Pumps	590,161	36,722
Cooling Tower	19,771	---
HVAC Sub-Total	1,101,655	328,043
Lights	700,096	700,096
Electric Equipment	176,822	176,822
Non-HVAC Sub-Total	876,918	876,918
Grand Total	1,978,573	1,204,961

It is clear from Table 17 that, since the proposed building uses heat pumps, A large amount of the load associated with the chiller/boiler pumps and cooling tower has been reduced. Table 18 shows the annual costs for the proposed and reference buildings as generated by HAP.

Table 18: Annual costs for the proposed and reference buildings (HAP)

	Reference Building	Proposed Building
Component	**Cost ($)**	**Cost ($)**
Air System Fans	18,614	11,207
Heating and Cooling	18,860	11,475
Pumps	44,259	2,868
Cooling Tower	1,551	---
HVAC Sub-Total	83,283	25,550
Lights	54,668	54,668
Electric Equipment	13,808	13,808
Non-HVAC Sub-Total	68,476	68,476
Grand Total	151,759	94,026

The annual energy and cost savings in the proposed building over the reference building are shown in Table 19 on the basis of results produced by HAP. LEED Canada states that all energies have to be compared in MJ; hence ,energies in both the proposed and reference buildings have been converted to MJ.

Table 19: Annual energy and cost savings for the medical office building (HAP)

	Energy (kWh)	Energy (MJ)	Energy Costs ($)
Reference Building	1,978,573	7,122,862	151,759
Proposed Building	1,204,961	4,337,859	94,026
Savings	773,612	2,785,003	57,731
Savings (%)	39.10		38.04

It is evident from Table 19 that the proposed building is 39.10% more energy efficient than the MNECB reference building. The cost savings are 38.04% for the proposed building with respect to the MNECB reference building. Energy and atmosphere, prerequisite 2 in LEED Canada states that, the proposed building must be 25% more energy efficient than the MNECB reference building. Since the medical office building is 39.10% more energy efficient than the MNECB reference building, therefore, the requirement of EAp2 is fulfilled. The energy cost savings in Table 19 are 38.04% and when this is compared with Table 20, it shows that the medical office building scores 4 points with HAP simulation for EAc1.

Table 20: LEED Canada EAc1 points distribution for MNECB path

Points	MNECB Energy Cost Savings
1	24%
2	29%
3	33%
4	38%
5	42%
6	47%
7	51%
8	55%
9	60%
10	64%

The results of EE4 simulation are shown in Table 21. The proposed building is 38.31% more energy efficient than the MNECB reference building; hence, the requirement for EAp2 is fulfilled. It is also evident from Table 21 that the proposed building is 37.25% more energy cost efficient than the MNECB reference building. When this value is compared with Table 20, it is clear that the medical office building scores 3 points with EE4 simulation for EAc1.

Table 21: Annual energy and cost savings for the medical office building (EE4)

	Energy (kWh)	Energy (MJ)	Energy Costs ($)
Reference Building	2,417,909	8,704,473	180,853
Proposed Building	1,491,628	5,369,863	113,478
Savings	926,281	3,334,610	67,375
Savings (%)	38.31		37.25

10. Conclusions and Recommendations

Buildings in Canada represent a large amount of energy demand and contribute to massive GHG emissions. The heating and cooling energy requirements make up a significant portion of total energy requirements for the buildings. Green buildings are more energy efficient and produce less GHG emissions than non-green buildings. Hence, they have economic as well as environmental benefits. Green building is a relative term, LEED Canada Green Building Rating System establishes the standard for buildings and evaluates their environmental performance. This report has sought to analyze a medical office building for LEED Canada EAp2 and EAc1.

It is evident in this project that energy and associated costs for the medical office building are less than the MNECB reference building. The major portion of energy savings has come from the ground source heat pumps working in a closed loop. The heat pumps provide heating and cooling to the medical office building. Hence, they replace the need for having chiller and boiler and associated large pumping requirements. The better U-values for the walls and roof of the medical office building have also contributed to the energy savings.

One of the tasks of this project is to assess HAP for LEED Canada energy performance modelling. HAP has the capability to model most of the requirements for the proposed and reference buildings. But performance of closed-loop ground source heat pumps have been approximated by a thermodynamically equivalent system. EE4 is specifically designed to check the compliance of the proposed building against the MNECB reference building. EE4 may not predict the annual energy requirements for the medical office building accurately but it provides a consistent and uniform means of checking the compliance to the MNECB reference building. When the medical office building is analyzed in HAP, the improvements in the building have lead to 39.10% savings in energy than the MNECB reference building. The savings in energy costs are 38.04% with respect to the reference building. The relative results of EE4 are quite close to HAP, the energy savings are 38.31% and cost savings are 37.25%.

LEED Canada EAc1 awards credit points for energy cost savings, and the medical office building has scored 4 credit points when analyzed in HAP and 3 credit points when analyzed in EE4.

There is potential for energy savings by having connected lighting power intensity less than the MNECB reference building lighting intensity. Moreover, further savings may be achieved by controlling the lights with automatic controls such as occupancy sensors or automatic daylight dimming.

The medical office building may be analyzed by incorporating renewable energy for electricity generation into the building. This way the building may be qualified for LEED Canada Energy and Atmosphere Renewable Energy Credit 2. This credit requires that at least 5% on-site electricity generation should be from renewable energy such as photovoltaics, wind or biomass. EAc2 awards 1 point for 5% renewable energy, 2 points for 10% and 3 points for 20% renewable energy. By integrating renewable energy its effect on EAc1 may also be analyzed. Both HAP and EE4 do not have the capability to conduct renewable energy analysis. Hence, sophisticated software such as EnergyPlus, TRNSYS or ESP-r is required. Another recommendation is that a sensitivity analysis may be conducted on a large sample of different buildings at least 30 buildings so that error is minimized. The degree of sensitivity for different parameters on the energy and costs savings should be established. Once a database of sensitivity of parameters is organized, it would be easier and less costly in the future to make buildings greener.

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Appendices

Appendix 1: MNECB/CBIP Default Parameters Table

Table 22: Space function default assumptions (NRC, 1999)

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 Appendix 2	Lighting Power Density (W/m^2)
Assembly						
Auditorium/Exhibit	5	2.5	30	1.5	C	17.2
Religious Worship	5	1	15	1.5	I	26.9
Theatre - Performance	7.5	2.5	30	1.0	I	16.2
Theatre - 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
Heath/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

Appendix1: MNECB/CBIP Default Parameters Tables *(Continue)*

Table 22: Space function default assumptions *(Continue)* (NRC, 1999)

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 Appendix 2	Lighting Power Density (W/m^2)
Hotel/Motel						
Banquet Room	10	1	90	0.75	B	25.8
Hotel Pre-function	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: Enclosed offices, all open plan offices without partitions or with partitions lower than 1.37 m below the ceiling. Offices less than 84 m 2 .	20	7.5	90	0.5	A	19.4
Category 2: Open plan offices 84 m 2 or larger with partitions 1.07 m to 1.37 m below the ceiling.	20	7.5	90	0.5	A	20.4
Category 3: Open plan offices 84 m 2 or larger with partitions higher than 1.07 m below the ceiling.	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

Appendix1: MNECB/CBIP Default Parameters Tables *(Continue)*

Table 22: Space function default assumptions *(Continue)* (NRC, 1999)

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 Appendix 2	Lighting Power Density (W/m^2)
Retail						
Type A: Jewellery merchandising,	30	2.5	40	1.0	C	53.8
Type B: Fine merchandising, *such as fine apparel and* accessories, china, art, crystal and silver, where detailed display and examination of merchandise is important.	30	2.5	40	1.0	C	34.4
Type C: Mass merchandising, such as general apparel, variety, stationery, books, sporting goods, hobby, cameras, gifts and luggage, displayed in a warehouse type of building, where focused display and detailed examination.	30	2.5	40	1.0	C	33.4
Type D: General merchandising, such as general apparel, variety, stationery, books, sporting goods, hobby, cameras, gifts and luggage, displayed in a department store type of building, where general display and examination of merchandise is adequate	30	2.5	40	1.0	C	35.5
Type E: Food and miscellaneous, such as bakeries, hardware and house wares, grocery, appliances and furniture, where appetizing appearance is important.	30	2.5	40	1.0	C	30.1
Type F: Service establishments where functional performance is important.	30	2.5	40	1.0	C	29.1
Tailoring	30	2.5	40	1.0	C	22.6
Dressing/Fitting Rooms	30	0	40	0.25	C	15.1

Appendix1: MNECB/CBIP Default Parameters Tables *(Continue)*

Table 22: Space function default assumptions *(Continue)* (NRC, 1999)

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 Appendix 2	Lighting Power Density (W/m^2)
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	180	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

Appendix1: MNECB/CBIP Default Parameters Tables *(Continue)*

Table 22: Space function default assumptions *(Continue)* (NRC, 1999)

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 Appendix 2	Lighting Power Density (W/m^2)
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	26.9
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

Appendix 2: MNECB/CBIP Default Operating Schedules

Table 23: Schedule A (NRC, 1999)

	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	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	0.7	0.5	0.3	0.2	0.2	0.2	0.05	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

Appendix 2: MNECB/CBIP Default Operating Schedules *(Continue)*

Table 24: Schedule B (NRC, 1999)

	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	0.1	0	0	0	0	0	0	0	0.1	0.2	0.5	0.9	0.8	0.5	0.2	0.2	0.3	0.6	0.9	0.9	0.9	0.6	0.4	0.3
Sat	0.3	0	0	0	0	0	0	0	0.1	0.2	0.5	0.9	0.8	0.5	0.2	0.2	0.3	0.6	0.9	0.9	0.9	0.6	0.6	0.5
Sun	0.3	0	0	0	0	0	0	0	0	0.1	0.4	0.5	0.5	0.4	0.2	0.2	0.2	0.5	0.7	0.7	0.5	0.3	0.1	0.1
Lighting																								
Mon - Fri	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sat	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sun	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.5	0.5
Receptacle																								
Mon - Fri	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sat	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sun	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.5	0.5
Fans																								
Mon - Fri	On	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sat	On	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sun	On	Off	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	On	On	On	Off	Off
Cooling																								
Mon - Fri	Off	Off	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sat	Off	Off	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sun	Off	Off	Off	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	24	24	24	24	24	24	24	Off	Off
Heating																								
Mon - Fri	22	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Sat	22	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Sun	22	18	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	18	18
Hot Water																								
Mon - Fri	0.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.7	0.7	0.4	0.5	0.6	0.6	0.4	0.3	0.3	0.4	0.5	0.8	0.8	0.9	0.9	0.6
Sat	0.6	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.7	0.7	0.4	0.5	0.6	0.6	0.4	0.3	0.3	0.4	0.5	0.8	0.8	0.9	0.9	0.7
Sun	0.6	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.7	0.7	0.4	0.5	0.6	0.6	0.4	0.3	0.3	0.4	0.5	0.8	0.8	0.5	0.5	0.5

Appendix 2: MNECB/CBIP Default Operating Schedules *(Continue)*

Table 25: Schedule C (NRC, 1999)

	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	0.1	0.2	0.5	0.5	0.7	0.7	0.7	0.7	0.8	0.7	0.5	0.3	0.3	0	0	0	0
Sat	0	0	0	0	0	0	0	0.1	0.2	0.5	0.6	0.8	0.9	0.9	0.9	0.8	0.7	0.5	0.2	0.2	0	0	0	0
Sun	0	0	0	0	0	0	0	0	0	0.1	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.2	0	0	0	0	0	0
Lighting																								
Mon - Fri	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.6	0.5	0.05	0.05	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.6	0.5	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	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.6	0.05	0.05	0.05	0.05	0.05	0.05
Receptacle																								
Mon - Fri	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.6	0.5	0.05	0.05	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.6	0.5	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	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.6	0.05	0.05	0.05	0.05	0.05	0.05
Fans																								
Mon - Fri	Off	Off	Off	Off	Off	Off	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	On	On	On	On	On	On	On	On	On	On	On	On	On	On	Off	Off	Off	Off
Sun	Off	Off	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	Off	Off	Off	Off	Off	Off
Cooling																								
Mon - Fri	Off	Off	Off	Off	Off	Off	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	24	24	24	24	24	24	24	24	24	24	24	24	24	24	Off	Off	Off	Off
Sun	Off	Off	Off	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	24	24	24	Off	Off	Off	Off	Off	Off
Heating																								
Mon - Fri	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	18	18	18	18
Sat	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	18	18	18	18
Sun	18	18	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	18	18	18	18	18	18
Hot Water																								
Mon - Fri	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.2	0.3	0.4	0.8	0.8	0.8	0.8	0.6	0.4	0.3	0.2	0.2	0.05	0.05	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.2	0.3	0.5	0.9	0.9	0.9	0.9	0.7	0.5	0.3	0.2	0.2	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	0.1	0.2	0.4	0.8	0.8	0.6	0.4	0.3	0.2	0.05	0.05	0.05	0.05	0.05	0.05

Appendix 2: MNECB/CBIP Default Operating Schedules *(Continue)*

Table 26: Schedule D (NRC, 1999)

	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	0.1	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.5	0.2	0.1	0.3	0.3	0.3	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	0.05	0.3	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.5	0.5	0.7	0.7	0.7	0.3	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	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.3	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.5	0.5	0.7	0.7	0.7	0.3	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
Fans																								
Mon - Fri	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	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	Off	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	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	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	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	0.05	0.5	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.3	0.5	0.5	0.5	0.3	0.05	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

Appendix 2: MNECB/CBIP Default Operating Schedules *(Continue)*

Table 27: Schedule E (NRC, 1999)

	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	0.2	0.7	0.9	0.9	0.9	0.9	0.5	0.9	0.8	0.8	0.2	0	0	0	0	0	0
Sat	0	0	0	0	0	0	0	0	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	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	0.05	0.4	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.4	0.05	0.05	0.05	0.05	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.5	0.9	0.9	0.9	0.9	0.9	0.7	0.5	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	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.4	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.4	0.05	0.05	0.05	0.05	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.5	0.9	0.9	0.9	0.9	0.9	0.7	0.5	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
Fans																								
Mon - Fri	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	On	Off	Off	Off	Off	Off	Off
Sat	Off	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	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	Off	24	24	24	24	24	24	24	24	24	24	24	24	Off	Off	Off	Off	Off	Off
Sat	Off	Off	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	24	24	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	18	20	22	22	22	22	22	22	22	22	22	22	22	18	18	18	18	18	18
Sat	18	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	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	0.05	0.1	0.4	0.5	0.5	0.7	0.9	0.8	0.7	0.8	0.3	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.2	0.2	0.4	0.2	0.2	0.2	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

Appendix 2: MNECB/CBIP Default Operating Schedules *(Continue)*

Table 28: Schedule F (NRC, 1999)

	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	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.5	0.7	0.7	0.8	0.9	0.9
Sat	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.6	0.6	0.6	0.7	0.7	0.7
Sun	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5	0.3	0.3	0.2	0.2	0.2	0.3	0.4	0.4	0.6	0.6	0.8	0.8	0.8
Lighting																								
Mon - Fri	0.2	0.2	0.1	0.1	0.1	0.2	0.4	0.5	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.6	0.8	0.9	0.8	0.6	0.3
Sat	0.2	0.2	0.1	0.1	0.1	0.1	0.3	0.3	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.6	0.7	0.7	0.7	0.6	0.3
Sun	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.5	0.7	0.8	0.6	0.5	0.3
Receptacle																								
Mon - Fri	0.2	0.2	0.1	0.1	0.1	0.2	0.4	0.5	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.6	0.8	0.9	0.8	0.6	0.3
Sat	0.2	0.2	0.1	0.1	0.1	0.1	0.3	0.3	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.6	0.7	0.7	0.7	0.6	0.3
Sun	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.5	0.7	0.8	0.6	0.5	0.3
Fans																								
Mon - Fri	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sat	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sun	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Cooling																								
Mon - Fri	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sat	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sun	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Heating																								
Mon - Fri	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Sat	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Sun	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Hot Water																								
Mon - Fri	0.3	0.2	0.1	0.1	0.2	0.4	0.6	0.9	0.7	0.5	0.5	0.4	0.5	0.4	0.3	0.3	0.3	0.3	0.5	0.7	0.7	0.7	0.7	0.5
Sat	0.3	0.2	0.1	0.1	0.2	0.4	0.5	0.8	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.5	0.7	0.7	0.7	0.7	0.5
Sun	0.3	0.2	0.1	0.1	0.2	0.4	0.4	0.6	0.9	0.7	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.3	0.4	0.6	0.6	0.6	0.6	0.5

Appendix 2: MNECB/CBIP Default Operating Schedules *(Continue)*

Table 29: Schedule G (NRC, 1999)

	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	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sat	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sun	0.9	0.9	0.9	0.9	0.9	0.9	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Lighting																								
Mon - Fri	0	0	0	0	0	0.2	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0.9	0.9	0.9	0.8	0.6	0.3
Sat	0	0	0	0	0	0.2	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0.9	0.9	0.9	0.8	0.6	0.3
Sun	0	0	0	0	0	0.2	0.5	0.5	0	0	0	0	0	0	0	0	0	0	0.9	0.9	0.9	0.8	0.6	0.3
Receptacle																								
Mon - Fri	0.2	0.2	0.2	0.2	0.2	0.2	0.8	0.8	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.2	0.9	0.9	0.7	0.5	0.5	0.5	0.3
Sat	0.2	0.2	0.2	0.2	0.2	0.2	0.8	0.8	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.2	0.9	0.9	0.7	0.5	0.5	0.5	0.3
Sun	0.2	0.2	0.2	0.2	0.2	0.2	0.8	0.8	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.2	0.9	0.9	0.7	0.5	0.5	0.5	0.3
Fans																								
Mon - Fri	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sat	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sun	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Cooling																								
Mon - Fri	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sat	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sun	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Heating																								
Mon - Fri	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Sat	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Sun	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Hot Water																								
Mon - Fri	0.05	0.05	0.05	0.05	0.05	0.2	0.8	0.7	0.5	0.4	0.2	0.2	0.2	0.3	0.5	0.5	0.7	0.7	0.4	0.4	0.2	0.2	0.1	0.1
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.2	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.7	0.9	0.7	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.2	0.3	0.3	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.4	0.3	0.2	0.2	0.2	0.2	0.1

Appendix 2: MNECB/CBIP Default Operating Schedules *(Continue)*

Table 30: Schedule H (NRC, 1999)

	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	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sat	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sun	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Lighting																								
Mon - Fri	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sat	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sun	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Receptacle																								
Mon - Fri	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sat	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sun	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Fans																								
Mon - Fri	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sat	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sun	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Cooling																								
Mon - Fri	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sat	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sun	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Heating																								
Mon - Fri	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Sat	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Sun	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Hot Water																								
Mon - Fri	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sat	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sun	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Appendix 2: MNECB/CBIP Default Operating Schedules *(Continue)*

Table 31: Schedule I (NRC, 1999)

	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	0	0	0	0	0	0	0	0.10	0.10	0.10	0.40	0.80	0.80	0.80	0.60	0.40	0.10
Sat	0	0	0	0	0	0	0	0	0	0.10	0.10	0.10	0.40	0.60	0.80	0.60	0.40	0.20	0.40	0.80	0.80	0.60	0.40	0.10
Sun	0	0	0	0	0	0	0	0.20	0.40	0.80	0.80	0.40	0.20	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	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.50	0.50	0.80	0.90	0.90	0.90	0.90	0.90	0.50
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.50	0.50	0.80	0.90	0.90	0.90	0.80	0.60	0.80	0.90	0.90	0.90	0.90	0.50
Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.90	0.90	0.90	0.90	0.50	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	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.80	0.80	0.80	0.80	0.80	0.80	0.10
Sat	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.20	0.20	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.10
Sun	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.80	0.80	0.80	0.80	0.80	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Fans																								
Mon - Fri	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On
Sat	Off	Off	Off	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	On	On	On	On	On	On	On	On
Sun	Off	Off	Off	Off	Off	Off	On	On	On	On	On	On	On	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
Cooling																								
Mon - Fri	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	24	24	24	Off
Sat	Off	Off	Off	Off	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	24	24	24	24	24	24	24	Off
Sun	Off	Off	Off	Off	Off	Off	24	24	24	24	24	24	24	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off	Off
Heating																								
Mon - Fri	18	18	18	18	18	18	18	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	18
Sat	18	18	18	18	18	18	18	18	18	20	22	22	22	22	22	22	22	22	22	22	22	22	22	18
Sun	18	18	18	18	18	18	20	22	22	22	22	22	22	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	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.20	0.20	0.20	0.40	0.90	0.90	0.90	0.80	0.60	0.20
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.20	0.20	0.20	0.40	0.80	0.90	0.80	0.60	0.40	0.40	0.90	0.90	0.80	0.60	0.20
Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.20	0.40	0.40	0.20	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Appendix 3: MNECB Prescriptive Requirements for Assemblies (Toronto)

Table 32: MNECB reference roofs, walls and floors U-values (NRC, 1997)

Assembly Type	Principle Heating Source		
	Electricity	Heat Pump, Oil, Propane	Natural gas
	U-value (W/m^2.^{0}C)		
Type 1: Attic type roofs	0.140	0.200	0.200
Type 2: Parallel-chord trusses and joist-type roofs	0.230	0.230	0.230
Type 3: Concrete decks with rigid insulations roofs	0.290	0.410	0.470
Walls	0.330	0.480	0.550
Type 1: Parallel-chord trusses and joist-type floors	0.220	0.220	0.220
Type 2: Concrete slabs with rigid insulations	0.290	0.410	0.470

Appendix 4: MNECB Prescriptive Requirements for Fenestration (Toronto)

Table 33: MNECB reference fenestration U-values (NRC, 1997)

Fenestration Type	Fenestration-to-Wall Ratio	Principle Heating Source		
		Electricity	Heat Pump, Oil, Propane	Natural gas
		U-value (W/m^2.^{0}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	1.60	1.80	1.80

Appendix 5: Summary Comparison of the Proposed and Reference Buildings

Table 34: Comparison of the proposed and reference buildings

Component	Reference Building	Proposed Building
Weather	Toronto	Toronto
Design day temperatures	Summer: 29 ^{0}C Winter: -17 ^{0}C	Summer: 29 ^{0}C Winter: -17 ^{0}C
Schedules	Appendix 1 and 2	Appendix 1 and 2
U-values (W/m^2.^{0}C)	Walls: 0.480 Windows: 2.40 Roofs: 0.410 Doors: 1.533 Exposed floors: 0.410	Walls: 0.302 Windows: 3.521 Roofs: 0.227 Doors: 1.533 Exposed floors: 0.568
Lighting load	Appendix 1	Appendix 1
Equipments load	Appendix 1	Appendix 1
Ventilation	Appendix 1	Appendix 1
Occupancy	Appendix 1	Appendix 1
Heat gains from occupants	Sensible heat gain: 75 W/Occupant Latent heat gain: 55 W/Occupant	Sensible heat gain: 75 W/Occupant Latent heat gain: 55 W/Occupant
Thermostat set-points	Cooling: Occupied: 24 ^{0}C Unoccupied: 35 ^{0}C Heating: Occupied: 22 ^{0}C Unoccupied: 18 ^{0}C	Cooling: Occupied: 24 ^{0}C Unoccupied: 35 ^{0}C Heating: Occupied: 22 ^{0}C Unoccupied: 18 ^{0}C
Infiltration L/(s.m^2), based on floor area	0.25	0.25
Supply temperature	Heating: 43 ^{0}C Cooling: 13 ^{0}C	Heating: 43 ^{0}C Cooling: 13 ^{0}C
Supply fan	Forward curved draw thru type, 1000 Pa, 55% combined motor impeller efficiency	Forward curved draw thru type, motor: 18.4 kW, 75% efficiency
Return fan	Draw thru, 250 Pa, 30%	Forward Curved, draw thru

Component	Reference Building	Proposed Building
	combined motor impeller efficiency	motor: 18.4 kW, 75% efficiency
Economizer	Integrated enthalpy economizer operational at all times	None
Heat recovery	No heat recovery	90% Sensible and Latent
Air system	VAV air handling unit	Common make-up air unit, VAV reverse flow technology
Terminal system	VAV box	Terminal fans, Detailed data in chapter 5
Heating equipment	Electric boiler, Efficiency: 80%	Closed loop zonal heat pumps Detailed data in chapter 5
Cooling equipment	Electric Centrifugal Chiller, COP: 5.2	Closed loop zonal heat pumps Detailed data in chapter 5
Cooling tower	Closed loop tower Fan: constant speed fan, 17.2 kW Pump: constant speed, head: 180 kPa, efficiency: 70%	GSHP equivalent open loop system Central loop pump: variable speed, head: 89.5 kPa, efficiency: 85%

Appendix 6: HAP Output Report for the Reference Building

Table 35: Detailed heating and cooling loads for the reference building

	Design Cooling			Design Heating		
ZONE LOADS	**Details**	**Sensible (W)**	**Latent (W)**	**Details**	**Sensible (W)**	**Latent (W)**
Window & Skylight Solar Loads	1801 m²	200299	-	1801 m²	-	-
Wall Transmission	1260 m²	4027	-	1260 m²	27373	-
Roof Transmission	1522 m²	13039	-	1522 m²	24324	-
Window Transmission	1801 m²	19052	-	1801 m²	248529	-
Skylight Transmission	0 m²	0	-	0 m²	0	-
Door Loads	51 m²	2515	-	51 m²	3061	-
Floor Transmission	1841 m²	-84	-	1841 m²	0	-
Partitions	3502 m²	-99	-	3502 m²	1271	-
Overhead Lighting	206011 W	144284	-	0	0	-
Electric Equipment	42414 W	39481	-	0	0	-
People	647	34976	35590	0	0	0
Infiltration	-	5179	11069	-	40399	9
Total Zone Loads	-	462717	46659	-	344958	9
Zone Conditioning	-	505016	46659	-	320726	9
Plenum Roof Load	40%	8692	-	0	0	-
Plenum Lighting Load	15%	30910	-	0	0	-
Return Fan Load	35695 L/s	29866	-	19137 L/s	-16883	-
Ventilation Load	6211 L/s	18204	78668	6211 L/s	281569	0
Supply Fan Load	35695 L/s	64837	-	19137 L/s	-36651	-
Total System Loads	-	657526	125327	-	548761	9
Central Cooling Coil	-	653836	125409	-	0	0
Terminal Reheat Coils	-	0	-	-	548640	-
Total Conditioning	-	653836	125409	-	548640	0
Key:	Positive values are cooling loads Negative values are heating loads			Positive values are heating loads Negative values are cooling loads		

Appendix 7: HAP Output Report for the Proposed Building

Table 36: Detailed heating and cooling loads for the proposed building

	Design Cooling			Design Heating		
ZONE LOADS	**Details**	**Sensible (W)**	**Latent (W)**	**Details**	**Sensible (W)**	**Latent (W)**
Window & Skylight Solar Loads	1801 m^2	184962	-	1801 m^2	-	-
Wall Transmission	1260 m^2	2178	-	1260 m^2	14821	-
Roof Transmission	1522 m^2	5393	-	1522 m^2	13503	-
Window Transmission	1801 m^2	18962	-	1801 m^2	247350	-
Skylight Transmission	0 m^2	0	-	0 m^2	0	-
Door Loads	51 m^2	2515	-	51 m^2	3061	-
Floor Transmission	1841 m^2	-116	-	1841 m^2	0	-
Partitions	3502 m^2	-34	-	3502 m^2	1057	-
Overhead Lighting	206011 W	144284	-	0	0	-
Electric Equipment	42414 W	39481	-	0	0	-
People	647	34965	35583	0	0	0
Infiltration	-	4601	7971	-	35891	0
Total Zone Loads	-	437191	43554	-	315683	0
Zone Conditioning	-	490670	43554	-	312696	0
Plenum Roof Load	40%	3596	-	0	0	-
Plenum Lighting Load	15%	30900	-	0	0	-
Return Fan Load	6146 L/s	18400	-	6146 L/s	-18400	-
Ventilation Load	6146 L/s	-6465	5859	6146 L/s	31790	0
Ventilation Fan Load	6146 L/s	18400	-	6146 L/s	-18400	-
Space Fan Coil Fans	-	7509	-	-	-2660	-
Total System Loads	-	563009	49413	-	305027	0
Terminal Unit Cooling	-	563082	49498	-	0	0
Terminal Unit Heating	-	0	-	-	305026	-
Total Conditioning	-	563082	49498	-	305026	0
Key:	Positive values are cooling loads Negative values are heating loads			Positive values are heating loads Negative values are cooling loads		

Appendix 8: Different Scenarios for the Medical Office Building

Table 37: Energy and costs comparison with no heat recovery in the proposed building

	Reference Building		Proposed Building	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	143,577	11,271
Heating and Cooling	248,276	18,860	141,209	10998
Pumps	590,161	44,259	36,722	2,873
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	321,507	25,098
Lights	700,096	54,668	700,096	54,668
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	876,918	68,476
Grand Total	1,978,573	151,759	1,198,425	93,574
Savings (%)			39.43	38.34

Appendix 8: Different Scenarios for the Medical Office Building

Table 38: Energy and costs comparison with sensible and latent heat recovery throughout the year in the proposed building

	Reference Building		Proposed Building	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	143,577	11,207
Heating and Cooling	248,276	18,860	147,744	11,475
Pumps	590,161	44,259	36,722	2,868
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	328,043	25,550
Lights	700,096	54,668	700,096	54,668
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	876,918	68,476
Grand Total	1,978,573	151,759	1,204,961	94,026
		Savings (%)	39.10	38.04

Appendix 8: Different Scenarios for the Medical Office Building (*Continue)*

Table 39: Energy and costs comparison when only in winter sensible and latent heat recovery in the proposed building

	Reference Building		Proposed Building	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	143,577	11,220
Heating and Cooling	248,276	18,860	134,756	10,491
Pumps	590,161	44,259	36,722	2,871
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	315,054	24,582
Lights	700,096	54,668	700,096	54,668
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	876,918	68,476
Grand Total	1,978,573	151,759	1,191,972	93,058
		Savings (%)	39.76	38.67

Appendix 8: Different Scenarios for the Medical Office Building (*Continue)*

Table 40: Energy and costs comparison when U-values are reduced, sensible and latent heat recovery throughout the year in the proposed building

U-values W/m^2.^{0}C	Walls: 0.302, Windows: 2.5210, Roof: 0.227, Floor: 0.227, Doors: 1.533			
	Reference Building		**Proposed Building**	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	143,738	11,239
Heating and Cooling	248,276	18,860	140,100	10,880
Pumps	590,161	44,259	30,047	2,350
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	313,884	24,468
Lights	700,096	54,668	700,096	54,668
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	876,918	68,476
Grand Total	1,978,573	151,759	1,190,802	92,944
		Savings (%)	39.82	38.76

Table 41: Energy and costs comparison when lighting load is reduced to 12 W/m^2 and sensible and latent heat recovery throughout the year in the proposed building

	Reference Building		Proposed Building	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	142,749	11,547
Heating and Cooling	248,276	18,860	141,454	11,365
Pumps	590,161	44,259	38,399	3,104
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	322,602	26,016
Lights	700,096	54,668	382,057	30,921
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	558,879	44,729
Grand Total	1,978,573	151,759	881,481	70,745
		Savings (%)	55.45	53.38

Table 42: Energy and costs comparison when lighting load is reduced to 12 W/m^2 and only in winter sensible and latent heat recovery in the proposed building

	Reference Building		Proposed Building	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	142,749	11,547
Heating and Cooling	248,276	18,860	131,557	10,400
Pumps	590,161	44,259	38,339	3,104
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	312,705	25,051
Lights	700,096	54,668	382,057	30,921
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	558,879	44,729
Grand Total	1,978,573	151,759	871,584	69,780
		Savings (%)	55.95	54.02

Appendix 8: Different Scenarios for the Medical Office Building (*Continue)*

Table 43: Energy and costs comparison when lighting load is reduced to 12 W/m^2, U-values are reduced and only in winter sensible and latent heat recovery in the proposed building

U-values W/m^2.^{0}C	Walls: 0.302, Windows: 2.5210, Roof: 0.227, Floor: 0.227, Doors: 1.533			
	Reference Building		**Proposed Building**	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	142,679	11,600
Heating and Cooling	248,276	18,860	116,987	9,428
Pumps	590,161	44,259	33,211	2,700
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	292,877	23,729
Lights	700,096	54,668	382,057	30,921
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	558,879	44,729
Grand Total	1,978,573	151,759	851,756	68,458
		Savings (%)	56.94	54.89

Table 44: Energy and costs comparison when lighting load is reduced to 12 W/m^2, U-values are reduced, only in winter sensible and latent heat recovery and demand controlled ventilation (CO_2 sensors) in the proposed building

U-values W/m^2.^{0}C	Walls: 0.302, Windows: 2.5210, Roof: 0.227, Floor: 0.227, Doors: 1.533			
	Reference Building		**Proposed Building**	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	128,509	10,489
Heating and Cooling	248,276	18,860	117,219	9,481
Pumps	590,161	44,259	33,211	2,711
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	278,940	22,682
Lights	700,096	54,668	382,057	30,921
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	558,879	44,729
Grand Total	1,978,573	151,759	837,819	67,411
		Savings (%)	57.66	55.58

Appendix 8: Different Scenarios for the Medical Office Building (*Continue)*

Table 45: Energy and costs comparison when lighting load is reduced to 12 W/m^2, U-values are reduced by interruption in thermal bridging, only in winter sensible and latent heat recovery and demand controlled ventilation (CO_2 sensors) in the proposed building

U-values W/m^2.^{0}C	Walls: 0.137, Windows: 1.243, Roof: 0.138, Floor: 0.227, Doors: 1.533			
	Reference Building		**Proposed Building**	
Component	**Energy (kWh)**	**Cost ($)**	**Energy (kWh)**	**Cost ($)**
Air System Fans	242,448	18,614	127,240	10,439
Heating and Cooling	248,276	18,860	94,965	7,706
Pumps	590,161	44,259	21,439	1,752
Cooling Tower	19,771	1,551	0	0
HVAC Sub-Total	1,101,655	83,283	243,644	19,898
Lights	700,096	54,668	382,057	30,921
Electric Equipment	176,822	13,808	176,822	13,808
Non-HVAC Sub-Total	876,918	68,476	558,879	44,729
Grand Total	1,978,573	151,759	802,523	64,627
		Savings (%)	59.44	57.41

Appendix 9: EE4 simulation with and without heat recovery

Table 46: EE4 simulation for the medical office building without heat recovery

	Energy (kWh)	Energy (MJ)	Energy Costs ($)
Reference Building	2,626,428	9,455,141	196,716
Proposed Building	1,742,380	6,272,568	132,762
Savings	884,048	3,182,573	63,954
Savings (%)	33.66		32.51

Table 47: EE4 simulation for the medical office building with heat recovery

	Energy (kWh)	Energy (MJ)	Energy Costs ($)
Reference Building	2,417,909	8,704,473	180,853
Proposed Building	1,491,628	5,369,863	113,478
Savings	926,281	3,334,610	67,375
Savings (%)	38.31		37.25