ENERGY ANALYSIS USING CARRIER HAP PROGRAM AND DEEP LAKE WATER COOLING (DLWC) FEASIBILITY ANALYSIS FOR RYERSON UNIVERSITY

by

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Abstract

The objective of this project is to determine the total annual energy summary in terms of cost and Greenhouse Gas (GHG) emission of 16 buildings at Ryerson University (RU). In addition, the Deep Lake Water Cooling (DLWC) feasibility analysis of RU is another objective of this project in terms of total energy consumption and amount of gas emission reduction. The total audit area of RU was 86% of the total campus area. Building energy simulation program, Carrier HAP (Hourly Analysis Program), has been used to make an integrated evaluation of building energy consumption. An energy simulation involves hour-by-hour calculations for all 8,760 hours in a year.

In this project, an energy audit was conducted for the 16 existing buildings to establish the base case model, "Ryerson University", to determine its annual energy consumption across all usage. There are two sources of energy used at RU. Electricity uses for lighting, plug load, miscellaneous and cooling, and remote steam is used for cooling and heating. For the base case model, total energy consumption was 251 TJ. To reduce the total energy consumption of the base case model, HVAC systems were investigated to analyze their energy-based performance and impact on the GHG emission. There is no Heat Recovery Ventilation (HRV) system coming from the investigation of HVAC system. The sensitivity analysis was conducted using HRV system with air system. By using HRV system with air system, total of 5.6% energy would be saved for cooling and 76% energy would be saved for heating of RU. The energy intensity was determined to be 1.04 GJ/m^2 only for 16 buildings of RU and comparatively it is lower than other universities in Canada which have a range of 1.64 GJ/m^2 to 2.26 GJ/m^2.

In the DLWC system, cool lake water at 4°C was used for building air conditioning. To reduce the cooling energy costs, DLWC system was considered as an alternative chilled water source. The Rogers Business Building (RBB) already has DLWC system. For DLWC system, chilled water was served by Enwave to the RBB. According to base case analysis of the RBB with conventional chillers, the electricity consumption was 924594 kWh for RBB due to chillers. With the implementation of DLWC system for the rest of the 15 buildings, total energy saving due to cooling would be 89.2% and GHG emission reduction would be 89% for CO_2, 70% for NO_x and 70.4% for SO_x due to elimination of chillers.

Acknowledgements

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He also helped me to provide valuable information, solve critical problems and answer questions during this project. Without his counselling and feedback it would be difficult for me to deal with such a big project.

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Thirdly, I would like to thank all of the Campus Planning staff who supplied necessary documents and provided key information required to complete this project.

Finally, I want to thank my wife and family for encouraging me to complete this project.

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NOMENCLATURE / NOTATION

A/C	AIR CONDITIONING
ACH	AIR CHANGE PER HOUR
ARI	AIR CONDITIONING AND REFRIGERATION INSTITUTE
ASHRAE	AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIRCONDITIONING ENGINEERS
ASME	AMERICAN SOCIETY OF MECHANICAL ENGINEERS
AST	APPARENT SOLAR TIME
B.H.P	BRAKE HORSE POWER
BLAST	BUILDING LOAD ANALYSIS AND SYSTEM THERMODYNAMICS
BTU	BRITISH THERMAL UNIT
CAD	COMPUTER - AIDED DESIGN
CAV	CONSTANT AIR VOLUME
CBIP	COMMERCIAL BUILDING INCENTIVE PROGRAM
CFM	CUBIC FEET PER MINUTE
C-factor	Thermal Conductance (Btu/h-ft^2-^{o}F)
CL	CLOSED LOOP
CLTD	COOLING LOAD TEMPERATURE DIFFERENCE METHOD
CO_2	Carbon Dioxide
COP	COEFFICIENT OF PERFORMANCE
CSA	CANADIAN STANDARD ASSOCIATION
CTF	CONDUCTION TRANSFER METHOD
CWEC	CANADIAN WEATHER FOR ENERGY CALCULATIONS
DB	DRY BULB
DDW	DESIGN DEVELOPMENT WIZARD
DHW	DOMESTIC HOT WATER
DLWC	DEEP LAKE WATER COOLING
DOE	DEPARTMENT OF ENERGY USA
DWG	CAD DRAWINGS
DX System	DIRECT EXPANSION HVAC SYSTEM

ECWT	ENTERING CHILLED OR COOLING WATER TEMPERATURE
EEMW	ENERGY EFFICIENCY MEASURE WIZARD
EER	ENERGY EFFICIENCY RATING
ESP-R	ENVIRONMENTAL SYSTEM PERFORMANCE
EWT	ENTERING WATER TEMPERATURE
GHG	GREEN HOUSE GAS
GLHE	GROUND LOOP HEAT EXCHANGER
GPM	GALLON PER MINUTE
GSHP	GROUND SOURCE HEAT PUMP
HAP	HOURLY ANALYSIS PROGRAMS
HP	HEAT PUMP
HRV	HEAT RECOVERY VENTILATION
HSPF	HEATING SEASONAL PERFORMANCE FACTOR
HVAC	HEATING VENTILATION AND AIR CONDITIONING
KWH	KILOWATT HOUR
LCHWT	LEAVING CHILLED WATER TEMPERATURE
LEED	LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN
LWTP	LAKESHORE WATER TREATMENT PLANT
MBH	THOUSANDS BTU PER HOUR
MNECB	MODEL NATIONAL ENERGY CODE OF CANADA FOR BUILDINGS
MNECH	MODEL NATIONAL ENERGY CODE OF CANADA FOR HOUSES
N/A	NOT AVAILABLE
NBSLD	U.S. NATIONAL BUREAU OF STANDARDS
NRC	NATIONAL RESEARCH COUNCIL
NRCan	NATURAL RESOURCES CANADA
OA	OUTSIDE AIR FLOW RATE
OBC	ONTARIO BUILDING CODE
Pa	PASCAL (PRESSURE UNIT N/M^2)
R-VALUES	THERMAL RESISTANCE OF THE INSULATION ($h.ft^2$-°F/BTU)
RETScreen	INTERNATIONAL CLEAN ENERGY PROJECT ANALYSIS SOFTWARE
RH	RELATIVE HUMIDITY

RU	RYERSON UNIVERSITY
SD	SYSTEMATIC DESIGN
SHGC	SOLAR HEAT GAIN COEFFICIENT
SEER	SEASONAL ENERGY EFFICIENCY RATIO
SKYCALC	SKY CALCULATION
TFM	TRANSFER FUNCTION METHOD
THR	TON-HOUR
TMY/TRY	TYPICAL METEOROLOGICAL YEAR
TRNSYS	TRANSIENT SYSTEMS SIMULATION
T-S diagram	TEMPERATURE ENTROPY DIAGRAM
U-factor	THERMAL TRANSMITTANCE
U VALUE	OVERALL HEAT TRANSFER COEFFICIENT (BTU/ h.ft^2-°F)
VAV	VARIABLE AIR VOLUME
VENT	DUCT DESIGN PROGRAM
WF	WEIGHTING FACTORS
WSHP	WATER SOURCE HEAT PUMP

CHAPTER-1

1. Introduction

The building sector, one of the fastest growing in terms of energy consumption, accounts for over 40% of final energy, study in Spain (Rey et al., 2007). In recent years, there has been quite an interest in the areas of Rational Use of Energy and Energy Saving. With increasing energy demands all over the world, energy management and conservation has become a key focus in the global arena. Countries all over the world continue to become more industrialized which naturally increases the demand for energy resources. In the last few years, manufacturing and service industries, as well as government organizations have all been under enormous economic and environmental pressures.

Although many people realize the importance of investing in energy efficient solutions, high capital investment and lack of payback have been a deterrent for many companies and organizations. Furthermore, commercial buildings are usually built with a low first cost as priority. The building's long-term operational costs, which are usually paid by the tenant(s) rather than the owner, are not important to the owner.

Saving money on energy bills is encouraging to organizations and individuals alike. This is especially true for educational institutions due to their long operating hours which mean that their energy bills represent a substantial portion of their operating costs. Therefore, they have a strong incentive to initiate and continue an ongoing energy cost control program. *"No cost or very low cost operational changes can often save a customer or an industry 10-20% on utility bills; capital cost programs with payback times of two years or less can often save an additional 20-30%"* (Turner, 2001). In many cases these energy cost control programs will also result in a reduction of energy consumption, as well as emissions of environmental pollutants.

Due to economic and environmental reasons, organizations around the world are constantly come under pressure to reduce energy consumption. As energy cost is one of the main cost drivers for business, reduction in energy consumption leads to reduction in operating costs, and thereby helps to improve the profitability of organizations. One of the main environmental concerns relating to energy consumption is the emission of carbon dioxide (CO_2), which is a "greenhouse gas" that contributes to global warming. Due to the release of CO_2 during burning of fossil fuels, CO_2 emissions can be closely correlated to energy use.

Reduction in energy consumption can be achieved through energy efficiency and energy conservation programs. Such programs involve the promotion of efficient or effective use of energy, which helps to save energy and results in reduced environmental pollution and operating costs (Jayamaha, 2007).

In 2005, the commercial/institutional sector in Canada produced 36.84 Mt of CO_2 in GHG emissions excluding electricity (NRCan, 2007) and, when production of electricity was added, the GHG emissions went up to 65.28 Mt of CO_2 (an increase of approximately 77%). Of this 65.28 Mt of CO_2 produced, 45% is contributed by the production of electricity, with 38% of it being produced by natural gas sources. A graphical representation of the contribution among the various resources is shown in Figure 1.1.

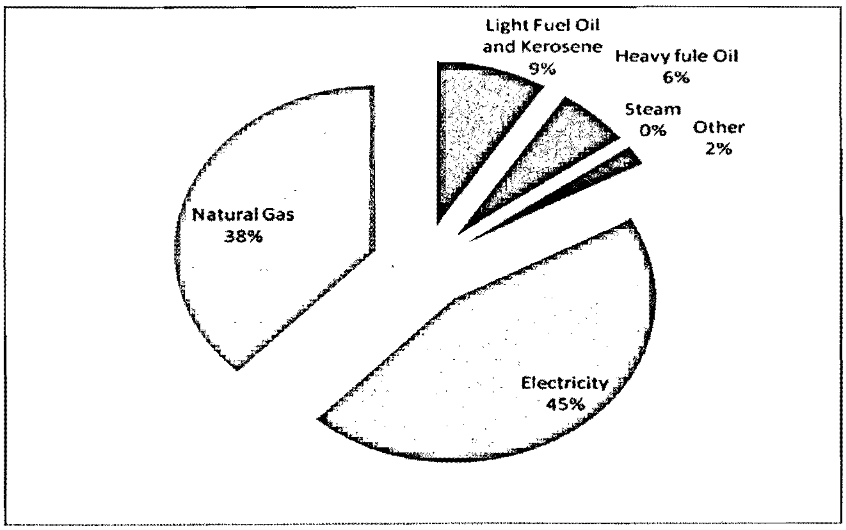

Figure 1.1: GHG Emissions by Energy Source in (Mt of CO_2) (NRCan, 2007)

1.1. Energy Management

Energy management is a procedure for containing and reducing the overall energy consumption and energy costs of an organization. Some typical objectives of energy management, which depend on the needs of each individual organization, include lowering operating cost, increasing profitability, reducing environmental pollution and improving working conditions. For an energy management program to be successful, it needs the commitment and support of the organization's management and should be in system with the organization's objectives.

Energy management requires a systematic approach from the formation of a suitable team, to achieving and maintaining energy savings. A typical process is outlined in Figure 1.2.

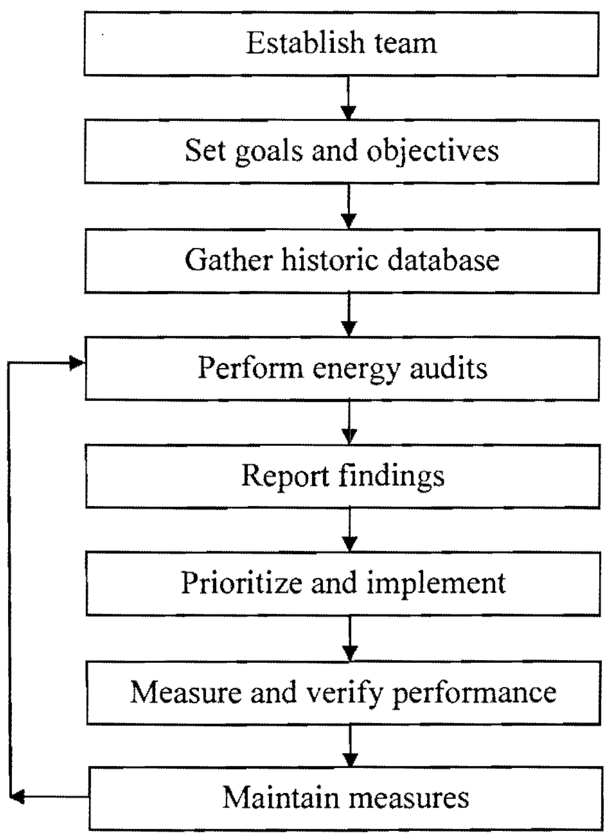

Figure 1.2: Typical Energy Management Program (Jayamaha, 2007)

The most important part of an energy management program is an energy audit to identify potential energy savings measures. Chapter 4 covers the energy auditing procedure of RU.

1.2. Building Energy Simulation Overview

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. Accounting for all these variables, as well as their interactions, is a daunting task, especially because some change by the hour. Given this complexity, rigorous calculations of annual building energy costs were rarely performed before personal computers became common place.

Software packages for building energy performance simulation carry out the numerous and complex equations that, when combined, describe how buildings use energy. The most sophisticated of these programs is the ones which are capable of calculating building energy consumption hour by hour for an entire year.

To understand the simulation approach, it is useful to visualise such a system as an electrical network of time dependent resistances and capacitances subjected to time dependent potential differences. The currents to result in each branch of the network are then equivalent to the heat flows between the building's parts. Constructional elements, room contents, glazing systems, plant components, renewable energy devices, etc, may be treated as network 'nodes' and characterised by capacitance, with the inter-node connections characterised by conductance (Clarke, 2001).

From a mathematical viewpoint, several complex equation types must be solved to accurately represent such a system and, because these equations represent heat transfer processes that are highly inter-related, it is necessary to apply simultaneous solution techniques if the performance prediction is to be both accurate and preserve the spatial and temporal integrity of the modelled system.

Once established, a simulation program can be applied throughout the design process, from the early concept stage through detailed design. It is more efficient to use a single simulation program throughout the design process than to use a progression of tools from simplified to detailed and ignore the many theoretical discontinuities and pernicious assumptions.

It is possible to use simulation at an early design stage to determine the optimum combination of zone layout and constructional scheme that will provide a climate responsive solution and so minimise the need for mechanical plant. Some simulations might focus on the choice of constructional materials and their relative positioning within multi-layered constructions so that good temperature and load levelling is attained. Also, alternative daylight capture and shading strategies might be investigated to ensure glare avoidance, excess solar gain control and minimum luminary usage.

Simulation allows users to understand the interrelation between design and performance parameters, to identify potential problem areas, and so implement and test appropriate design modifications.

As the built environment is extremely complex, so the building simulation models are often become very sophisticated, it is usually too time consuming to apply these models manually to a design project. During the last two decades, a range of computer software has been developed, based on simulation models. These computer applications are able to speed up the calculation process dramatically. These applications are typically classified as:

- Energy analysis systems
- Lighting analysis systems
- HVAC systems
- Structural analysis systems.

1.3. Building Energy Analysis

A building is a highly complex energy system, especially when allowing a high degree of interaction with its surrounding environment with the aim of improving its energy performance. Therefore, given the relevance of the building sector in energy consumption, the introduction of rigorous energy analysis tools able to appropriately assess operational energy implications of different design options should be promoted. Developed countries need a high rate of energy consumption to maintain their standard of living and comfort. The current challenge is to seek sustainable development, maintaining activity and therefore achieving energy saving. For acceptance of energy performance of buildings these objectives are followed:

- Establishing a calculation method for the integrated energy performance of buildings.
- Application of minimum requirements on the energy performance of new buildings.
- Energy certification of buildings.
- Energy audits in large buildings.
- Regular inspection of boilers and air conditioning systems

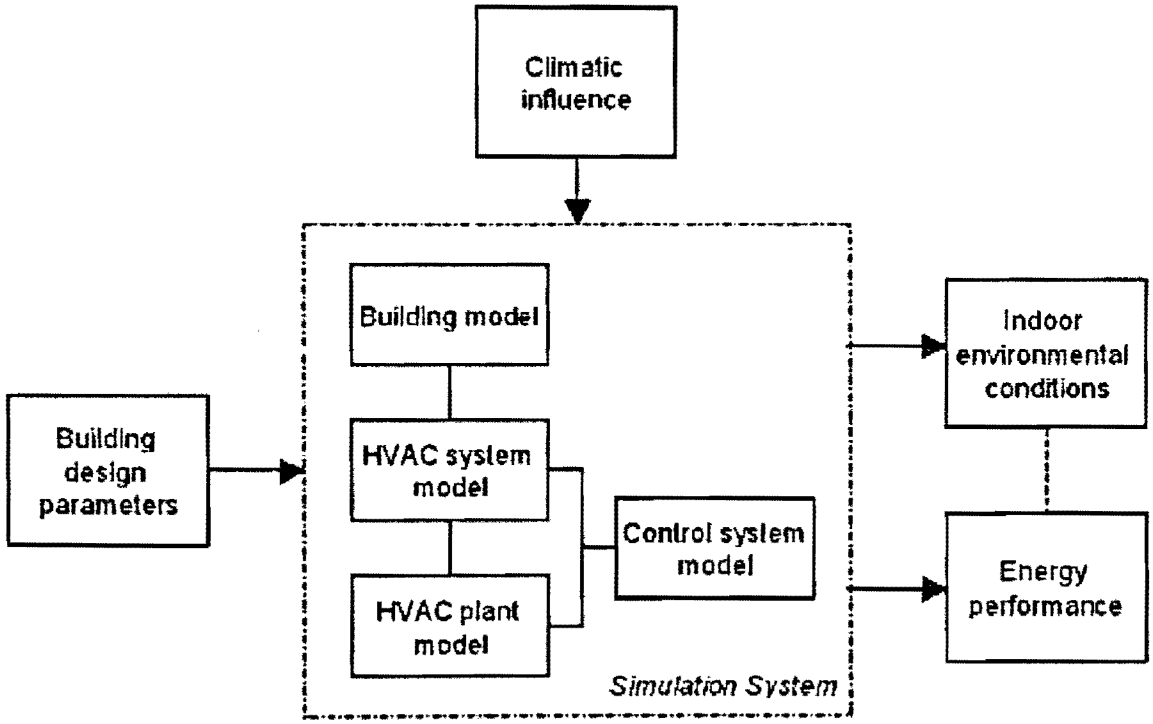

Figure 1.3: Basic Models of a Simulation System (Clarke & Irving, 1988)

According to Figure1.3, there are four basic models within the simulation system that are used for representing the major components that affect the building's energy flow (Clarke & Irving, 1988). These models include:

1. Building Model
2. HVAC System Model

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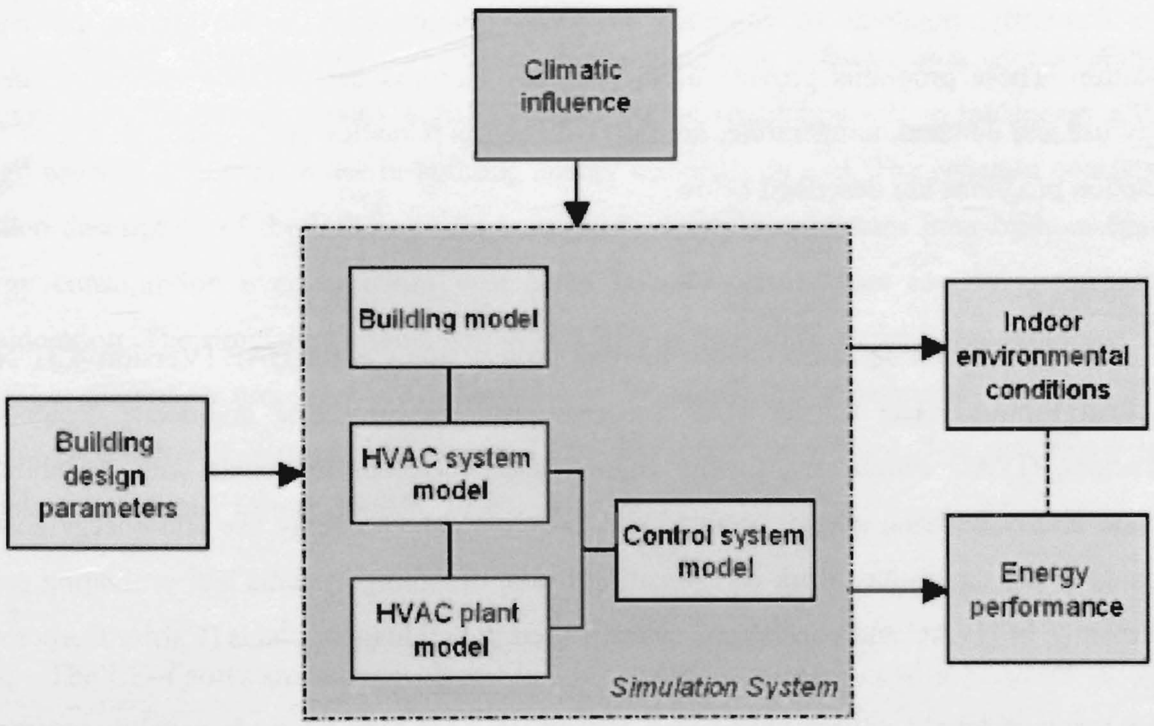

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1. Building Model
2. HVAC System Model

3. HVAC Plant Model

4. Control System Model

As can be seen from Figure 1.3, the objective is to provide comfortable indoor environmental conditions while at the same time come up with the right energy balance for maintaining optimum levels of fuel consumption. Comparison of different design options based on their life cycle costs can also be considered as an objective. The influence of climate has an impact on the system's performance. The inputs include building design parameters.

1.4. Energy Analysis Simulation Software

Currently, hundreds of computer programs are available in the market for energy simulation. These programs provide users with key building performance indicators such as energy use and demand, temperature, humidity, and costs (Crawley et al., 2005). A few of these simulation programs are described below.

Carrier HAP

The simulation software chosen for this project was Carrier HAP (Version 4.31 North American Edition). The Carrier HAP Program provides consulting engineers, design/build contractors, HVAC contractors, facility engineers and other professionals with the ability to simulate hourly building energy performance to derive annual energy use and energy costs. It also aids in the day-to-day work of estimating loads, designing systems and evaluating energy performance of HVAC and non-HVAC systems used in buildings or plants (Carrier Corporation, 2006).

Key features of the program include: User Interface, Building Wizard, System Design, Energy Analysis, Climate Analysis, Load Calculation, System Design Reports, Air System Analysis, Plant Equipment, Utility Rate, and Energy Analysis Reports. Furthermore, HAP's 8760 hour energy analysis capabilities are very useful for green building design (Carrier Corporation, 2006).

The program is a powerful tool for designing systems and sizing system components. HAP can easily handle projects involving:

- Small to large buildings.

- Systems including packaged rooftops, packaged and built-up central air handlers, fan coils, and more.
- Many types of constant air volume (CAV) and variable air volume (VAV) system controls.
- Small office buildings, retail stores, strip shopping centers, schools, churches, restaurants, large office buildings, hotels, malls, hospitals, factories and multi-use buildings.
- New design, retrofit or energy conservation work.

Chapter 4 describes Ryerson University buildings simulation procedure using Carrier HAP simulation program.

eQUEST

eQUEST is simple freely available energy simulation software that uses DOE-2 as a simulation engine (Hirsch, 2006). eQUEST plays a great simulation role in the energy efficient design process. It is easy to use in building energy use analysis tool. The program consists of a detailed description of the building being analyzed. eQUEST calculates hour-by-hour building energy consumption over an entire year using hourly weather data for the location under consideration. The simulation engine within eQUEST is derived from the latest version of DOE-2.2. The simulation processes are accomplished by combining a Schematic Design Wizard, Design Development Wizard, and Energy Efficiency Measure Wizard. The results are in the graphical and tabular format (Hirsch, 2008).

EE-4

The EE-4 software was developed to support the financial incentive program as well as support compliance checking with the performance path option for the Model National Energy Code for Buildings (MNECB) as well as the Commercial Building Incentive Program (CBIP) (Beausoleil-Morrison, 2001). It is derived directly from Energy Pro software which was developed to demonstrate compliance with MNECB and uses the DOE-2.1 engine. EE-4 automates energy use assessment, and applies all the specific ecoENERGY for New Building's (eENB) rules to verify that a design is at least 25% more energy efficient than is constructed to meet MNECB requirements. It can also be used to perform non-compliance energy analysis and consequently predict a building's annual energy consumption and assess the impact of design changes to the building.

DOE-2

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

Building Loads Analysis and System Thermodynamics (BLAST)

The BLAST (Building Load Analysis and System) simulation program was developed by the US Army Construction Engineering Research Laboratories in collaboration with University of Illinois to simulate virtually any type of building, whether new or retrofit (Crawley et al., 2005). The BLAST system is a set of computer programs for predicting heating and cooling energy consumption in buildings, and analyzing energy costs. BLAST can be used to investigate the energy performance of new or retrofit building design options of almost any type and size. In addition to performing peak load (design day) calculations necessary for mechanical equipment design, BLAST also estimates the annual energy performance of the facility, which is essential for the design of solar and total energy (cogeneration) systems and for determining compliance with design energy budgets.

TRNSYS (Transient Systems Simulation)

TRNSYS is a transient system simulation program designed to solve complex energy system problems by breaking the problem down into a series of smaller components. TRNSYS is used primarily to simulate thermal energy systems. Each physical component in the system, such as a pump or solar collector, is represented by a different FORTRAN subroutine. The subroutines are combined into an executable file controlled with an input file, which describes what physical components are involved in the system and how they are connected. TRNSYS has been used for simulating solar thermal systems as well as general HVAC systems (Crawley et al, 2005).

TRACE 700

The TRACE 700 simulation program was developed by the Trane Company and is divided into 5 distinct phases: Load, Design, System Simulation, Equipment Simulation and Economic Analysis (Trane, 2008). Different load methodologies such as ASHRAE Radiant Time Series (RTS) or Cooling Load Temperature Difference (CLTD) can be chosen by the designer.

Building heat gains (based on the geometry and internal heat loads of the building) are calculated on a monthly basis in the design phase. The building is then simulated on an annual basis, i.e., 8760 hours during system phase. During the equipment phase, the program uses the hourly coil loads from the systems phase to determine how cooling, heating and air movement will consume energy (Trane, 2008).

EnergyPlus

EnergyPlus (Crawley et al. 2005) is a modular, structured software tool based on the most popular features and capabilities of BLAST and DOE-2.1E. It is primarily a simulation engine; input and output are simple text files. EnergyPlus grew out of a perceived need to provide an integrated (simultaneous loads and systems) simulation for accurate temperature and comfort prediction. Loads calculated at a user-specified time step (15-minute default) are passed to the building systems simulation module at the same time step.

The EnergyPlus building systems simulation module, with a variable time step (down to 1 minute as needed), calculates heating and cooling system and plant and electrical system response. This integrated solution provides more accurate space temperature prediction crucial for system and plant sizing, occupant comfort and occupant health calculations. EnergyPlus has two basic components: a heat and mass balance simulation module and a building systems simulation module.

1.5. Deep Lake Water Cooling (DLWC) System

Many cities around the world are located near ocean shores or deep lakes. The cities of Toronto, Stockholm and Honolulu, and the Cornell University campus are showing the world what can be done using cold deep water to provide the cooling of large buildings, providing a large saving in energy and cutting down on carbon emissions and pollution from energy generating plants.

Deep-water air-conditioning could be considered for other major cities located near the ocean or deep lakes, as it has the advantages of low cost, great savings on energy and on air-conditioning chemicals. Deep-water air-conditioning is suitable for both large and midsize to small communities or for universities, hospitals or hotel resorts (Cummins, 2006).

Currently there is a Deep Lake Water Cooling (DLWC) system in Toronto that uses the water from Lake Ontario to cool the city's central district. This system offered by Enwave Energy Corporation, Toronto. Enwave's DLWC is the world's largest lake-source cooling system. And it is the ultimate in renewable, clean, green energy. This system has been proven to be very effective as it reduces electricity use by up to 90% compared with conventional air-conditioning (Enwave, 2006).

1.6. Overview of Ryerson University Campus Energy Consumption

Due to the increasing need for energy, everyone should be responsible for energy management. An energy cost savings of 5-15 percent is usually obtained quickly with little to no required capital expenditure with an aggressive energy management program. An eventual savings of 30 percent is common, and savings of 50, 60 and even 70 percent have been obtained. These savings all are from retrofit activities. New buildings designed to be energy efficient often operate on 20 percent of the energy (with a corresponding 80 percent savings) normally required by existing buildings.

From the various energy simulation studies in US and Canada in recent year, it is clear that air conditioning systems consume around 50% energy of the total electricity use in the office buildings. So, the air conditioning system is the main issue for maximum energy consume.

Table 1.1 described the floor area of All Ryerson University buildings.

Table 1.1: Floor Area of All Ryerson University Buildings

Sl. No.	Name of the Ryerson University buildings	Total gross floor area (m^2)	% of total floor area
1	School of Image Art (IMA)	9345	
2	Heaslip House Continuing Education (CED)	4180	
3	Kerr Hall (KNE/KNW/KSE/KSW)	52409	
4	Engineering Building (ENG)	22350	
5	Jorgenson Hall (JOR)	10964	
6	Library Building (LIB)	18487	
7	Podium (POD)	21730	
8	Eric Palin Hall (EPH)	13942	
9	Sally Horsfall Eaton Centre for Studies in community Health (SHE)	7077	
10	Student Campus Centre (SCC)	4180	
11	School of Interior Design (SID)	4373	
12	Victoria Building (VIC)	12708	
13	Heidelberg Centre-School of Graphic Communications Management (HEI/GCM)	2985	
Total floor area served by the central chillers plant (located on Library building)		**184730**	66
14	Rogers Communication Centre (RCC)	13100	
15	Pitman Hall Residence (PIT)	17866	
Total floor area served by the central chillers plant (located on Rogers Communication Ccentre)		**30966**	11
16	***Rogers Business Building(RBB)(Existing Deep Lake Water Cooling System)***	**24378**	9
17	Oakham House (OAK)	2033	
18	Research and Graduate Studies (GER)	2860	
19	International Living/ Learning Centre (ILLC)	9735	
20	South Bound Building (SBB)	6494	
21	Recreation & Athletics Centre (RAC)	4280	
22	Theatre School (THR)	2925	
23	Civil Engineering Building (MON)	2843	
24	Architecture Building (ARC)	7239	
25	Okeefe House	848	
26	ORI Office	723	
27	PRO/BND	851	
28	Ryerson Book Store	106	
Total floor area served by the self cooling system		**40946**	14
Total floor area All Ryerson University buildings		**281020**	**100**

The Ryerson University complex consists of 28 residential, office and educational buildings. Total area occupied approximately 281,020 square meters is shown in Table 1.2. Total audit area of Ryerson University was 240,074 square meters. According to the base case energy audit, Ryerson University has two central cooling plants. The large one has capacity of 3100 tonnes. It is located at Ryerson Library Building. It serves 66% of the total campus area including 13 office and educational and library buildings, with area 184,730 square meters. These 13 buildings are considered for Deep Lake Water Cooling (DLWC) feasibility analysis. The smaller one has the capacity of 530 tonnes. It is located at Ryerson Rogers Communication Centre, with area 30966 square meters and serves 11% of the total campus area. Self cooling system serves 14% of the total campus area. Only 9% of the total cooling area is served by Deep Lake Water Cooling (DLWC) system. The percentage of area is shown in Figure 1.4.

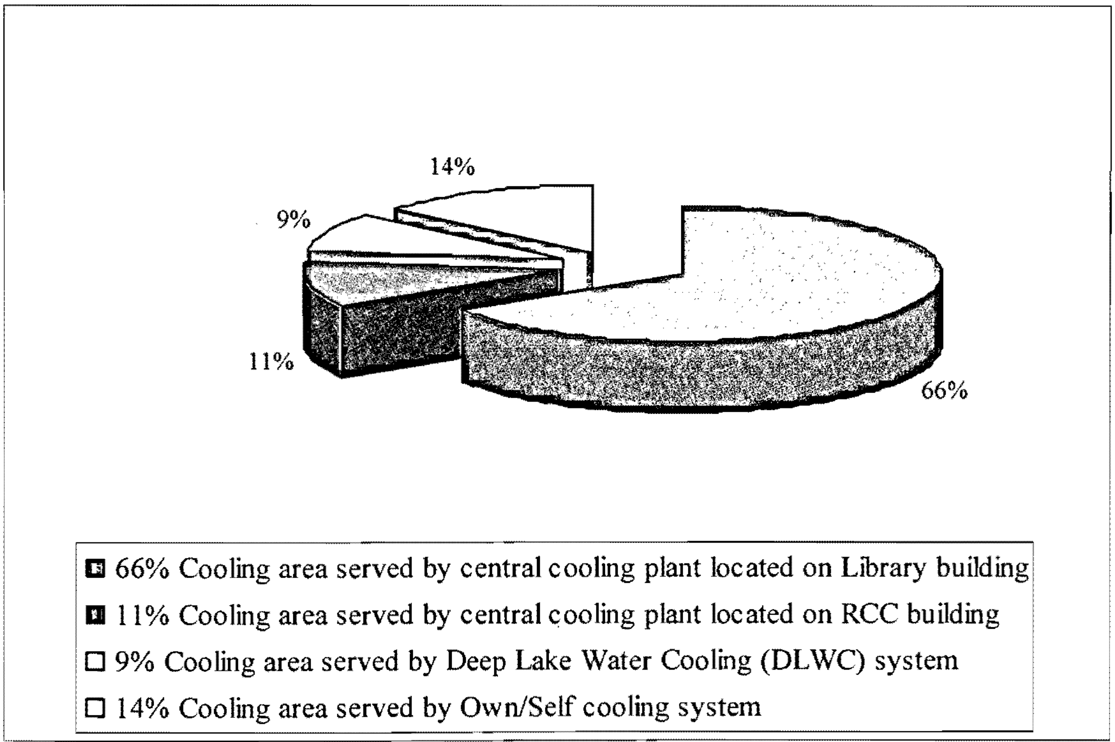

Figure1.4: All Ryerson University Buildings' Cooling Served by the Different Cooling Systems

Ryerson University has two meters (Meter-1 and Meter-2) for steam consumption for space heating and hot water demand. The required steam is supplied by Enwave. Meter-2 serves the Rogers Business Building which covers 9% of total area and Meter-1 serves 20 other

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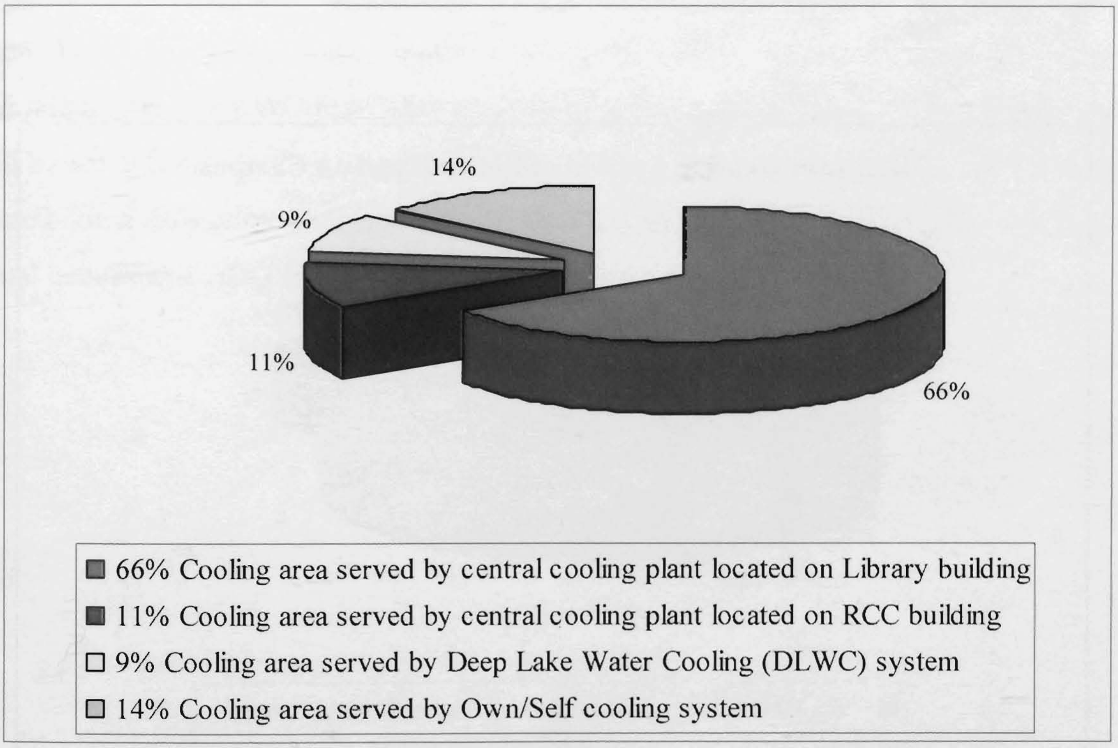

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Ryerson University has two meters (Meter-1 and Meter-2) for steam consumption for space heating and hot water demand. The required steam is supplied by Enwave. Meter-2 serves the Rogers Business Building which covers 9% of total area and Meter-1 serves 20 other buildings with area 221464 square meters which cover 79% of the total area. Self heating system (heat pump and other source) serves 12% of the total area. Table 1.2 shows heating area breakdown. Figure 1.5 shows different heating systems of Ryerson campus.

Table 1.2: Floor Area of All Ryerson University Buildings for Heating

Remote and self heating for Ryerson buildings	**Total Floor Area (sq m)**	**% of total Heating Area**
Served area by the remote steam for RBB building (Meter-2)	24378	9
Served area by the remote steam (Meter-1)	223127	79
Self heating system	33515	12
Total area for all Ryerson Campus	**281020**	**100**

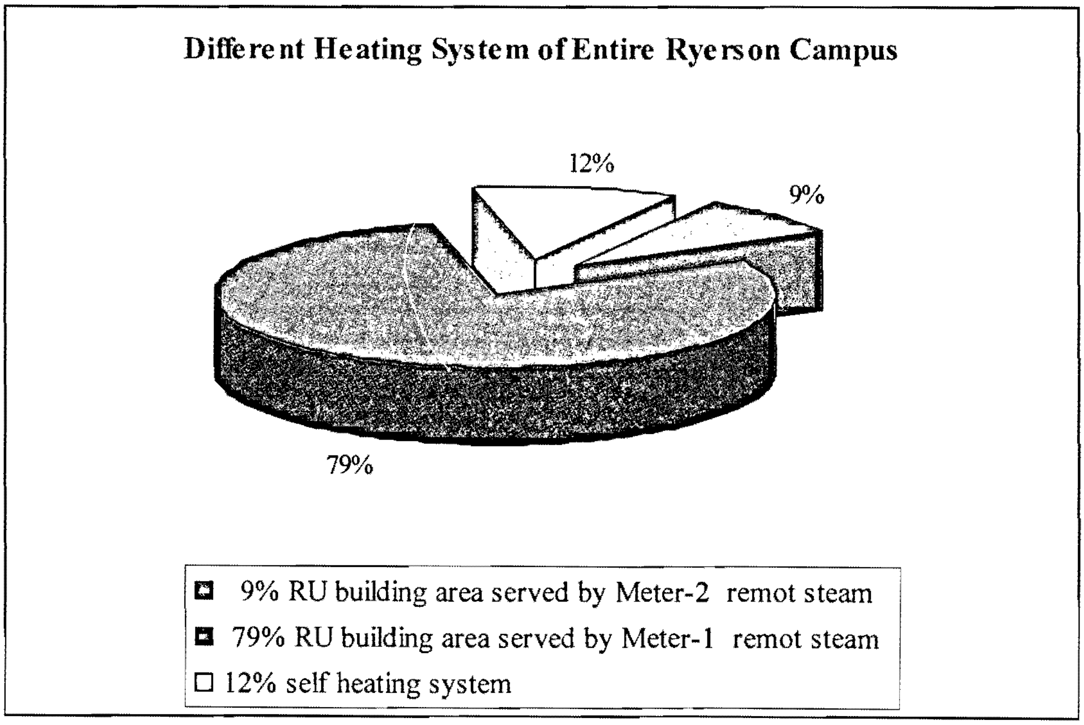


Figure 1.5: Different Heating Systems of Ryerson Campus

buildings with area 221464 square meters which cover 79% of the total area. Self heating system (heat pump and other source) serves 12% of the total area. Table 1.2 shows heating area breakdown. Figure 1.5 shows different heating systems of Ryerson campus.

Table 1.2: Floor Area of All Ryerson University Buildings for Heating

Remote and self heating for Ryerson buildings	**Total Floor Area (sq m)**	**% of total Heating Area**
Served area by the remote steam for RBB building (Meter-2)	24378	9
Served area by the remote steam (Meter-1)	223127	79
Self heating system	33515	12
Total area for all Ryerson Campus	**281020**	**100**

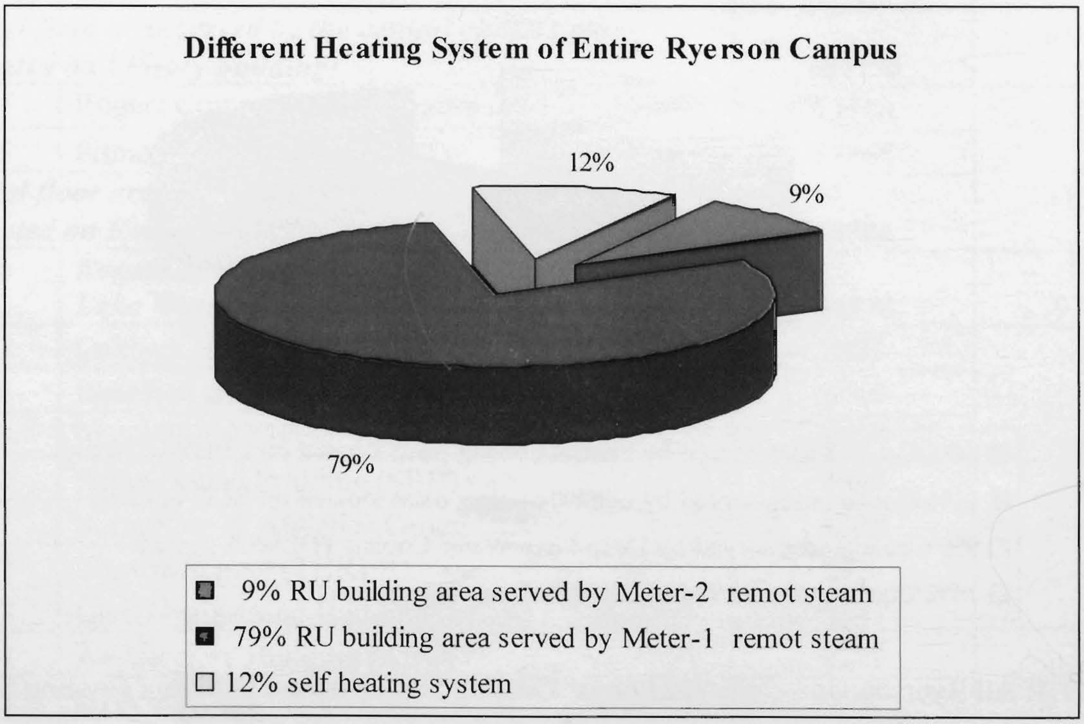


Figure 1.5: Different Heating Systems of Ryerson Campus

1.7. Methodology used for Modeling of All Ryerson University (RU) Buildings

Figure 1.6 below describes the methodology used by Carrier HAP energy simulation software for complying with data collected from the campus planning of Ryerson University and ASHRAE 90.1. The whole project work is performed and analyzed according to the following methodology.

For energy auditing, all building HVAC and Non-HVAC data is collected from the building drawing and Ryerson Campus Planning. All buildings are modeled in two different ways. The base case model and the base case model with heat recovery are both evaluated for energy sensitivity analysis. Energy simulation program Carrier HAP is used for simulating all Ryerson buildings. Deep Lake Water Cooling (DLWC) system is used for space air-conditioning. Due to DLWC feasibility analysis of Ryerson University, DLWC system model is created by using base case building data. Building base case model and DLWC system model are compared for a feasibility analysis. All calculations are designed to determine the amount of potential benefit and GHG emission reduction.

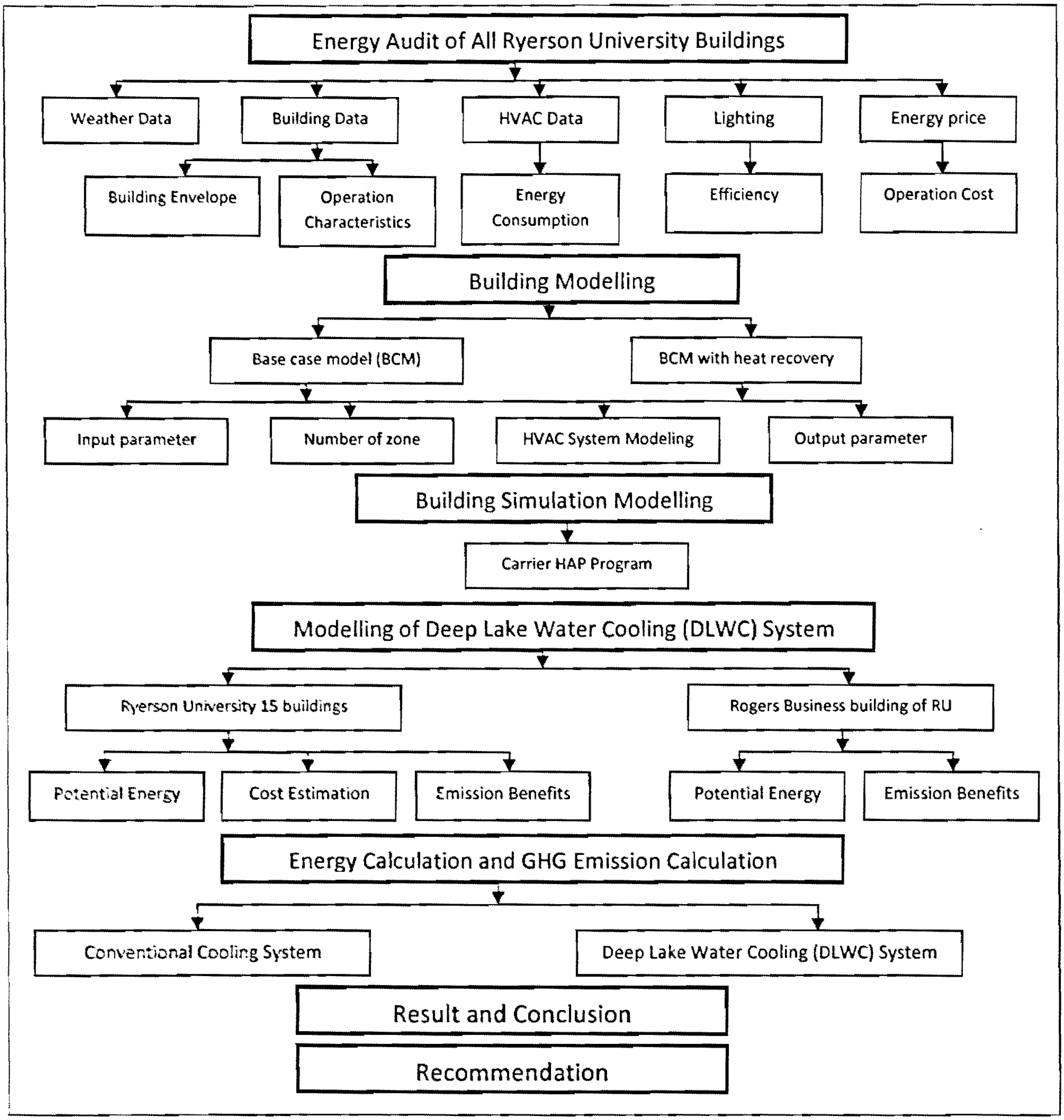


Figure 1.6: Flow Chart of Modelling the All Ryerson University (RU) Buildings

1.8. The Objective of the Study

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

- An energy audit and base case energy simulation of all Ryerson University buildings using the Carrier HAP energy simulation program. These consist of a detailed examinations of how the facility uses energy, how the facility loses and wastes energy, how much the facility pays for that energy, and recommended energy conservation measures to increase efficiencies.
- Deep Lake Water Cooling (DLWC) feasibility analysis for the entire RU campus.

The following scenarios will be assessed as part of the energy audit:

a. Base-case building with standard chiller, and
b. Building with Deep Lake Water Cooling

The following information will be gathered or estimated for each case:

i. Total annual energy consumption with breakdown for heating/cooling/electricity
ii. Annual CO_2, SO_x and NO_x reduction for conventional air-conditioning system and DLWC system.
iii. Total annual energy cost for conventional chiller and for the Deep Lake Water Cooling system.

CHAPTER-2

2. Deep Lake Water Cooling (DLWC) System

Deep lake water cooling (DLWC), and Seawater district cooling (DSC), is a technology which is beginning to make a significant impact on energy conservation as a feasible alternative to conventional central air conditioning systems (Looney, 2007).

2.1. Background of the Deep Lake Water Cooling (DLWC) Concept

In every part of the world's tropical oceans, seawater temperatures decrease with depth. The existence of the deep-water ocean heat sink results from natural climatic processes. In this natural climatic process, water is cooled at the poles, becomes dense, and sinks into the deep ocean.

Deep water cooling is an energy efficient way to air-condition buildings located near large bodies of water. The general idea of the system is to draw the cold energy from the body of water and distribute it to the desired locality. In this way it provides cooling. Deep water cooling requires little or no energy for actual cooling and it is different from conventional refrigeration methods which consume large amounts of energy to chill water or cooling medium. The only energy needed is to transfer the coldness of the water from the source to the desired warm area.

Toronto is a place where a large concentrated demand for cooling is located beside a large, possibly inexhaustible source of water that remains at just above the freezing point.

The large concentrated demand for cooling is in Toronto's downtown business district, the centre of which is less than one kilometre from Lake Ontario's north shore. This district is a forest of several dozen high-rise office buildings that would be uninhabitable.

The large source of cold water lies within Lake Ontario whose greatest depth is 243 metres. Below about 80 meters depth that is reached from six kilometres to Toronto, the water temperature remains at close to 4^{o}C throughout the year. With this result when the surface of the lake falls below 4°C in the winter, surface water becomes cold and it sinks. In summer Surface water becomes warm, but being less dense than the water below it remains at the surface. The result over the millennium has been the accumulation of a huge body of deep cold water. The top of this water is warmed in summer and replenished in winter.

Chicago is a city that might be thought also to lie beside such a reservoir of cold water. The depth of Lake Michigan certainly contains a huge amount of water at 4°C, larger than that in Lake Ontario. On the other hand, southern part of Lake Michigan is relatively shallow, and Chicago lies some 50 kilometres from any point where the depth of the lake is greater than 80 metres. It might be financially feasible the construction of a six-kilometre tunnel in the bed of Lake Ontario to serve Toronto with cold water. The construction of a 50-kilometre tunnel in the bed of Lake Michigan to serve Chicago would almost certainly be too costly compared with acceptable alternatives.

Other large cities with a high demand for cooling lie near a body of water, usually sea water, that is cold enough to be used for cooling or partial cooling for at least a part of the year. Boston, New York, Philadelphia, Portland, San Francisco, Seattle, Tokyo, and Vancouver are the examples. But only Toronto is close to water that remains cold enough to supply all of its cooling requirements.

Robert Tamblyn of Engineering Interface Ltd proposed and first studied the idea of using the nearby source of cold water to cool buildings in downtown Toronto. It concluded that the free cool concept was technically and economically sound, and worthy of further study. Attempts were made during the 1980s and the latest was in 1988 to move the scheme towards implementation.

Customer connections, heat exchangers, and interim financing charges are included in the cost of the system. Operating costs would be substantially lower than for on-site systems chiefly on account of reduced energy use: operation of the lake-water pumping system would require less than 10 percent of the energy required to operate chillers delivering the same amount of cooling. According to study the general cost per unit of cooling, including capital costs, would be substantially less than the cost per unit for on-site alternatives (Canadian Urban Institute, 1993).

2.2. Importance of DLWC System

There is a great demand for air conditioning to provide a comfortable indoor environment for human beings throughout the warm months of the year. As a result, there is also an equally high demand for energy to operate these systems. Demand can be reduced by DLWC system for energy considerably. By eliminating the use of conventional air-conditioning methods, energy consumption can be lowered providing many benefits to the user and the environment. The most significant is the economic benefits that are a direct result of energy savings. As the cost of energy has increased over the years and will continue to increase in the future, considerable savings can be realized by a consumer through the use of a DLWC system. Such a system would free up energy from electricity grids, thereby reducing the electrical overloads. Users would be less affected by energy restrictions during hot summers when conventional air-conditioners are traditionally consuming much the city's energy. Since DLWC mainly relies on a widely abundant and renewable source, there is no risk of a shortage. The reduced energy consumption is also beneficial to the environment as power generation (fossil-fuel burning) is a significant contributor to air pollution. Less energy would need to be produced if the system is large enough to meet the demands of a city during the summer months. Also, DLWC system can eliminate the use of conventional cooling methods using chillers, condensers and cooling towers, with the use of CFCs (chlorofluorocarbons) and increase air pollution and humidity. Generally, DLWC has got many benefits- economical and environmental. These benefits can make this technology as an attractive alternative.

Main Benefits of Deep Lake Water Cooling (Enwave, 2006):

- Compared to conventional chillers, Deep Lake Water Cooling system reduces electricity usage by 90%.
- Harmful ozone depleting refrigerants, such as CFC's and HCFC's, are reduced.
- Tonnes of carbon dioxide are avoided, which is equivalent to take thousands cars off the road.
- DLWC minimizes buildings exposure to increased rate and volatile energy markets because it relies on renewable energy source.

- Customers will avoid increasingly restrictive CFC regulation because DLWC is a CFC-free chilling technology.
- Clean drinking water is produced because the water used in the cooling process comes from a deeper part of Lake Ontario.
- Deep Lake Water Cooling reduces noise, pollution and humidity generated by chillers, fans and cooling towers.
- Reduces the strain on our electricity infrastructure, including transmission grids and local distribution networks.
- Enhances Toronto's world-class reputation as a place to live, provides cleaner air for breathing and makes Toronto a leader in sustainable energy.

2.3. Example of Deep Water Cooling (DWC) System

In order to show examples of DWC system in Canada two case studies are described. The first, a medium scale saltwater cooling system in Halifax, Canada, was constructed in 1986. This is one of the oldest deep water cooling systems in operation. The second, a large-scale network in Toronto, Canada, began operation in 2004 and continues to expand. These projects provide an interesting set of complimentary and contrasting features. They differ in scale, one uses saltwater and the other lake water, and one was constructed by a developer to serve one building complex and the other was constructed by a company that provides cooling as a service to multiple sites. However, both projects were and are successful economically and in terms of electrical demand displacement (Newman & Herbert, 2009).

Case study one: Purdy's wharf, Halifax:

On the waterfront of Halifax, the Purdy's wharf office complex is placed, and the buildings extend out over the harbour on pilings. Cold seawater is drawn from the bottom of the harbour through a pipe to a titanium heat exchanger in the basement of the complex. There the buildings' closed loop of cooling water is cooled by the seawater, and it is then pumped to each floor of the building where fans blow air over the cooling coils to cool the air. The seawater is returned to the harbour floor. The project consists of an 18-story tower, a 22-story tower, and a

4-story retail centre, and was constructed from 1983 to 1989. The total area cooled by the system was 65,000 m^2.

The seawater cooling system was a $400,000 upgrade over a conventional cooling system, primarily due to expensive titanium heat exchangers. Although the cold ocean water is freely available, pumping costs bring the water into the building cost $30,000 per year. Other operational costs include cathodic protection of the saltwater intake at $3500 per year for copper bars. Estimated annual savings, however, total $177,350 reduced electricity load, building maintenance and operation load with respect to a conventional air conditioning system. The simple payback was estimated to be 2.3 years. The system cannot functions year round due to fluctuate harbour temperatures; this was understood at the time of construction. Since construction, Purdy's wharf has demonstrated that deep water cooling systems can provide financial benefits even when they cannot operate year round.

In order to mitigate the corrosive power of seawater, Purdy's wharf required innovative technologies. Piping is corrosion resistant polyvinyl and polystyrene. The pumps are made of stainless steel. One of the obstacles to this project was control of marine growth. Initially chlorine was used to prevent marine growth in the system, but this was both costly and potentially environmentally damaging. That system was replaced by cathodic protection provided by copper plates.

To provide the required cooling performance, the water temperature must be below 10°C. The intake for the pumping system is located less than 200 m offshore at a depth of 18 m where conditions are appropriate for cooling for 10.5 months a year. Purdy's wharf operates conventional chillers in the late summer when harbour temperatures are too high (Newman & Herbert, 2009).

Case study two: Enwave, Toronto:

Purdy's wharf initiative is smaller than Enwave's Deep Lake Water Cooling project. Pipes extend 5 km into Lake Ontario and draw water from a depth of 83 m to the John Street pumping station where heat exchangers cool Enwave's closed cooling loop that snake through downtown Toronto. The lake water, slightly warmed, then goes on to supply Toronto with drinking water. The idea of providing cooling to Toronto using lake water had been considered at various times, but the project began in earnest in 2002. As of June 2006, 46 buildings were signed to the system and 27 were already connected. As the system nears capacity energy savings will be 85 million kWh, for a CO_2 reduction of 79,000 tonnes annually, or the equivalent of 15,800 cars. The total cooling area will be 3,200,000 m^2, or 50 times the area of the Purdy's wharf development. Energy savings are about 90%.

The total cost of the Enwave project in Toronto was over $235 million, including $175 million in capital costs and $55 million for a new city water intake. In 2005, the deep lake cooling system was operating at 51% of planned capacity but was still generating sufficient cash flow to cover its operating and financial costs and a lender therefore predicted that continued growth in the company's profitability is highly predictable and from the customer's perspective connecting to the deep water cooling system is advantageous, as illustrated by the case of Toronto City Hall. The air conditioning capital costs required to tap into Enwave's system were estimated at $2.5 million as compared to $3.1 million for a conventional system, with additional operating cost savings of $100,000 per year.

Enwave's system uses one-tenth of the electricity of a standard air conditioning system and it frees up 61MW of electricity from Ontario's electricity grid during peak period. This savings avoid total emission of 79,000 tonnes of carbon dioxide, and reduce the need for water for cooling towers by 714 million litres of water. Capital costs continue as the urban pipeline network expands. Low interest loans were provided by the Federal government and incentives for companies were provided by Toronto Hydro to hit their buildings up to the system in order to overcome the high initial capital cost (Newman & Herbert, 2009).

Cornell's reliance on fossil fuels has been reduced by the renewable resource tapped by Lake Source Cooling (LSC) of New York State. Since coming on line, LSC has saved 86,000,000 kilowatt-hours of electricity or an average of 25,000,00 kWh per year which is enough to continuously supply 2500 homes in Tompkins County. This represents about an 86% reduction in energy use for campus cooling (Cornell University, 2006).

LSC has also reduced the pollutants associated with electricity generation (greenhouse gases, acid rain, and the effects of mining and transporting oil and coal). Based on data collected through New York State's Public Service Commission, all the energy savings translates to a significant, permanent reduction in local and regional air pollution. Table 2.1 depicts actual emissions reductions associated with LSC.

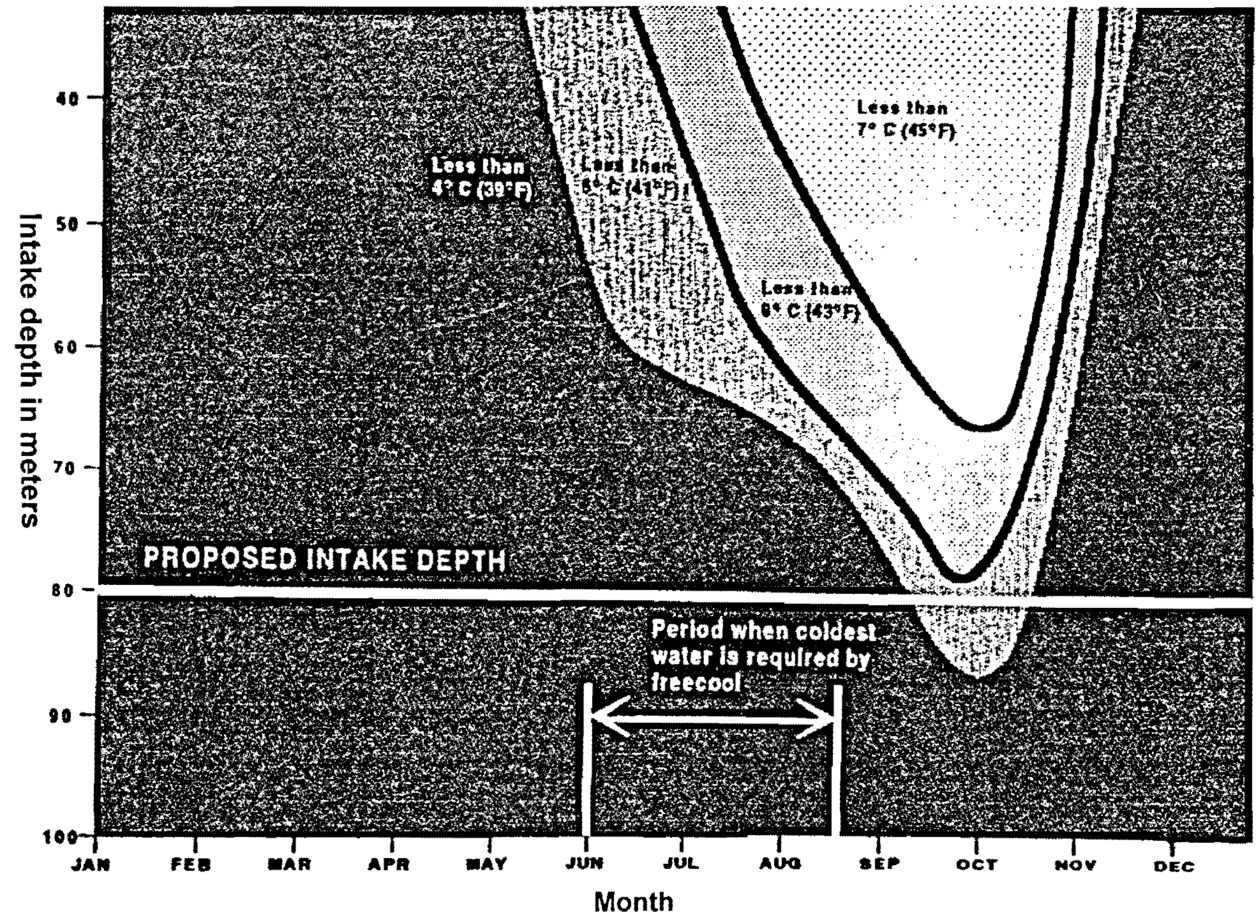
Table 2.1: Annual Emissions Reductions due to LSC (Cornell University, 2006)

Fiscal Year Ending	kWh Saved	SO_2 (tons)	NOx (tons)	CO_2 (tons)
2001	18,200,000	26.4	11.6	7,850
2002	24,600,000	35.7	15.6	10,610
2003	25,500,000	37.0	16.2	10,998
2004	17,900,000	26.0	11.4	7,720

2.4. Working Procedure of Enwave DLWC system

A relatively new technology which uses one-tenth of the electricity of a standard air conditioning system is Deep Lake Water Cooling (DLWC) system. DLWC is an environmentally-friendly, reliable, cost-effective, long-term method of cooling. This system has already been used in buildings around Toronto such as the Air Canada Centre, the Metro Toronto Convention Centre, Steam Whistle Brewery, a telecommunication facility at 151 Front Street West, Rogers Business Building at Dundas Street that offered by the Enwave Energy Corporation.

A DLWC system can be broken down into four systems: the water intake and outfall, heat exchange, close loop distribution and finally the air-cooling system. Enwave's three intake pipes draw water 39.2°F (4°C) from 5 kilometres off the shore of Lake Ontario at a depth of 262.5 ft (80 metres) below the surface shown in the Figure 2.1. Naturally cold water makes its way to the City's John Street Pumping Station. There, heat exchangers facilitate the energy transfer between the icy cold lake water and the Enwave closed chilled water supply loop. The water drawn from the lake continues on its regular route through the John Street Pumping Station for normal distribution into the City water supply. Enwave uses only the coldness from the lake water, not the actual water, to provide the alternative to conventional air-conditioning (Eliadis, 2003). The basic element of Enwave DLWC is shown in Figure 2.2.



Source: Canadian Urban Institute

Figure 2.1: Temperature of Lake Ontario at Different Depths Throughout the Year

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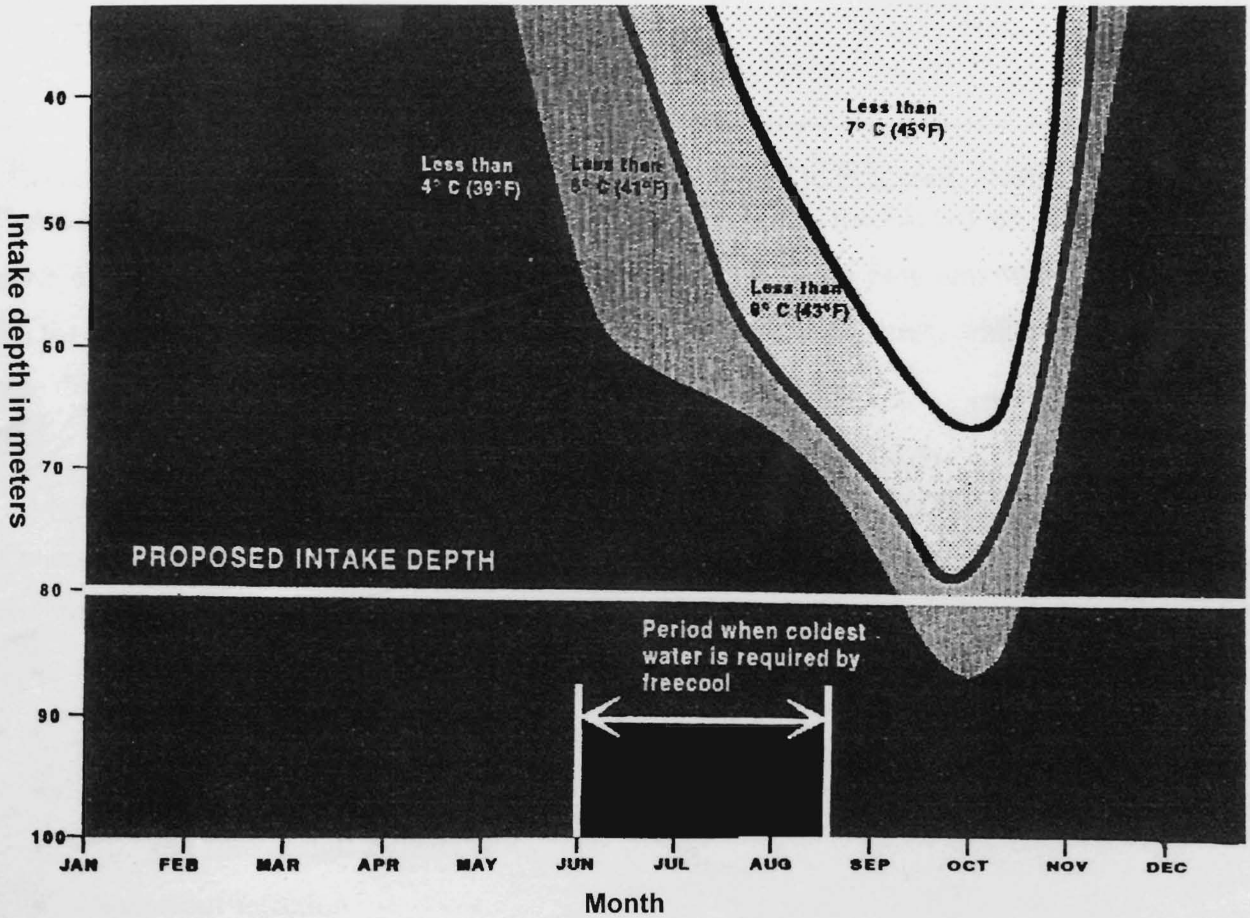

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Figure 2.1: Temperature of Lake Ontario at Different Depths Throughout the Year

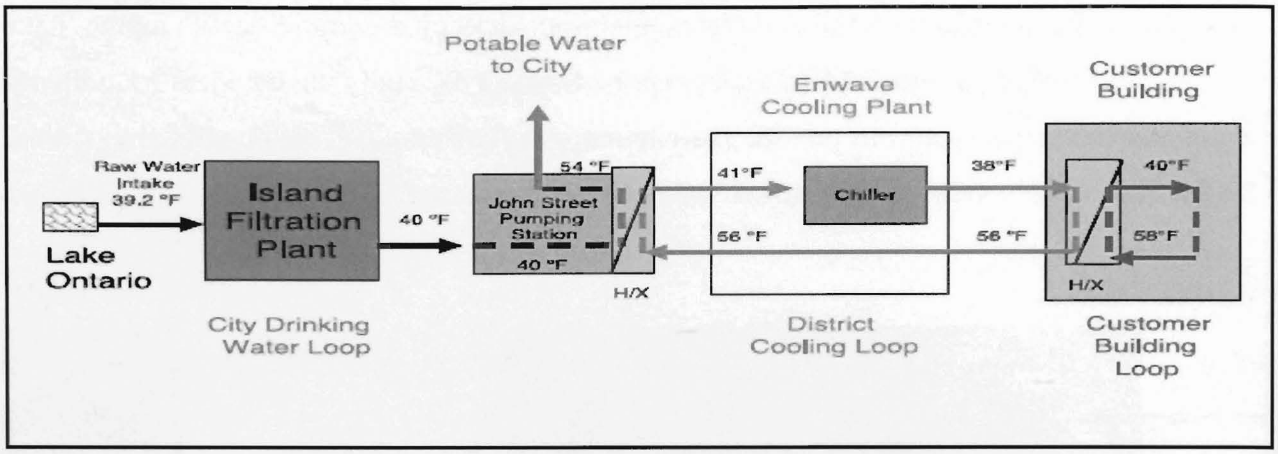

Figure 2.2: Basic Elements of Enwave Deep Lake Water Cooling System (Eliadis, 2003)

CHAPTER-3

3. Carrier HAP Energy Simulation Program

3.1. Carrier HAP Overview

There are a large number of computer programs on the market designed to help the HVAC professional in many ways. Only a few years ago, due to the limitations of the computing power and memory of personal computers (PC), the scope of the programs were quite limited, and for sophisticated programs, one had to use mainframe computers, which were relatively more difficult to access and use for the typical HVAC professional.

During the past few years, the rapid and substantial progress of PCs allowed the development of many sophisticated programs for these practical, fast and inexpensive computers. At present, there are programs available which are capable of assisting the HVAC professional in:

- Design heating and cooling load analysis
- Energy analysis
- Psychrometric analysis
- Pipe and duct design and sizing
- Equipment selection
- Economic analysis

Here, one of the commercially available heating and cooling load calculation programs will be briefly reviewed. The program is called HAP (Hourly Energy Analysis Program) and is also capable of simulating the energy consumption of a building. HAP program is a part of a series of programs available from Carrier Corporation which are known as the E20-II, which include pipe and duct design and economic analysis programs as well (Crawley et al., 2005).

3.2. Introduction to "Carrier HAP" Program

Carrier HAP is the building energy simulation software developed by Carrier Corporation where HAP means hourly analysis program. This computer tool helps engineers to design and size HVAC systems for different facilities. It consists of two tools. The first tool is used to estimate the load and design system. The second tool is used to simulate energy use and to calculate energy cost. This combination of two tools in single package saves time and effort. It also simulates hourly building energy performance to determine annual energy use and cost of energy (Carrier Corporation, 2006).

HAP estimates design cooling and heating loads for commercial 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.
- Determines required airflow rates for spaces, zones and the system.
- Sizes cooling and heating coils.
- Sizes air circulation fans.
- Sizes chillers and boilers.

HAP estimates 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. 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:

- 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 stepped, time-of-day and demand charges, if specified.
- Generates tabular and graphical reports of hourly, daily, monthly and annual data.

HAP is comprised of three branches: an input branch and two analysis branches:

Weather and Space Input Branch: The first branch of HAP handles data entry for the basic weather and building data used in both design load and energy analysis calculations.

Design Load Branch: The second branch of HAP estimates hourly cooling and heating design loads. Design loads data may be used to size air terminals, cooling and heating equipment.

Energy Analysis Branch: The third branch of HAP performs detailed hourly simulations of air system and plant operation. Simulation results are used to compute annual energy consumption. The program considers a variety of fuel types as well as electrical energy and demand charges in order to compute the annual operating costs for the building.

3.3. Different Calculation Engines

In order to conduct a building simulation, HAP uses combination of six different calculation engines (Crawley et al, 2005):

- To analyze dynamic heat transfer in the building, producing space cooling and heating loads, the loads engine uses the ASHRAE Transfer Function Method.
- The "Systems engine" simulates the thermo-mechanical operation of the airside system.
- The Loads Engine and the Systems Engine are integrated by the "Sizing Engine" and helps to estimate the proper size for diffusers, air terminal, fans, coils and humidifiers.
- The "Plant engine" simulates the operation of chilled water and hot water plants.
- Energy and fuel consumptions data from the system and plant calculations are collected by the "Building engine" and combines it with utility rate specifications to produce energy consumptions and energy costs.

- Life cycle costs are determined by the "Life Cycle Engine" which combines the energy costs with the equipment costs, operating costs and maintenance costs.

3.4. Carrier HAP Strength and Limitation

Carrier HAP program has some strengths and few a limitation which are described as below (Carrier Corporation, 2006):

Carrier HAP Strength:

- Carrier HAP program is a powerful tool for designing systems and sizing system components.
- HAP can easily handle projects and archive features.
- Equally good for small, medium and large building energy modeling.
- Carrier HAP can be used for new design, retrofit or energy conservation work.
- Systems including packaged rooftops, built-up central air handlers, fan coils, and terminal unit and more.
- Different types of constant air volume (CAV) and variable air volume (VAV) system controls are available.
- Comprehensive system sizing information, component loads, and building temperatures can be gathered from design report.
- Building simulation reports provide hourly, daily, monthly, and annual energy and cost performance data.
- HAP can be used for complex utility structures.
- This program provides more than 50 design, energy analysis reports and graphs.
- Carrier HAP is used for estimating life cycle cost of components as well as equipment.
- All Reports can be exported to word processors and spreadsheets for further use.

Carrier HAP Limitation:

- Carrier HAP is not suitable for research work.
- Up to100 buildings are permitted per project.

- Up to100 plants and 250 systems are permitted per project.
- Up to 250 systems are permitted per project.
- Up to 2500 spaces can be inputted per project.
- Air system has a limit of spaces up to 100 spaces.
- Limitation for input full geometric description of wall, roof, floors, windows, skylights and doors.
- Weather data cannot be edited and is only available from Carrier.

3.5. Carrier HAP Weather Data

Weather Data refers to the temperature, humidity and solar radiation conditions experienced by the building and its HVAC equipment. In HAP, this term is also used to refer to information about the geographical location of the building, the nature of local time and local soil properties. Weather data has a significant effect on building loads and equipment operation. It plays a key role in load calculations and system performance calculations. The weather form consists of three main parts (Carrier Corporation, 2006).

- It provides a database of design weather data for more than 800 cities worldwide.
- It uses Typical Meteorological Year (TMY) and Typical Reference Year (TRY) type hourly weather data for energy simulation.

HAP deals with two distinct kinds of weather data:

- **Design Weather Data** is used to perform cooling and heating design load estimates. Cooling design weather data consists of 24-hour profiles of temperature and humidity representing warmer than normal conditions, and clear sky solar radiation profiles representing maximum sunshine conditions for each month. This data is used to estimate design cooling loads according to standard industry practices. Heating design weather data consists of information about the winter design temperature and humidity. This data is used to determine design heating loads according to standard industry practices.

- **Simulation Weather Data** is required when performing 8,760 hours energy simulations. Simulation weather data refers to the 8,760 hours sequence of actual weather data used to simulate building loads and HVAC equipment operation over the course of a year. Results of these simulations are used to compute annual energy use and energy costs. This data is only used in HAP and not in HAP System Design Load.

The operating calendar defines the sequence of days during the year. Because energy simulations are dynamic, thermal performance on one day affects performance on one or more subsequent days. Internal heat gains and equipment operation are usually closely tied to human activity in the building, which turns to the day of the week and holidays. Therefore, it is important to define the sequence of days for the 365-days simulation year.

In HAP, a project only uses one set of weather data at a time. This is in contrast to data such as spaces, systems and plants for which multiple items can exist in each category of data. Rather, one set of weather data exists and the current weather data that has been defined is used for all program calculations (Carrier Corporation, 2006). Weather Properties of Toronto is shown in Figure 3.1.

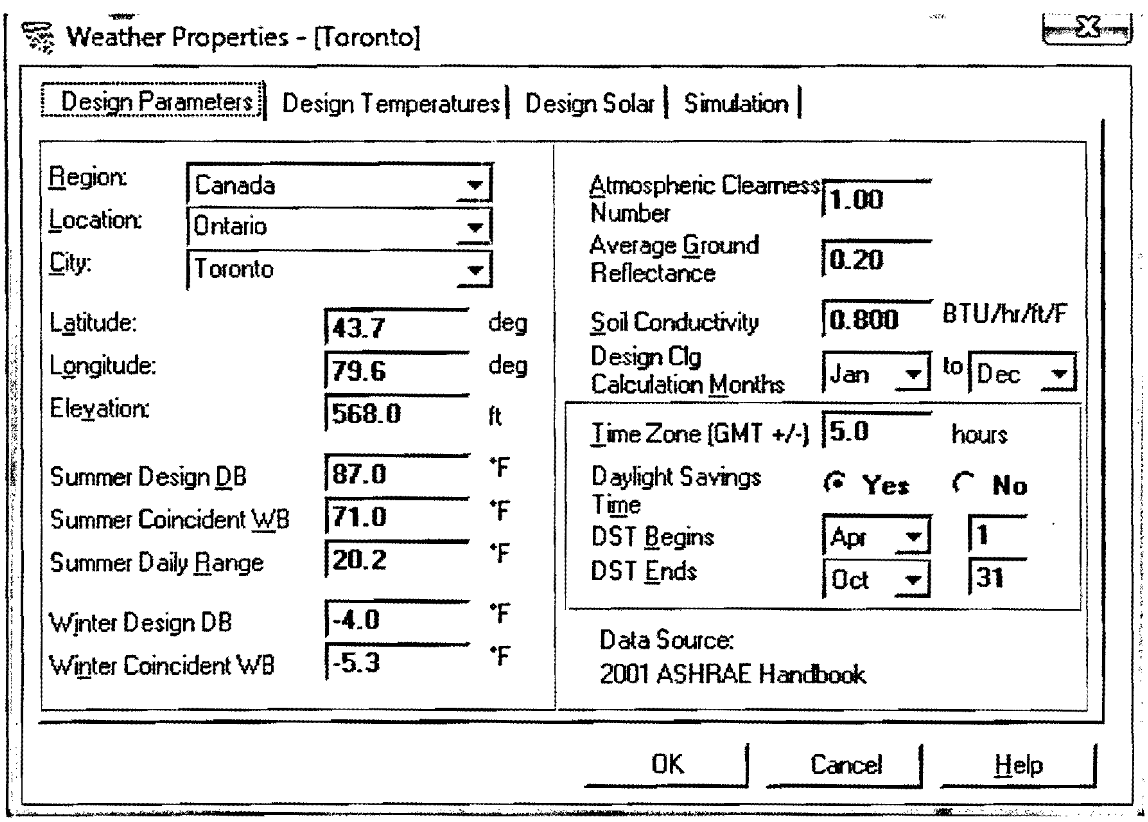

Figure 3.1: Weather Properties Screen (Carrier Corporation, 2006)

The thermal envelope or the thermal environment determines how a building will respond to external environmental factors. The physical layout of the building, the site location, the orientation, its outer construction, all determine the thermal environment of the building, which are needed for proper energy simulation and analysis.

The thermal environment can be subdivided into one or more zones as shown in Figure 3.2. Building construction is defined as an entire collection of interior and exterior features of the structure. Building may consist of one or more zones. A zone is defined as a group of surfaces that can interact with each other thermally and have a common air mass at roughly the same temperature. Surfaces are walls, roofs, ceilings, floors, partitions, windows, shading devices. Surfaces consist of a series of materials called "construction". Construction is a group of homogeneous one-dimensional material layers. Each surface must have a single construction definition, and each construction is made up of one or more materials (Siddique, 2008).

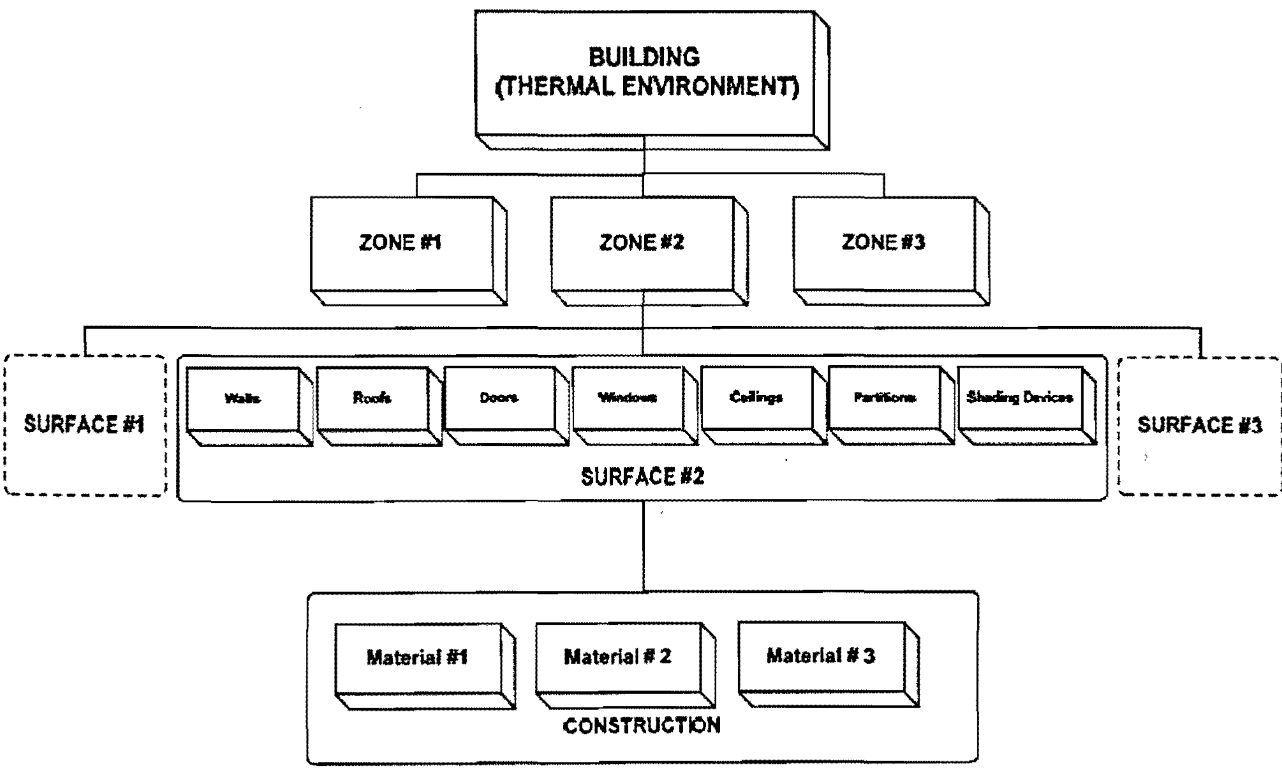

Figure 3.2: Simulation Modeling of the Thermal Environment (Siddique, 2008)

3.6. Space Usage and Interior Environment

Thermal simulation requires information about the functions taking place inside the building and how, these might add or subtract heat from the zones. Thermal simulation requires information on air leakage to and from the building to determine its effect on the building heating and cooling needs. Nothing is constant inside a building-people come and go, lights and equipment get turned on and off, etc. and the thermal simulation needs details on what is happening through the day and year within a building (Siddique, 2008).

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

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

Types of Internal Gains:

- People
- Lights
- Equipment
- Infiltration

Heat Additions from Internal Gains:

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

HVAC System:

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

There are two systems:

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

Zone Sizing:

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

3.7. Heat Balance Method

For sizing equipments, the heat balance method is used such as fans, chillers, boilers, etc. Based on design criteria and thermal properties of the building, the cooling, heating, latent and fresh air loads of the building will be estimated to determine the design flow rate and capacity of the air-conditioning system and its equipment (Chen and Wang, 2002).

There are many methods for the determination of building thermal energy and load, for example, the room response method, equivalent temperature difference method, harmonized wave decomposition method and finite difference method. The simplified methods such as the degree-day method and the bin method are used to predict the energy consumption of buildings or total cooling and heating load (Chen and Wang, 2002).

3.7.1. Building Energy Analysis Method

There are many methods for estimating building energy consumption and, in general, they can be divided into two categories (Chen & Wang, 2002):

1. Steady-State Method
2. Dynamic Method

Steady-state methods, such as the effective heat transfer method, degree day method, bin method, temperature frequency method and full load coefficient method, are simple to use, but they cannot provide information about the variation of energy consumption with the time and do not consider the effect of thermal storage in the building structure (Chen & Wang, 2002).

Dynamic methods are more detailed and usually require hourly calculations over the whole year for the analysis of annual load and energy consumption. Conversion from the heat gains to cooling load can be carried out by the heat balance method (Chen & Wang, 2002).

3.7.2. Transfer Function Method

The Transfer Function Methodology (TFM) is a dynamic means of accounting for heat transfer. Although there are other methods of accounting for heat transfer, Carrier's HAP program utilizes TFM in its calculations because it extends the analysis to account for specific system behaviour to control the air temperature in the thermostat zones.

Different software programs use different methodologies for calculating heating and cooling loads. For example, the "Design Master HVAC" software program uses the Cooling Load Temperature Difference (CLTD) method, Trane's TRACE program uses the Transfer Function Method (TFM), and Carriers' HAP also uses the Transfer Function Method (TFM). The TFM is based on two important concepts (MacQuiston et al, 2005).

Conduction Transfer Function (CTF): The Conduction Transfer Functions are used by TFM to describe the heat flux at the inside of a wall, roof, partition, ceiling, or floor as a function of previous values of the heat flux and previous values of inside and outside temperatures. Conduction Transfer Function coefficients depend only on the physical properties of the wall or roof and not on the construction of the rest of the zone. Conduction Transfer Function coefficients for walls, roofs, partition, floors, and ceilings, can be determined using the Conduction Transfer Function routines (Chen and Wang, 2002).

Weighting Factor: The Weighting factors are also known as Room Transfer functions and are used by relating a current variable to its past values and other variables at discrete time intervals. These intervals are usually at 1-hour period for transfer functions used in building analysis (Chen and Wang, 2001).

3.8. Fundamental Terminologies of HAP

In using the HAP, input of following six main categories of data related to building and its HVAC equipments are necessary.

1. Element: Elements are the components of the building, which are responsible for heat gain or loss. In other words, its main characteristic is to affect the heat transfer of the facility. Examples for the elements are walls, windows, doors, roofs, skylights, floors, partitions, lighting, people, electric equipment, miscellaneous heat sources and infiltration (Carrier Corporation, 2006).

2. Space: In general, a space means a single room. But for some applications, it may be more efficient for a space to represent a group of rooms even an entire building. A space consists of a number of "elements" such as walls, roofs, windows. So, a space is a region of the building comprised of one or more heat flow elements and is served by one or more air distribution terminals. All spaces for the portion of the building being analyzed must be defined so system design calculations or energy simulations can be performed (Carrier Corporation, 2006).

3. Zone: A zone is a group of one or more spaces having a single thermostatic control. Zones are often used differently for different applications. In some systems, each room contains a thermostat. Therefore, each zone contains one space representing a single room. In other situations, one thermostat is allocated to a group of rooms. For preliminary block load estimates, a zone might be defined as the entire building. The choice of zones affects system operation, the accuracy of system design and energy analysis calculations, and the effort required to model the system (Carrier Corporation, 2006).

4. Air System: The air system is the equipment and controls used to provide cooling and heating of the building which serves one or more zones. The air temperature of each zone is controlled by thermostat. Examples of air systems are packaged rooftop units, packaged vertical units, split systems, packaged DX fan coils, hydronic fan coils and water source heat pumps. In all cases, the air system also includes associated ductwork, supply terminal and controls (Carrier Corporation, 2006).

5. Plant: The plant is composed of the equipment and controls used to provide cooling or heating to coils in one or more air systems such as the chiller plants, hot water boiler plants and steam boiler plants (Carrier Corporation, 2006).

6. Building: The building is the envelope containing all the HVAC systems under consideration. Though literally, building represents one individual structure it can also represent a group of structures. For example, a "building" could represent a campus in which all the structures are served by a common set of plant equipment (Carrier Corporation, 2006).

3.9. Using HAP to Design Systems and Plants

In conceptual terms, how to use HAP to design systems and plants? The basic five steps procedure are needed for designing systems and plants (Carrier Corporation, 2006) and can be shown in Figure 3.3.

1. **Define the Problem:** Before using HAP, it is needed to define the scope and objectives of the energy analysis. For example, what type of building is involved? What type of systems and equipment are required for HVAC? What special requirements are to be considered for system features?

2. **Gathering Data:** Before performing energy analysis, information about the building, its environment and its equipment must be gathered. Data involves HVAC as well as non-HVAC systems, following specific types of data include:
   - Climate data for the building site.
   - Construction material data for walls, roofs, windows, doors, exterior shading devices and floors, and for interior partitions between conditioned and non-conditioned regions.
   - Building size and layout data including wall, roof, window, door and floor areas, exposure orientations and external shading features.
   - Internal load characteristics determined by levels and schedules for occupancy, lighting systems, office equipment, appliances and machinery within the building.
   - Data concerning HVAC equipment, controls and components to be used.

3. **Enter Data into HAP:** To enter climate, building and HVAC equipment data into HAP. Then define the following types of data which are needed for energy analysis work:

   a. Enter Weather Data: Weather data defines the temperature, humidity and solar radiation conditions the building encounters during the course of a year. These conditions play an important role in influencing loads and system operation.

   b. Enter Space Data: A space is a region of the building comprised of one or more heat flow elements and served by one or more air distribution terminals. To define a space, all elements which affect heat flow in the space must be described. Elements include walls, windows, doors, roofs, skylights, floors, occupants, lighting, electrical equipment, miscellaneous heat sources, infiltration, and partitions. Also information about the construction of walls, roofs, windows, doors and external shading devices is needed, as well as information about the hourly schedules for internal heat gains.

c. Enter Air System Data: An Air System is the equipment and controls used to provide cooling and heating to a region or zones of a building. Zones are groups of spaces having a single thermostatic control. Examples of systems include central station air handlers, packaged rooftop units, packaged vertical units, split systems, packaged DX fan coils, hydronic fan coils and water source heat pumps. In all cases, the air system also includes associated ductwork, supply terminals and controls. To define an air system, the components, controls and zones associated with the system should be defined as well as the system sizing criteria.

d. Enter Plant Data: A Plant is the equipment and controls used to provide cooling or heating to coils in one or more air systems. It includes chiller plants, hot water boiler plants and steam boiler plants. This step is optional; it is only required if we are sizing chiller or boiler plants. To define a plant for design purposes, the type of plant and the air systems it serves must be defined. This data is entered on the plant input form.

4. **Generate Design Reports:** Once weather, space, air system and plant data has been entered, HAP can be used to generate system and plant design reports. Design procedure is shown in Figure 3.3.

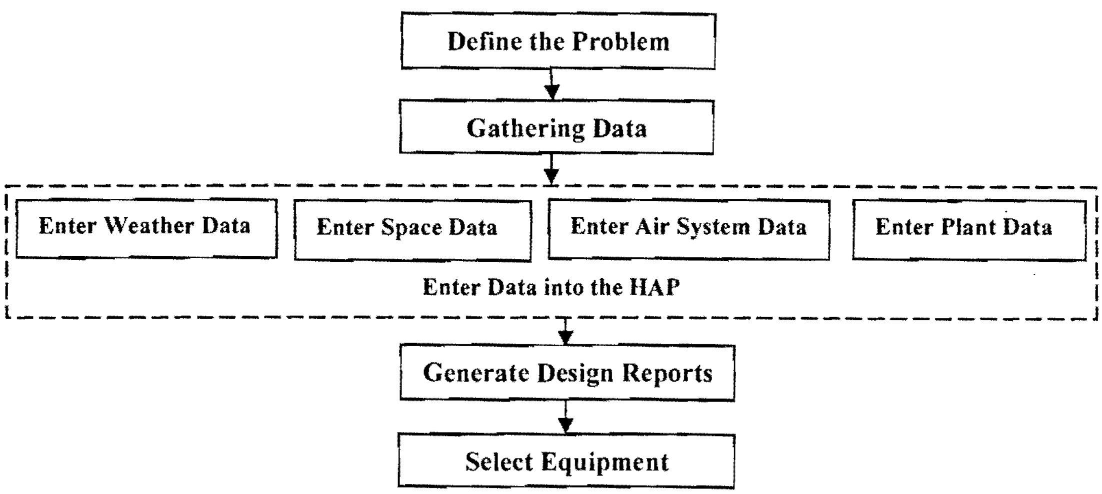

Figure 3.3: Design Procedure of Systems and Plants using HAP

5. **Select Equipment:** Finally, the data from the generated reports used to select the appropriate cooling and heating equipment from product catalogs or electronic catalog software. System and plant design reports provide information necessary to select all the components of your HVAC system including air handlers, packaged equipment, supply terminals, duct systems, piping systems and plant equipment.

3.10. Using HAP to Estimate Energy Use and Cost

In conceptual terms, how to use HAP to estimate annual energy use and energy costs for a building is an important concern. For doing an energy analysis, all energy analysis work requires the same general five step procedure shown in Figure 3.3 below. Note that, certain steps are identical or similar to those used for system design which is already described in previous section. If a system design has already been performed for a building, all of the data entered for design can be reused for the energy analysis, and this significantly reduces the effort needed to complete the energy analysis. Note that energy analysis features are only available in the HAP program and not in HAP System Design Load (Carrier Corporation, 2006).

In order to do an energy analysis, the first two steps involve defining the problem as well as data gathers are the same as described in previous "designing of systems and plants" section. Weather data and space data which include defining zones are also the same as described in the previous section (Carrier Corporation, 2006). Energy Analysis procedure is shown in Figure 3.4.

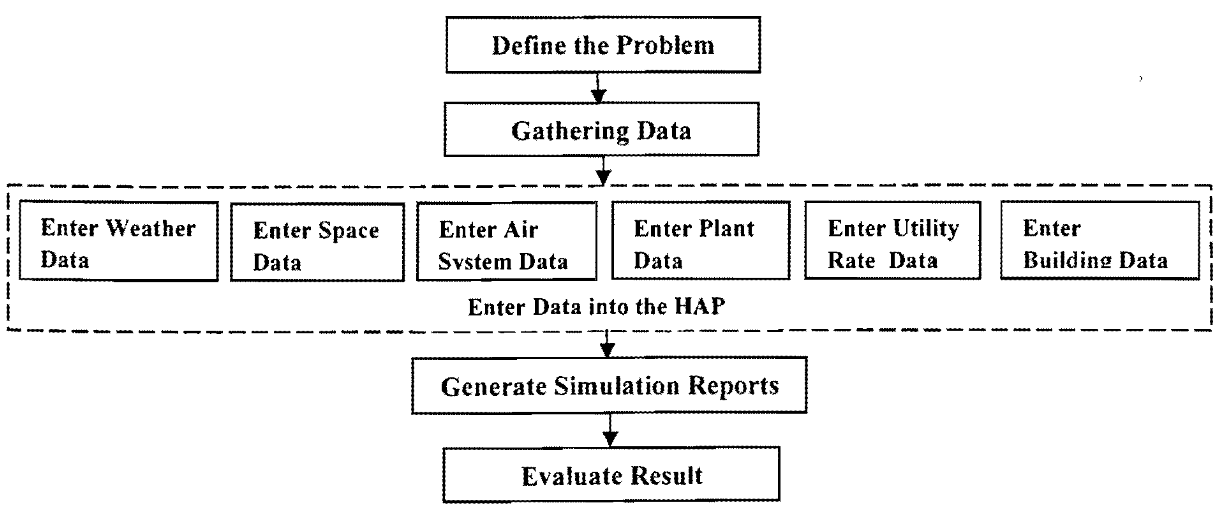

Figure 3.4: Energy Analysis Procedure

An Air System is the equipment and controls used to provide cooling and heating to a region of a building. An air system serves one or more zones. To define an air system, the components, controls and zones associated with the system must be defined as well as the system sizing criteria. For energy analysis, performance information about DX cooling equipment and electric and combustion heating equipment must also be defined. All of these data are entered into the air system input form (Carrier Corporation, 2006).

A Plant is the equipment and controls used to provide cooling via chilled water or heating via hot water or steam to coils in one or more air systems. This step is optional; it is only required if chilled water, hot water or steam plants are used in assigning building. To define a plant for energy analysis purposes, the type of plant and the air systems must be defined along with its configuration, controls and distribution system information. This data is entered on the plant input form (Carrier Corporation, 2006).

Utility rate data defines the pricing rules for electrical energy use and fuel use. An electric rate structure must be defined for all energy studies. One fuel rate for each non-electric fuel source must also be defined. Electric rate data is entered using the electric rate form. Fuel rate data is entered using the fuel rate form (Carrier Corporation, 2006).

A Building is simply the container for all energy-consuming equipment included in a single energy analysis case. Building data consists of lists of plants and systems included in the building, utility rates used to determine energy costs and data for non-HVAC energy or fuel use. Data is entered using the building form (Carrier Corporation, 2006).

When all input data has been entered, HAP can be used to generate simulation reports. Simulation reports for individual air systems and plants included in analysis can also be generated. Use the same procedure but select air system or plant items instead. System and plant simulation reports provide more detailed performance information for individual pieces of equipment. They are often useful for learning about equipment performance and for troubleshooting unexpected results (Carrier Corporation, 2006).

In order to design system and plant for HVAC and to generate energy simulation reports for a building, the Carrier HAP works by following methodology are as shown in Figure 3.5.

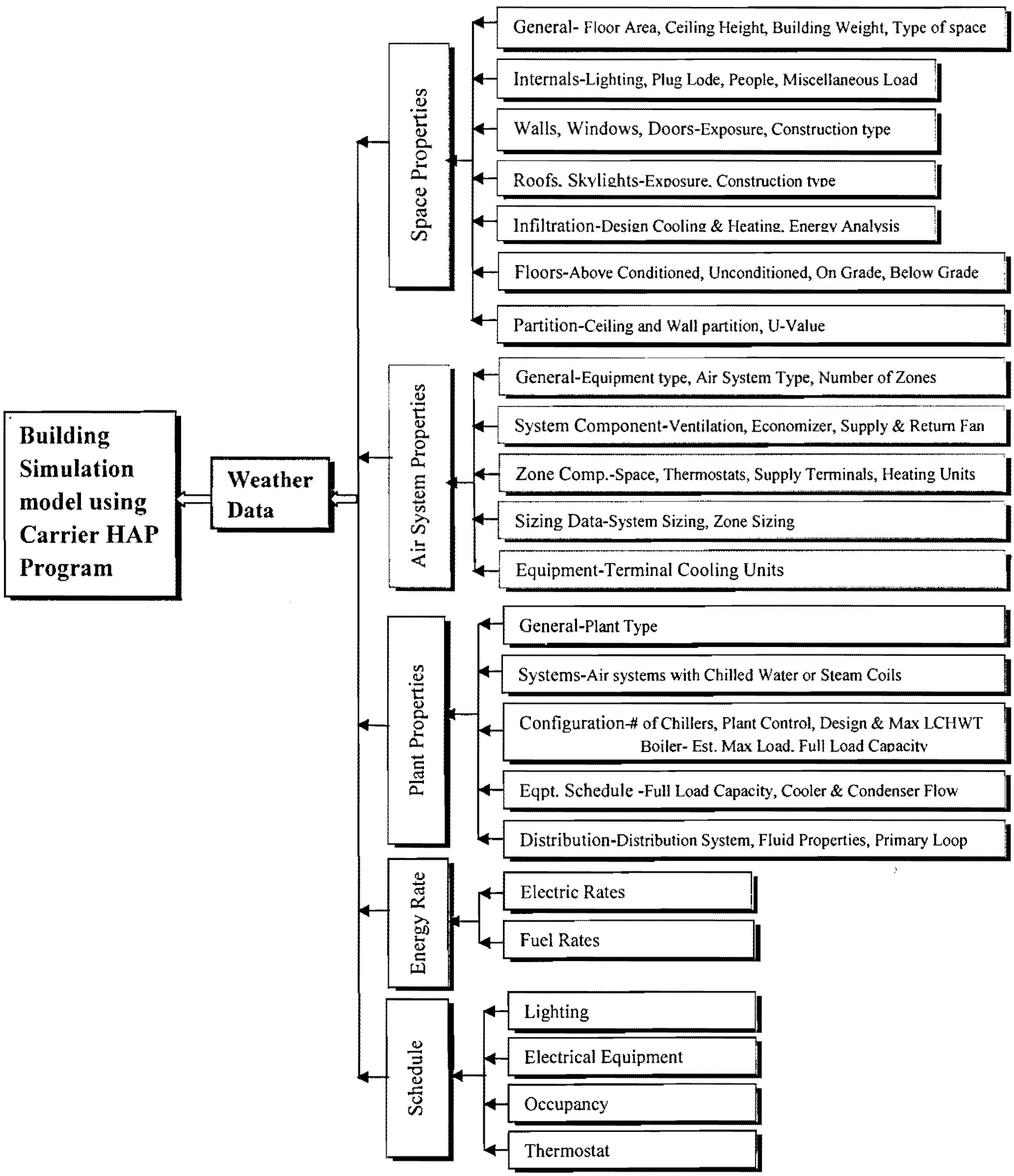

Figure 3.5: Flowchart for Building Simulation Model using Carrier HAP Program

CHAPTER-4

4. Energy Audit of Ryerson University Campus

4.1. Overview of Energy Assessment / Audit

Energy assessment/audit has become an accepted first step in identification and implementation of various energy efficiency opportunities in residential, commercial, institutional and industrial facilities. An energy audit is an organized survey which consists of a detailed examination of how a facility uses energy, what the facility pays for that energy, what are the probable sources of energy wastes and losses and finally, a recommended program for changes in operating practices or energy-consuming equipment that will cost effectively save dollars on energy bills.

The objective of an energy audit is to identify economical energy/cost saving measures that do not adversely affect the quality of work/product and the environmental consequences of the equipment and processes. Energy audit is a needed step in implementation of any detailed and sizable energy efficiency project. Often there will be the need for engineering design before implementation of the project.

The major impetus behind an energy audit is that the analysis of energy consumption and identification of potential conservation measures in facilities relate to various disciplines of engineering, that are often beyond the expertise of one person or small engineering firms.

Currently, there are hundreds of computer programs on the market for energy simulation. These programs provide users with key building performance indicators such as energy use and demand, temperature, humidity, and costs (Crawley et al., 2008).

Project Approach

To conduct an energy audit study, several activities are typically carried out depending on the type of the audit and the size and function of the audited building. The energy audit serves to identify all of the energy streams into a facility and to quantify energy use from an economical standpoint. Thus, the main purpose of an energy audit is to identify quantitatively where a facility of a building, such as, using energy and the opportunities to save energy and reduce costs. The approach used in Ryerson University campus energy audit was as follows:

Step 1 – Identify Energy Audit Scope and Objectives

The first step in conducting an energy audit is to understand the scope and objectives. The scope of the audit includes understanding which building(s) will be audited. A clear understanding of the objectives is also vital to the success of the audit. This will help determine the outcome of the audit and the type of work that needs to be completed in order to achieve the objectives. Based on the objectives, one can decide which kind of audit to perform (i.e. mini-audit or maxi-audit). The objective will also help to determine the type of simulation software to use since there are numerous packages on the market that perform audits to varying degrees of complexity.

i. Mini-audit:

This audit requires detailed analysis of energy invoices (preferable for the last 3-5 years), some tests and measurements to quantify energy uses and losses and to evaluate the economic potential of energy conservation measures. So, this step energy audit can be called as Energy Survey and Analysis. This includes a more detailed building survey and energy analysis.

This level analysis identifies and provides the savings and cost analysis of all practical measures that meet the owner's constraints and economic criteria, along with a discussion of any effect on operation and maintenance procedures.

It also lists potential capital-intensive improvements that require more thorough data collection and analysis, along with an initial judgment of potential costs and savings. This level of analysis is adequate for most buildings and measures.

ii. Maxi-audit:

This audit is usually conducted as a part of detailed energy study. It contains an evaluation of how much energy is used for each function such as lighting, process, etc. It also requires a model analysis, such as computer simulation, to determine energy use patterns on a year-round basis, taking into account such variables as weather data.

Step 2 – Building and Utility Data Analysis

The main purpose of this step is to evaluate the characteristics of the energy systems and the patterns of energy-use for the building. The building characteristics can be collected from the architectural (i.e. building dimensions, construction details), mechanical (i.e. HVAC and DHW system design and operational data) and electrical (i.e. lighting system, motors, etc.) drawings. The energy-use patterns can be obtained from a compilation of utility bills over several years. Analysis of the historical variation of the utility bills allows the energy auditor to determine if there are any seasonal and weather effects on the building energy-use.

Step 3 – Building Walk-through

A building walk-through is a visual scan of the facility which aids in identifying potential energy savings measures. Some of the activities involved in this step include: identifying customer needs and concerns, checking the current operating and maintenance procedures, determining the conditions of major energy-use equipment, and estimating the occupancy, equipment, and lighting. The outcomes of this step are essential because they determine whether the building requires any further energy auditing work.

Step 4 – Developing Baseline for Building Energy-Use

Using the information from steps 2 and 3, the energy engineer now has all the required information to develop a base-case or baseline simulation model that represents the existing energy-use and operating conditions for the building. The simulation results should be comparable with the actual data; otherwise, further refinement of the model is necessary to improve the accuracy of the simulation. This model will be used as a reference to estimate the energy savings incurred from the proposed energy conservation opportunities.

Step 5 – Evaluation of Energy Conservation Measures

When the baseline simulation model has been completed, it accurately represents the existing energy consumption for the building; it is then updated to include energy conservation alternatives. A comprehensive list of energy conservations measures should be prepared using the information from the walk-through, as well as research. After these measures have been incorporated into the baseline model, the simulation is run once again. The results are compared with the baseline simulation results from step 4 to determine the projected savings. This procedure is repeated for all the energy conservation alternatives.

Step 6 – Economic Analysis

When the projected energy savings have been determined, the associated costs are estimated. An estimate of the initial costs required to implement the energy conservation measures are pertinent when evaluating the cost-effectiveness of each energy conservation opportunity. Using the estimated costs and savings, an economic analysis is carried out to make a comparative evaluation of energy saving measures. Energy study approach is shown in Figure 4.1.

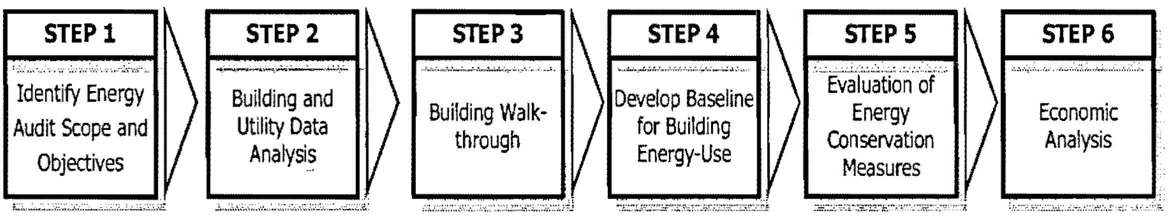

Figure 4.1: Energy Study Approach (Crawley et al., 2008)

4.2. History of Ryerson University

Ryerson University campus is located in geographical coordinate of 43°40' N and 79°25' W, Toronto, Ontario, Canada (http://boating.ncf.ca/latlong.html). The University is now one of the most applied-to universities in Ontario, and the University began in 1948 as the Ryerson Institute of Technology under the visionary leadership of Howard H. Kerr. From day one, Ryerson has undergone constant evolution in the heart of Toronto, establishing its unique focus on career-ready education.

Since 1948, Ryerson has built its reputation on the strength of its academic curriculum, and offers close to 100 PhDs, master's, and undergraduate programs, with a total enrolment of

25,000 and more than 65,000 registrations annually in the G. Raymond Chang School of Continuing Education.

Guided by a bold new Academic Plan, an ambitious research agenda, and its reputation with business and community leaders continues to rise (http://www.ryerson.ca/about/history.html). The RU campus map is shown in Figure 4.2.

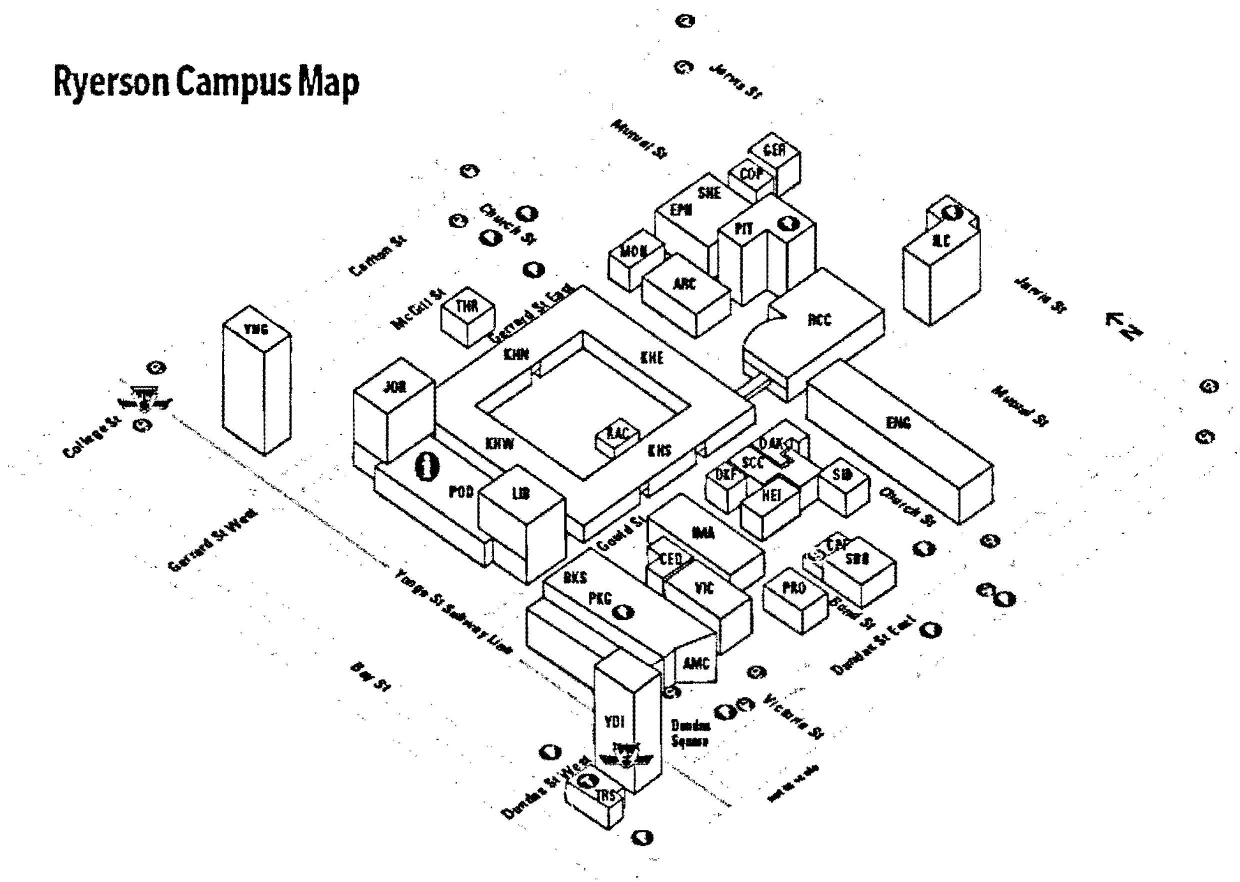

Figure 4.2: Ryerson University Campus Map

4.3. Site Visit of Ryerson University

There are 28 buildings in Ryerson University campus including residential, office and educational buildings. There are two central chiller plants in RU. One of them is located on the Library building. It serves 184730 m^2 of the total campus area which includes 13 buildings. The

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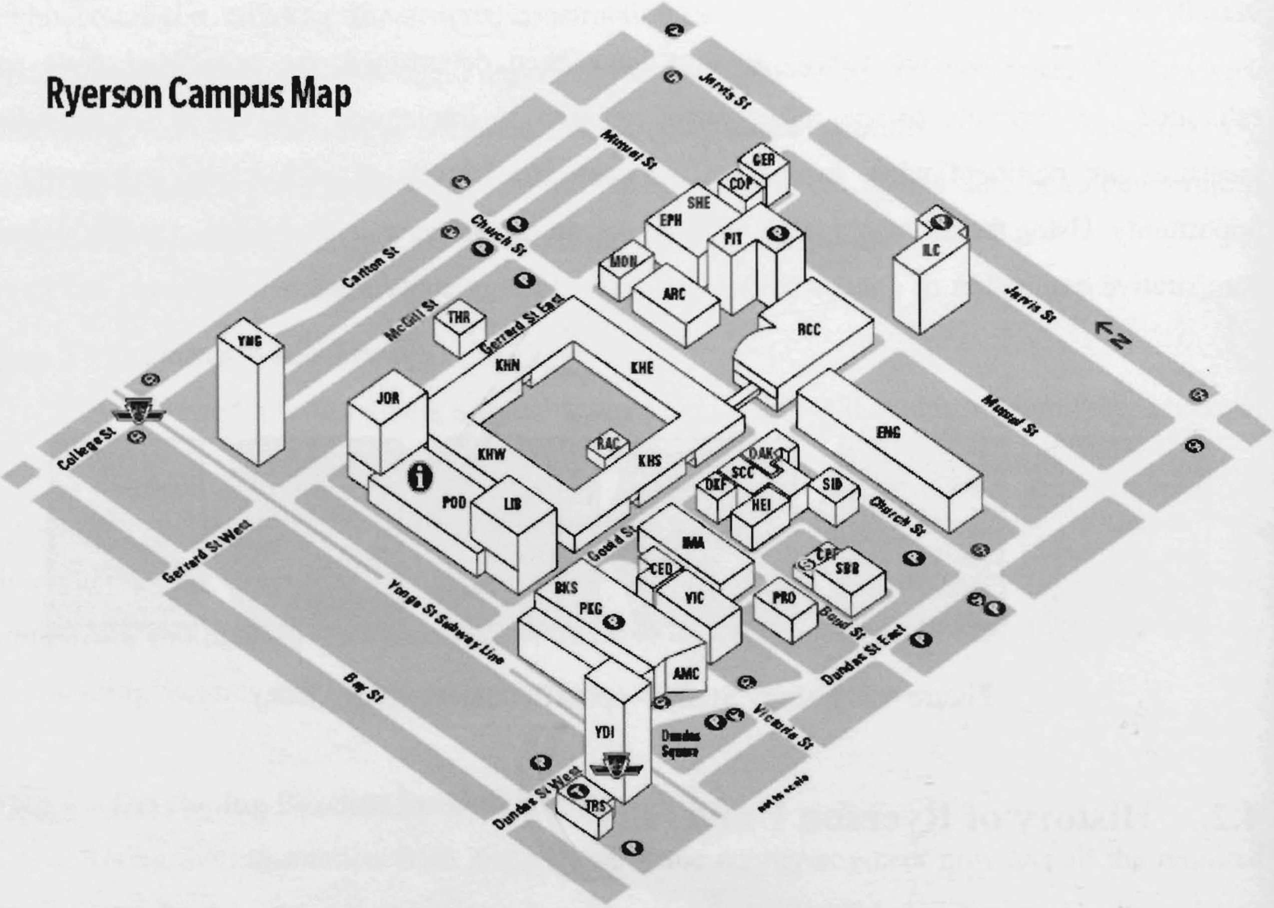

Figure 4.2: Ryerson University Campus Map

4.3. Site Visit of Ryerson University

There are 28 buildings in Ryerson University campus including residential, office and educational buildings. There are two central chiller plants in RU. One of them is located on the Library building. It serves 184730 m^2 of the total campus area which includes 13 buildings. The other chiller plant is located at Ryerson's Rogers Communication Centre. It serves 30966 m^2 of total campus area which includes 2 buildings. Only DLCW for Rogers Business building is served by Enwave. The address of Ryerson buildings for energy audit is shown in Table 4.1.

Table 4.1: List of Ryerson Buildings for Energy Audit and Base Case Simulation

Sl. No.	Name of the Building	Address
Central Chiller Plant Located on the Library building		
1	Heaslip House Continuing Education (CED)	297 Victoria Street
2	School of Image Art (IMA)	122 Bond Street
3	Victoria Building (VIC)	285 Victoria Street
4	Jorgenson Hall (JOR)	380 Victoria Street
5	Library Building (LIB)	350 Victoria Street
6	Podium Building (POD)	350 Victoria Street
7	George Vari Engineering and Computing Centre (ENG)	243 Church Street
8	Eric Palin Hall (EPH)	87 Gerrard Street East
9	Sally Horsfall Eaton Centre for Studies in community Health (SHE)	99 Gerrard Street East
10	School of Interior Design (SID)	302 Church Street
11	Student Campus Centre (SCC)	55 Gould Street
12	Heidelberg Centre-School of Graphic Communications Management (HEI/GCM)	125 Bond Street
13.a	Kerr Hall North (KHN)	43 Gerrard Street East
13.b	Kerr Hall South (KHS)	50 Gould Street
13.c	Kerr Hall East (KHE)	340 Church Street
13.d	Kerr Hall West (KHW)	379 Victoria Street
Central Chiller Plant Located on the RCC building		
14	Rogers Communications Centre (RCC)	80 Gould Street
15	Pitman Hall Residence (PIT)	160 Mutual Street
Remote Chilled Water Served by Enwave		
16	Rogers Business Building (RBB)	575 Bay Street West

4.4. Weather Data Specification

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

Design Weather Data is used to estimate cooling and heating design load as per industry standards. Cooling and heating design data consists of 24-hour profiles of temperature and humidity representing maximum condition for summer and winter design-day condition. Simulation Weather Data is used to perform hourly energy simulations. It refers to 8760 hours sequence of actual weather data to simulate building loads. These results can be used to estimate annual energy use and costs (Carrier Corporation, 2006). The design temperature of Toronto, Ontario, Canada is shown in Figure 4.3.

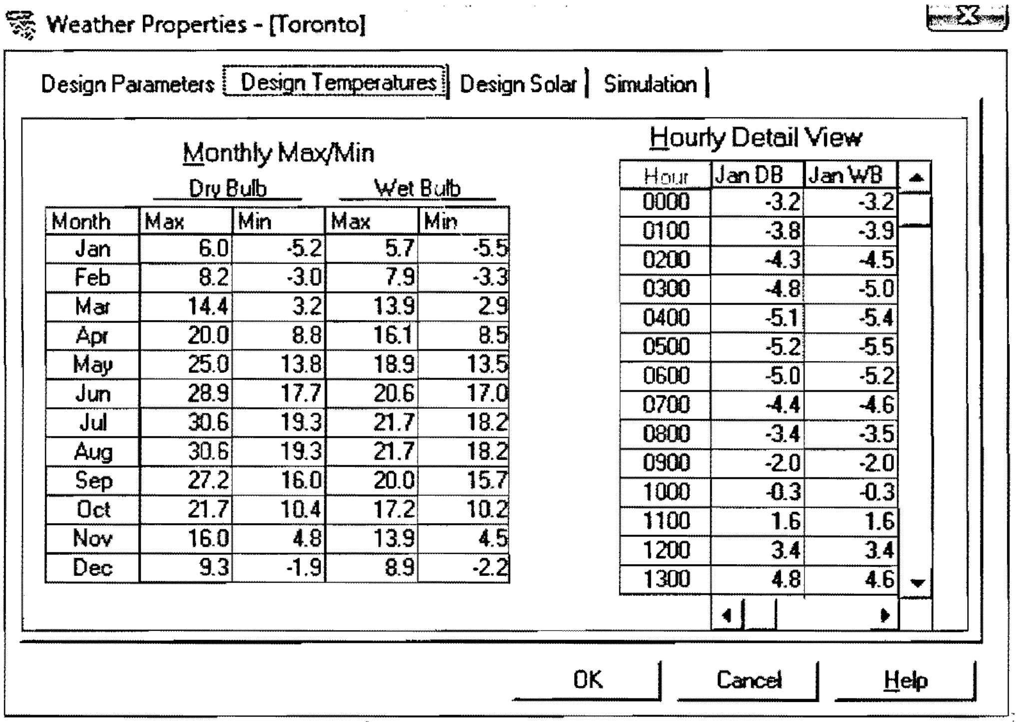

Figure 4.3: Weather Data Screen (Carrier, 2006)

4.5 Building Data

The building data and specification were collected from Campus Planning of Ryerson University. The blue print / buildings drawing, manuals and other data sources were used for collection of those data.

4.5.1. Building Envelope Specification

The role of the building envelope is to separate different environments, typically the interior from exterior, by managing the flow of air, moisture, and heat between them. The envelope must also consider the impact of architectural orientation and styles. Building envelope includes the foundation, floors, walls, fenestration (windows and doors), and roof. All building envelope specification was collected from architectural and structural drawings of the buildings according to following criteria (Carrier Corporation, 2006).

1. Floors: Above conditioned space; above unconditioned space; slab floor on grade; slab floor below grade.
2. Wall assembly: Exterior wall assembly (layers defined as inside to outside); interiors wall assembly (layers defined as inside to outside)
3. Window: Types of window depends on use of glass
4. Door: Types of door like sliding, entrance, revolving
5. Roof: Roof assembly (layers defined as inside to outside)
6. Skylight
7. Partition: Ceiling partition; and wall partition

The energy audit report of Ryerson campus was conducted for 16 individual buildings. These buildings are shown in Table 4.1. The data collection process of these buildings was almost same. For an example, School of Image Art (IMA) building envelope data are given in this section. The construction data for the walls, roof, windows and door assembly are shown in Table 4.2. to Table 4.5. The construction data for the walls, roof, windows and door assembly of other buildings are shown in Appendix-B.

Table 4.2: School of Image Art (IMA) Building Wall Construction

Wall Construction (Layers Inside to Outside)				
Surface Resistance	**Thickness (mm)**	**Density (kg/m^3)**	**Specific Heat (KJ/kg/K)**	**Weight (kg/m^2)**
5/8-in gypsum board	15.87	800.9	1.09	12.7
R-11 batt insulation	88.9	8.0	0.84	0.7
Air Space	0.0	0.0	0.0	0.0
4-in LW concrete block	101.6	608.7	0.84	61.8
4-in face brick	101.6	2002.3	0.92	203.4
Overall U-Value: 0.363 $W/m^2/K$				

Table 4.3: School of Image Art (IMA) Building Roof Construction

Roof Construction				
Surface Resistance (Layers Inside to Outside)	**Thickness (mm)**	**Density (kg/m^3)**	**Specific Heat (KJ/kg/K)**	**Weight (kg/m^2)**
Acoustic tile	19.05	480.6	0.84	9.2
Air space	0.0	0.0	0.0	0.0
3/4 –in wood board	19.05	544.6	1.21	10.4
8-in HW concrete	203.2	2242.6	0.84	455.7
R-11 batt insulation	88.9	8.0	0.84	0.7
Built-up roofing	9.525	1121.3	1.47	10.7
Overall U-Value: 0.337 $W/m^2/K$				

Table 4.4: School of Image Art (IMA) Building Window Construction

Window Construction **Frame Type:** Aluminum with thermal breaks					
Window Type	**Area (m^2)**	**Air Gap (mm)**	**Glazing Clear**		**Overall U-Value ($W/m^2/K$)**
			Outer (mm)	**Inner (mm)**	
Window-A	10	6.0	3.0	3.0	3.6
Window-B	8.4	6.0	3.0	3.0	3.604
Window-C	5	6.0	3.0	3.0	3.612
Window-D	1.6	6.0	3.0	3.0	3.656
Window-E	3.4	6.0	3.0	3.0	3.629
Overall shading co-efficient for each window = 0.747					

Table 4.5: School of Image Art (IMA) Building Door Assembly

Door Assembly	
Door Area= 9.3 m^2	Door U-Value= 1.703 $W/m^2/K$
Glass Area= 7.4 m^2	Glass U-Value= 3.293 $W/m^2/K$
	Glass shading co-efficient = 0.880
Door Area= 3.3 m^2	Door U-Value= 1.703 $W/m^2/K$
Glass Area= 2.6 m^2	Glass U-Value= 3.293 $W/m^2/K$
	Glass shading coefficient = 0.880

4.5.2. Building Operation

A building is divided into units referred to as "space" when analyzing its functionality. In its simplest sense, a space represents a single room. A space consists of a number of "elements" such as walls, roofs, windows, and internal heat gains which influence heat transfer into and out of the space. In addition, a space can be served by one or more air distribution terminals.

In order to analyze the thermal behaviour of a building, it is divided into “zones”. These do not always have to represent a single room. In some applications, it is more appropriate for a space to represent a group of rooms, a floor or even an entire building. The purpose of defining all spaces is for system design calculations or energy simulations to be performed.

All Ryerson buildings are used as space such as, classroom, office space, corridor, auditorium, conference room, laboratory, library space and cafeteria. Table 4.6 represents the percentage of conditional area for each Ryerson building.

Table 4.6: List of Conditioned Floor Area for Ryerson Buildings

Sl. No.	Name of the Building	Conditioned Floor Area (m^2)
1	Heaslip House Continuing Education (CED)	2302
2	School of Image Art (IMA)	7219
3	Victoria Building (VIC)	9788
4	Jorgenson Hall (JOR)	8188
5	Library Building (LIB)	15426
6	Podium Building (POD)	13421
7	George Vari Engineering and Computing Centre (ENG)	17583
8	Eric Palin Hall (EPH)	17334
9	Sally Horsfall Eaton Centre for Studies in community Health (SHE)	
10	School of Interior Design (SID)	2888
11	Student Campus Centre (SCC)	2993
12	Heidelberg Centre-School of Graphic Communications Management (HEI/GCM)	2399
13.a	Kerr Hall (KNE)	30125
13.b	Kerr Hall (KNW)	
13.c	Kerr Hall (KSE)	
13.d	Kerr Hall (KSW)	
14	Rogers Communications Centre (RCC)	10871
15	Pitman Hall Residence (PIT)	2166
16	Rogers Business Building (RBB)	16740

4.6. HVAC System Data

4.6.1. Air Distribution System

Air is normally treated in air handling units (AHUs) in order to control moisture content and temperature in buildings that are centrally cooled or heated. Once the air is treated, it is transported and distributed to various parts of the building. A typical air distribution system consists of fans, ducting, dampers, filters, air inlets, and air outlets, as shown schematically in Figure 4.4.

In systems like this, a mixture of outdoor air (provided for ventilation) and part of the air returning from conditioned spaces (return air) are filtered and then treated by the coils. Thenceforth, the fan transports the treated air through the supply ducting system, which distributes it in required quantities to the spaces to be conditioned via outlets and dampers. After performing the necessary cooling or heating, air is later returned from the conditioned spaces through the inlets and return ducting. Some of the return air is then re-circulated back to the AHU while the balance is expelled to allow sufficient fresh air to be added to the system. In an air distribution system, the fan provides the necessary energy to move the air by overcoming frictional losses in the ducting and pressure losses due to components in the system, such as filters, coils, and various fittings. The electrical energy required to operate the system can be minimized if the system design is optimized to reduce these losses.

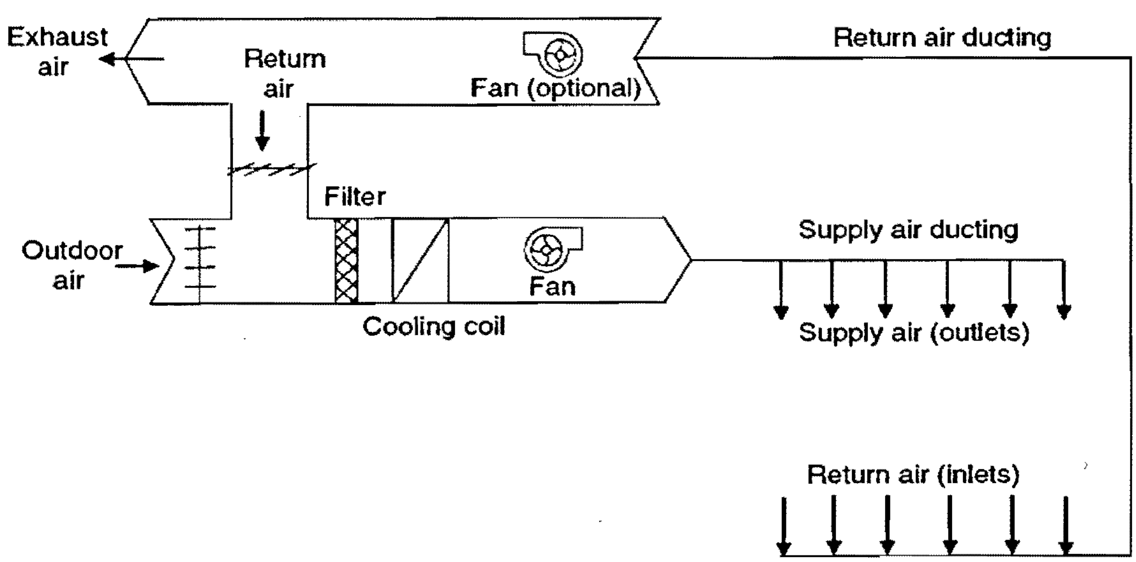

Figure 4.4: Typical Air Distribution System (Jayamaha, 2007)

4.6.1.1. Type of Air Distribution System

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

Single-Duct Systems:

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

Types of single-duct systems:

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

Dual-Duct Systems:

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

Types of dual-duct systems:

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

- Three-deck multi zone

Comparison between CAV and VAV System

Fans for air handling units are normally sized to handle the maximum airflow and it is required to meet peak load conditions. However, peak load conditions are usually experienced only for short periods of time and the capacity of air handling units is controlled to match requirements by varying the supply air temperature or the amount of air supplied. In constant air volume (CAV) systems, the capacity is controlled by varying the supply air temperature. In such systems, the fan is operated at a fixed speed to give a fixed quantity of air. This not only wastes energy by supplying a constant volume of air irrespective of the load, but also leads to high space relative humidity in air-conditioning systems at low loads due to higher operating supply air temperatures at part load.

To stay away from these shortcomings, variable air volume systems with devices such as discharge dampers, inlet guide vanes, or variable speed drives can be used to regulate the air volume with load while maintaining a fixed supply air temperature. Although discharge dampers and inlet guide vanes are able to reduce the air volume, the energy savings achieved are much less than for variable speed drives, which are able to closely follow the theoretical "cubic" fan power relationship. Cooling operation varies in the occupied and unoccupied periods as described in the fan/thermostat schedule. VAV system is shown in Figure 4.5.

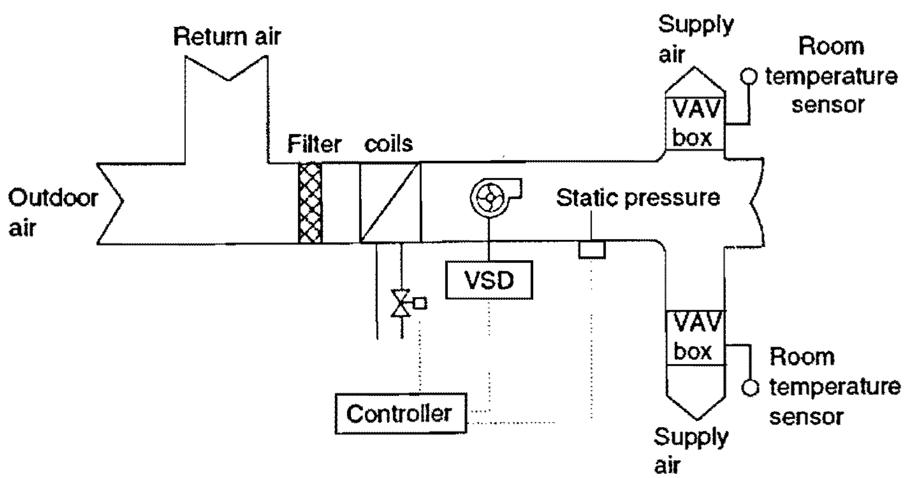

Figure 4.5: Arrangement of a VAV System (Jayamaha, 2007)

In the case of Ryerson University buildings, central air system is used for supply heating and cooling air to the specified zones for individual building. Zoning was done on the basis of the space function.

Every building has its own air distribution system. Two different types of air system are used in Ryerson buildings, VAV and CAV system. Most of the buildings have VAV air system. Air distribution systems for the individual building are shown in Table 4.7.

Table 4.7: HVAC Air Distribution System Properties of Ryerson Buildings

Sl. No.	Name of the Building	Air Distribution System Type	Air System Equipment Type	No. of Zone
1	Heaslip House Continuing Education (CED)	VAV	CHW AHU	63
2	School of Image Art (IMA)	CAV & VAV	CHW AHU	51
3	Victoria Building (VIC)	CAV	CHW AHU	93
4	Jorgenson Hall (JOR)	CAV	CHW AHU	98
5	Library Building (LIB)	VAV	CHW AHU	118
6	Podium (POD)	VAV	CHW AHU	68
7	Engineering Building (ENG)	VAV	CHW AHU	77
8	Eric Palin Hall (EPH)	VAV	CHW AHU	186
9	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)	VAV	CHW AHU	
10	School of Interior Design (SID)	VAV	CHW AHU	20
11	Student Campus Centre (SCC)	VAV	CHW AHU	36
12	Heidelberg Centre-School of Graphic Communications Management (HEI/GCM)	VAV	CHW AHU	28
13	Kerr Hall (KNE/KNW/KSE/KSW)	CAV	CHW AHU	380
14	Rogers Communications Centre (RCC)	VAV	CHW AHU	76
15	Pitman Hall (PIT)	VAV	CHW AHU	15
16	Ryerson Business Building (RBB)	VAV	CHW AHU	208

NB: VAV: Variable Air Volume System; CAV: Constant Air Volume System; CHW: Chilled Water.

HVAC data and specification were collected from the campus planning of Ryerson University. The building blue print, manuals and other data sources were used to collect the necessary data. For example, HVAC data for School of Image Art (IMA) is given in this section.

IMA building has two AHUs. Those air handling units' specifications are shown in Table 4.8.

Table 4.8: Air Handling Unit (AHU) Specification for IMA Building

AHU	GS-1	GS-2
System	VAV	CAV
Served Area (m^2)	3567	3652
Economizer	Integrated enthalpy control	Integrated enthalpy control
Supply Fan Capacity (L/s)	15000	18000
Supply Fan (kW)	35.4	35.4
Supply Fan Type	VFD	FC
Return Fan Capacity (L/s)	12500	14000
Return Fan (kW)	9.5	9.5
Return Fan Type	VFD	FC
Cooling Coil Supply Temp (°C)	12.8	12.8
Precool Coil Setpoint (°C)	15.6	15.6
Preheat Coil Setpoint (°C)	12.8	12.8

Exhaust Fan Schedule of IMA building is shown in Table 4.9.

Table 4.9: Exhaust Fan Schedule of IMA Building

Schedule of Exhaust Fan				
No.	**System**	**Capacity (CFM)**	**Motor (RPM)**	**Motor (HP)**
TE	Toilet Exhaust	2750	420	3/4
CME	Chemical Mixing Room	2184	935	1/3
E-1	Hood Exhaust	3900	510	1
E-2	Process Machine Exh.	1136	1430	1/3

Motorized Heaters Schedule of IMA building is shown in Table 4.10.

Table 4.10: Motorized Heaters Schedule of IMA Building

Schedule of Motorized Heaters				
No.	Location	Capacity (BTU/HR)	FAN (RPM)	Motor (HP)
FFH-1	Main Entrance Stair # 1	51,100	1000	1/20
FFH-2	Elevator Shaft Basement Floor	26, 400	700	1/50
UH-1	Stair # 2	49,000	1500	1/20
UH-2	Stair # 3	40,200	1500	1/30

Heating and Plumbing Pumps Schedule of IMA building is shown in Table 4.11.

Table 4.11: Heating and Plumbing Pumps Schedule of IMA Building

Schedule of Heating and Plumbing Pumps				
System	Capacity (GPM)	Head ft(wg)	Motor (RPM)	Motor (HP)
Chilled Water	840	50	1750	15
Condenser Water	190	50	1750	20
Booster Coil	125	50	1750	3
Condensate Pump Receiver	60	80	1750	2
Fire Pump	85	93	1750	5
Domestic Hot Water Circulating Pump	20	20	1750	1/4
Elevator Sump Pump	20	25	3450	1/2

Steam Injection Humidifier Schedule of IMA building is shown in Table 4.12.

Table 4.12: Steam Injection Humidifier Schedule of IMA Building

Schedule of Steam Injection Humidifier				
No.	Location and System	Capacity (CFM)	Steam Capacity (lb/hr)	Relative (%)
GS-1	GS-1st Floor	40,000	330	40
GS-2	GS-2nd Floor	40,000	330	40
SS-1	SS-3rd Floor	25,000	210	30

4.6.2. Economizer

The outdoor air economizer is an energy saving feature that can be incorporated into AHUs in some climates. The basis of this strategy is to use 100 percent outside air when it is below a certain temperature to cool the space rather than using a mixture of outside air and return air.

When the outdoor air dry-bulb temperature is below the indoor temperature, the economizer cycle can be programmed to convert the AHU to use 100 percent outdoor air by adjusting the position of the outdoor air and return air dampers. In order to activate this energy saving strategy it is better to use enthalpy (sensible and latent energy level) based controls in humid climates.

Figure 4.6 shows a typical arrangement of an AHU working on an economizer cycle. An economizer system normally includes indoor and outdoor temperature sensors, motorized dampers, and controls. Since the outdoor air damper needs to be large enough to provide 100 percent outside air, this becomes a constraint when fitting economizers to existing AHUs.

In Ryerson University buildings, every air system has economizer with integrated enthalpy control for energy savings.

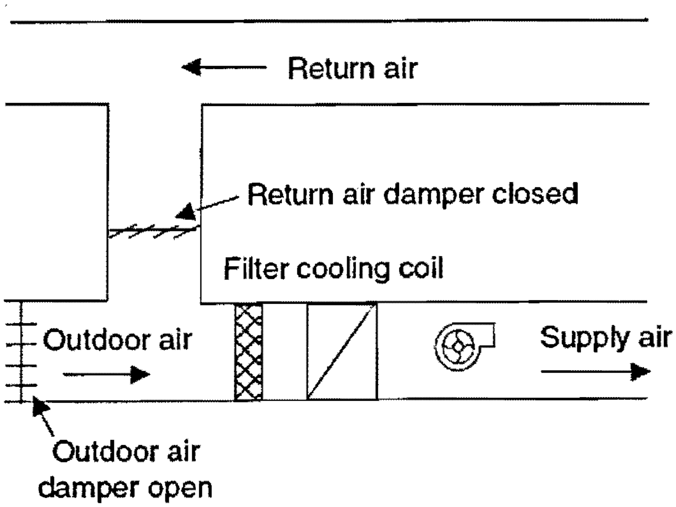

Figure 4.6: Typical Arrangement of an AHU on Economizer Mode (Jayamaha, 2007).

4.7. Lighting System Data

Lighting fixtures produce convective as well as radiative heat gains. The type of lighting fixture used influences the relative sizes of the convective and radiative components and the way in which radiative heat gains are distributed. From the electrical drawing of these buildings, the lighting load (kW) was calculated. Total lighting load (kW) were calculated based on the lamp types, fixtures, total number of lamp used in the specific area, types of exit lights. Plug loads were also calculated for the lab equipments, computers, printers and electrical appliances. Some assumptions were made for those lighting load and plug load according to ASHRAE 90.1 standard (ASHRAE, 2004) due to lack of information.

The lighting specification of the Ryerson buildings is shown in Table 4.13.

Table 4.13: Lighting Specification of Ryerson University Buildings

Type	Lamp Watts	Lamp Type	Use	Description
A1	32	T8	Washrooms, Corridors, Service Desks and Cove Location	Strip Fixture Mounted
C1	26	PL QT	Corridors, Vestibules and Classrooms	Recessed Compact Fluorescent Down Light
F1	32	T8	Located in Stair	Long Surface Wall Mounted
F3	32	T8	General Areas, Mechanical Spaces and Non-Public lighting	Long Fluorescent Strip Chain Hung
F4	32	T8	All Classroom Whiteboard	-
F6	32	T8	Classroom and Corridor	Ceiling Mounted Recessed Fluorescent
F8	32	T8	Non-Public Corridor	-
K1	32	CFL	Ryerson Corridor	-
L1	75	PAR	-	Recessed Mounted
T1	25	CFL	-	Recessed Mounted compact Fluorescent

4.8. Energy Price and Operation Cost (Flat Rate and TOU)

Electricity price is very important for calculation of total energy cost. Two types of electricity price are used in Toronto area. Those are Time of Use (TOU) and Flat Rate which are shown in Table 4.14. Hydro TOU prices for different seasons of the year includes on peak, mid peak and off peak hour (Toronto Hydro, 2007).

Table 4.14: Hydro Price (¢/kWh) for Toronto Area according to Time of Use and Flat Rate

Time of Use (TOU) and Flat Rate of Hydro Price for Toronto Area						
	Winter Weekdays (Nov. 1- Apr. 30)		Summer Weekdays (May 1- Oct. 31)		All Weekend and Holiday	
Hour	Mode	Price (¢/kWh)	Mode	Price (¢/kWh)	Mode	Price (¢/kWh)
1	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
2	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
3	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
4	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
5	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
6	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
7	Off Peak	14.7	Mid Peak	11.7	Off Peak	7.7
8	Off Peak	14.7	Mid Peak	11.7	Off Peak	7.7
9	Off Peak	14.7	Mid Peak	11.7	Off Peak	7.7
10	Off Peak	14.7	Mid Peak	11.7	Off Peak	7.7
11	Mid Peak	11.7	On Peak	14.7	Off Peak	7.7
12	Mid Peak	11.7	On Peak	14.7	Off Peak	7.7
13	Mid Peak	11.7	On Peak	14.7	Off Peak	7.7
14	Mid Peak	11.7	On Peak	14.7	Off Peak	7.7
15	Mid Peak	11.7	On Peak	14.7	Off Peak	7.7
16	Mid Peak	11.7	On Peak	14.7	Off Peak	7.7
17	On Peak	14.7	Mid Peak	11.7	Off Peak	7.7
18	On Peak	14.7	Mid Peak	11.7	Off Peak	7.7
19	On Peak	14.7	Mid Peak	11.7	Off Peak	7.7
20	Mid Peak	11.7	Mid Peak	11.7	Off Peak	7.7
21	Mid Peak	11.7	Mid Peak	11.7	Off Peak	7.7
22	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
23	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
24	Off Peak	7.7	Off Peak	7.7	Off Peak	7.7
Flat Rate (All Year) : 10.0 ¢/kWh						

CHAPTER-5

5. Base Case Model Energy Simulation with Carrier HAP

Ryerson University has two central conventional chiller plants and they were installed in the Library building and RCC building. In order to determine the base case heating and cooling demand, and determine the annual heating, cooling and electricity cost, the Carrier HAP program was used.

5.1. Creating Input Data File (IDF) for HAP Simulation

5.1.1. Location and Design Climate

Ryerson University is located in downtown Toronto, Ontario. The addresses for all of the University buildings are shown in Table 4.1. Sixteen buildings were selected for an energy audit out of 28 buildings. The total area of those buildings is 240074 m^2 (86% of the total RU area).

The IDF for HAP includes data relevant to the characteristics that directly impact the thermal loads on the building. These characteristics are concerned with the orientation, geometric shape, the weather data, the internal loads including sensible heat, HVAC system, as well as the material construction of the building.

Most of the input data has already been described in Chapter 4. The weather data, as well as the existing/assumed HVAC system data, would also need to be inputted into HAP. The latest Toronto simulation weather data file was provided by Carrier HAP. According the HAP weather data, the annual solar heat gain for Toronto is shown in Table 5.1.

Table 5.1: Annual Solar Heat Gain for Toronto (Carrier Corporation, 2006)

Design Day Maximum Solar Heat Gains (W/m²)										
Month	**Multiplier**	**N**	**NNE**	**NE**	**ENE**	**E**	**ESE**	**SE**	**SSE**	**S**
January	1.00	55.4	55.4	55.4	204.6	440.5	599.1	733.7	784.5	796.4
February	1.00	70.2	70.2	140.5	368.8	566.5	716.6	777.2	783.0	778.6
March	1.00	86.6	86.6	284.0	509.9	670.6	743.4	752.8	708.2	686.0
April	1.00	103.0	193.6	433.1	593.5	693.5	713.7	660.8	577.9	534.4
May	1.00	114.5	315.6	505.3	642.7	683.2	667.7	575.2	466.2	410.5
June	1.00	150.6	351.2	529.9	649.8	672.5	640.1	535.0	414.8	357.5
July	1.00	117.5	302.0	503.2	627.2	675.7	651.5	563.0	452.9	400.5
August	1.00	108.5	200.8	419.9	565.1	672.5	685.3	638.2	558.0	517.5
September	1.00	89.8	89.8	277.5	468.3	634.9	703.9	724.5	687.2	660.8
October	1.00	72.2	72.2	125.5	355.8	548.4	679.2	750.6	760.5	747.5
November	1.00	55.9	55.9	55.9	213.6	422.5	605.2	713.7	762.7	777.2
December	1.00	48.7	48.7	48.7	143.1	377.0	544.2	693.6	759.2	777.9
Month	**Multiplier**	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	**HOR**	
January	1.00	784.7	733.6	600.0	440.3	205.8	55.4	55.4	350.8	
February	1.00	780.4	774.1	717.2	560.8	374.0	135.3	70.2	508.3	
March	1.00	705.0	748.6	748.6	665.9	513.9	271.8	86.6	653.8	
April	1.00	572.3	655.6	707.9	698.7	596.1	419.8	217.8	757.4	
May	1.00	459.5	574.0	656.8	696.5	631.6	507.6	317.2	810.7	
June	1.00	410.3	535.2	634.5	683.9	638.6	534.4	348.4	823.7	
July	1.00	450.1	562.4	647.1	680.8	618.0	503.5	310.1	803.3	
August	1.00	552.0	633.8	682.2	673.9	575.3	408.0	214.5	745.5	
September	1.00	686.8	721.6	716.0	623.7	476.8	276.1	89.8	629.2	
October	1.00	761.4	752.5	674.7	551.1	351.3	133.0	72.2	494.1	
November	1.00	768.4	705.6	605.7	409.9	219.8	55.9	55.9	345.2	
December	1.00	759.2	679.0	561.9	352.4	163.3	48.7	48.7	284.1	

5.1.2. Space Data Input

Carrier HAP uses space data or building envelope data of the selected Ryerson University buildings. Space data includes for each building:

- Building area, ceiling height and weight, types of space, outdoor air requirements
- Walls, windows, doors construction
- Floor and roof constructions
- Infiltration air in terms of CFM, CFM/ft², ACH
- Type of partitions, area, U-value

Carrier HAP space properties screen of IMA building is shown in Figure 5.1.

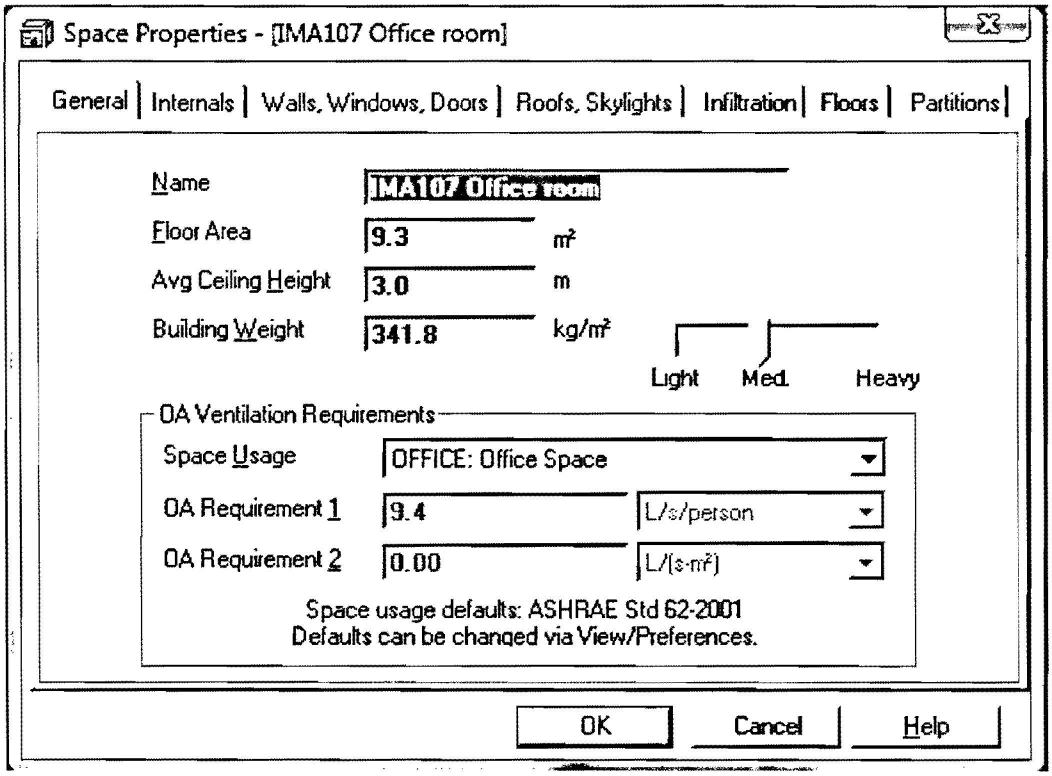

Figure 5.1: Carrier HAP Space Properties Screen of IMA Building

Table 5.2 represents percentage of exposed wall area and exposed glass area of selected audit buildings.

Table 5.2: Percentage of Exposure Area of Ryerson Buildings

Sl. No.	Name of building	Wall Exposed Area (%)	Glass Exposed Area (%)
1	Heaslip House Continuing Education (CED)	66	34
2	School of Image Art (IMA)	93.5	6.5
3	Victoria Building (VIC)	78	22
4	Jorgenson Hall (JOR)	45	55
5	Library Building (LIB)	90	10
6	Podium Building (POD)	62	38
7	Engineering Building (ENG)	51	49
8 and 9	Eric Palin Hall (EPH) and Sally Horsfall Eaton Centre for Studies in Community Health (SHE)	54	46
10	Student Campus Centre (SCC)	49	51
11	School of Interior Design(SID)	60	40
12	Heidelberg Centre-School of Graphic Communications Management (HEI/GCM)	68	32
13a	Kerr Hall (KNE)	75	25
13b	Kerr Hall (KNW)	91	9
13c	Kerr Hall (KSE)	76	24
13d	Kerr Hall (KSW)	71	29
14	Rogers Communications Centre (RCC)	61	39
15	Pitman Hall Residence (PIT)	90	10
16	Rogers Business Building (RBB)	74	26

5.1.3. Zoning of the building

A zone of individual RU building was a group of one or more spaces having a single thermostatic control. Zones are often used differently for different applications. In some systems, each room contains a thermostat. Therefore, each zone contains one space representing a single room. In other situations, one thermostat is allocated to a group of rooms. For preliminary block load estimates, a zone might be defined as the entire building. The choice of zones affects system operation, the accuracy of the system design and energy analysis calculations, and the effort required to model the system. Figure 5.2 shows the zonal configuration in HAP for the simulation model.

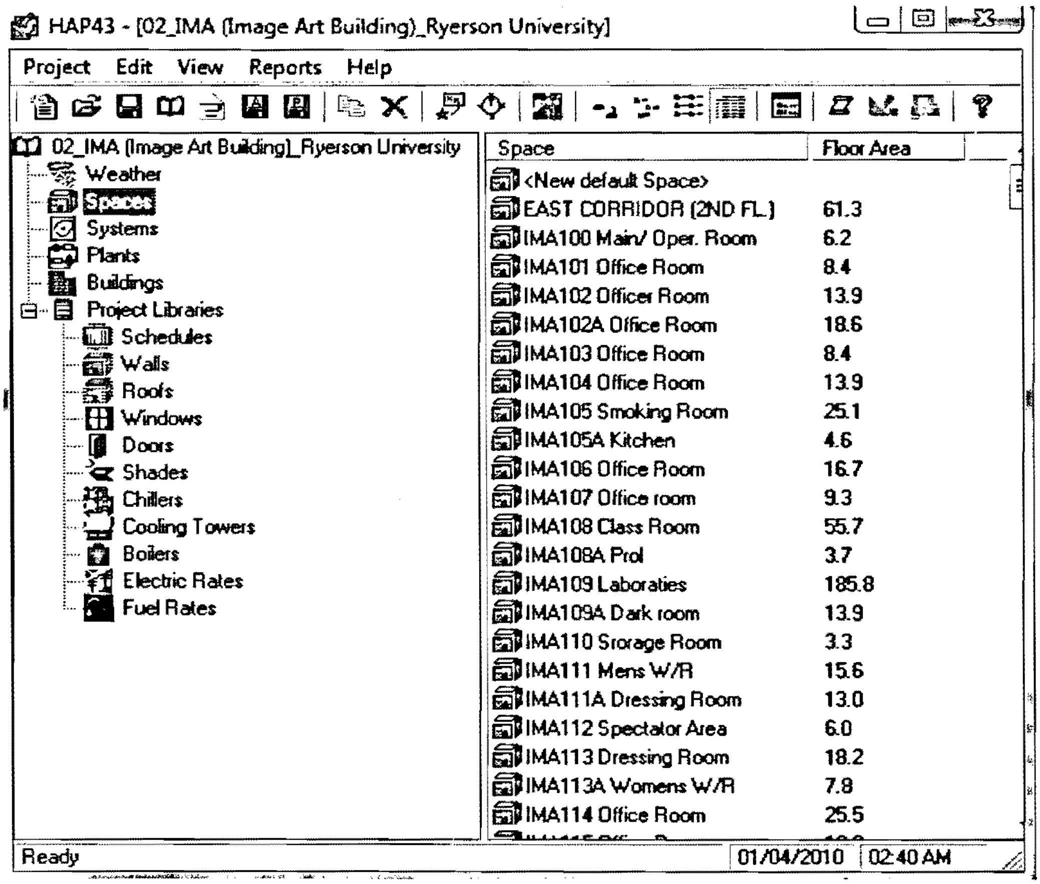

Figure 5.2: Space (Zone) Input Data Form of Scenario

5.1.4. Building Use Information

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

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

The Carrier HAP uses two types of schedule-fractional and fan/thermostat. Fractional schedules are used to describe the variation of internal heat load (i.e., lighting, equipment, control of outside ventilation in an HVAC system and hot water in a domestic water heating system and all these are the fractional schedules). Fan/thermostat schedules are used to define the hours in HVAC equipment. The occupied and unoccupied thermostat set points are assigned to each hour in HVAC system (Carrier, 2006).

The schedules for lighting, occupancy activity, equipment, heating and cooling are summarized in Table 5.3. These are the actual schedules used by the Ryerson University buildings.

Table 5.3: Ryerson University Operating Schedules

Occupants, Lighting, Equipment, and Fan Thermostat Operating Schedule of Ryerson University			
In hour → Schedule ↓		0- 6 am	7-24 am
Occupancy Activity	Mon-Fri	0%	100%
	Saturday	0%	40%
	Sunday	0%	5%
Lighting	Mon-Fri	100%	100%
	Saturday	100%	100%
	Sunday	20%	20%
Equipment	Mon-Fri	70%	70%
	Saturday	40%	40%
	Sunday	20%	20%
Thermostat Control (Cooling)	Mon-Fri	100%	100%
	Saturday	100%	100%
	Sunday	100%	100%

5.1.5. HVAC Equipment Data

There are two central chiller plants in Ryerson University campus. One is located in the Library building (**Part-1**) and other is located in the Rogers Communications building (**Part-2**). For cooling, designated buildings of Ryerson University are served by these two central chiller plants. The configurations of central chillers and cooling towers are shown in Table 5.4. For heating, remote steam is supplied by Enwave for the entire Ryerson campus. B.A.C. (North, South, East and West) cooling Tower are located on Library building and B.A.C. (RCC) is located on RCC building.

Table 5.4: List of Central Chiller Plants in the Library and the RCC Building of RU

CHILLERS AND COOLING TOWERS CAPACITY	
Chillers Plant Located in the Library building	
Make	**Capacity**
McQuay Absorption # 1	1200 Ton or 4220 kW
McQuay Absorption # 2	1200 Ton or 4220 kW
Carrier Chiller # 3	500 Ton or 1758 kW
York Chiller # 4	100 Ton or 352 kW
York Chiller # 5	100 Ton or 352 kW
Total Capacity	**3100 Ton or 10903 kW**
Chillers Plant Located in the RCC building	
Make	**Capacity**
Trane Chiller # 1	265 Ton or 932 kW
Trane Chiller # 2	265 Ton or 932 kW
Total Capacity	**530 Ton or 1864 kW**
Cooling Tower Located in the Library and RCC building	
Make	**Model Number**
(South) B.A.C.	VLT1200
(East) B.A.C.	Info plate missing
(North) B.A.C.	VLT1200
(RCC) B.A.C.	T1662NCR
(West) Marley Cooling	NC-240859-A1

Part-1 has two absorption water chillers with each capacity of 1200 tons. Absorption chillers configurations are shown in Table 5.5.

Table 5.5: Double Effect Absorption Water Chillers Configuration

Chiller Plant: Double Effect Absorption Water Chiller (Capacity: 1200 Tons) Type NC (Steam-fired Chiller) Model NO. NC-73U		
Field	Units	Object
Chiller Name: McQuay		
Condenser Type	-	Water Cooled
Full load Capacity	Ton or kW	1200 Tons or 4220 kW
COP	-	1.46
Fuel or Energy Type	-	Steam
Fuel Consumption	lbs/hr	11760
Entering Cooling Water Temperature	^{o}F	85
Leaving Cooling Water Temperature	^{o}F	44
Chilled Water Flow Rate	GPM	2880
Chilled Water Pressure Drop	ft.H_2O	22.8
Cooling Water Flow Rate	GPM	5280
Cooling Water Pressure Drop	ft.H_2O	34.9
PUMP SPECIFICATION		
NO. 1 Absorbent Pump	kW	7.5
NO. 2 Absorbent Pump	kW	3.7
Refrigerant Pump	kW	1.1
Purge Pump	kW	0.75
Total RLA	Amps	37

Part-1 has three electric chillers. One chiller has capacity of 500 tons and other two chillers of 100 tons each. Electric chiller configurations are shown in Table 5.6. and Table 5.7.

Table 5.6: Carrier Electric Chillers Configuration

Chiller Plant: Electric		
Field	Units	
Chiller Name: Carrier		
Chiller Type		Centrifugal Water Cooled
Refrigerant Type		R-134a
Condenser Type	-	Water Cooled
Full load Capacity	Ton or kW	500 Ton or 1758 kW
Fuel or Energy Type	-	Electric
Full Load Power	kW/Ton	0.597
Entering Chilled Water	^{o}F	85
Leaving Chilled Water	^{o}F	44
Chilled Water Flow Rate	GPM	1200
Chilled Water Pressure Drop	ft.H_2O	12.9
Cooling Water Flow Rate	GPM	1500
Cooling Water Pressure Drop	ft.H_2O	27
Condenser Water Pump	HP or kW	15 HP / 11.22 kW

Table 5.7: York Electric Chiller Configuration

Chiller Plant: Electric		
Field	Units	
Chiller Name: York		
Chiller Type		Air-Cooled Scroll Chiller
Condenser Type	-	Air Cooled
Full load Capacity	Ton	100 Ton
Fuel or Energy Type	-	Electric
Full Load Power	kW/Ton	1.2
Full Load COP		2.8
Entering Chilled Water Temperature	°F	85
Leaving Chilled Water Temperature	°F	44
Chilled Water Flow Rate	GPM	240
Chilled Water Pressure Drop	ft.H_2O	10.7
Cooling Water Flow Rate	GPM	300
Cooling Water Pressure Drop	ft.H_2O	20

Part-2 has two chillers each with a capacity of 265 tons. Electric chillers configurations are shown in Table 5.8.

Table 5.8: Trane Electric Chiller Configuration

Chiller Plant: Electric		
Field	Units	
Chiller Name: Trane		
Chiller Type		Centrifugal water Cooled
Refrigerant Type		
Condenser Type	-	Water Cooled
Full load Capacity	Ton	275 Ton
Fuel or Energy Type	-	Electric
Full Load Power	kW/Ton	1.18
Full Load COP		2.8
Entering Chilled Water	^oF	85
Leaving Chilled Water	^oF	44
Chilled Water Flow Rate	GPM	660
Chilled Water Pressure Drop	ft.H_2O	16.2
Cooling Water Flow Rate	GPM	825
Cooling Water Pressure Drop	ft.H_2O	27

Cooling Tower configurations are shown in Table 5.9.

Table 5.9: Cooling Tower Configuration

Cooling Tower (Marley Cooling Technologies) Model NC 240859-A1		
Field	Units	Object
Fluid Type		Fresh City Water
Condenser Water Flow Rate	GPM	4800
Condenser Pump Head	m or ft WG	50 ft WG
Condenser Pump Mechanical	%	80
Condenser pumps Electrical	%	94
Hot water	^{o}F	95
Cold water	^{o}F	85
Design Approach	^{o}F	10
Full Load Fan	HP	50
Chilled Water set point	^{o}F	85
Set Point Control		Variable Speed Fan

5.2. Simulation Results

Generally, building simulation reports contain energy consumption and energy cost data produced by the building energy simulation. These reports can be used to compare energy use and energy costs for alternate designs or to investigate energy use patterns for an individual building case. Carrier HAP offers thirteen different building simulation reports (Carrier Corporation, 2006).

Each report is summarized below:

- Monthly and hourly simulation results for central cooling and heating plant.
- The Annual Cost Summary for comparing annual energy cost results for buildings.
- The Annual Energy and Emissions Summary report for comparing annual energy cost results for buildings.
- Component Costs reports contain annual energy costs for a single building.

- Detailed reports contain tables of monthly energy and cost data for a single building case.
- Use profiles contain the hour-by-hour energy use profile for a building for one energy source or fuel type.
  - Annual components and energy costs
  - HVAC and non-HVAC cost totals
  - Monthly components and energy costs
  - Monthly, daily and hourly air system simulation reports

5.2.1. Cooling Load Simulation

Peak cooling load for the building depends on building orientation, exposure and the overall thermal transfer value of building envelopes. Other key variables include space internal loads, design outdoor-indoor temperature difference, etc.

The individual RU buildings are located in different orientation. The internal space loads and usage of every zone of each building are different. Depending on the above key variables, peak cooling load occurs on a different day and time for each building.

Two central chiller plants are located in Ryerson University campus. One is located in Library building with total capacity of 10903 kW (including **part-1** buildings) and another is located in Rogers Communications Center (RCC) with total capacity of 1864 kW (including **part-2** buildings). Enwave provides remote chilled water for Rogers Business Building (RBB).

HAP hourly simulation result provides 8760 hours of cooling load data. The maximum cooling plant load was taken from 8760 Carrier HAP simulation result. The maximum cooling plant load occurred on July 7th at 1700 hour for the central chiller plant in Library building with a total load of 10809 kW, on July 7th at 1600 hour for the central chiller plant in the RCC building with a total load of 1070 kW, and on July 9th at 1200 hour for the RBB with load of 2538 kW.

Table 5.10 represents the peak cooling load and its occurring time for each building.

Table 5.10: Peak Cooling Load for Individual Building of RU

Sl. No.	Name of building	Peak Cooling Load (kW)	Peak Cooling Load Occur	
			Month_Day	Hour
1	Heaslip House Continuing Education (CED)	221	July_7th	1700
2	School of Image Art (IMA)	535	July_7th	1700
3	Victoria Building (VIC)	786	July_7th	1700
4	Jorgenson Hall (JOR)	737	Aug_5th	1400
5	Library Building (LIB)	1372	Aug_4th	1200
6	Podium (POD)	1067	Aug_4th	1200
7	Engineering Building (ENG)	1981	July_7th	1700
8	Eric Palin Hall (EPH)	1466	July_7th	1600
9	Sally Horsfall Eaton Centre (SHE)			
10	Interior Design (SID)	185	July_7th	1800
11	Student Campus Centre (SCC)	202	July_7th	1700
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	154	July_7th	1700
13a	Kerr Hall (KNE)	359	Aug_5th	1400
13b	Kerr Hall (KNW)	362	Aug_5th	1400
13c	Kerr Hall (KSE)	1123	Aug_5th	1400
13d	Kerr Hall (KSW)	981	Aug_5th	1400
	Total Peak Cooling Load	**11531**		
14	Rogers Communications Centre (RCC)	858	July_7th	1200
15	Pitman Hall (PIT)	222	Aug_5th	1400
	Total Peak Cooling Load	**1080**		
16	Rogers Business Building (RBB)	**2538**	July_9th	1200

Table 5.11 represents the maximum cooling plant load for each building and load occurring time.

Table 5.11: Maximum Cooling Plant Load for Selected Buildings of RU

Sl. No.	Name of building	Maximum Cooling Plant Load (kW)
*Maximum Cooling Load Occurs on July 7th at 1700 hour for Central Chiller Plant in Library Building **(Part-1)***		
1	Heaslip House Continuing Education (CED)	221
2	School of Image Art (IMA)	535
3	Victoria Building (VIC)	786
4	Jorgenson Hall (JOR)	682
5	Library Building (LIB)	1189
6	Podium Building (POD)	1032
7	Engineering Building (ENG)	1981
8	Eric Plan Hall (EPH)	1399
9	Sally Horsfall Eaton (SHE)	
10	Interior Design (SID)	184
11	Student Campus Centre (SCC)	202
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	154
13a	Kerr Hall (KNE)	324
13b	Kerr Hall (KNW)	287
13c	Kerr Hall (KSE)	934
13d	Kerr Hall (KSW)	899
	Total Max Plant Cooling Load (kW) =	**10809**
*Maximum Cooling Load Occurs on July 7th at 1600 hour for Central Chiller Plant in RCC Building **(Part-2)***		
14	Rogers Communications Centre (RCC)	858
15	Pitman Hall (PIT)	212
	Total Max Plant Cooling Load (kW) =	**1070**
Maximum Cooling Load Occurred on July 9th at 1200 in RBB Building		
16	Rogers Business Building (RBB)	**2538**

According to Ryerson Campus Planning energy consumption data, the cooling load was calculated for six months (May 1st to October 31st). Table 5.12 shows the RU chilled water demand. It also shows that cooling load in kWh per m^2 for building gross area and conditioned area.

Table 5.12: Chilled Water Demand of Ryerson University

Sl. No.	Name of building	Cooling Load (kWh)	Gross area (m^2)	Cooling Load (kWh/m^2)	Conditioned area (m^2)	Cooling Load (kWh/m^2)
1	Heaslip House Continuing Education (CED)	205136	4180	49	2302	89
2	School of Image Art (IMA)	596157	9345	64	7219	83
3	Victoria Building (VIC)	781200	12708	61	9788	80
4	Jorgenson Hall (JOR)	1078274	10964	98	8188	132
5	Library Building (LIB)	1727593	18487	93	15426	112
6	Podium Building (POD)	1258069	21730	58	13421	94
7	Engineering Building (ENG)	1890651	22350	85	17583	108
8	Eric Palin Hall (EPH)	1481285	21019	70	17334	85
9	Sally Horsfall Eaton (SHE)					
10	Interior Design (SID)	162072	4373	37	2888	56
11	Student Campus Centre (SCC)	198614	4180	48	2993	66
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	159308	2985	53	2399	66
13	Kerr Hall (KNE/ KNW/KSE/KSW)	3549164	52409	68	30125	118
14	Rogers Communications Centre (RCC)	830394	13100	63	10871	76
15	Pitman Hall (PIT)	190740	3828	50	2165	88
16	Rogers Business Building (RBB)	1845076	24378	76	16740	110
	Total:	**15953733**	**226036**	**70**	**159443**	**100**

5.2.2. Space Heating Calculation by Carrier HAP

Generally in the winter time, the temperature of the outside is very cold. Maximum peak heating load occur at that cold condition and during a specific time. Peak heating load also depends on key parameters of the building. Carrier HAP provides 8760 hours simulation result for heating. By analyzing the HAP hour by hour result, peak heating load and maximum heating plant load were determined. Peak heating load occurring time for each Ryerson building is shown in Table 5.13.

Table 5.13: Peak Heating Load for Individual Building of RU

Sl. No.	**Name of building**	**Peak Heating (kW)**	**Peak Heating Load Occurred**	
			Month_Day	**Hour**
1	Heaslip House Continuing Education (CED)	136	January_27th	700
2	School of Image Art (IMA)	463	January_27th	700
3	Victoria Building (VIC)	464	January_27th	600
4	Jorgenson Hall (JOR)	425	January_27th	800
5	Library Building (LIB)	232	January_27th	700
6	Podium Building (POD)	375	January_27th	700
7	Engineering Building (ENG)	1792	January_27th	800
8	Eric Palin Hall (EPH)	510	January_27th	700
9	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)			
10	Interior Design (SID)	113	January_27th	700
11	Student Campus Centre (SCC)	128	January_27th	700
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	93	January_27th	700
13a	Kerr Hall (KNE)	471	January_27th	700
13b	Kerr Hall (KNW)	621	January_27th	500
13c	Kerr Hall (KSE)	1333	January_25th	2200
13d	Kerr Hall (KSW)	1021	January_2nd	1200
14	Rogers Communications Centre (RCC)	362	January_27th	700
15	Pitman Hall (PIT)	168	January_27th	700
	Total Peak Heating Load (kW) =	**8707**		
16	Rogers Business Building (RBB)	**1076**	January_15th	200

The main heating source for all Ryerson University buildings is remote steam. Heating load was determined by the total amount of steam consumption. Maximum plant heating load was determined by adding all of the buildings heating load at a specific hour when maximum total plant load occurs.

According to HAP hourly analysis, on January 27th at 800 hour, the maximum plant heating load was 8135 kW for the space heating of 15 RU buildings. On January 15th at 200 hour, maximum heating load occurred at RBB building was 1076 kW. Table 5.14 shows the maximum plant heating loads for 16 buildings of RU.

Table 5.14: Maximum Plant Heating Load for 16 Buildings of RU

Sl. No.	Name of building	Maximum Heating Plant Load (kW)
Maximum Heating Load Occurred on January 27th at 800 hour for 15 Buildings		
1	Heaslip House Continuing Education (CED)	123
2	School of Image Art (IMA)	440
3	Victoria Building (VIC)	397
4	Jorgenson Hall (JOR)	425
5	Library Building (LIB)	228
6	Podium Building (POD)	333
7	Engineering Building (ENG)	1792
8	Eric Palin Hall (EPH)	470
9	Sally Horsfall Eaton Centre (SHE)	
10	Interior Design (SID)	99
11	Student Campus Centre (SCC)	102
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	78
13a	Kerr Hall (KNE)	455
13b	Kerr Hall (KNW)	598
13c	Kerr Hall (KSE)	1261
13d	Kerr Hall (KSW)	881
14	Rogers Communications Centre (RCC)	306
15	Pitman Hall (PIT)	147
Total Max Plant Heating Load (kW) =		**8135**
Maximum Heating Load Occurred on January 15th at 200 hour for RBB Building		
16	Rogers Business Building (RBB)	1076

5.2.3. Comparison of Electricity Consumption

Ryerson University Building's electricity demand over the past 3 fiscal years was obtained from the Ryerson University Campus Planning department. There were a total of nine bills. Some buildings were included under one bill. The data shown in Table 5.15 is based on total electricity consumption. Electricity bill for Fiscal Year 2005 to 2007 is shown in Appendix C. The Fiscal Year is starts from the month of May and end of the month of April of the next year.

Table 5.15: Actual Electricity Consumption of Ryerson University Buildings

		Total Electricity Consumption		
	Fiscal Year (May-April)	2005-2006	2006-2007	2007-2008
Sl. No.	**Name of the Buildings**	**(kWh)**	**(kWh)**	**(kWh)**
1	VIC, IMA, CED	3,608,472	4,067,896	3,599,652
2	ENG	4,472,078	4,408,548	4,111,201
3	Kerr Hall (KNE/KNW/KSE/KSW)	8,306,896	8,771,259	7,130,113
4	EPH, SHE	3,813,068	4,057,548	3,609,473
5	JOR, LIB, POD	16,895,386	18,376,049	20,399,668
6	SCC, HEI, OAK	1,650,957	1,705,010	1,732,166
7	SID	364,543	435,840	373,760
8	RCC, PIT	5,500,402	5,397,903	5,607,650
9	RBB	-	-	4,001,970

Figure 5.3 illustrates the total electricity consumption data of selected Ryerson buildings graphically.

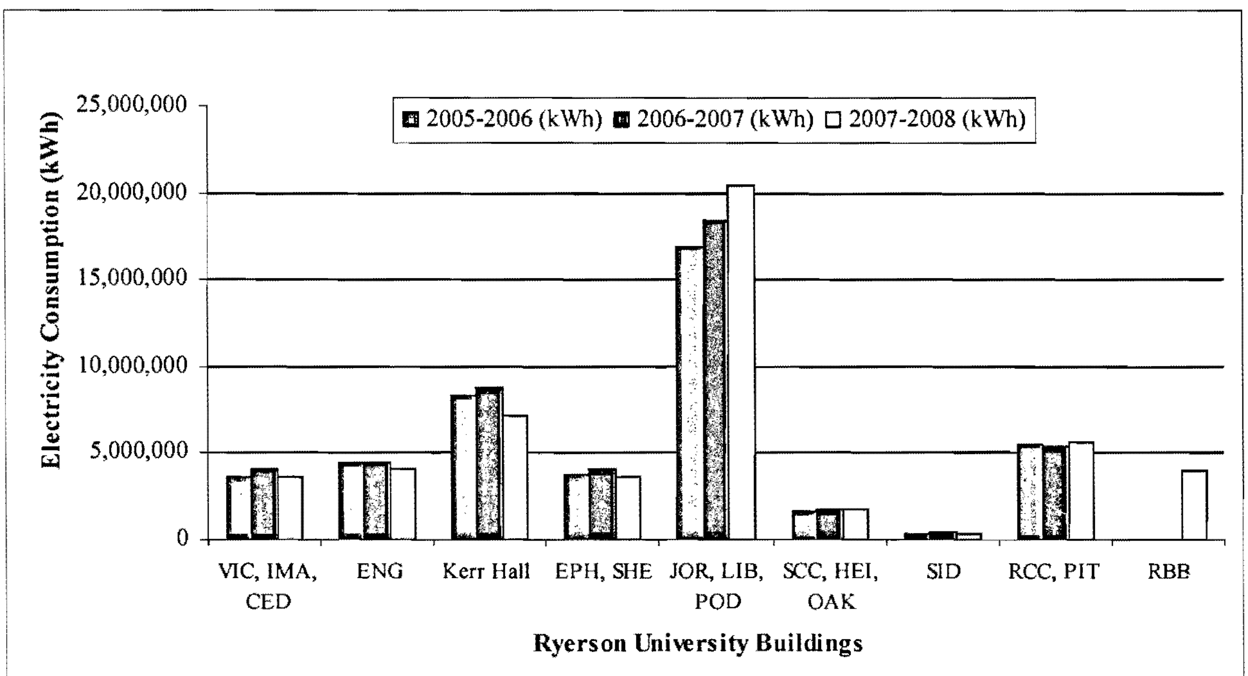

Figure 5.3: Actual Fiscal Year Electricity Consumption of Ryerson University Buildings

buildings were included under one bill. The data shown in Table 5.15 is based on total electricity consumption. Electricity bill for Fiscal Year 2005 to 2007 is shown in Appendix C. The Fiscal Year is starts from the month of May and end of the month of April of the next year.

Table 5.15: Actual Electricity Consumption of Ryerson University Buildings

		Total Electricity Consumption		
	Fiscal Year (May-April)	2005-2006	2006-2007	2007-2008
Sl. No.	**Name of the Buildings**	**(kWh)**	**(kWh)**	**(kWh)**
1	VIC, IMA, CED	3,608,472	4,067,896	3,599,652
2	ENG	4,472,078	4,408,548	4,111,201
3	Kerr Hall (KNE/KNW/KSE/KSW)	8,306,896	8,771,259	7,130,113
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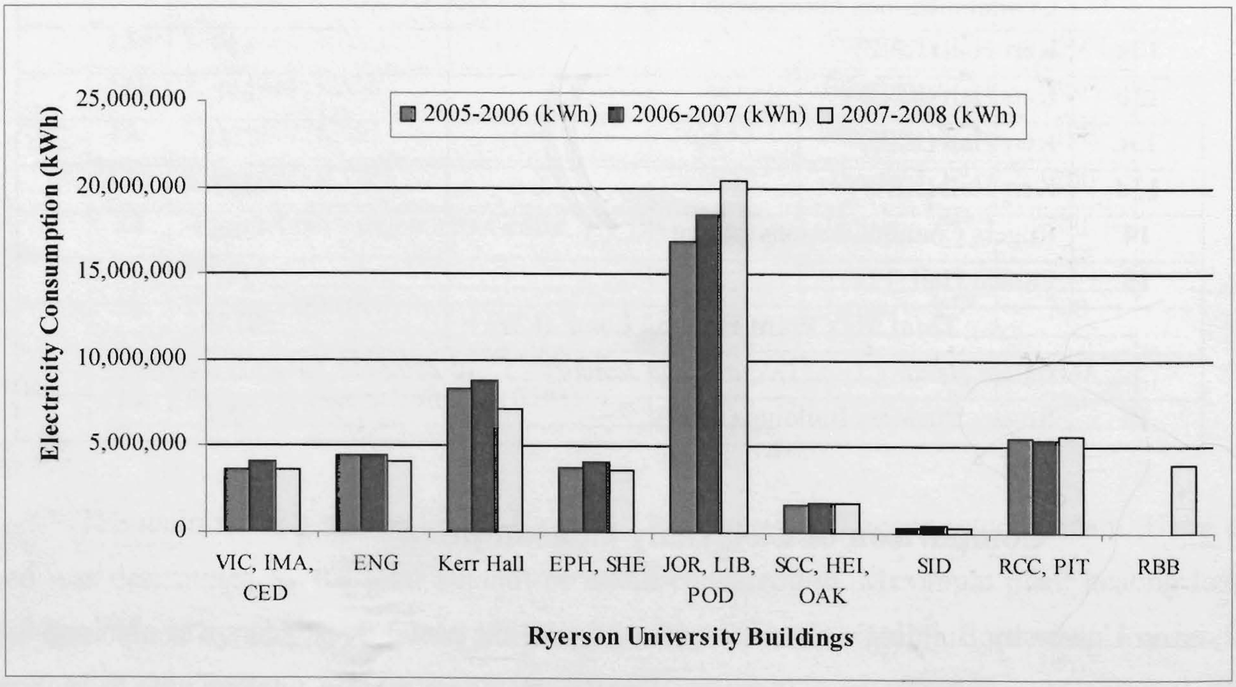

Figure 5.3: Actual Fiscal Year Electricity Consumption of Ryerson University Buildings

Table 5.16 illustrates in kWh/m^2 electricity consumption (including chiller electricity consumption) for three fiscal years of Ryerson University.

Table 5.16: Per Square Meter Electricity Comparison for Three Fiscal Years

Sl.	Fiscal Year (May-April)	Gross	2005-2006	2006-2007	2007-2008
No.	Name of the Buildings	(m^2)	(kWh/m^2)	(kWh/m^2)	(kWh/m^2)
1	VIC, IMA, CED	26233	138	155	137
2	ENG	22350	200	197	184
3	Kerr Hall (KNE/KNW/KSE/KSW)	52409	159	167	136
4	EPH, SHE	21019	181	193	172
5	JOR, LIB, POD	51181	330	359	399
6	SCC, HEI, OAK	9198	179	185	188
7	SID	4373	83	100	85
8	RCC, PIT	30966	178	174	181
9	RBB	24378	-	-	164

The chiller plant for part-1 is located in the Library Building. The electricity consumption for part-1 chiller plant included Jorgenson Hall, the Library building and the Podium building electricity bill. The part-2 chiller electricity consumption included RCC building and Pitman Hall electricity bill. Electricity consumption for Part-1 and Part-2 chiller plant was calculated based on the design of 10903 kW and 1864 kW chiller model. Table 5.17 describes annual chiller electricity consumption.

Table 5.17: Annual Chillers Electricity Consumption

Electricity	Library Chillers Consumption	RCC Chillers Consumption
	(kWh)	(kWh)
Chiller Input	1229193	146555
Chiller Misc. Electric	394722	-
Chilled Water Pump	863513	67860
Cooling Tower Fan	664352	30272
Total Consumption	**3151780**	**244687**

The HAP program provided simulated electricity consumption result for each building. Table 5.18 represents the difference of electricity consumption between Campus Planning billing year 2006 (January-December) for 15 buildings and HAP result. Only billing year 2007 (Jan-Dec) was used for RBB. The electricity bill is shown in Appendix C. From the Table 5.18, it is seen that the electricity consumption difference for JOR, LIB, POD buildings is 7.7% because the central chiller plant is located in the Library building. Kerr Hall has different types of laboratories. So, the electricity consumption difference of Kerr Hall is 8.4%. The difference of RCC and PIT is 6.5%, because RCC has chiller plant and Pitman Hall is a residential building with heat pump equipment from 4th floor to 13th floor for every room.

Table 5.18: The Comparison of Electricity Consumption for 16 Ryerson Buildings

Sl. No.	Name of Building	Bill from Campus Planning of RU (kWh)	HAP Result (kWh)	Difference (%)
1	Heaslip House Continuing Education (CED)	3893040	3794216	2.5
2	School of Image Art (IMA)			
3	Victoria Building (VIC)			
4	Jorgenson Hall (JOR)	17960970	16570677	7.7
	Chiller Plant_LIB			
5	Library Building (LIB)			
6	Podium Building (POD)			
7	Engineering Building (ENG)	4451690	4396600	1.2
8	Eric Palin Hall (EPH)	3974560	3844099	3.3
9	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)			
10	Interior Design (SID)	400000	390869	2.3
11	Student Campus Centre (SCC)	924080	911249	1.4
12	Heidelberg Centre-School of Graphic Communications Management (HEI)			
13	Kerr Hall (KNE, KNW, KSE, KSW)	8590220	7863450	8.4
	Chiller Plant_RCC	5360462	5010384	6.5
14	Rogers Communications Centre (RCC)			
15	Pitman Hall (PIT)			
16	Rogers Business Building (RBB)	4001970	3945188	1.4
Total Annual Electricity Consumption		**49,556,992**	**46,726,697**	**5.7**

Electricity consumption, in kWh/m^2 depends on the use of the space in each building. In the RU building, there are two types of electricity consumption. They are HVAC and Non-HVAC. The air system fans, pumps and cooling tower fans are included in HVAC system. The lighting, equipments, and miscellaneous electricity are included in Non-HVAC system. Different types of pumps are used in Ryerson buildings. They are:

- Domestic hot and cold water pump
- Heat pump
- Heating glycol pump
- Sanitary sump pump
- Storm pump and Jockey pump and Fire pump

Table 5.19 represents the comparison of per square meter electricity consumption of 16 individual Ryerson buildings. For Pitman Hall, total conditioned floor area for electricity consumption is 15712 m^2.

Table 5.19: Per Square Meter Electricity Comparison for Gross and Conditional Area

Sl. No.	Name of the Building	HAP Result (kWh)	HAP Annual Energy (GJ)	Electricity Consumption per unit Gross Area (kWh/m^2)	Electricity Consumption per unit Cond. Area (kWh/m^2)
1	Heaslip House Continuing Education (CED)	517658	1864	124	225
2	School of Image Art (IMA)	1424168	5127	152	197
3	Victoria Building (VIC)	1852390	6669	146	189
4	Jorgenson Hall (JOR)	2514762	9053	229	307
5	Library Building (LIB)	6671607	24018	361	432
6	Podium Building (POD)	4232528	15237	195	315
7	Engineering Building (ENG)	4396600	15828	197	250
8	Eric Palin Hall (EPH)	3844099	13839	183	222
9	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)				
10	Interior Design (SID)	390869	1407	89	135
11	Student Campus Centre (SCC)	465118	1674	111	155
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	446131	1606	149	186
13	Kerr Hall (KNE, KNW, KSE, KSW)	7863450	28308	150	261
14	Rogers Communications Centre (RCC)	1811528	6522	138	167
15	Pitman Hall (PIT)	2954169	10635	165	188
16	Rogers Business Building (RBB)	3945188	14203	162	236
	Total	**43330230**	**155990**	**180**	**250**
	Chiller Plant_LIB Building	3151780	11346		
	Chiller Plant_RCC Building	244687	881		
	Total	**46726697**	**168217**		

5.2.4. Steam Consumption

Ryerson University has two remote steam meters. Remote steam is served by meter-1 for all Ryerson University buildings, except Rogers Business Building. Meter-2 only serves remote steam for RBB. Table 5.20 represents total amount of steam delivered to the entire Ryerson University campus.

Table 5.20: Actual Remote Steam Consumption of Ryerson University Buildings (Meter-1 & 2)

		Total Steam Consumption		
	Fiscal Year (May-April)	2005-2006	2006-2007	2007-2008
Meter No.	Name of the Buildings	(lb)	(lb)	(lb)
1	All Ryerson Building except RBB	107,411,195	97,313,777	95,854,985
2	Rogers Business Building (RBB)	-	4,786,006	5,262,143

Figure 5.4 and 5.5 illustrates total steam consumption data of selected Ryerson buildings graphically for Meter-1 and Meter-2. In Figure 5.5, the Fiscal year 2006-2007 indicates only the month (September-March) and 2008-2009 indicates the month (May-January) steam consumption.

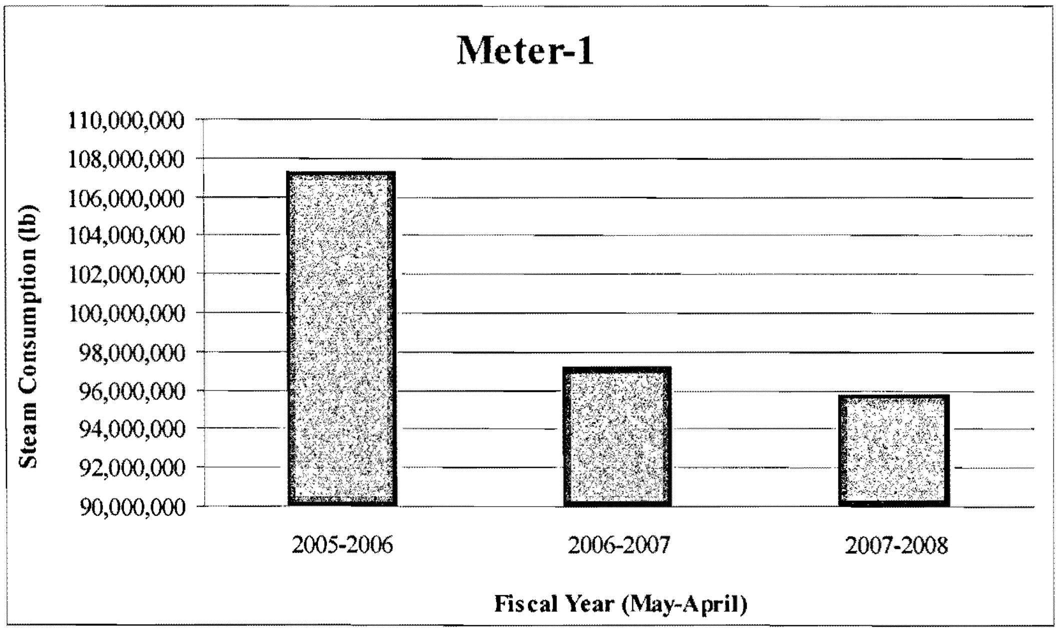

Figure 5.4: Actual Fiscal Year Steam Consumption of Ryerson University Buildings

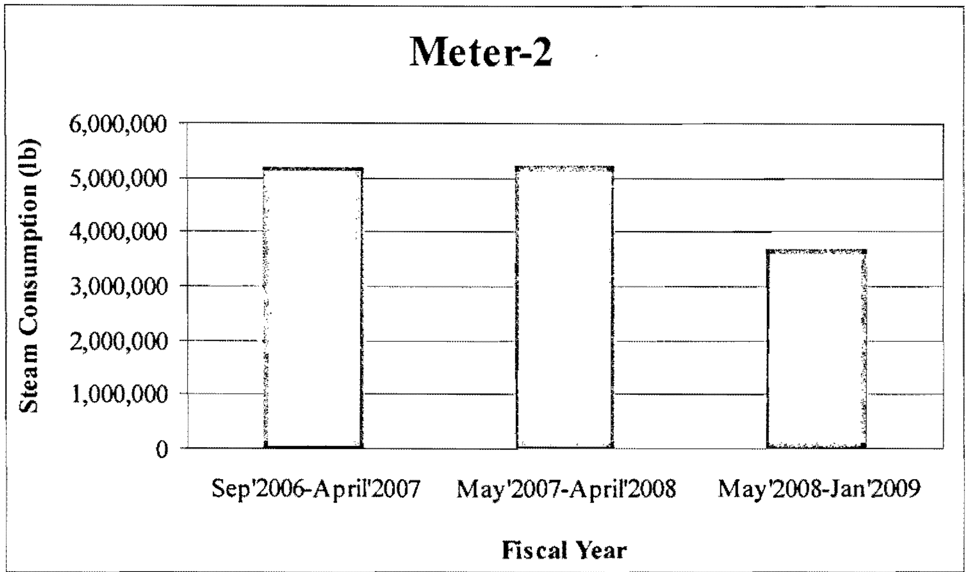

Figure 5.5: Actual Fiscal Year Steam Consumption of RBB Building

The simulation result of Carrier HAP presents the annual steam consumption for the 16 individual buildings of RU. The result also presents per unit gross area steam consumption and determined annual energy uses in GJ. Table 5.21 shows the simulated steam consumption. From the Table 5.21, it is clear that the steam consumption (kWh/m^2) of Kerr Hall is too high because Kerr Hall uses a Constant Air Volume (CAV) air system for an HVAC system.

Table 5.21: Simulation of Steam Consumption of RU

Sl. No.	Name of building	Annual Remote Steam Load (kWh)	Annual Energy Uses (GJ)	Steam Consumption	
				per Gross Area (kWh/m^2)	per Cond. Area (kWh/m^2)
1	Heaslip House Continuing Education (CED)	183831	662	44	80
2	School of Image Art (IMA)	833069	2999	89	115
3	Victoria Building (VIC)	664253	2391	52	68
4	Jorgenson Hall (JOR)	403630	1453	37	49
5	Library Building (LIB)	232707	838	13	15
6	Podium Building (POD)	585197	2107	27	44
7	Engineering Building (ENG)	1736162	6250	78	99
8	Eric Palin Hall (EPH)	547752	1972	26	32
9	Sally Horsfall Eaton Centre (SHE)				
10	Interior Design (SID)	95374	343	22	33
11	Student Campus Centre (SCC)	190450	686	46	64
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	160195	577	54	67
13	Kerr Hall (KNE, KNW, KSE, KSW)	9849907	35460	188	327
14	Rogers Communications Centre (RCC)	321243	1156	25	30
15	Pitman Hall (PIT)	146650	528	38	68
	Total Steam Load (kWh)	**15950420**	**57422**	**79**	**112**
16	Rogers Business Building (RBB)	1307372	4707	54	78

The total gross area of Ryerson University is approximately 281020 m^2. Enwave serves remote steam to RU by the two individual meters. Meter-1 serves 20 buildings with an area of 223127 m^2 including absorption chiller and Meter-2 serves RBB building with total area of 24378 m^2. The central chillers plant located in Library building, has two absorption chillers that include steam consumption in Meter-1. 90.3% (95656508 lb) of actual steam consumption is calculated from Meter-1 for the total area of 201658 m^2 which include 15 audit buildings in the year 2006 (January-December). The steam consumption bill is shown in Appendix C and 90.3% steam consumption is shown in Appendix E. The difference between the simulation result and the actual steam consumption was 6.26% higher than HAP result. For the RBB, the steam consumption year was considered 2007(January-December) and actual steam consumption was 5804648 lb (according to the Campus Planning billing record). The difference between the simulation result and the actual steam consumption for Meter-2 was

6.94% higher than HAP result. The comparison of base case annual steam consumption with Carrier HAP simulation result is shown in Table 5.22.

Table 5.22: Comparison of Base Case Annual Steam Consumption with Carrier HAP simulation

Purpose	**HAP Steam Consumption**		**Actual Steam Consumption**
(Meter-1)	**(kWh)**	**(lb)**	**(lb)**
Fifteen Buildings of RU	15950420	Steam enthalpy at 250 psig = 825.8 (BTU/lb)	
Two Absorption Chiller	5751754		
Total Annual Steam	**21702174**		
Total Annual Steam	**74047818 kBTU**	**89667980**	**95656508**
Difference (%)			**6.26**
(Meter-2)			
Rogers Business Building (RBB)	1307372		
	4460753 kBTU	**5401736**	**5804648**
Difference (%)			**6.94**

Table 5.23 indicates the electricity and natural gas consumption for both HVAC and Non-HVAC components and the total amount of CO_2 and N_2O produced as a result.

Table 5.23: CO_2 and N_2O by HVAC and Non-HVAC Components for the Base Case

Electricity Consumption Due to		**Steam Produced by Natural Gas (NG) Consumption**	**Total Amount of CO_2 and N_2O Produced (kg) – Based on Emission Factors**
HVAC Component (kWh)	**Non-HVAC Component (kWh)**	**(m^3)**	
49,556,992		**2615627 m^3 NG**	
11,199,880 kg CO_2		**4974923 kg CO_2**	**16,174,803 kg CO_2**
9911 kg N_2O		**86 kg N_2O**	**9998 kg N_2O**
Average Annual Emission Factor of Electricity (CO_2) = 0.226 kg/kWh (Gordon & Fung, 2009) and N_2O= 0.0002 kg/kWh (NRCan, 2004)		Emission Factor of Natural Gas = 1.902 kg/m^3 (NRCan, 2007) and N_2O= 0.033 g/m^3 (NRCan, 2004)	85% Efficiency from NG to steam conversion

Figure 5.6 and 5.7 represent the amount of CO_2 and N_2O produced by the electricity and natural gas consumption for the three fiscal years of 15 Ryerson University buildings.

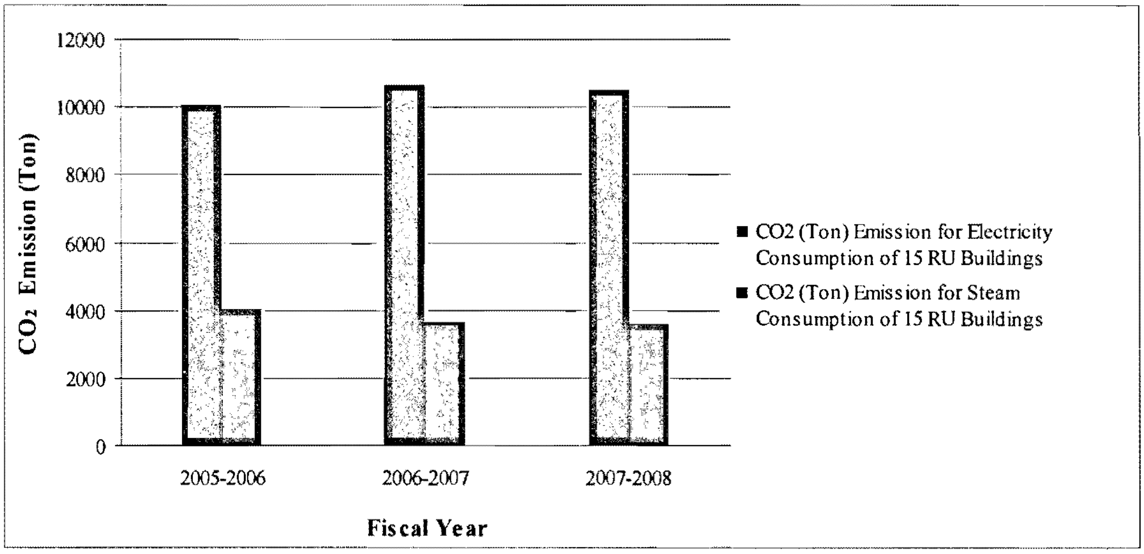

Figure 5.6: CO_2 Produce by HVAC and Non-HVAC Components for the Base Case

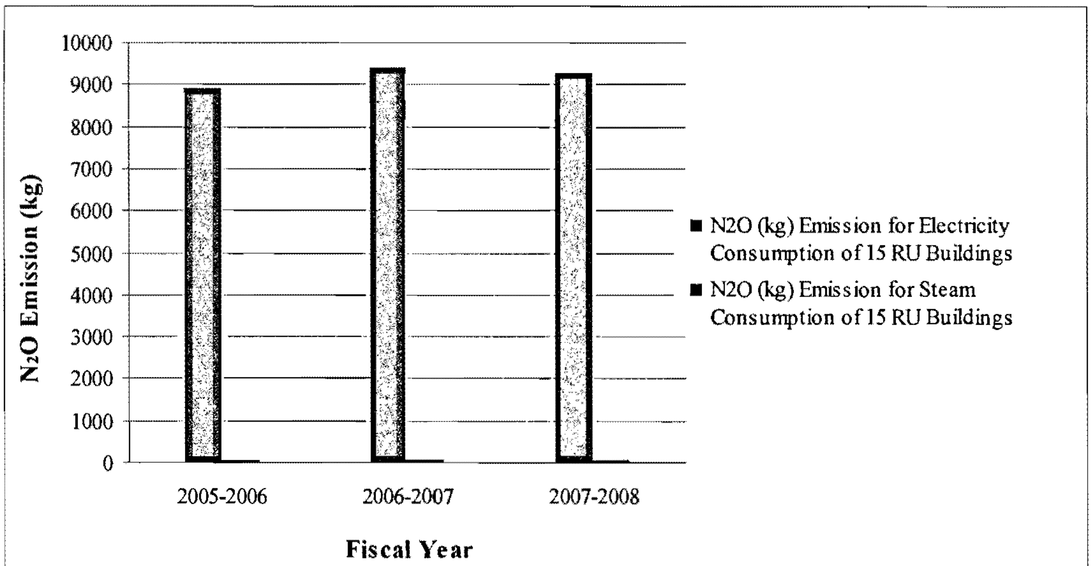

Figure 5.7: N_2O Produce by HVAC and Non-HVAC Components for the Base Case

Based on the base case model for RU buildings, Table 5.24 represents the annual energy consumption for HVAC and Non-HVAC components. Figure 5.8 represents the annual component energy demand by Carrier HAP building simulation for 16 buildings of RU. As per the graph, the air system fan uses 6%, cooling uses 21%, heating uses 23%, pumps use 1%, lights use 26%, equipment uses 19%, and miscellaneous electricity uses 4% of the total energy. The Annual component energy demand for each building is shown in Appendix F.

Figure 5.6 and 5.7 represent the amount of CO_2 and N_2O produced by the electricity and natural gas consumption for the three fiscal years of 15 Ryerson University buildings.

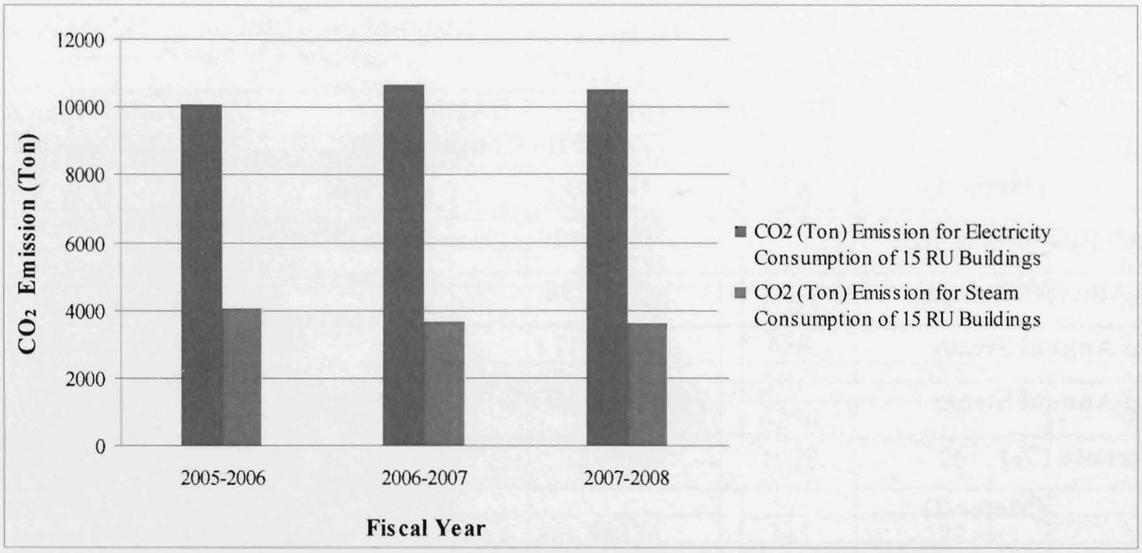

Figure 5.6: CO_2 Produce by HVAC and Non-HVAC Components for the Base Case

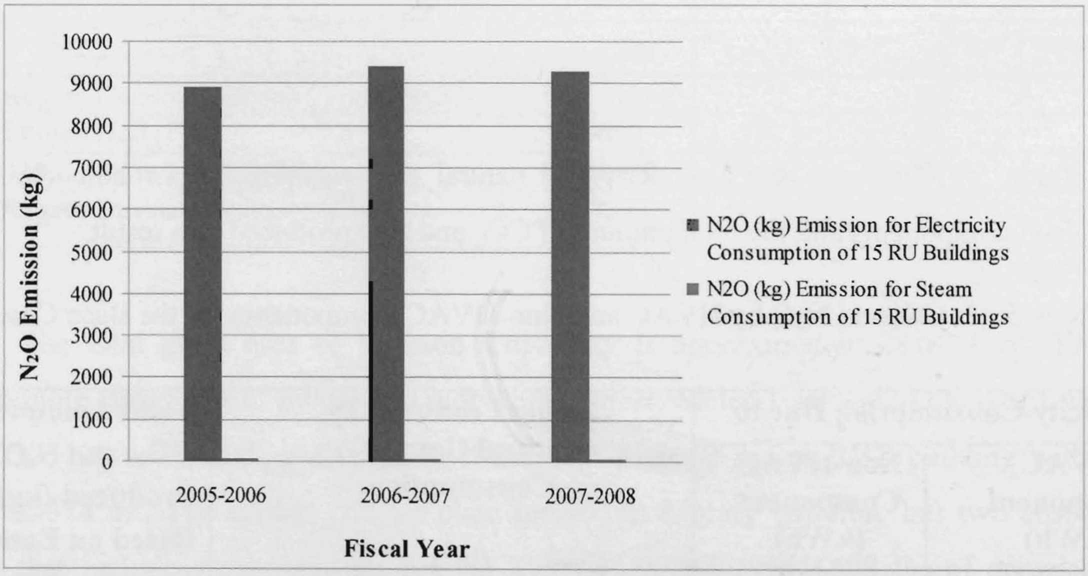

Figure 5.7: N_2O Produce by HVAC and Non-HVAC Components for the Base Case

Based on the base case model for RU buildings, Table 5.24 represents the annual energy consumption for HVAC and Non-HVAC components. Figure 5.8 represents the annual component energy demand by Carrier HAP building simulation for 16 buildings of RU. As per the graph, the air system fan uses 6%, cooling uses 21%, heating uses 23%, pumps use 1%, lights use 26%, equipment uses 19%, and miscellaneous electricity uses 4% of the total energy. The Annual component energy demand for each building is shown in Appendix F.

Table 5.24: Annual Electricity Demand for HVAC and Non-HVAC System from HAP

Sl. No.	Building Name	Air System Fans	Cooling	Heating	Pumps	Lights	Equipment	Misc. Electric	Total
		(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)
1	CED	254	738	662	31	722	353	504	3264
2	IMA	1052	2146	2999	30	2265	1457	323	10272
3	VIC	327	2812	2391	220	3612	2179	331	11872
4	JOR	1692	3882	1453	173	3938	1932	1319	14389
5	LIB	1588	6219	838	125	10000	9332	2973	31075
6	POD	1219	4529	2107	84	6737	4774	2423	21873
7	ENG	1352	6806	6250	297	6768	6618	793	28884
8	EPH	1447	5333	1972	147	7409	4220	616	21144
9	SHE								
10	SID	206	583	343	7	854	243	97	2333
11	SCC	240	715	686	10	1013	412	0	3076
12	HEI	255	574	577	7	791	552	0	2756
13a	KNE	302	1555	4956	91	1727	859	200	9690
13b	KNW	225	1342	6250	71	1502	574	144	10108
13c	KSE	2043	5340	17088	288	5385	3136	890	34170
13d	KSW	1005	4540	7165	284	5142	3837	603	22576
14	RCC	713	2846	1156	97	3082	2629	0	10523
15	PIT	181	524	528	118	4583	4665	1089	11688
16	RBB	1519	6642	4707	150	7454	5081	0	25553
Total :		15620	57126	62128	2230	72984	52853	12305	275246

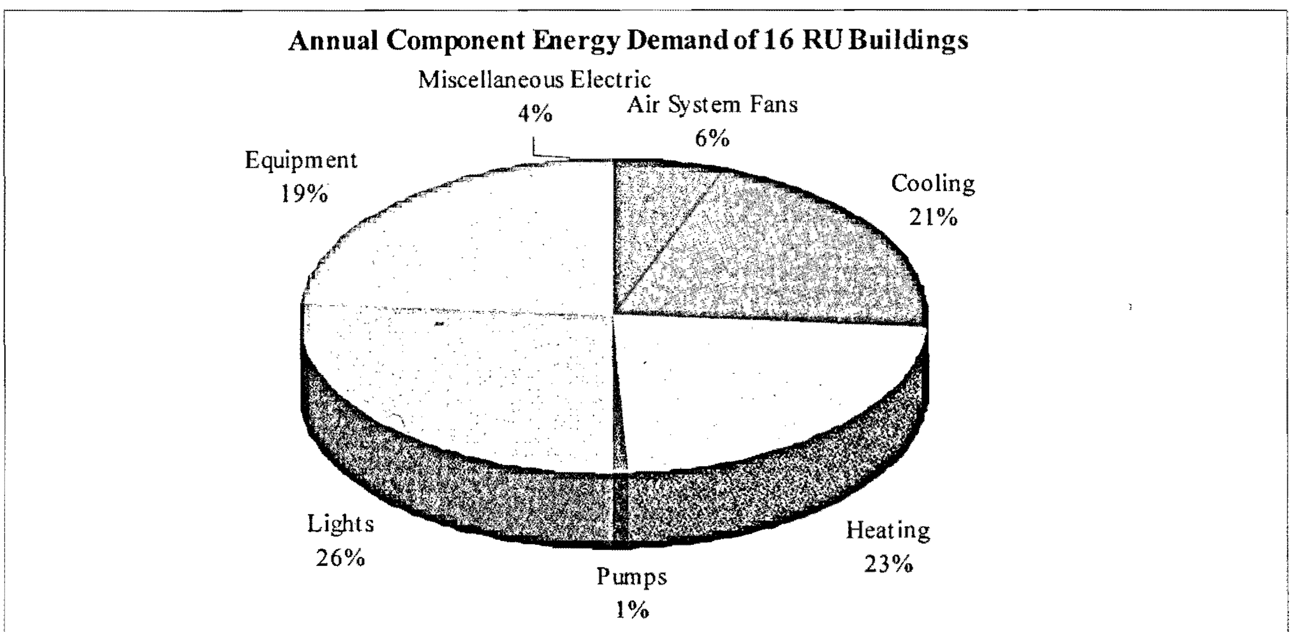

Figure 5.8: Annual Component Energy Demand of 16 RU Buildings from Carrier HAP

Table 5.24: Annual Electricity Demand for HVAC and Non-HVAC System from HAP

Sl. No.	Building Name	Air System Fans	Cooling	Heating	Pumps	Lights	Equipment	Misc. Electric	Total
		(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)
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4	JOR	1692	3882	1453	173	3938	1932	1319	14389
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13d	KSW	1005	4540	7165	284	5142	3837	603	22576
14	RCC	713	2846	1156	97	3082	2629	0	10523
15	PIT	181	524	528	118	4583	4665	1089	11688
16	RBB	1519	6642	4707	150	7454	5081	0	25553
Total :		15620	57126	62128	2230	72984	52853	12305	275246

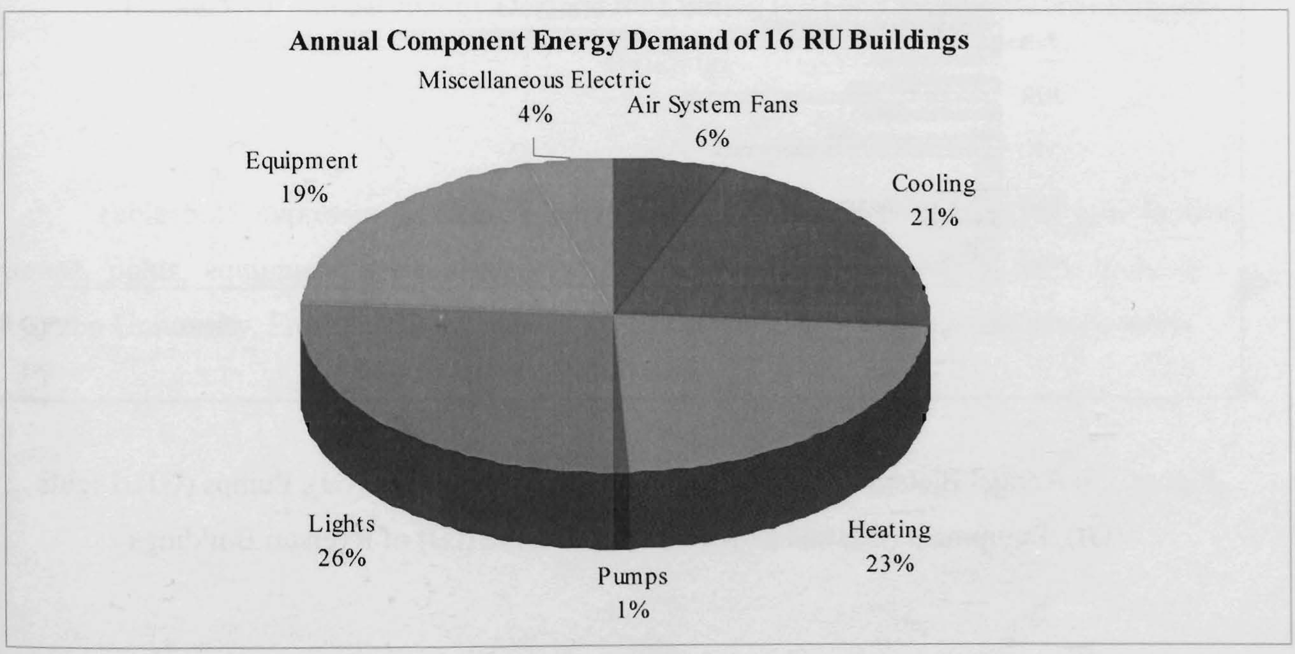

Figure 5.8: Annual Component Energy Demand of 16 RU Buildings from Carrier HAP

Figure 5.9 represents annual electricity consumption for lights (GJ), equipment (GJ) and miscellaneous electric (GJ) of 16 Ryerson buildings. From the graph, it is clear that the Library building uses a large amount of electricity due to the lights and equipment compared to other buildings.

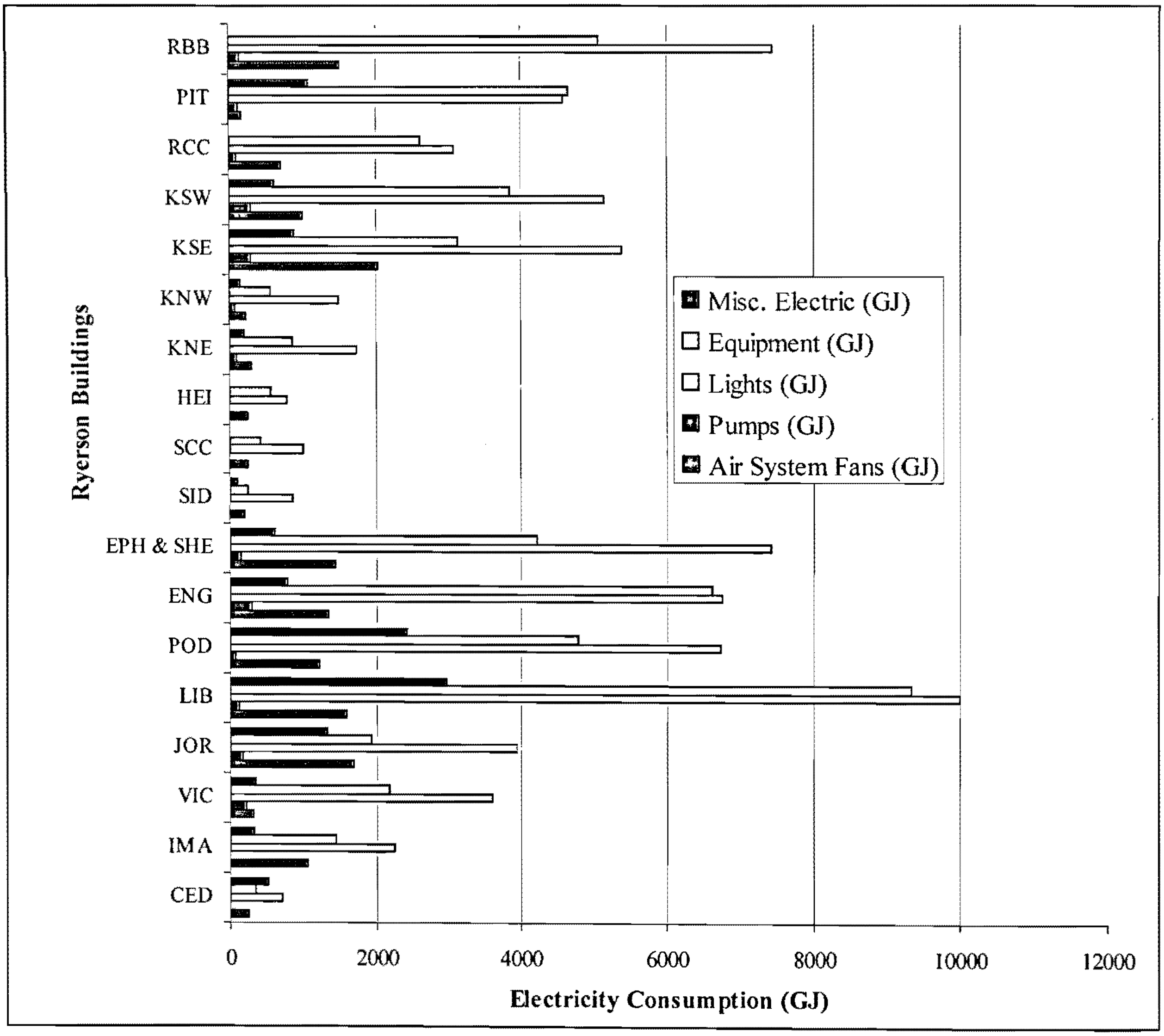

Figure 5.9: Annual Electricity Consumption for Air System Fans (GJ), Pumps (GJ), Lights (GJ), Equipment (GJ) and Miscellaneous Electric (GJ) of Ryerson Buildings

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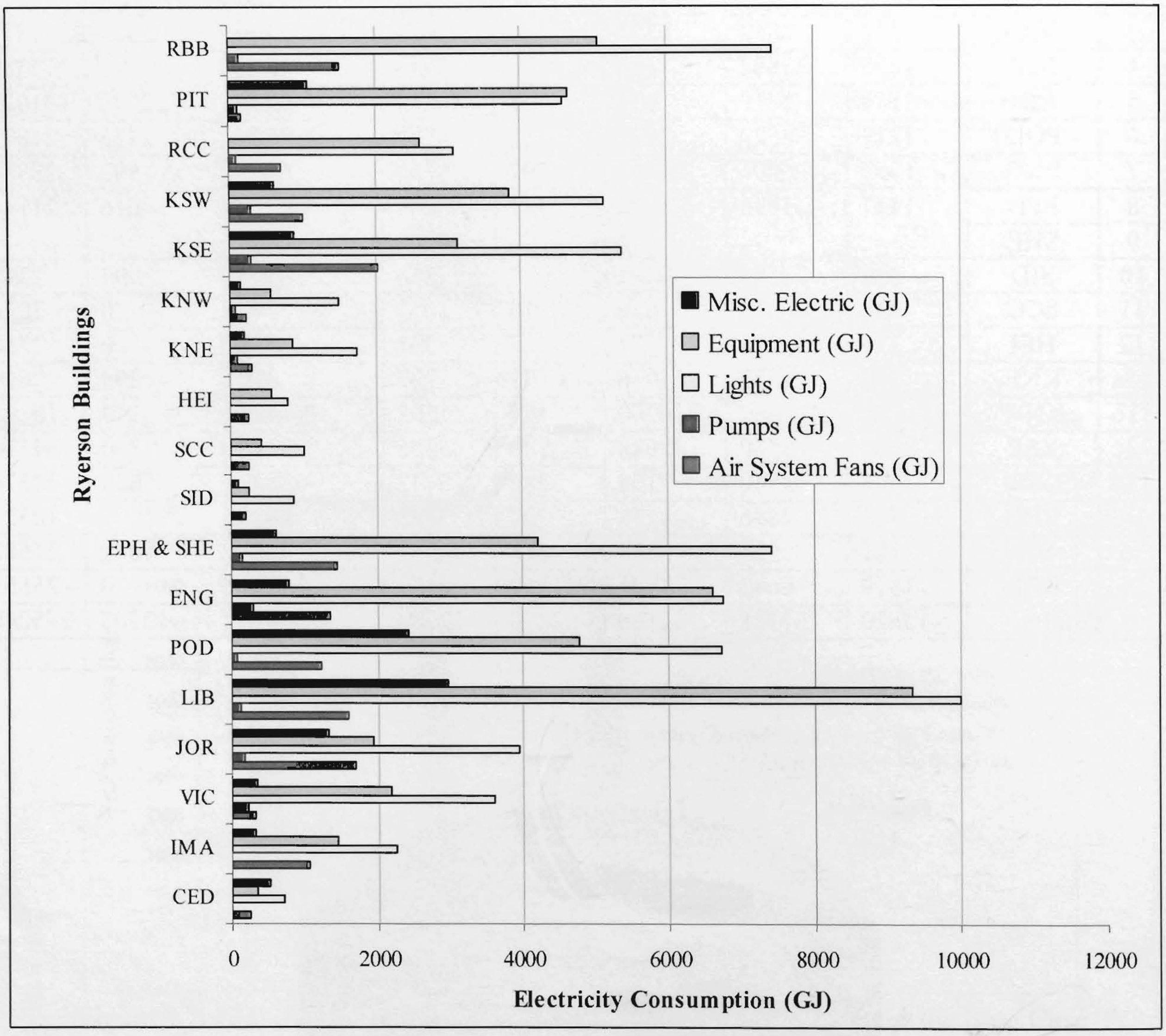

Figure 5.9: Annual Electricity Consumption for Air System Fans (GJ), Pumps (GJ), Lights (GJ), Equipment (GJ) and Miscellaneous Electric (GJ) of Ryerson Buildings

Annual energy consumption for cooling (GJ) and heating (GJ) of Ryerson buildings are shown in Figure 5.10. According to the graph, Kerr Hall South East has the highest heating load due to the use of CAV air system.

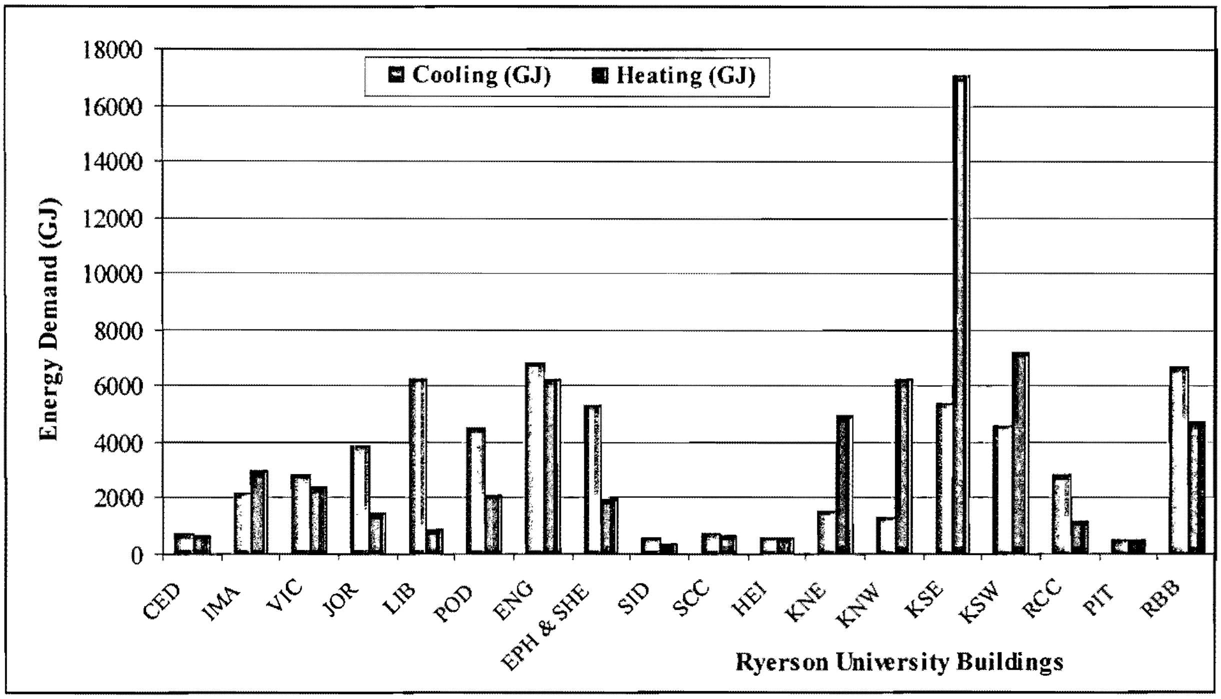

Figure 5.10: Annual Energy Demand for Cooling (GJ) and Heating (GJ) of Ryerson Buildings

Table 5.25 expresses the annual energy consumption in GJ/m^2 for air system fans, pumps, lights, equipment, misc. electricity, cooling and heating load for each building of Ryerson University. From this table, it is easy to understand the energy consumption sector.

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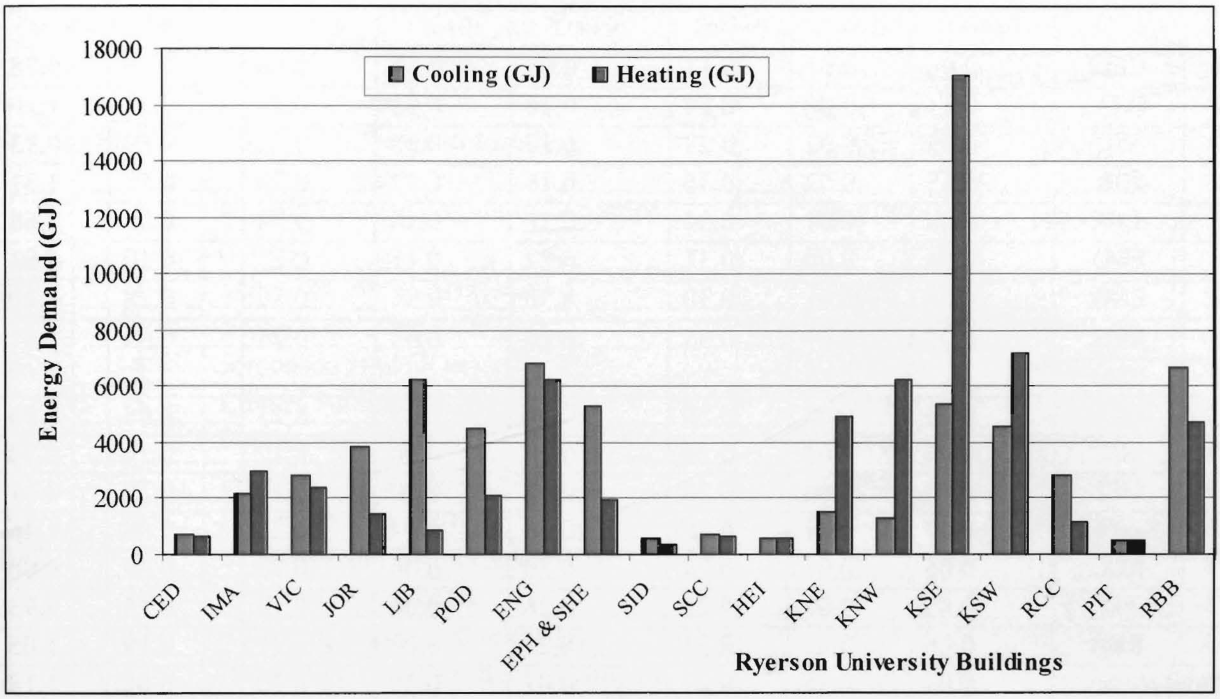

Figure 5.10: Annual Energy Demand for Cooling (GJ) and Heating (GJ) of Ryerson Buildings

Table 5.25 expresses the annual energy consumption in GJ/m^2 for air system fans, pumps, lights, equipment, misc. electricity, cooling and heating load for each building of Ryerson University. From this table, it is easy to understand the energy consumption sector.

Table 5.25: Annual Energy Demand per Unit Gross Area (GJ/m^2)

Sl. No.	Building Name	Air System Fans	Pumps	Lights	Equipment	Misc. Electric	Cooling	Heating	Total
		(GJ/m^2)	(GJ/m^2)	(GJ/m^2)	(GJ/m^2)	(GJ/m^2)	(GJ/m^2)	(GJ/m^2)	(GJ/m^2)
1	CED	0.06	0.01	0.17	0.08	0.12	0.18	0.16	**0.78**
2	IMA	0.11	0.00	0.24	0.16	0.03	0.23	0.32	**1.10**
3	VIC	0.03	0.02	0.28	0.17	0.03	0.22	0.19	**0.93**
4	JOR	0.15	0.02	0.36	0.18	0.12	0.35	0.13	**1.31**
5	LIB	0.09	0.01	0.54	0.50	0.16	0.34	0.05	**1.68**
6	POD	0.06	0.00	0.31	0.22	0.11	0.21	0.10	**1.01**
7	ENG	0.06	0.01	0.30	0.30	0.04	0.30	0.28	**1.29**
8	EPH	0.07	0.01	0.35	0.20	0.03	0.25	0.09	**1.01**
9	SHE								
10	SID	0.05	0.00	0.20	0.06	0.02	0.13	0.08	**0.53**
11	SCC	0.06	0.00	0.24	0.10	0.00	0.17	0.16	**0.74**
12	HEI	0.09	0.00	0.26	0.18	0.00	0.19	0.19	**0.92**
13	Kerr H.	0.07	0.01	0.26	0.16	0.04	0.24	0.68	**1.46**
14	RCC	0.05	0.01	0.24	0.20	0.00	0.22	0.09	**0.80**
15	PIT	0.05	0.03	0.26	0.26	0.06	0.14	0.14	**0.93**
16	RBB	0.06	0.01	0.31	0.21	0.00	0.27	0.19	**1.05**
Total (GJ/m^2):		0.07	0.25	0.27	0.01	0.30	0.22	0.05	**1.18**

5.3. Sensitivity Analysis for Cooling and Heating Load

The importance of ventilation in today's energy efficient building is universally recognized. Because of the energy savings generated, the system of choice is often a heat recovery ventilator (HRV). An HRV is a mechanical ventilation device that helps making building inside healthier, cleaner and more comfortable by continuously replacing indoor air with fresh outdoor air. HRVs are sometimes called air-to-air heat exchangers because they preheat or precool incoming air using exhaust air. A ventilation reclaim device is used for the HRV system. In base case simulation, there is no HRV system in air system for every building. Ventilation reclaim has two options 1) sensible heat and 2) sensible and latent heat. For the sensitivity analysis, the sensible and latent heat option was selected with HRV system. The thermal efficiency of this equipment was 90%. With the implementation of HRV system, 5.6%

energy saving was achieved for cooling load. Table 5.26 represents the comparison between base case air system and air system with the HRV.

Table 5.26: Comparison of Annual Cooling Load with Heat Recovery Ventilation (HRV) system for 16 buildings of Ryerson University.

Sl. No.	Name of building	Annual Cooling Load Base Case (kWh)	Annual Cooling Load Using HRV (kWh)
1	Heaslip House Continuing Education (CED)	205136	199554
2	School of Image Art (IMA)	596157	538568
3	Victoria Building (VIC)	781200	749012
4	Jorgenson Hall (JOR)	1078274	1054452
5	Library Building (LIB)	1727593	1685691
6	Podium Building (POD)	1258069	1205502
7	Engineering Building (ENG)	1890651	1809594
8	Eric Palin Hall (EPH)	1481285	1439614
9	Sally Horsfall Eaton Centre (SHE)		
10	Interior Design (SID)	162072	156802
11	Student Campus Centre (SCC)	198614	192125
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	159308	152387
13	Kerr Hall (KNE, KNW, KSE, KSW)	3549164	3105112
14	Rogers Communications Centre (RCC)	830394	808045
15	Pitman Hall (PIT)	190740	185299
16	Rogers Business Building (RBB)	1845076	1784892
Annual Total Cooling Load (kWh) =		**15953733**	**15066649**
		Annual Savings (%)	**5.6%**

Figure 5.11 graphically expresses the comparison of cooling load between base case and with heat recovery system.

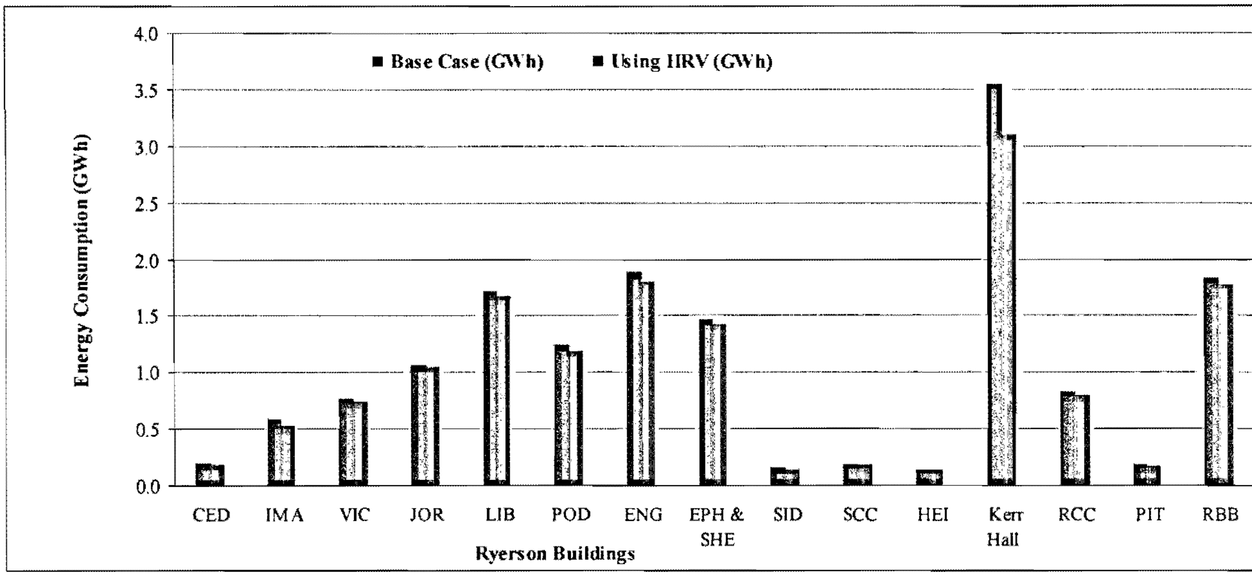

Figure 5.11: Comparison of Cooling Load Between Base Case and with Heat Recovery System

The sensitivity analysis offers a before and after comparison, and in the before scenario, there is no HRV system. The HRV system was added to base case building simulation with 90% thermal efficiency for sensible and latent heat option. With the implementation of the HRV system, 76% energy saving was achieved for the heating load. Table 5.27 describes annual heating load between base case and with heat recovery ventilation.

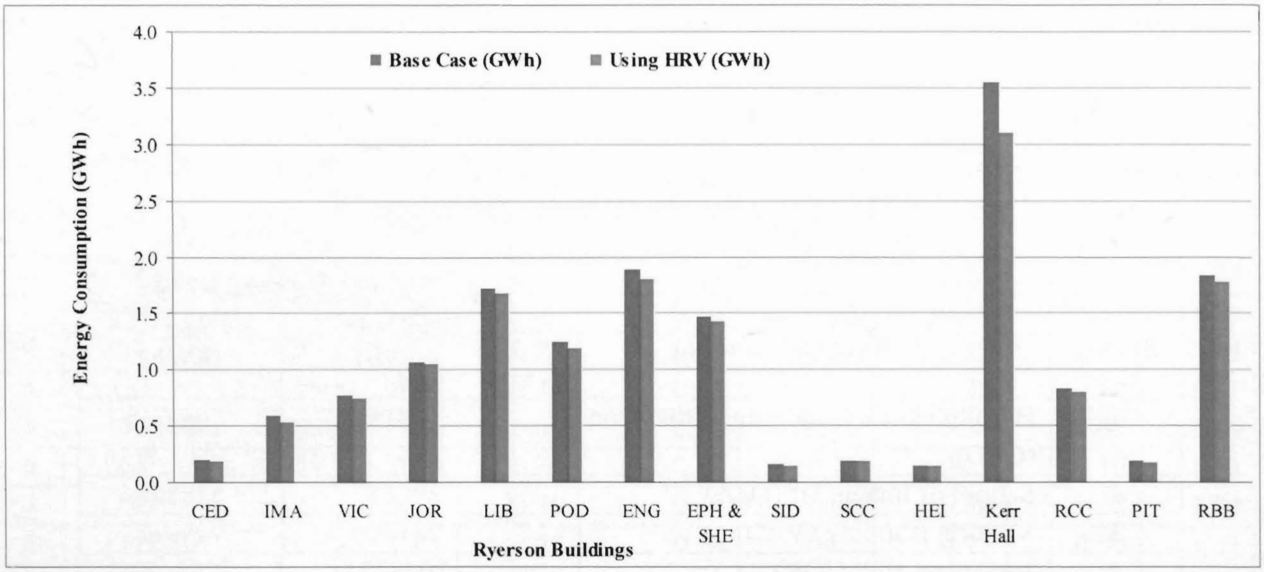

Figure 5.11: Comparison of Cooling Load Between Base Case and with Heat Recovery System

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Table 5.27: Comparison of Annual Heating Load with Heat Recovery Ventilation (HRV) for 16 Buildings of Ryerson University

Sl. No.	Name of building	Annual Heating Load	
		Base Case (kWh)	Using HRV (kWh)
1	Heaslip House Continuing Education (CED)	183831	122401
2	School of Image Art (IMA)	833069	376969
3	Victoria Building (VIC)	664253	314498
4	Jorgenson Hall (JOR)	403630	264693
5	Library Building (LIB)	232707	140976
6	Podium Building (POD)	585197	150695
7	Engineering Building (ENG)	1736162	827190
8	Eric Palin Hall (EPH)	547752	145137
9	Sally Horsfall Eaton Centre (SHE)		
10	Interior Design (SID)	95374	53490
11	Student Campus Centre (SCC)	190450	63135
12	Heidelberg Centre-School of Graphic Communications Management (HEI)	160195	29332
13	Kerr Hall (KNE, KNW, KSE, KSW)	9849907	801755
14	Rogers Communications Centre (RCC)	321243	206009
15	Pitman Hall (PIT)	146650	101972
16	Rogers Business Building (RBB)	1307372	491510
	Annual Total Cooling Load (kWh) =	**17257792**	**4089762**
		Annual Savings (%)	76%

Figure 5.12 graphically expresses the comparison of heating load between base case and with the heat recovery system. From the graphical analysis, it becomes apparent that Kerr Hall uses more steam due to the use of CAV air system. As a result, HRV provides the highest savings.

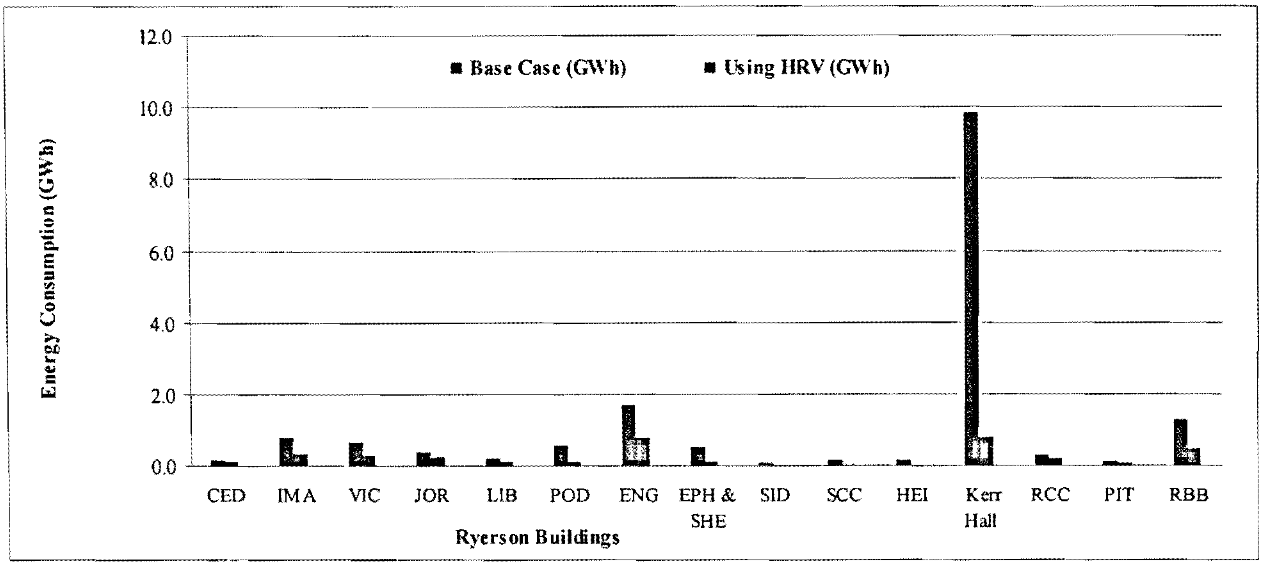

Figure 5.12: Comparison of Heating Load Between Base Case and with Heat Recovery System

5.4. Energy Intensity

The numbers of energy consumption were determined in relation to the total campus floor area. Energy intensity also depends on the age of the building, the energy source, the physical characteristics of the building, the air-conditioning settings, the floor area, the type of facilities, the degree to which energy conservation measures are implemented, and so forth. All floor area was used for the feasibility study, except unused space, void and mechanical room. Each factor affects the level of energy intensity independently and in its own complex way. Table 5.28 describes the energy intensity for each building of RU.

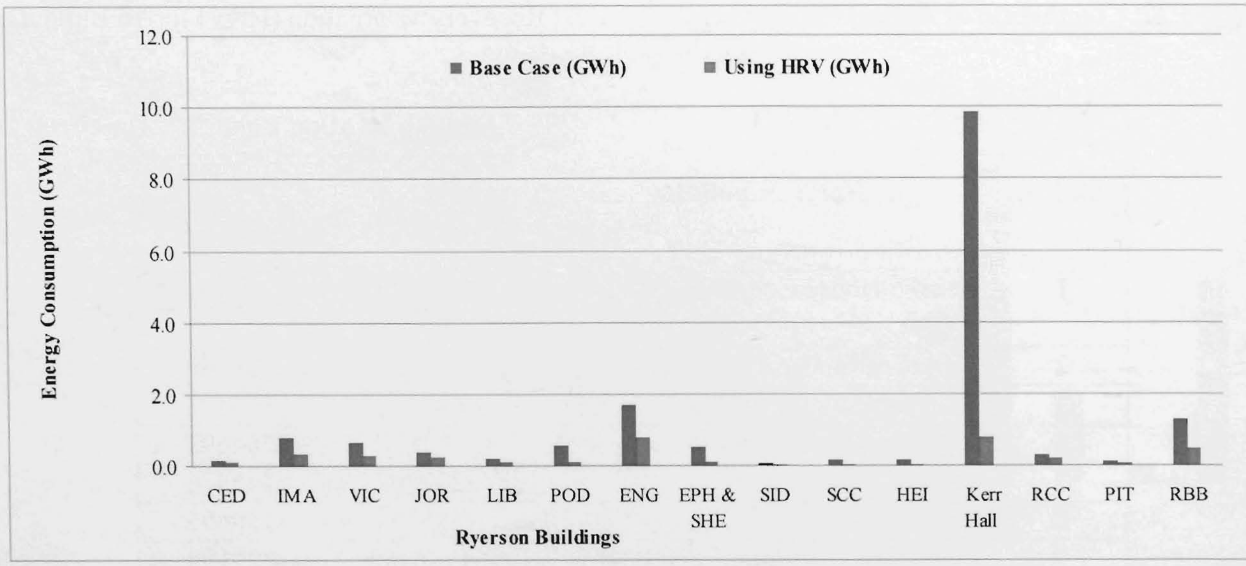

Figure 5.12: Comparison of Heating Load Between Base Case and with Heat Recovery System

5.4. Energy Intensity

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Table 5.28: Without Chiller Energy Intensity GJ/m^2 for 16 Ryerson University Buildings

Sl. No.	Name of the Building	Gross Area	Annual Energy Electricity	Annual Energy Steam	Total Energy	Energy Intensity
		(m^2)	(GJ)	(GJ)	(GJ)	(GJ/m^2)
1	Continuing Education (CED)	4180	1864	662	2526	0.60
2	School of Image Art (IMA)	9345	5127	2999	8126	0.87
3	Victoria Building (VIC)	12708	6669	2391	9060	0.71
4	Jorgenson Hall (JOR)	10964	9053	1453	10506	0.96
5	Library Building (LIB)	18487	24018	838	24856	1.34
6	Podium Building (POD)	21730	15237	2107	17344	0.80
7	Engineering Building (ENG)	22350	15828	6250	22078	0.99
8 & 9	Eric Palin Hall (EPH) & SHE	21019	13839	1972	15811	0.75
10	Interior Design (SID)	4373	1407	343	1750	0.40
11	Student Campus Centre (SCC)	4180	1674	686	2360	0.56
12	Heidelberg Centre-School (HEI)	2985	1606	577	2183	0.73
13	Kerr Hall	52409	28308	35460	63768	1.22
14	RCC Building (RCC)	13100	6522	1156	7678	0.59
15	Pitman Hall (PIT)	17866	10635	528	11163	0.73
16	Rogers Business Building (RBB)	24378	14203	4707	18910	0.78
	Total	**240074**	**155990**	**62129**	**218119**	**0.91**
		Conditioned Area				
		(m^2)				
	Chiller_LIB	188541	11346	20706	32052	0.17
	Chiller_RCC	13037	881		881	0.06

Figure 5.13 represents energy intensity for each building and chillers in GJ/m^2.

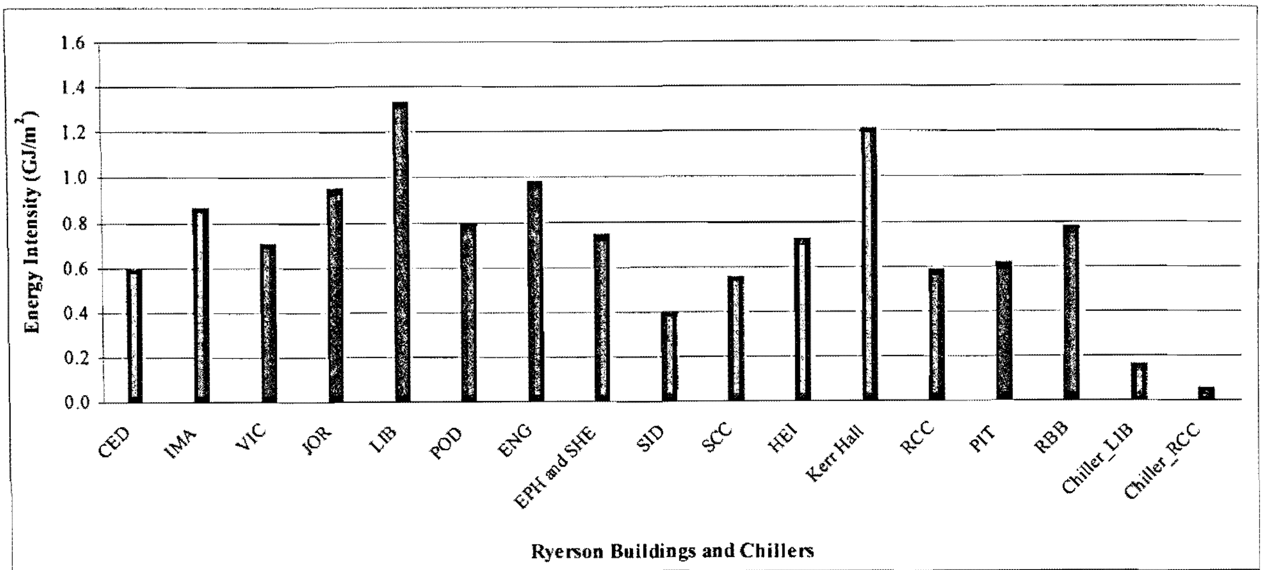
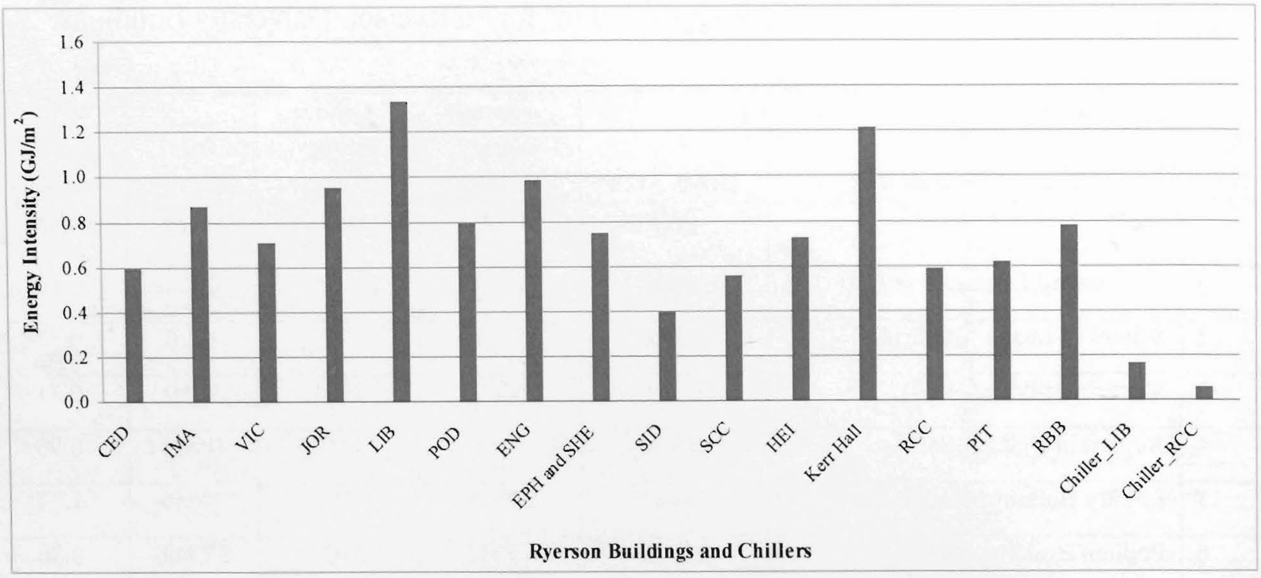


Figure 5.13: Energy Intensity GJ/m^2 for 16 Buildings and Chillers of Ryerson University

For the total chilled water production, the chiller consumes energy. So chiller energy intensity was added for each building. Table 5.29 and Figure 5.14 show the total energy intensity for each building including chiller energy intensity.

Table 5.29: Total Energy Intensity for each Building with and without Chillers

Building Name	**Total Energy Intensity**	
	Without Chiller	**With Chiller**
	(GJ/m^2)	**(GJ/m^2)**
CED	0.60	0.78
IMA	0.87	1.04
VIC	0.71	0.89
JOR	0.96	1.13
LIB	1.34	1.52
POD	0.80	0.97
ENG	0.99	1.16
EPH and SHE	0.75	0.92
SID	0.40	0.57
SCC	0.56	0.74
HEI	0.73	0.90
Kerr Hall	1.22	1.39
RCC	0.59	0.65
PIT	0.73	0.75
RBB	0.78	0.78



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	Without Chiller (GJ/m^2)	**With Chiller (GJ/m^2)**
CED	0.60	0.78
IMA	0.87	1.04
VIC	0.71	0.89
JOR	0.96	1.13
LIB	1.34	1.52
POD	0.80	0.97
ENG	0.99	1.16
EPH and SHE	0.75	0.92
SID	0.40	0.57
SCC	0.56	0.74
HEI	0.73	0.90
Kerr Hall	1.22	1.39
RCC	0.59	0.65
PIT	0.73	0.75
RBB	0.78	0.78

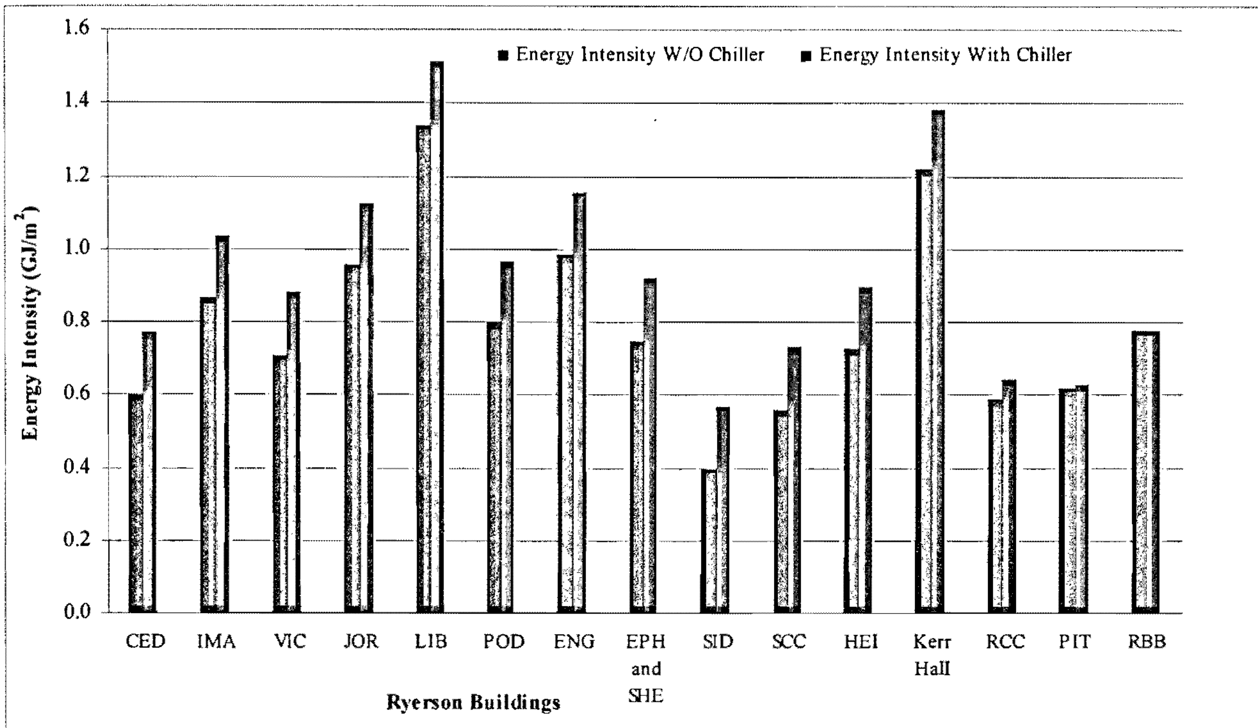


Figure 5.14: Energy Intensity (including chiller energy consumption) GJ/m^2 16 Buildings of RU

The NRCan 2003 survey collected data on the total campus floor area from the energy consumption data. To establish energy intensity ratios this data was used. Many factors have a direct bearing on energy intensity. The weather which is one of the leading factors affects energy consumption in different ways across Canada. Its impact is noticeable especially in regions where heating and cooling account for a significant portion of energy consumption. For example, the Prairies are relatively colder than British Columbia, and the quantity of energy used for heating in the Prairies is accordingly greater. Energy intensity also depends on the age of the building, the energy source, the physical characteristics of the building, the air-conditioning settings, the floor area, the type of facilities, the degree to which energy conservation measures are implemented, and so forth. Independently, each factor affects the level of energy intensity and in its own complex way (NRCan, 2005).

Figure 5.15 shows, for each region, the energy intensity of universities, expressed in gigajoules per square metre (GJ/m^2). Floor area is the total area of all the buildings of a sector. Total energy intensity for 16 buildings of Ryerson University was determined 1.04 GJ/m^2 which is much lower than the other universities.

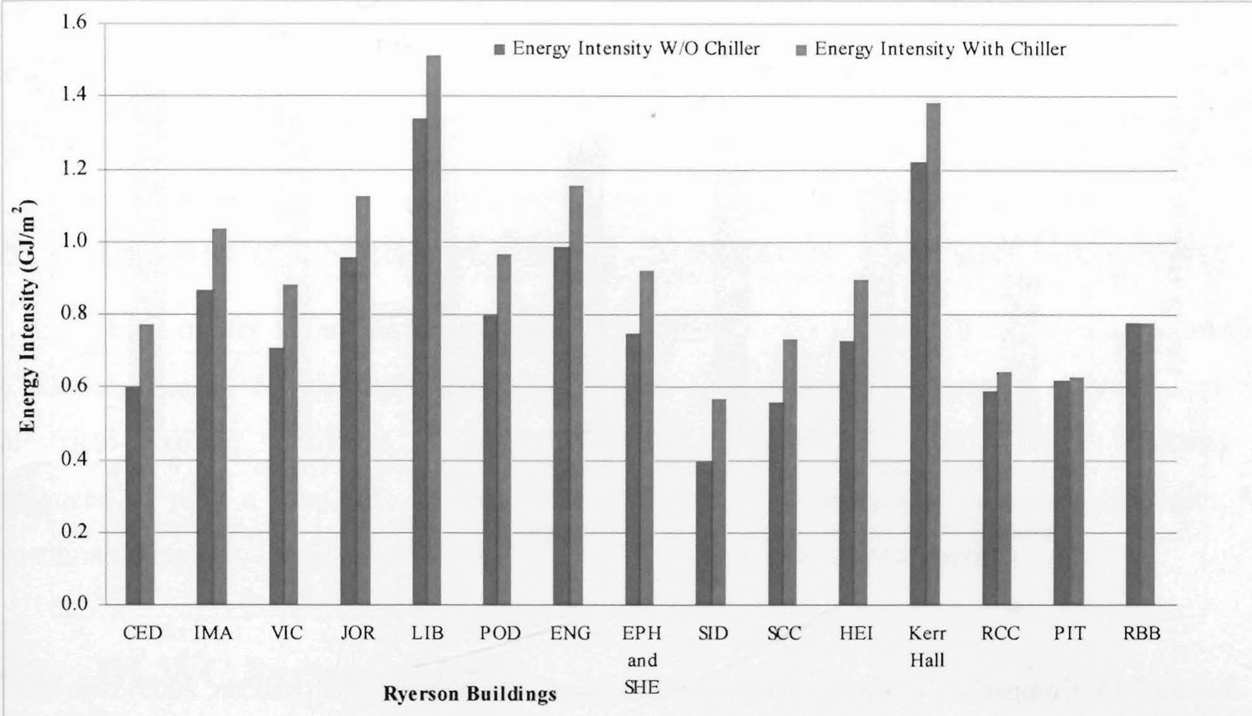


Figure 5.14: Energy Intensity (including chiller energy consumption) GJ/m^2 16 Buildings of RU

The NRCan 2003 survey collected data on the total campus floor area from the energy consumption data. To establish energy intensity ratios this data was used. Many factors have a direct bearing on energy intensity. The weather which is one of the leading factors affects energy consumption in different ways across Canada. Its impact is noticeable especially in regions where heating and cooling account for a significant portion of energy consumption. For example, the Prairies are relatively colder than British Columbia, and the quantity of energy used for heating in the Prairies is accordingly greater. Energy intensity also depends on the age of the building, the energy source, the physical characteristics of the building, the air-conditioning settings, the floor area, the type of facilities, the degree to which energy conservation measures are implemented, and so forth. Independently, each factor affects the level of energy intensity and in its own complex way (NRCan, 2005).

Figure 5.15 shows, for each region, the energy intensity of universities, expressed in gigajoules per square metre (GJ/m^2). Floor area is the total area of all the buildings of a sector. Total energy intensity for 16 buildings of Ryerson University was determined 1.04 GJ/m^2 which is much lower than the other universities.

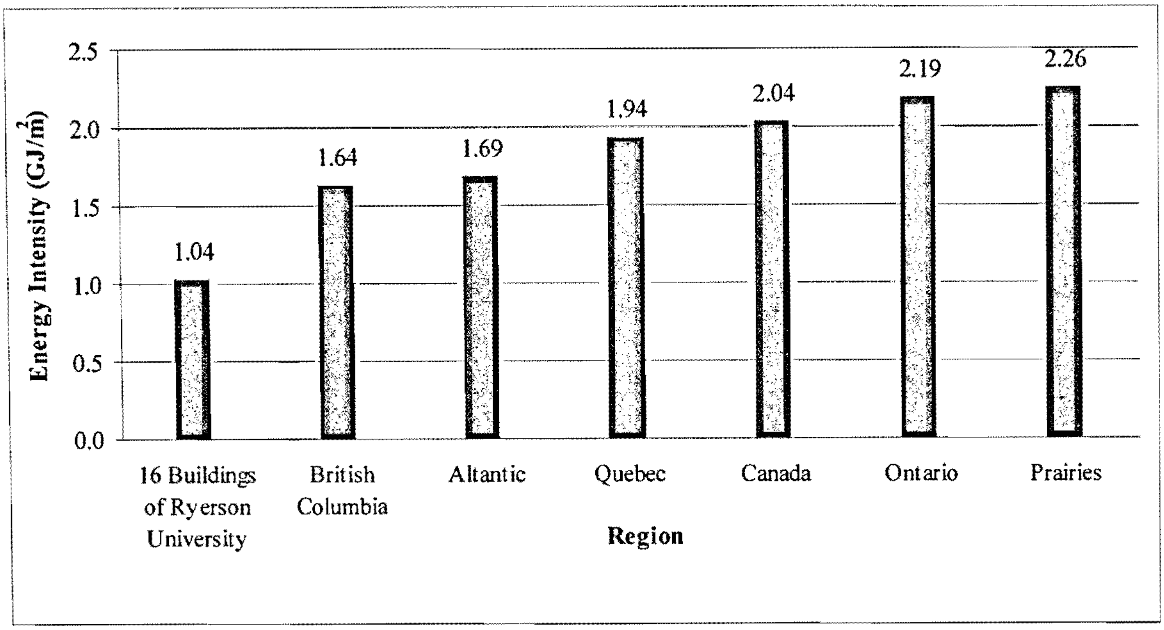


Figure 5.15: Comparison of Energy Intensity of Regional Universities, 2003 (NRCan, 2005) with RU

Figure 5.16 shows the total energy intensity per area vs. Ryerson buildings' gross area for each building including chiller energy intensity. According to the building gross area, it is clear that the Library Building has high energy consumption. The Library building uses more light and plug load than other buildings.

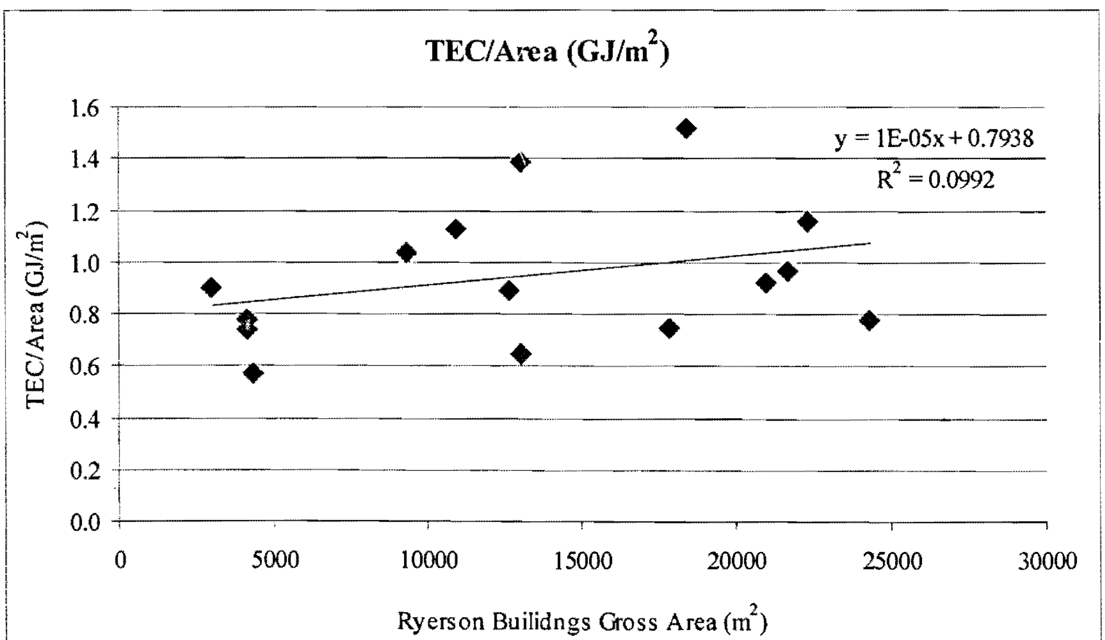
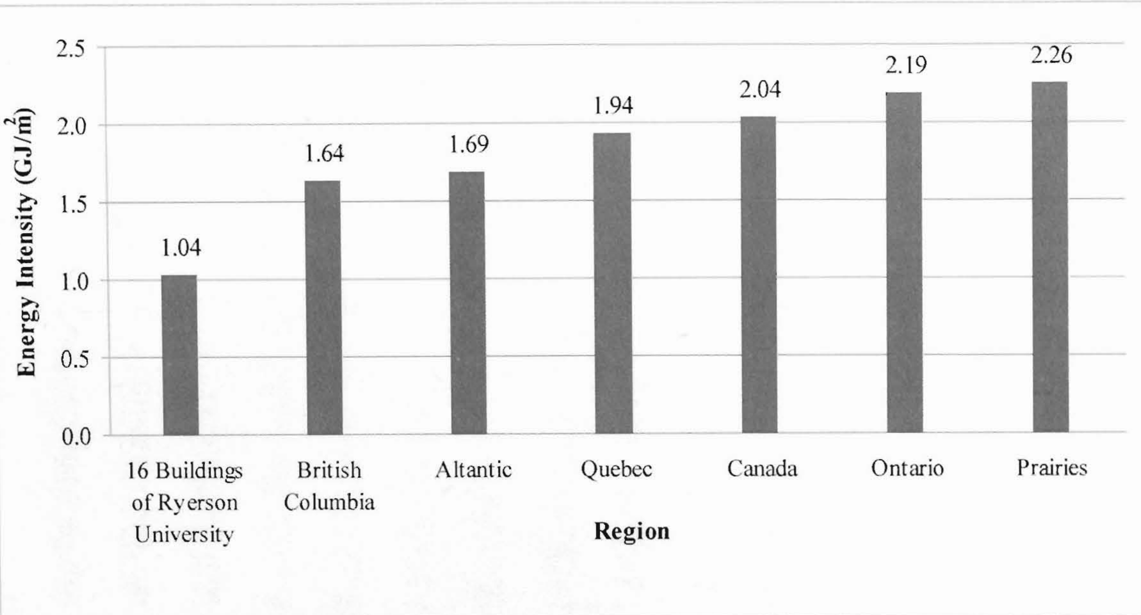


Figure 5.16: Energy Consumption GJ/m^2 vs. Ryerson Buildings Gross Area (m^2)



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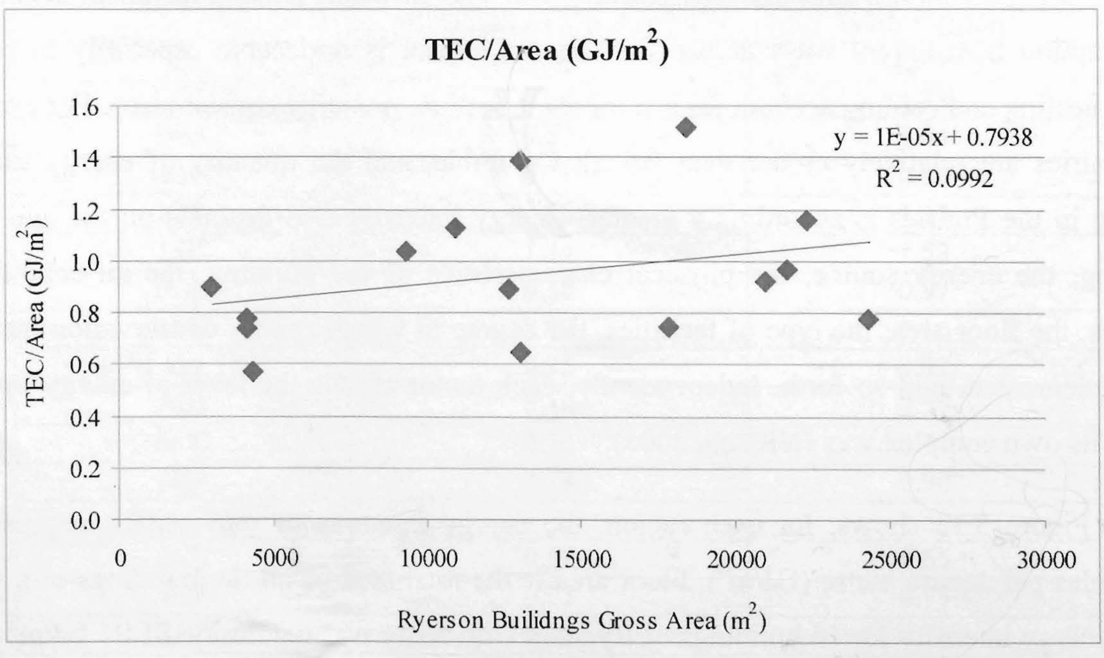

Figure 5.16: Energy Consumption GJ/m^2 vs. Ryerson Buildings Gross Area (m^2)

CHAPTER-6

6. Feasibility Study of DLWC System in Ryerson University

It is a matter of fact that in conventional chillers, CFCs are used. It becomes apparent that CFCs are blamed for damaging the ozone layer. The coal-fired generating stations used for electrical peaking contribute to global warming. However, the district energy industry is balanced to play a vital role around the world become committed to develop strategies for sustainable energy. Deep Lake Water Cooling (DLWC) system is one such strategy.

6.1. DLWC System of RBB

Ted Rogers School of Management (RBB) located at 575 Bay Street, is one of the main educational building of Ryerson University. The RBB is in the heart of the City of Toronto. Total building area of RBB is 24378 m^2. It includes classrooms, offices, auditoriums etc. From May 1st to October 31st, air-conditioning is required for this building. Deep Lake Water Cooling (DLWC) was chosen as the best alternative solution to meet the cooling requirements for RBB. The DLWC has been provided by the Enwave since 2006. According to Campus Planning data, the total remote chilled water consumption of RBB for year 2007 (May 1st to October 31st) was of 1936358 kWh.

Table 6.1 tabulates the total remote chilled water consumption of RBB.

Table 6.1: Chilled Water Consumption for the Year of 2007 of RBB

Year-2007	Chilled Water Consumption	Chilled Water Consumption
Month	**(Ton-hr)**	**(kWh)**
May	50027	175945
June	104070	366014
July	114476	402612
August	124155	436653
September	105148	369805
October	52695	185328
Total	**550,571**	**1936358**

Figure 6.1 graphically presents the chilled water consumption per month. As per graph, it is clear that the cooling demand of RBB for the month of August is higher than any other month.

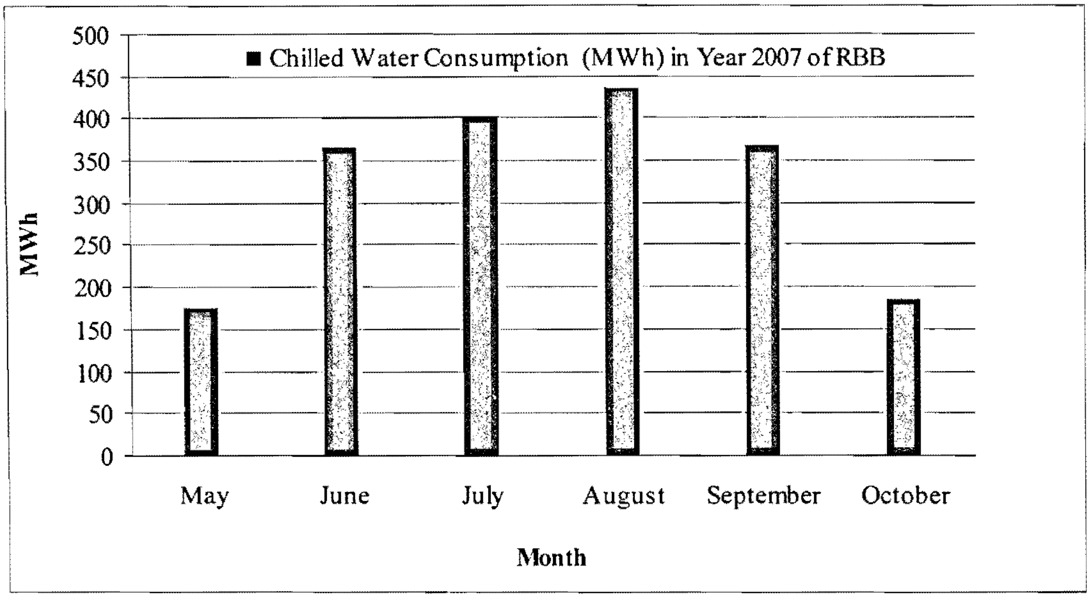

Figure 6.1: Actual Chilled Water Consumption (MWh) in Year 2007 for RBB

According to base case simulation of RBB building, HAP results provided chilled water consumption of 1.8 GWh for the month May to October. Table 6.2 represents the chilled water consumption difference which of 4.7%.

Table 6.2: Chilled Water Consumption difference of RBB

Building Name	Actual Chilled Water Energy Consumption	HAP Chilled Water Energy Consumption	Difference
	(kWh)	(kWh)	(%)
RBB	1936358	1845076	4.7

6.1.1. Potential Benefit of DLCW for RBB

Carrier HAP provides the simulated hour by hour remote chilled water requirement. For the potential savings and GHG emission benefit comparison with conventional chiller, a total load of 2538 kWh conceptual electric chillers was designed.

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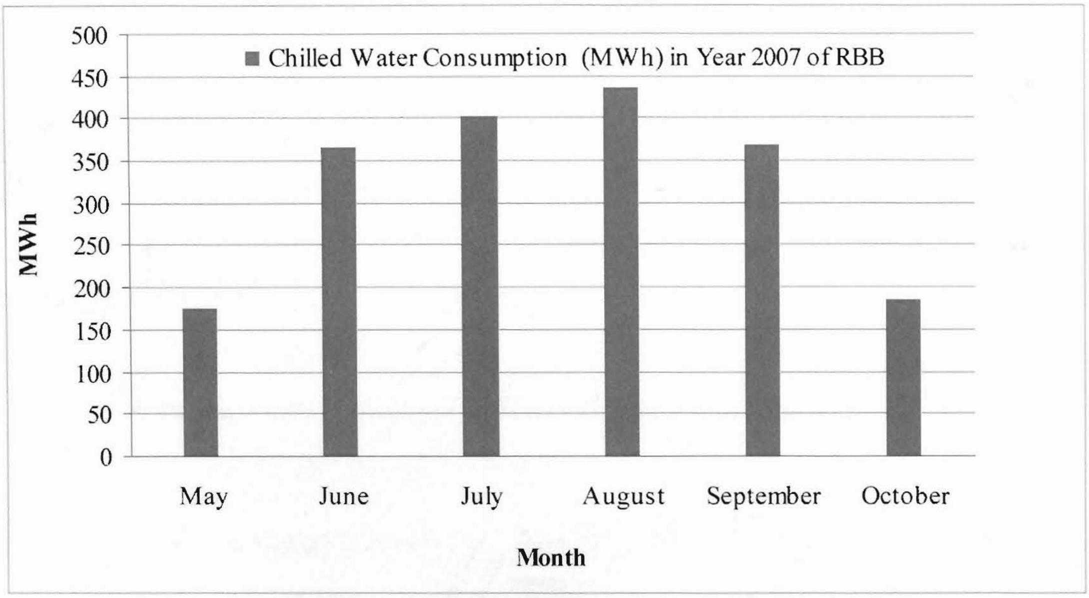

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For base case simulation, the chiller electricity consumption was 924594 kWh as shown in Table 6.3.

Table 6.3: Electricity Consumption for Model Chiller Plant of RBB.

Electricity	**Consumption**
	(kWh)
Chiller Input	683466
Chilled water pump	109126
Cooling Tower Fan	132001
Total	**924594**

The model chiller and cooling tower specification are shown in Table 5.6, 5.7 and 5.8 and Table 5.9. A set of 8760 hour data was analyzed from the HAP simulation result. The total cooling load for the RBB was of 1845076 kWh. From the hourly analysis, electricity consumption for the base case chiller was 924594 kWh with GHG emission of 204829 kg of CO_2, 203 kg of NOx and 511 kg of SO_2. For analyzing the GHG production, hourly GHG emission factors were used (Gordon and Fung, 2009) as tabulated in Table 6.4.

Table 6.4: Hourly Electricity and GHGs Production for Base Case

Year	Electricity Consumption (kWh)	CO_2 (kg)	NO_x (kg)	SO_2 (kg)
2007	924594	204829	203	511

According to Enwave chilled water consumption data, the overall plant efficiency of Enwave is between 0.2 kW/Ton and 0.3 kW/Ton for delivering chilled water to the RBB. The maximum peak cooling load of 2538 kW occurs on July 9th at 1200 hour. For total DLWC system electricity consumption calculation, Enwave plant efficiency, minimum outdoor temperature of 11.2°C and maximum outdoor temperature 32.3°C was considered. Total calculation is shown in Appendix D. Table 6.5 gives a summary of the result.

Table 6.5: Hourly Electricity and GHGs Production for DLWC

Year	Electricity Consumption (kWh)	CO_2 (kg)	NOx (kg)	SO_2 (kg)
2007	132931	30176	35	35

Table 6.6 represents the total saving of electricity consumption and reduction of gas emission for conventional chiller and DLWC system. As per Table 6.6, 791663 kWh of electricity was saved for air-conditioning of RBB. GHGs emission was calculated from the HAP hourly analysis. The total amount of gas emissions (CO_2, NO_x, SO_2) reduction was 175093 kg.

Table 6.6: Annual Electricity Savings and Emissions Reductions due to DLWC for RBB

Year	kWh Saved	CO_2 (kg)	NOx (kg)	SO_2 (kg)
2007	791663	174652	238	203
(%) Reduced	86	85	85	85

6.2. Proposed DLWC System of Ryerson University Campus

Ryerson University campus is situated in downtown Toronto. Specially, in summer time, in the month of May to October, campus buildings become very hot. This is the main reason that campus needs air-conditioning for each building.

The University has two central cooling plants. The largest plant has a capacity of 3100 tons where 5 chillers are used. It is located at Ryerson Library Building. It serves 66% of the total campus area. Smaller plant has capacity of 530 ton where 2 chillers are used. It is located at Ryerson Rogers Communication Centre and serves 11% of the total area. Rogers Business Building already has DLWC system. This DLWC system serves 9% of the total campus area for

RBB. 77% of total campus area, served by 2 different chiller plants is considered for DLWC feasibility analysis. The proposed flow diagram for DLWC system is shown in Figure 6.2.

To implement this DLWC system within the Ryerson buildings would require minimal effort. The buildings already have heat exchangers which could be connected to the DLWC system supply pipe. Enwave already has the DLWC system plant for serving the required amount of remote chilled water for the selected buildings. Furthermore, some minor upgrades to the existing cooling system would need to be implemented. After it is completed, existing chillers and cooling towers can be decommissioned.

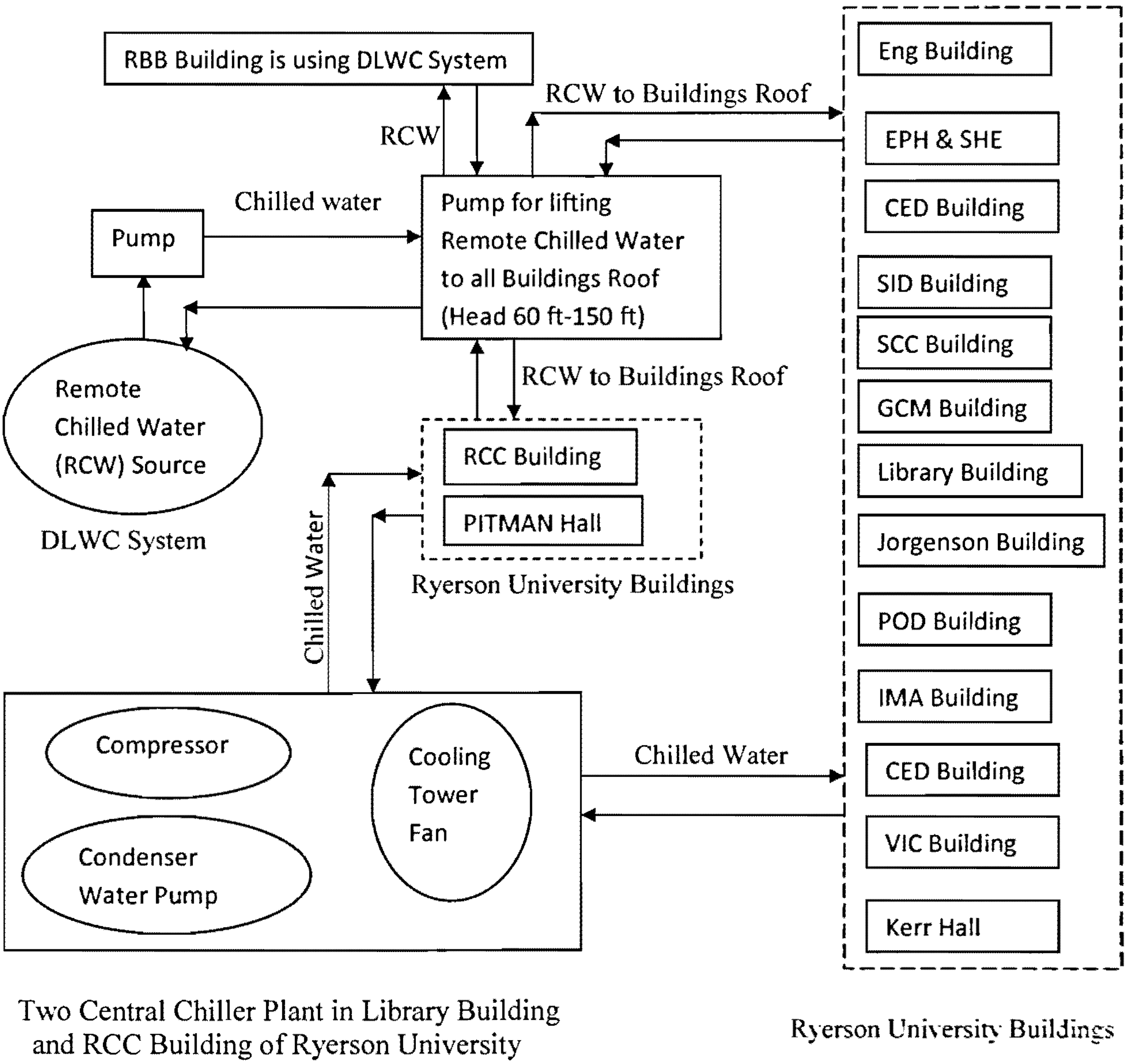


Figure 6.2: Proposed DLWC System for Entire Ryerson University Campus

Based on the Rogers Business Building case study, the total energy savings and amount of reduction of gas emission for rest of selected buildings of RU was determined.

6.3. Comparison between existing Conventional Chiller and DLWC System

Analyzing the base case energy demand for two central chiller plants of RU, Carrier HAP has given hour by hour energy consumption data. For Library chiller plant, two types of energy are used for chiller input. They are steam and electricity. Another chiller plant only uses electricity for its input.

6.3.1. Potential Benefit for DLWC of RU Buildings

DLWC systems generate huge energy savings primarily by eliminating the chiller-based cooling.

Based on the estimated energy savings, the overall plant efficiency of Enwave was considered between 0.2 kW/ton and 0.3 kW/ton for delivering the chilled water to the RBB. Total steam consumption for Library chiller plant was 5751754 kWh and electricity consumption was 3151780 kWh. Table 6.7 presents the total energy savings due to the use of DLWC system. This represents about 89.2% reduction in energy consumption for RU campus cooling.

Table 6.7: Energy Consumption due to Conventional Chillers and DLWC System

Energy Consumption By	Energy Consumption due to Conventional Chillers (kWh)	Energy Consumption due to DLWC System (kWh)	Energy Savings (%)
Steam Consumption by Chillers in the Library Building	5751754	-	100
Electricity Consumption by Chillers in the Library Building	3151780	924646	70.6
Electricity Consumption by Chillers in the RCC Building	244687	70351	71.2
Total Energy Consumption(kWh)	**9148221**	**994997**	**89.2**

Figure 6.3 graphically presents the total energy consumption of conventional chillers and DLWC.

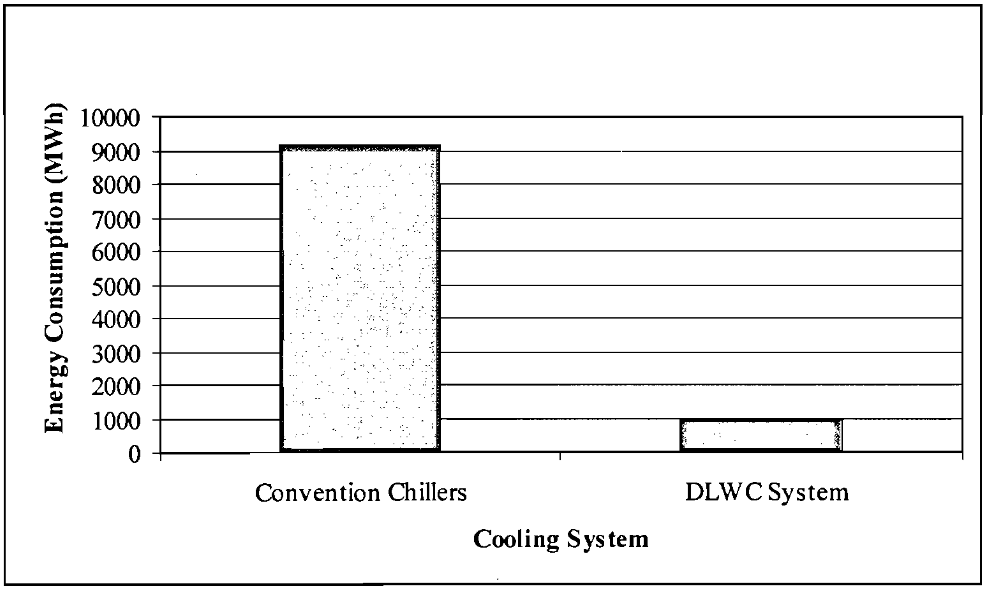


Figure 6.3: Annual Energy Consumption for Conventional Chillers and DLWC System

For Ryerson University cooling, the annual energy costs were estimated based on Time of Use (TOU) price and Flat Rate price. Steam cost was calculated by using the flat rate of \$0.03/lb. The total cost of 91% for TOU price and 91.5% for Flat Rate price are reduced due to the use of DLWC system for air conditioning of Ryerson University. TOU prices are shown in

Table 4.14. From hourly analysis, Annual energy cost due to conventional chillers and DLWC system are shown in Table 6.8.

Table 6.8: Annual Energy Cost due to Conventional Chiller and DLWC System

Type of Energy Consumption by Chillers	Total Annual Cost		Total Savings (TOU)	Total Annual Cost		Total Savings of Electricity Cost Due to Flat Rate For Conventional Chillers
	Chillers (TOU)	DLWC System (TOU)		Chillers (Flat Rate)	DLWC System (Flat Rate)	
	($)	($)	(%)	($)	($)	(%)
Steam used by Chillers in the Library Building	840064	-	100	840064	-	**7.5**
Electricity used by Chillers in the Library Building	339826	99928	91.5	315172	92465	
Electricity used by Chillers in the RCC Building	27321	8043	70.6	24469	7035	
Total Cost ($)	**1207221**	**107971**		**1179750**	**99500**	
Total Cost Reduced (%)	**91%**			**91.5%**		
Steam (Flat Rate) = $0.03/lb and electricity (Flat Rate) = $ 0.10/kWh						

Figure 6.4 represents the annual energy cost due to conventional chillers and DLWC system. As per the graph, it is clear that the DLWC system generates a large amount of energy cost savings for air-conditioning of Ryerson University. The graph also represents the benefit of Flat Rate price. If Ryerson University uses TOU price, it will pay 7.5% more on its electricity bill.

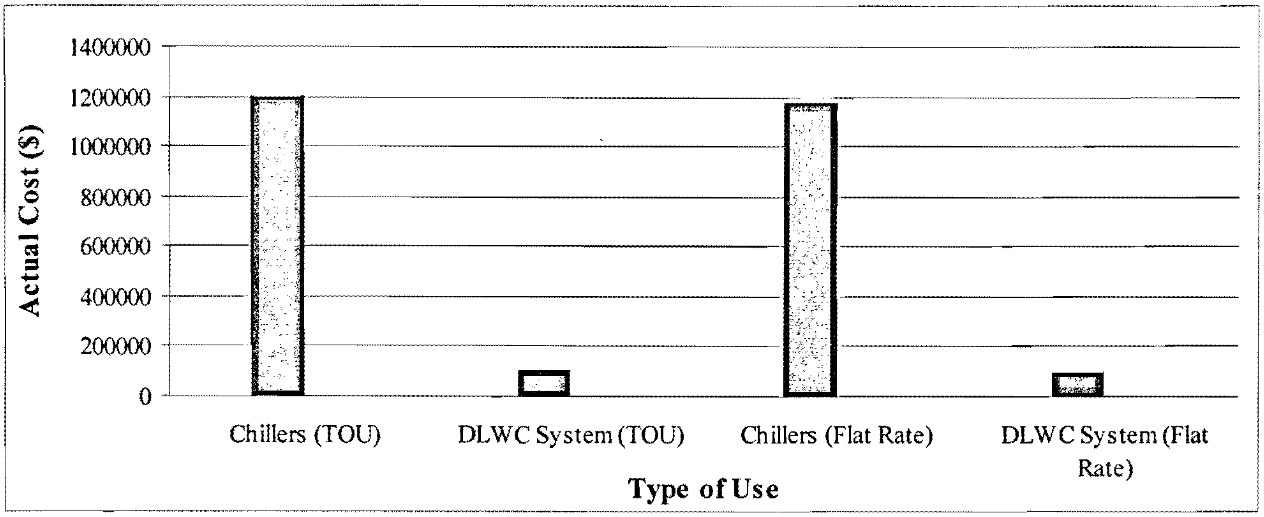


Figure 6.4: Annual Energy Cost due to Conventional Chiller and DLWC System

6.3.2. GHGs Emission of RU Buildings

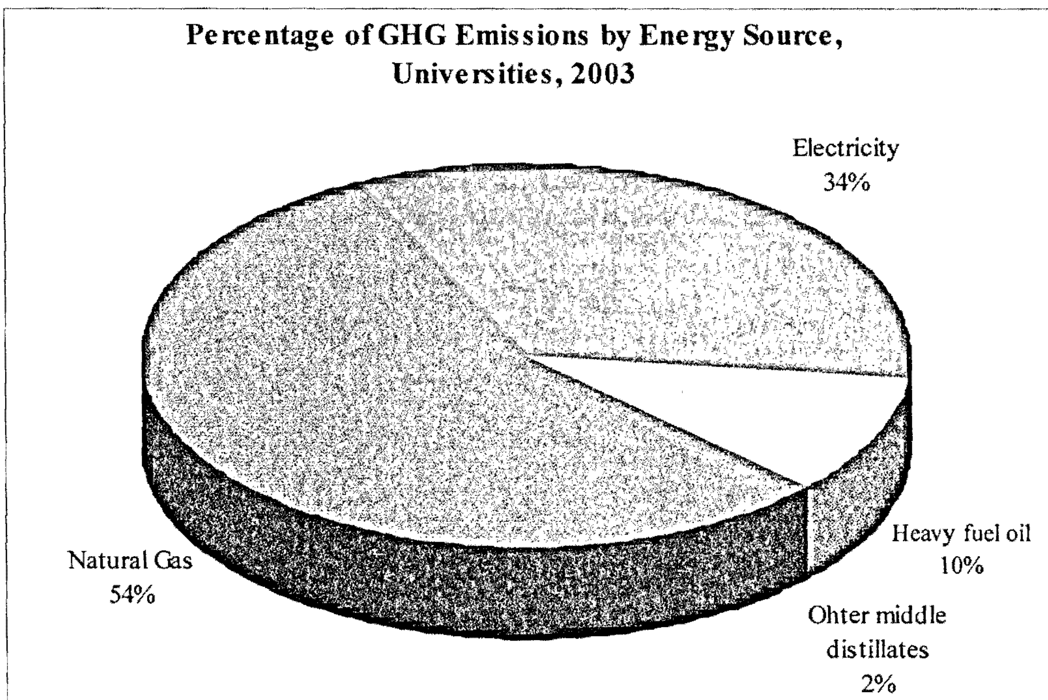
The energy survey report (NRCan, 2005) for consumption of energy for universities. In 2003, considers three types of GHGs: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Table 6.9 shows, for each region, the total GHG emissions of universities are associated with their three main energy sources, namely natural gas, electricity and heavy fuel oil.

In 2003, the energy consumption of universities alone produced more than 2 million tonnes of GHG emissions. This emission is equivalent to the average annual emissions of approximately 595000 compact cars or 389000 sport utility vehicles. Ontario universities accounted for 37 percent of the total emissions, compared with 25 percent for the Prairies, 18 percent for Quebec, 12 percent for the Atlantic region, and 8 percent for British Columbia and the Territories. GHG emissions by energy source for universities are shown in Table 6.9.

Table 6.9: GHG Emissions (thousands of tonnes) by Energy Source for Universities (NRCan, 2005)

Region	Natural Gas	Electricity	Heavy fuel oil	Total Energy
Atlantic	-	62	156	251
Quebec	183	150	27	366
Ontario	500	237	5	746
Prairies	314	190	-	514
British Columbia	93	63	3	160
Total	1090	701	198	2037

The percentage of GHG emissions attributed to each of the energy sources is shown in Figure 6.5. The use of natural gas accounted for 54 percent of the universities' GHG emissions, compared with 34 percent for electricity and 10 percent for heavy fuel oil. Regionally, the use of natural gas accounted for 67 percent of the universities' GHG emissions in the Prairies, 57 percent in British Columbia and the Territories, 52 percent in Quebec and 50 percent in Ontario. The use of heavy fuel oil was the main source of emissions for the Atlantic region, because it is accounted for 62 percent of this region's emissions (NRCan, 2005).



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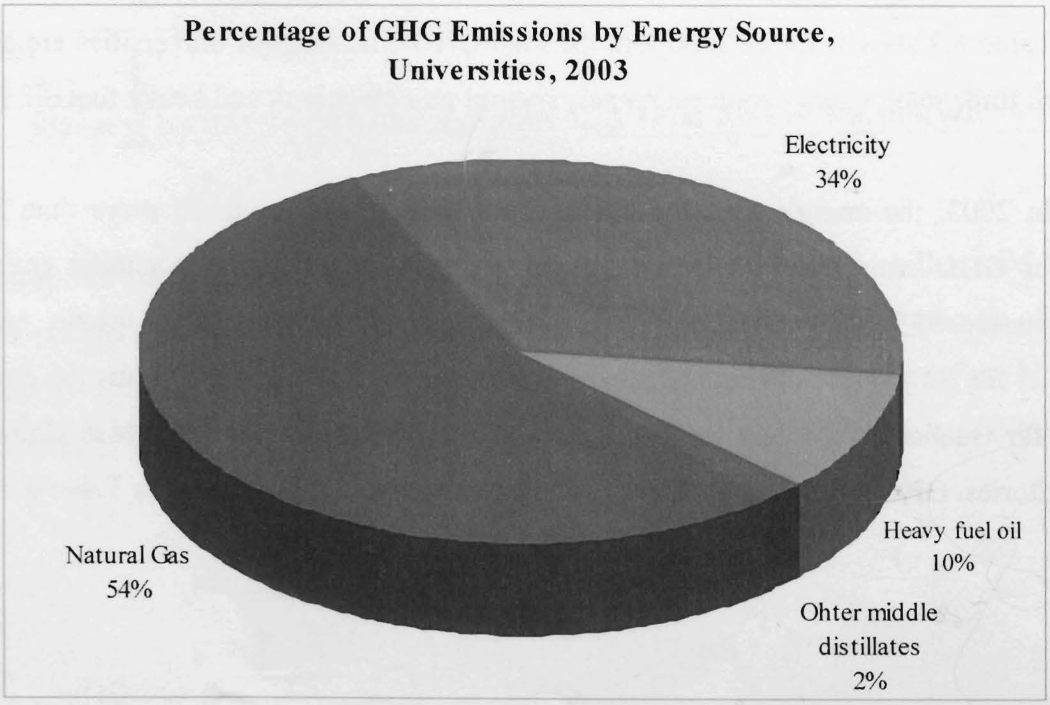


Figure 6.5: Percentage of GHG Emissions by Energy Source for Universities (NRCan, 2005)

Due to the calculation of total steam consumption for chiller plant of RU, some factors were considered. For example, low pressure steam required 1200 BTUs to 1400 BTUs of input energy to produce 1 pound of steam. Steam is produced at 85% efficiency. One standard m^3 natural gas (NG) has 35.312 kBTU. Steam is produced by using Natural Gas (www.energysolutionscenter.org/boilerburner/Eff_Improve/Steam_Distribution/Steam_Trap_Leaks.asp). Table 6.10 indicates the natural gas consumption and the total amount of CO_2 produced. Table 6.10 also represents the conversion of natural gas and steam.

Table 6.10: Natural Gas and Steam Conversion Table

Steam Consumption due to absorption chiller (kWh)	5751754	
Natural Gas Consumption (m^3) due to produced steam	655560	Steam is produced at 85% efficiency
Total amount of CO_2 produced (kg) – Based on emission factors	1246875 kg CO_2	Emission Factor of Natural Gas = 1.902 kg/m^3 (NRCan, 2007)

In a feasibility study project of RU, three types of GHGs are considered: carbon dioxide (CO_2), nitrous oxide (N_2O) and Sulphur dioxide SO_2. Table 6.11 shows the total GHG emissions of Ryerson University associated with their two main energy sources, namely natural gas and electricity. In 2006, the energy consumption of Ryerson University alone produced 2183 tonnes of CO_2, 0.96 tonnes of N_2O and 2.4 tonnes of SO_2 emissions. Gas emissions due to conventional chiller and DLWC system are shown in Table 6.11. The emission calculation was done in an hourly manner. For electricity, TOU emission factors were used (Gordon and Fung, 2009).

Table 6.11: GHGs Emission due to Conventional Chiller and DLWC System

Type of Energy Consumption	Total amount of CO_2 produce by chillers (kg)	Total amount of CO_2 produce by DLWC System (kg)	Total amount of SO_x produce by chillers (kg)	Total amount of SO_x produce by DLWC System (kg)	Total amount of NO_x produce by chillers (kg)	Total amount of NO_x produce by DLWC System (kg)
Steam used by Chillers in the Library Building	1246875	-	-	-	20	-
Electricity used by Chillers in the Library Building	677523	207133	1971	604	787	241
Electricity used by Chillers in the RCC Building	55587	16410	161	49	65	19
Total Gas Emission (Ton)	**2183**	**246**	**2.40**	**0.71**	**0.96**	**0.29**
Total Gas Emission Reduction (%)	**89**		**70.4**		**70**	
NO_x emission factor for Natural Gas =0.03 gm/m^3 (NRCan, 2004)						

Figure 6.6 shows the percentage of GHG emission reduction associated with the use of DLWC, reduction of 89% of CO_2, 70.4% of SO_2 and 70% of N_2O were achieved.

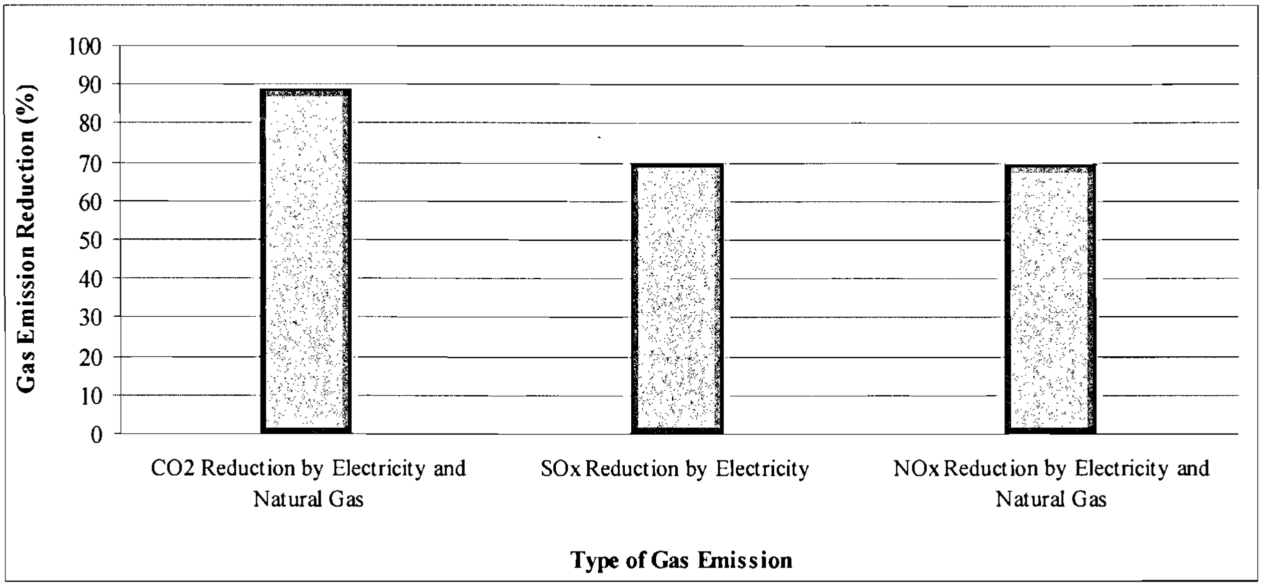


Figure 6.6: Percentage of Gas Emission Reduction due to DLWC System

Figure 6.7 shows the percentage of CO_2 and NO_x emissions attributed to each of the energy sources. According to base case analysis, the use of natural gas accounted for 63 percent of the Ryerson University GHGs emissions, compared with 37 percent for electricity of total energy use for chillers.

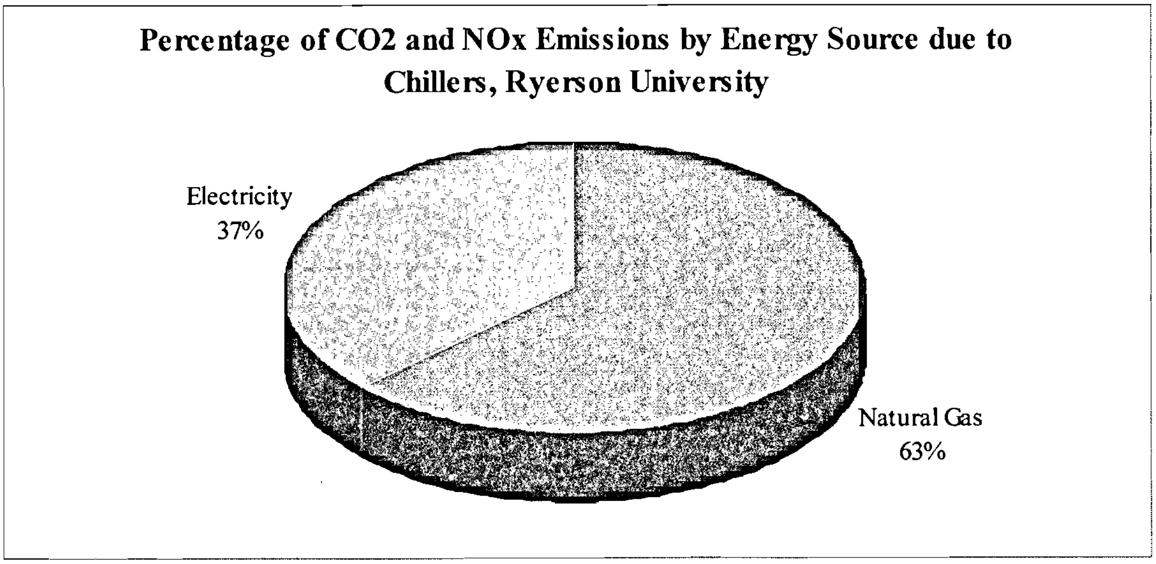
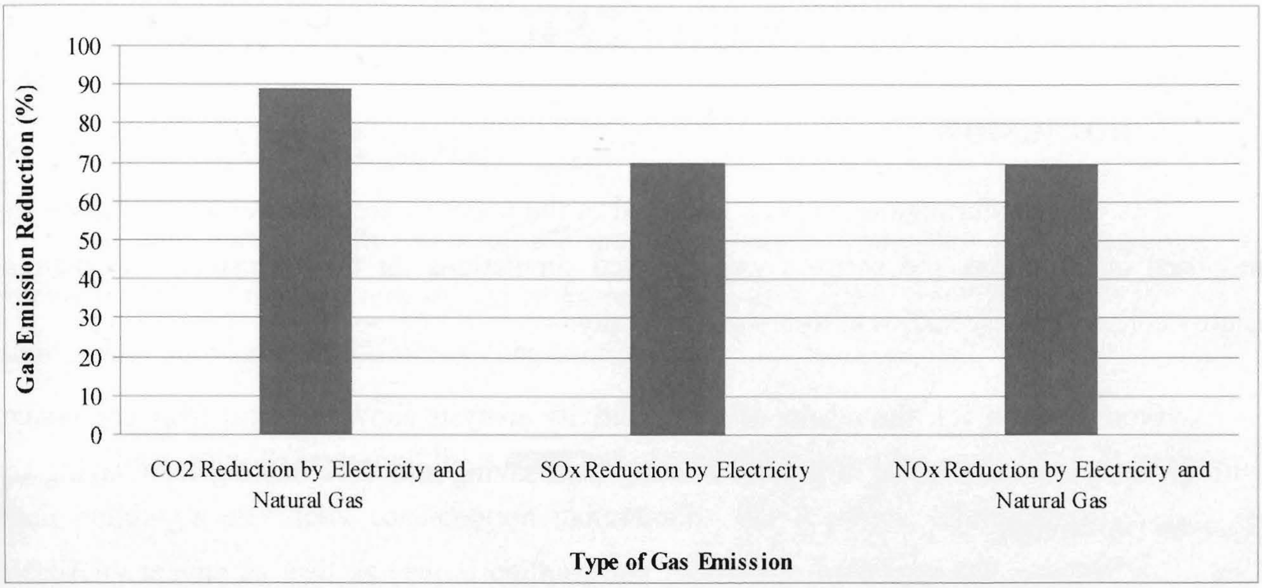


Figure 6.7: Percentage of CO_2 and NO_x Emission by Energy Source for Ryerson University due to Chillers



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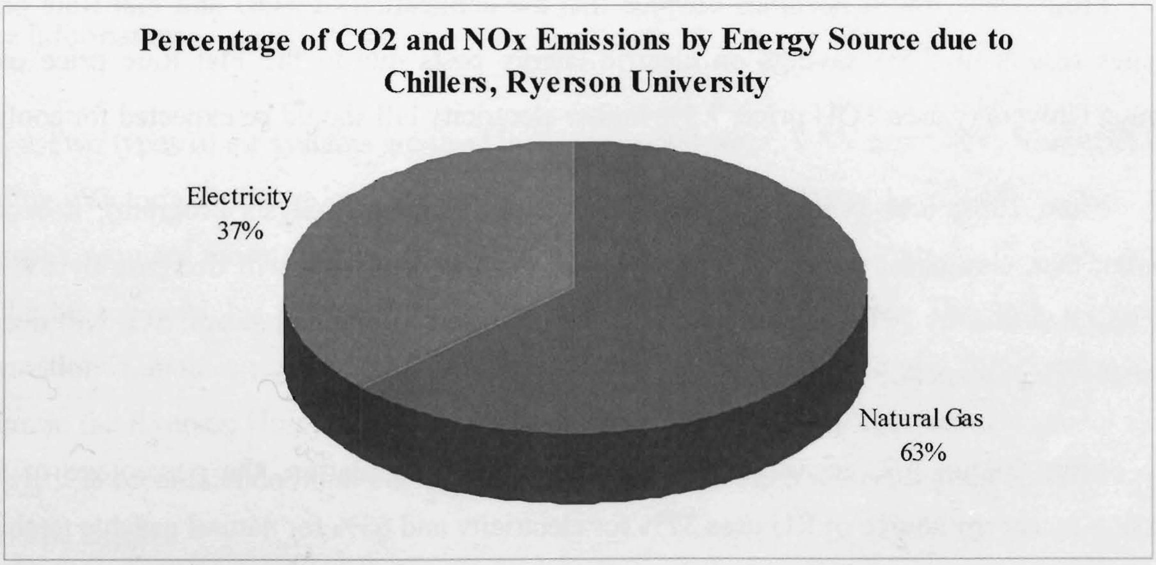

Figure 6.7: Percentage of CO_2 and NO_x Emission by Energy Source for Ryerson University due to Chillers

CHAPTER-7

7. Conclusion

The above information that was reviewed in the previous sections was used to audit the proposed interventions and perform well targeted simulations for the assessment of potential energy conservation scenarios at Ryerson University.

From Section 5.3, the results of the sensitivity analysis show that heat recovery system with air system would result in a 5.6% cooling load saving and 76% heating load saving for Ryerson University.

In Section 5.4, energy intensity of Ryerson University was determined and compared with other regional universities. From Figure 5.13, it is clear that the total energy intensity of Ryerson University was 1.04 GJ/m^2 which is much lower than the other universities.

From Section 6.3.1, it becomes apparent that the implementation of DLWC system over the conventional HVAC system would result in 89.2% energy savings due to chillers, with the energy consumption from 9148221 kWh to 994997 kWh.

From Table 6.8, it becomes obvious that the application of TOU and Flat Rate pricing schemes results in 7.5% savings on electric energy costs due to the Flat Rate price use. If Ryerson University uses TOU price, 7.5% higher electricity bill should be expected for cooling.

From Table 6.11 (which is based on Carrier's Hourly Analysis Program), it becomes apparent that, comparing base case with DLWC, the CO_2 emission will decrease by 89% and NO_x will decrease by 70% for chillers due to the use of electricity and steam. SO_x will decrease by 70.4% for chillers due to use of electricity.

From Figure 6.7, according to base case energy simulation, the percentage of GHG emission by energy source of RU uses 37% for electricity and 63% for natural gas due to chiller.

DLWC system is both technically and economically feasible today and, once installed, the energy supply is inexhaustible, renewable, and has minimal environmental impacts.

CHAPTER-8

8. Recommendations

In this energy audit, 86% of the area of Ryerson University was considered; the remaining 14% of the total area should be properly audited in order to achieve the proper energy audit result, 100% area of RU needs to be considered.

Since many Ryerson buildings shear one electricity meter, it becomes difficult to evaluate each building's electricity consumption individually. For a proper electricity audit, separate electricity meters as well as central chiller plant electricity meters should be installed in each building.

The main obligation of electricity simulation for each building is a lack of information about plug load. The plug load of Library building and the RCC Building has different types of pump due to chiller plants. EPH and SHE, the Engineering Building, Kerr Hall have different types of laboratories. The plug load information for these buildings are not readily available.

The steam consumption bill from the Campus Planning was not clear to get total steam usage information.

Two types of air systems are used in Ryerson buildings, VAV and CAV. Kerr Hall, IMA building, Victoria Building and Jorgenson Hall have CAV system. In HVAC system, CAV system is requires more energy than VAV. To reduce energy consumption, all CAV systems should be replaced by VAV systems. Some buildings are very old. The lack of building information is another reason causing in proper energy consumption result. The existing HVAC system in the Ryerson University does not have any energy recovery equipment. In order to save energy, it is recommended that energy recovery equipment such as, ventilation reclaim systems should be used.

For DLWC system feasibility study, Enwave chilled water bill was not provided. To determine DLWC system, cooling cost should be provided.

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Appendix A: GHG Emission factors of Natural Gas (Source: NRCan, 2007)

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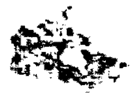

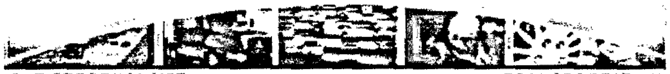

FOR PERSONAL USE — TRANSPORTATION

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APPENDIX A: CONVERSION AND EMISSIONS FACTORS USED

Factor / Conversion	Description	Fuel	Value	Units	Source
Energy Content	Amount of energy in primary fuel	Natural Gas	0.03723	Gj/m³	Natural Resources Canada, Issues Tables, 1998–1999, 1999, www.nccp.ca/NCCP/national_process/issues/index_e.html
		Liquid Petroleum Gas (LPG/propane)	25.53	Gj/m³	National Energy Board [of Canada], *An Energy Market Assessment – Conversion Factors*, Retrieved December 2004
		Light Fuel Oil #2	38.68	Gj/m³	Natural Resources Canada, *Canada's Emissions Outlook: An Update*, 1999
		Heavy Fuel Oil #6 (Bunker C)	41.73	Gj/m³	
Capacity Factor	Average efficiency of combustion over year	Natural Gas	80%	%	Marbek Resource Consultants
		Liquid Petroleum Gas (LPG/propane)	70%	%	
		Light Fuel Oil #2	80%	%	
		Heavy Fuel Oil #6 (Bunker C)	80%	%	
GHG Emissions Factors	Industrial combustion	Natural Gas	1.902	$kgCO_2e/m^3$	Environment Canada, *Canada's Greenhouse Gas Inventory, 1990–2002*; Annex 7: Emission Factors, August 2004
		Liquid Petroleum Gas (LPG/propane)	1534	$kgCO_2e/m^3$	
		Light Fuel Oil #2	2840	$kgCO_2e/m^3$	
		Heavy Fuel Oil #6 (Bunker C)	3112	$kgCO_2e/m^3$	
GHG Emissions Factors	Ontario average in 2002	Electricity	0.253	$kgCO_2e/kWh$	Environment Canada, *Canada's Greenhouse Gas Inventory, 1990–2002*; Annex 13: Electricity Intensity Tables, August 2004
	Quebec average in 2002	Electricity	0.0013	$kgCO_2e/kWh$	
	Nova Scotia average in 2000	Electricity	0.759	$kgCO_2e/kWh$	
Volume Conversion	–	–	1000	litres/m³	www.onlineconversion.com/

Appendix A: GHG Emission Factors of Natural Gas (Source: NRCan, 2004)

A13.1.1.2 Methane (CH_4)

Emissions of CH_4 from fuel combustion are technology dependent. Sectoral emission factors (Table A13-1) have been developed based on technologies typically used in Canada. The factors were developed based on a review of emission factors for combustion technologies and an analysis of combustion technologies (SGA, 2000). The emission factor for the producer consumption of natural gas was developed based on a technology split for the upstream oil and gas industry (CAPP, 1999) and technology-specific emission factors from the U.S. EPA report AP-42 (EPA, 1996).

TABLE A13-1: Emission Factors for Natural Gas and NGLs (Energy Stationary Combustion Sources)

Source	Emission Factors		
	CO_2	CH_4	N_2O
Natural Gas	**g/m³**	**g/m³**	**g/m³**
Electric Utilities	1891[1]	0.49[2]	0.049[2]
Industrial	1891[1]	0.037[2]	0.033[2]
Producer Consumption	2389[1]	6.5[3,4]	0.06[2]
Pipelines	1891[1]	1.9[2]	0.05[2]
Residential, Commercial, Agriculture	1891[1]	0.037[2]	0.035[2]
Natural Gas Liquids	**g/L**	**g/L**	**g/L**
Ethane	976[1]	n/a	n/a
Propane	1500[1]	0.024[2]	0.108[2]
Butane	1730[1]	0.024[2]	0.108[2]

Appendix B: Building Envelop Data of Ryerson University (Source: Campus Planning, RU)

Building Envelop Data of Ryerson University Buildings				
Building Name	**Item**	**Overall U-value**	**Shade Coefficient**	**Glass Shade Coefficient**
		W/m2/K		
Heaslip House	East Wall Assembly	0.377		
Continuing	North Wall Assembly	0.31		
Education (CED)	South Wall Assembly	0.354		
	Roof Assembly	0.322		
	Type-1 Window Assembly	3.601		0.747
	Type-2 Window Assembly	3.617		0.747
	Type-3 Window Assembly	3.629		0.747
	Type-4 Window Assembly	6.329		0.747
	Type-5 Window Assembly			0.747
	Type-6 Window Assembly			0.747
	Door Assembly	3.293		
Victoria	Wall Assembly	0.478		
Building (VIC)	Roof Assembly	0.317		
	Window Assembly	2.69		0.641
	Door properties Assembly	1.703	3.293	
Jorgenson	East Wall Assembly	0.327		
Hall (JOR)	North Wall Assembly	0.403		
	South Wall Assembly	0.403		
	West Wall Assembly	0.316		
	Roof Assembly	0.476		
	Type-1 Window Assembly	3.61		0.747
	Type-2 Window Assembly	3.611		0.747
	Type-3 Window Assembly	3.612		0.747
	Type-4 Window Assembly	3.613		0.747
	Type-5 Window Assembly	3.615		0.747
	Type-6 Window Assembly	5.617		0.747
	Door Assembly	1.703	3.293	

Appendix B: Building Envelop Data of Ryerson University (Source: Campus Planning, RU)

Building Name	Item	Overall U-value	Shade Coefficient	Glass Shade Coefficient
		$W/m^2/K$		
Library Building (LIB)	East Wall Assembly	0.347		
	North Wall Assembly	0.348		
	South Wall Assembly	0.348		
	West Wall Assembly	0.348		
	Roof Assembly	0.352		
	Type-1 Window Assembly	3.594		0.747
	Type-2 Window Assembly	3.605		0.747
	Type-3 Window Assembly	3.612		0.747
	Type-4 Window Assembly	3.613		0.747
	Type-5 Window Assembly	3.615		0.747
	Type-6 Window Assembly	5.617		0.747
	Door Assembly	1.703	3.293	
Podium (POD)	East Wall Assembly	0.344		
	South Wall Assembly	0.344		
	West Wall Assembly	0.344		
	Roof Assembly	0.379		
	Type-1 Window Assembly	3.594		
	Type-2 Window Assembly	3.595		
	Type-3 Window Assembly	3.6		
	Type-4 Window Assembly	3.606		
	Door Assembly	1.703	3.293	
Engineering	Wall Assembly-1	0.376		
Building (ENG)	Wall Assembly-2	0.323		
	Wall Assembly-3	0.407		
	Roof Assembly-1	0.549		
	Roof Assembly-2	0.358		
	Type-1 Window Assembly	3.62		0.648
	Type-2 Window Assembly	3.087		0.427
	Type-3 Window Assembly	3.03		0.435
	Type-4 Window Assembly	3.571		0.747
	Type-5 Window Assembly	3.18		0.833
	Type-6 Window Assembly	3.041		0.479
	Type-7 Window Assembly	3.654		0.792
	Door Assembly	1.073	3.293	

Appendix B: Building Envelop Data of Ryerson University (Source: Campus Planning, RU)

Building Name	Item	Overall U-value	Shade Coefficient	Glass Shade Coefficient
		W/m²/K		
EPH Eric	East Wall Assembly	0.384		
Palin Hall (EPH)	North Wall Assembly	0.363		
	South Wall Assembly	0.363		
	West Wall Assembly	0.329		
	Window Assembly	3.668		0.747
Sally Horsfall	East Wall Assembly	0.385		
Eaton Centre (SHE)	North Wall Assembly	0.329		
	South Wall Assembly	0.363		
	West Wall Assembly	0.329		
	Window Assembly	3.617		0.747
	Door Assembly	1.073	3.293	
	Roof Assembly	0.386		
Interior Design (SID)	East Wall Assembly	0.344		
	North Wall Assembly	0.348		
	South Wall Assembly	0.386		
	West Wall Assembly	0.344		
	East Window Assembly	3.618		0.747
	North Window Assembly	3.624		0.747
	South Window Assembly	3.612		0.747
	West Window Assembly	3.631		0.747
	Roof Assembly	0.505		
	Door Assembly	1.073	3.293	
Student Campus	East Wall Assembly	0.33		
Centre (SCC)	North Wall Assembly	0.339		
	South Wall Assembly	0.321		
	West Wall Assembly	0.321		
	Roof Assembly	0.348		
	Type-1 Window Assembly	3.271		0.751
	Type-2 Window Assembly	3.286		0.751
	Type-3 Window Assembly	3.266		0.751
	Type-4 Window Assembly	3.624		0.747
	Type-5 Window Assembly	3.586		0.747
	Type-6 Window Assembly	3.584		0.747
	Type-7 Window Assembly	3.583		0.747
	Type-8 Window Assembly	3.29		0.751

Appendix B: Building Envelop Data of Ryerson University (Source: Campus Planning, RU)

Building Name	Item	Overall U-value	Shade Coefficient	Glass Shade Coefficient
		W/m²/K		
Rogers Business	North Wall Assembly	0.285		
Building (RBB)	South Wall Assembly	0.695		
	East Wall Assembly	0.233		
	West Wall Assembly	0.215		
	Type-1 Roof Assembly	0.235		
	Type-2 Roof Assembly	0.203		
	Type-3 Roof Assembly	0.388		
	Type-A Window Assembly	3.301	0.751	1.703
	Type-B Window Assembly	3.275	0.751	
	Type-C Window Assembly	3.321	0.751	
	Type-D Window Assembly	3.278	0.751	
	Door Assembly	1.703		
Heidelberg Centre-	North Wall Assembly	0.253		
School of Graphic	South Wall Assembly	0.233		
Communications	East Wall Assembly	0.27		
Management (HEI)	West Wall Assembly	0.285		
	Roof Assembly	0.379		
	Type-1 Window Assembly	3.301	0.751	
	Type-2 Window Assembly	3.299	0.751	
	Type-3 Window Assembly	3.321	0.751	
	Type-4 Window Assembly	3.329	0.751	
	Door Assembly	1.703		3.293
Pitman Hall (PIT)	Wall Assembly	0.319		
	Type-1 Window Assembly	3.185	0.641	
	Type-2 Window Assembly	3.339	0.811	
	Door Assembly	1.703		3.293

Appendix B: Building Envelop Data of Ryerson University (Source: Campus Planning, RU)

Building Name	Item	Overall U-value (W/m^2/K)	Shade Coefficient	Glass Shade Coefficient
Rogers	North Wall Assembly	0.203		
Communication	South Wall Assembly	0.244		
Centre (RCC)	East Wall Assembly	0.348		
	West Wall Assembly	0.2		
	Roof Assembly	0.497		
	Type-A Window Assembly	3.662	0.74	
	Type-B Window Assembly	3.635	0.74	
	Door Assembly	1.703		3.293
Kerr Hall (KNE)	Wall Assembly	0.32		
	Roof Assembly	0.317		
	Type-1 Window Assembly	3.14	0.628	
	Type-2 Window Assembly	3.645	0.747	
	Type-3 Window Assembly	2.782	0.696	
	Type-4 Window Assembly	3.623	0.747	
	Type-5 Window Assembly	2.816	0.71	
	Door Assembly	1.703		3.293
Kerr Hall (KNW)	Wall Assembly	0.361		
	Roof Assembly	0.305		
	Type-1 Window Assembly	3.686	0.792	
	Type-2 Window Assembly	3.18	0.833	
	Type-3 Window Assembly	3.659	0.747	
	Type-4 Window Assembly	3.611	0.747	
	Door Assembly	1.703		6.416
Kerr Hall (KSE)	Wall Assembly	0.186		
	Roof Assembly	0.317		
	Type-1 Window Assembly	2.646	0.82	
	Type-2 Window Assembly	2.657	0.641	
	Type-3 Window Assembly	2.709	0.641	
	Type-4 Window Assembly	2.629	0.641	
	Door Assembly	1.703		6.416
Kerr Hall (KSW)	Wall Assembly	0.351		
	Roof Assembly	0.317		
	Type-1 Window Assembly	3.611	0.747	
	Type-2 Window Assembly	3.641	0.747	
	Type-3 Window Assembly	3.625	0.747	
	Type-4 Window Assembly	3.617		
	Door Assembly	1.703		6.416

Appendix C: Hydro Bill Fiscal Year 2005 of Ryerson University (Source: Campus Planning, RU)

RYERSON UNIVERSITY

Hydro Kwh Report

Fiscal Year 2005

BUILDING	Total Of KWH	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
101 GERRARD ST.	115,953	9,453	8,420	12,000	9,600	7,280	7,200	9,600	11,400	9,120	17,000	7,680	7,200
111 BOND ST.	134,783	9,360	13,065	17,160	14,100	7,860	6,900	8,408	8,040	16,680	8,220	13,060	11,930
111 GERRARD ST.	146,708	7,040	15,628	8,560	8,080	8,400	7,760	34,880	6,800	11,650	22,560	6,950	8,400
112 BOND ST.	101,540	6,900	4,440	5,340	5,820	5,420	5,160	8,220	12,720	9,480	15,480	10,200	12,360
137 BOND ST.	53,380	3,560	3,120	3,680	3,600	3,640	3,800	3,640	9,080	4,320	5,260	4,840	4,840
160 MUTUAL ST.	5,500,402	402,544	478,057	524,977	505,440	607,161	519,172	426,544	378,775	415,394	386,617	435,143	420,579
17 GOULD ST.	2,230	100	146	174	160	140	120	168	292	242	284	224	180
240 JARVIS ST.	2,128,670	105,480	141,120	170,880	182,400	198,000	142,200	185,520	44,880	376,160	237,280	182,760	161,990
243 CHURCH ST.	4,472,078	392,961	379,881	370,538	365,224	401,260	395,354	381,486	333,507	344,894	335,804	389,498	381,671
285 VICTORIA ST.	3,608,472	292,909	277,062	252,226	261,707	262,644	305,081	317,247	310,337	340,134	307,808	346,093	335,225
300 VICTORIA ST.	366,066	29,460	25,600	25,566	25,120	23,520	25,280	33,440	37,600	35,200	38,080	31,040	36,160
302 CHURCH ST.	364,543	28,223	28,800	25,600	25,600	25,600	33,920	35,520	30,080	29,760	35,200	28,800	37,440
325 CHURCH ST.	950,192	64,152	67,290	85,200	82,800	88,750	52,800	92,400	74,400	76,800	96,400	70,800	98,400
341 CHURCH ST.	455,600	34,800	44,000	56,000	52,000	44,000	33,200	32,000	32,800	34,400	30,400	27,200	34,800
361 VICTORIA ST.	5,918,696	443,897	497,888	496,356	491,083	505,686	511,631	512,668	485,994	503,803	457,753	507,905	504,033
380 VICTORIA ST.	16,895,386	1,293,222	1,894,198	1,949,361	2,034,631	1,908,403	1,260,103	1,094,422	1,054,908	1,067,640	1,033,111	1,161,103	1,144,284
44 GERRARD ST.	243,200	8,640	20,320	25,120	24,960	26,560	23,360	22,560	16,480	17,440	20,160	18,240	19,360
50 GOULD ST.	2,388,200	204,200	192,000	192,000	200,000	192,000	193,600	203,200	190,400	166,400	209,600	196,800	248,000
55 GOULD ST.	1,650,957	129,497	129,370	125,195	125,620	138,833	140,257	143,489	140,471	151,950	137,997	151,436	136,842
87 GERRARD ST.	3,813,068	302,175	291,105	288,713	274,667	291,430	318,456	346,591	330,787	333,247	335,910	353,253	346,734
	49,310,122	3,768,572	4,511,509	4,634,646	4,692,611	4,746,587	3,985,354	3,892,002	3,509,751	3,944,714	3,730,924	3,943,024	3,950,428

Appendix C: Hydro Bill Fiscal Year 2006 of Ryerson University (Source: Campus Planning, RU)

RYERSON UNIVERSITY

Hydro Kwh Report

Fiscal Year 2006

BUILDING	Total Of KWH	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
105 BOND ST.	142,920							65,760	14,520	23,280	12,960	12,000	14,400
111 BOND ST.	134,783	9,360	13,065	17,160	14,100	7,860	6,900	8,408	8,040	16,680	8,220	13,060	11,930
111 GERRARD ST.	150,920	17,760	12,560	14,440	14,000	13,680	4,800	12,800	14,080	12,000	7,920	8,160	18,720
112 BOND ST.	113,420	8,340	4,320	5,280	4,980	5,460	5,040	12,480	7,320	21,180	14,540	12,900	11,580
160 MUTUAL ST.	5,397,903	435,797	467,053	531,296	507,309	531,540	456,982	409,506	363,246	429,900	400,621	443,874	420,579
17 GOULD ST.	2,105	116	138	154	134	144	88	198	158	302	266	212	195
240 JARVIS ST.	2,023,474	103,200	134,760	168,565	170,371	181,920	104,400	202,200	167,760	295,800	259,680	198,120	36,698
243 CHURCH ST.	4,408,548	391,686	361,124	395,347	365,015	383,607	399,589	385,599	317,857	344,088	322,155	360,809	381,671
285 VICTORIA ST.	4,067,896	335,225	316,902	314,239	330,723	314,920	333,862	324,632	293,279	321,954	301,173	573,400	307,585
300 VICTORIA ST.	335,998	29,928	28,640	23,520	19,360	24,480	22,080	28,320	24,640	42,240	31,680	29,750	31,360
302 CHURCH ST.	435,840	27,200	29,440	29,120	29,760	39,680	36,160	45,120	32,320	47,040	37,440	37,440	45,120
325 CHURCH ST.	985,230	69,630	85,200	93,600	84,000	92,400	73,200	98,400	64,800	91,200	72,000	73,200	87,600
341 CHURCH ST.	463,653	28,053	44,800	49,600	45,200	47,200	35,600	37,200	28,800	43,200	33,600	32,800	37,600
361 VICTORIA ST.	6,044,859	499,118	492,064	491,801	510,818	503,778	521,203	519,332	515,418	543,042	504,794	560,343	383,148
380 VICTORIA ST.	18,276,049	1,576,726	2,038,412	2,253,638	2,161,959	1,888,991	1,307,321	1,268,453	1,059,331	1,136,075	1,088,224	1,193,336	1,303,583
44 GERRARD ST.	256,000	13,760	20,960	26,400	24,160	26,560	22,240	24,960	14,400	23,840	17,920	19,360	21,440
50 GOULD ST.	2,726,400	214,400	220,800	225,600	217,600	244,800	216,000	240,000	163,200	297,600	222,400	211,200	252,800
55 GOULD ST.	1,705,010	130,739	125,610	120,345	118,719	128,576	151,915	150,162	145,861	164,646	159,837	164,491	144,109
87 GERRARD ST.	4,057,548	343,365	324,324	317,563	295,695	303,012	347,744	337,210	336,505	376,883	355,154	369,834	350,260
	51,728,556	4,234,402	4,720,173	5,077,668	4,913,904	4,738,609	4,045,125	4,170,739	3,571,535	4,230,950	3,850,784	4,314,290	3,860,378

Appendix C: Hydro Bill Fiscal Year 2007 of Ryerson University (Source: Campus Planning, RU)

RYERSON UNIVERSITY

Hydro Kwh Report
Fiscal Year 2007

BUILDING	Total Of KWH	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
101 GERRARD ST.	101,493	6,360	7,080	6,720	10,320	6,600	6,000	8,280	9,720	11,580	11,704	9,089	8,040
105 BOND ST.	600,781	12,480	9,360	8,400	16,800	204,000	2,700	79,200	36,900	38,700	72,900	61,138	58,203
111 BOND ST.	134,783	9,360	13,065	17,160	14,100	7,860	6,900	8,408	8,040	16,680	8,220	13,060	11,930
111 GERRARD ST.	120,560	10,320	11,280	10,560	12,240	11,520	10,640	9,600	8,880	8,640	8,400	8,640	9,840
112 BOND ST.	114,826	6,350	6,350	6,288	9,961	6,973	14,070	10,148	11,331	11,062	12,638	10,957	8,700
160 MUTUAL ST.	5,607,650	456,537	469,791	514,489	526,026	585,759	562,437	434,435	345,665	423,271	411,206	438,515	439,519
240 JARVIS ST.	1,695,757	84,600	93,600	91,800	181,920	145,697	181,800	138,500	194,400	180,000	208,800	165,600	29,040
243 CHURCH ST.	4,111,201	344,736	328,833	342,008	334,773	348,218	370,861	344,219	309,398	353,457	332,881	361,099	340,698
285 VICTORIA ST.	3,599,652	300,055	274,127	277,367	282,300	283,834	314,807	311,102	267,586	311,281	318,154	345,846	313,193
302 CHURCH ST.	373,760	38,080	28,800	25,280	31,680	27,200	30,400	34,880	29,760	30,400	29,440	34,880	32,960
325 CHURCH ST.	972,000	75,600	67,200	67,200	98,400	85,200	86,400	84,000	81,600	78,000	84,000	79,200	85,200
341 CHURCH ST.	451,600	40,800	42,400	39,200	50,800	39,200	34,000	32,400	32,400	35,200	36,400	32,400	36,400
361 VICTORIA ST.	4,354,372	499,118	353,497	344,744	340,403	355,408	375,406	361,257	326,265	358,869	328,871	367,229	343,305
380 VICTORIA ST.	20,399,668	1,931,675	2,245,454	2,255,319	2,310,771	2,132,309	1,794,324	1,365,876	1,174,055	1,254,884	1,195,488	1,265,902	1,473,609
50 GOULD ST.	2,775,741	235,800	204,800	188,800	252,400	217,600	238,400	249,600	219,141	273,600	204,800	256,000	234,800
55 DUNDAS ST.	4,001,970	328,122	301,745	309,217	314,001	338,144	351,566	343,745	296,203	353,670	345,600	372,047	347,910
55 GOULD ST.	1,732,166	134,705	126,335	136,602	138,336	143,112	142,121	161,963	155,970	169,439	142,727	142,620	138,236
87 GERRARD ST.	3,609,473	317,088	286,514	302,048	284,447	293,332	310,197	304,702	293,947	310,102	295,368	328,519	283,210
	54,757,454	4,831,786	4,870,252	4,943,201	5,209,676	5,231,967	4,833,030	4,282,315	3,801,262	4,218,834	4,047,598	4,292,741	4,194,793

Appendix C: Hydro Bill Fiscal Year 2008 of Ryerson University (Source: Campus Planning, RU)

RYERSON UNIVERSITY

Hydro Kwh Report

Fiscal Year 2008

BUILDING	Total Of KWH	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
105 BOND ST.	516,962	69,920	70,666	73,027	69,772	69,920	58,176	53,135	52,347				
160 MUTUAL ST.	3,683,022		477,016	530,643	518,228	557,499	432,346	402,137	353,352	411,800			
240 JARVIS ST.	1,234,169		77,509	169,020	110,700	153,900	116,100	138,600	210,600	257,740			
243 CHURCH ST.	3,090,654	339,848	334,581	345,392	342,894	360,034	370,736	355,791	301,571	339,806			
285 VICTORIA ST.	2,513,006	316,950	299,523	289,284	252,045	253,000	280,213	283,760	255,921	282,309			
300 VICTORIA ST.	110,613								51,760	58,853			
325 CHURCH ST.	692,968	69,600	58,400	81,600	74,400	88,750	81,500	78,000	73,200	87,517			
341 CHURCH ST.	52,200			52,200									
351 YONGE ST.	24,000			24,000									
361 VICTORIA ST.	3,160,978	332,744	321,783	343,063	350,391	366,309	383,475	377,380	333,184	352,651			
380 VICTORIA ST.	15,584,676	1,531,498	2,103,791	2,373,027	2,214,075	2,037,041	1,500,034	1,331,002	1,240,423	1,253,785			
50 GOULD ST.	2,244,815	243,200	222,400	238,400	235,200	272,266	238,400	280,000	212,800	302,149			
55 DUNDAS ST.	3,100,255	339,375	328,012	332,485	327,737	353,191	368,575	358,275	324,913	367,692			
55 GOULD ST.	1,225,657	131,782	124,087	121,121	127,439	138,173	145,932	145,970	140,877	150,276			
87 GERRARD ST.	2,850,263	289,198	273,710	283,358	276,509	293,439	325,829	338,307	366,658	403,257			
	40,084,237	3,664,114	4,691,478	5,256,621	4,899,391	4,943,521	4,301,316	4,142,356	3,917,606	4,267,835			

Appendix C: Hydro Bill Year 2006 (Jan-Dec) of Ryerson University (Source: Campus Planning, RU)

Building Name	Year-2006 January (kWh)	Year-2006 February (kWh)	Year-2006 March (kWh)	Year-2006 April (kWh)	Year-2006 May (kWh)	Year-2006 June (kWh)
VIC,IMA,CED	340134	307808	346093	335225	335225	316902
Kerr Hall	670203	667353	704705	752033	713518	712864
ENG	344,894	335,804	389,498	381,671	391,686	361,124
JOR,POD,LIB	1067640	1033111	1161103	1144284	1576726	2038412
EPH,SHE	333247	335910	353253	346734	343365	324324
SID	29760	35200	28800	37440	27200	29440
SCC,HEI,OAK	151950	137997	151436	136842	130739	125610
PIT,RCC	415394	386617	435143	420579	435797	467053

Building Name	Year-2006 July (kWh)	Year-2006 August (kWh)	Year-2006 September (kWh)	Year-2006 October (kWh)	Year-2006 November (kWh)	Year-2006 December (kWh)
VIC,IMA,CED	314239	330723	314920	333862	324632	293279
Kerr Hall	717401	728418	748578	737203	759332	678618
ENG	395,347	365,015	383,607	399,589	385,599	317,857
JOR,POD,LIB	2253638	2161959	1888991	1307321	1268453	1059331
EPH,SHE	317563	295695	303012	347744	337210	336505
SID	29120	29760	39680	36160	45120	32320
SCC,HEI,OAK	120345	118719	128576	151915	150162	145861
PIT,RCC	531296	507309	531540	456982	409506	363246

Building Name	Year-2006 Total (January-December) (kWh)
VIC,IMA,CED	3,893,040
Kerr Hall	8,590,220
ENG	4,451,690
JOR,POD,LIB	17,960,970
EPH,SHE	3,974,560
SID	400,000
SCC,HEI,OAK	1,650,152
PIT,RCC	5,360,462

Appendix C: Steam Consumption of Ryerson University for Meter-1 (Source: Campus Planning, RU)

Meter-1	
Fiscal Year-2005 (May-April)	**Steam Consumption (lb)**
May_2005	7,647,218
June_2005	2,617,669
July_2005	1,694,000
August_2005	1,854,757
Sept_2005	1,892,409
Oct_2005	6,084,417
Nov_2005	10,741,258
Dec_2005	13,600,716
Jan_2006	17,905,233
Feb_2006	17,267,436
March_2006	15,882,044
April_2006	10,224,038
Total	**107,411,195**

Meter-1	
Fiscal Year-2006 (May-April)	**Steam Consumption (lb)**
May_2006	7,651,590
June_2006	2,719,484
July_2006	2,532,838
August_2006	1,554,106
Sept_2006	2,997,085
Oct_2006	6,567,065
Nov_2006	10,503,550
Dec_2006	10,127,434
Jan_2007	16,884,195
Feb_2007	15,851,593
March_2007	9,161,666
April_2007	10,763,171
Total	**97,313,777**

Meter-1	
Fiscal Year-2007 (May-April)	**Steam Consumption (lb)**
May_2007	3,566,440
June_2007	2,801,018
July_2007	2,411,719
August_2007	2,224,515
Sept_2007	2,401,000
Oct_2007	3,786,249
Nov_2007	4,793,000
Dec_2007	15,781,554
Jan_2008	17,619,732
Feb_2008	16,400,608
March_2008	16,025,397
April_2008	8,043,753
Total	**95,854,985**

Meter-1	
Year-2006 (Jan-Dec)	**Steam Consumption (lb)**
Jan_2006	17,905,233
Feb_2006	17,267,436
March_2006	15,882,044
April_2006	10,224,038
May_2006	7,651,590
June_2006	2,719,484
July_2006	2,532,838
August_2006	1,554,106
Sept_2006	2,997,085
Oct_2006	6,567,065
Nov_2006	10,503,550
Dec_2006	10,127,434
Total	**105,931,903**

Appendix C: Steam Consumption of Ryerson University for Meter-2 (Source: Campus Planning, RU)

Meter-2	
Fiscal Year-2006 (May-April)	**Steam Consumption (lb)**
May_2006	-
June_2006	-
July_2006	-
August_2006	-
Sept_2006	248,579
Oct_2006	495,774
Nov_2006	585,672
Dec_2006	663,546
Jan_2007	950,792
Feb_2007	1,200,570
March_2007	641,073
April_2007	432,941
Total	**5,218,947**

Meter-2	
Fiscal Year-2007 (May-April)	**Steam Consumption (lb)**
May_2007	339,213
June_2007	186,729
July_2007	153,305
August_2007	149,093
Sept_2007	210,743
Oct_2007	300,677
Nov_2007	540,814
Dec_2007	698,698
Jan_2008	746,711
Feb_2008	764,775
March_2008	738,444
April_2008	432,941
Total	**5,262,143**

Meter-2	
Fiscal Year-2008 (May-April)	**Steam Consumption (lb)**
May_2008	347,690
June_2008	218,324
July_2008	194,155
August_2008	204,522
Sept_2008	241,088
Oct_2008	433,659
Nov_2008	573,457
Dec_2008	670,796
Jan_2009	838,608
Feb_2009	-
March_2009	-
April_2009	-
Total	**3,722,299**

Meter-2	
Year-2007 (Jan-Dec)	**Steam Consumption (lb)**
Jan_2007	950,792
Feb_2007	1,200,570
March_2007	641,073
April_2007	432,941
May_2007	339,213
June_2007	186,729
July_2007	153,305
August_2007	149,093
Sept_2007	210,743
Oct_2007	300,677
Nov_2007	540,814
Dec_2007	698,698
Total	**5,804,648**

Data Analysis and Calculation of chilled water for DLWC system:

From the spreadsheet (Comparison)

1. **Column A:** Represent Month/Day.
2. **Column B:** Represent Hour.
3. **Column C:** Represent total electric consumption for chiller (from chiller electricity consumption Excel sheet):

Total Electric Consumption for Chiller = [Chiller input (for compressor) + Pump + Cooling Tower Fan]

In this case, CO_2 gas emission can be calculated from required amount of electricity generated for the system running central chiller plant or DLWC system.

All data was taken from HAP simulation for chiller.

4. **Column D:** Represent total electric consumption (kWh) for Enwave DLWC system. This calculation was done by the equation (DLWC electricity consumption Excel sheet):

The total electricity consumption for DLWC system = (Electricity consumption for remote chilled water serves from source to Ryerson University building ground level)

Electricity consumption for remote chilled water serves from Enwave to Ryerson University (RU) building:

a) **According to EnWave information:**

Overall plant efficiency is between 0.2 kW/Ton and 0.3 kW/Ton

<u>Assumptions:</u>

- The rate of refrigerating system is Power (kW) requirements per Ton of refrigeration.

Make linear equation in terms of outdoor air temperature with those values for calculate Power requirements in order to remote chilled water serves from Enwave to RU building ground level.

- Assumption at the lowest outdoor temperature the Enwave overall plant efficiency is 0.2 kW/Ton and at the highest outdoor temperature the Enwave overall plant efficiency is 0.3 kW/Ton.

b) From Carrier HAP Weather Data information:

- From Carrier HAP weather data information, the lowest outdoor temperature in May is 11.2°C and highest in August is 32.3°C for DLWC System.

i) Linear Interpolation

The linear equation for **0.2 kW/Ton** with outdoor lowest temperature 11.2°C and **0.3 kW/Ton** with outdoor highest temperature 32.3°C is

y = mx + c is satisfied by **(11.2, 0.2)** and **(32.3, 0.3),**

So the solution is

$$y = \frac{x}{211} + \frac{31}{211}$$

where, **x** = outdoor temperature, °C and **y** = kWh/Ton

ii) <u>Conversion kW/Ton to kWh/kWh</u>

$$\frac{kW}{Ton} = \frac{kW}{3.52kW} = \frac{kWh}{3.52kWh},$$ where 1 kW=0.2843 Ton

So, **Electricity consumption for Remote Chilled Water serves from Enwave to RU building ground level =** (Remote Chilled Water Load) X $(\frac{kWh}{3.52kWh})$

5. **Column E, F, G:** Represent hourly **GHGs** Emission Factor **kg/kWh**

Conversion:

This unit converted from **Ton/GWh** to **kg/kWh.**

$$\frac{Ton}{GWh} = \frac{1000kg}{1000000kWh} = \frac{kg}{1000kWh}$$

6. **Column H, J, L:** Represent CO_2 , SOx and NOx emission for chiller

CO_2 emission for chiller = (CO_2 Emission Factor **kg/kW) X** (Total Electric Consumption for Chiller**)**

Same as follow for SOx and NOx

7. **Column I, K, M:** Represent CO_2 , SOx and NOx emission reduction for DLWC

CO_2 Emission for Enwave = (CO_2 Emission Factor **kg/kW) X** (Total Electric Consumption for Enwave**)**

8. Column Q, R, S, T: Represent comparison result for total electricity cost (Dollars):

Appendix E: Chilled Water Cost Calculation for Base Case Chillers

Library Chiller Plant Model for 13 Ryerson Building	
Chilled output for 13 buildings (kWh)=	**13231280**
Chilled water load for 13 buildings (kBTU)=	45145127
Steam consumption for chiller (kWh)=	5814941
Steam consumption for chiller (kBTU)=	19840579
Steam cost $ (0.025 $/lb)=	**496014**
Electricity Consumption	**(kWh)**
Chiller Input, Electricity (kWh)=	1229193
Misc. Electric (kWh)=	394722
Chilled Water pump (kWh)=	962927
Cooling Tower Fan (kWh)=	664352
Total (kWh)=	**3251194**
Electricity cost ($) @ $0.1/kWh=	**325119**
Chilled water cost	
Cooling cost ($)=	658,426
Misc. Electric ($)=	39472.2
Primary Chilled Water pump ($)=	22964.5
Condenser Pump ($)=	63386.8
Cooling Tower Fan ($)=	66435.2
Total cost ($)=	**850,685**
Chiller Output, Chilled water (kBTU)=	45145127
Chilled water cost ($/Ton-hr)	**0.23**

Appendix E: Steam Demand Calculation for Base Case (Meter-1)

	Name of Ryerson Buildings	**Gross Area (m^2)**
1	School of Image Art(IMA)	9345
2	Heaslip House Continuing Education (CED)	4180
3	Kerr Hall (KNE, KNW, KSE, KSW)	52409
4	Engineering Building (ENG)	22350
5	Jorgenson Hall (JOR)	10964
6	Library Building (LIB)	18487
7	Podium Building (POD)	21730
8	Eric Palin Hall (EPH)	13942
9	Sally Horsfall Eaton Centre for Studies in community Health (SHE)	7077
10	Student Campus Centre (SCC)	4180
11	School of Interior Design (SID)	4373
12	Victoria Building (VIC)	12708
13	Heidelberg Centre-School of Graphic	2985
14	Rogers Communications Center (RCC)	13100
15	MON_Civil Engineering Building	2843
16	South Bond Building (SBB)	6494
17	Architecture Building (ARC)	7239
18	Oakham House (OAK)	2033
19	Research and Graduate Studies (GER)	2860
20	Pitman Hall Residence (PIT)	3828
	Total area serves for Meter-1	**223127**

Appendix E: Steam Demand Calculation for Base Case (Meter-1)

Audit Area Serves for Meter-1

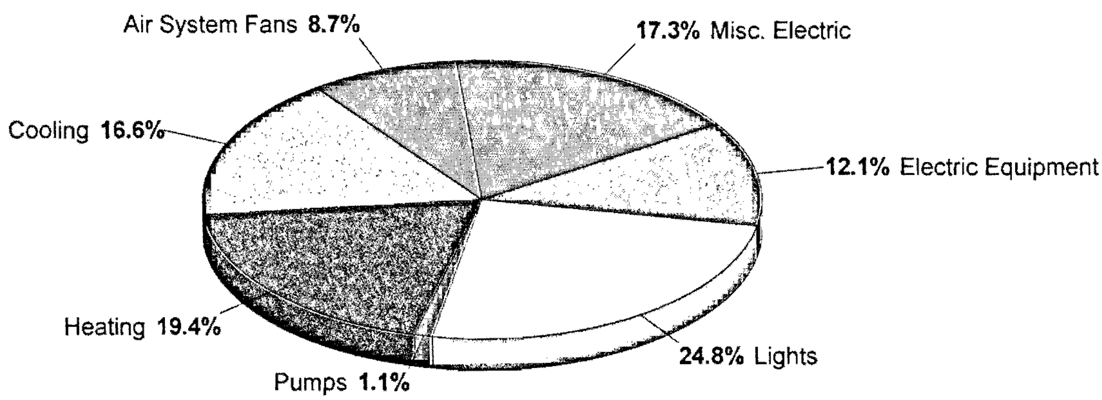
Sl. No.	**Name of Ryerson Buildings**	**Area**
		(m^2)
1	School of Image Art (IMA)	9345
2	Heaslip House Continuing Education (CED)	4180
3	Kerr Hall (KNE, KNW, KSE, KSW)	52409
4	Engineering Building (ENG)	22350
5	Jorgenson Hall (JOR)	10964
6	Library Building (LIB)	18487
7	Podium (POD)	21730
8	Eric Palin Hall (EPH)	13942
9	Sally Horsfall Eaton Centre for Studies in community Health (SHE)	7077
10	Student Campus Centre (SCC)	4180
11	School of Interior Design (SID)	4373
12	Victoria Building (VIC)	12708
13	Heidelberg Centre-School of Graphic	2985
14	Rogers Communications Center (RCC)	13100
15	Pitman Hall Residence (PIT)	3828
	Total audit area for Meter-1	**201658**

Total Steam demand for 15 buildings in Meter-1	**90.30%**

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - CED_Building (Flat Rate)

01_CED_Ryerson University 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	7,062	3.068	8.7
Cooling	13,416	5.828	16.6
Heating	15,681	6.812	19.4
Pumps	852	0.370	1.1
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	37,011	16.078	45.8
Lights	20,045	8.708	24.8
Electric Equipment	9,795	4.255	12.1
Misc. Electric	14,014	6.088	17.3
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	43,854	19.050	54.2
Grand Total	80,865	35.128	100.0

Note: Cost per unit floor area is based on the gross building floor area.

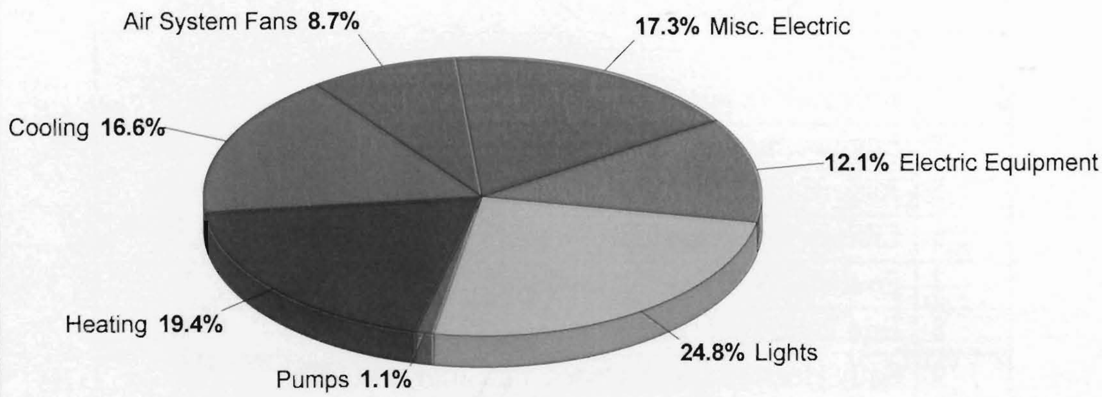
Gross Floor Area .... 2302.0 m²
Conditioned Floor Area .... 2302.0 m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - CED_Building (Flat Rate)

01_CED_Ryerson University 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	7,062	3.068	8.7
Cooling	13,416	5.828	16.6
Heating	15,681	6.812	19.4
Pumps	852	0.370	1.1
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	37,011	16.078	45.8
Lights	20,045	8.708	24.8
Electric Equipment	9,795	4.255	12.1
Misc. Electric	14,014	6.088	17.3
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	43,854	19.050	54.2
Grand Total	80,865	35.128	100.0

Note: Cost per unit floor area is based on the gross building floor area.

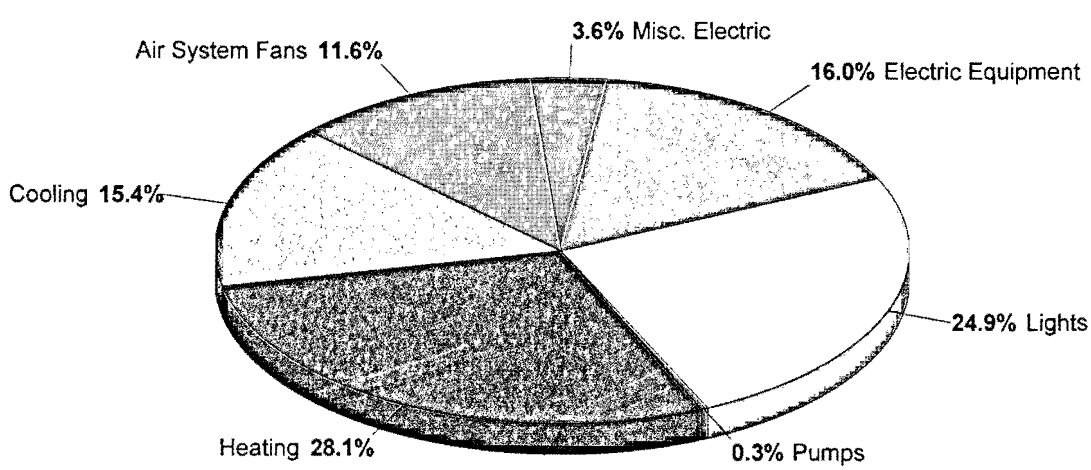
Gross Floor Area .... 2302.0 m²
Conditioned Floor Area .... 2302.0 m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - IMA_Building (Flat Rate)

02_IMA_Ryerson University 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	29,211	4.046	11.6
Cooling	38,988	5.401	15.4
Heating	71,064	9.844	28.1
Pumps	834	0.116	0.3
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**140,097**	**19.407**	**55.5**
Lights	62,926	8.717	24.9
Electric Equipment	40,484	5.608	16.0
Misc. Electric	8,969	1.242	3.6
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**112,379**	**15.567**	**44.5**
Grand Total	**252,476**	**34.974**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **7219.0** m²

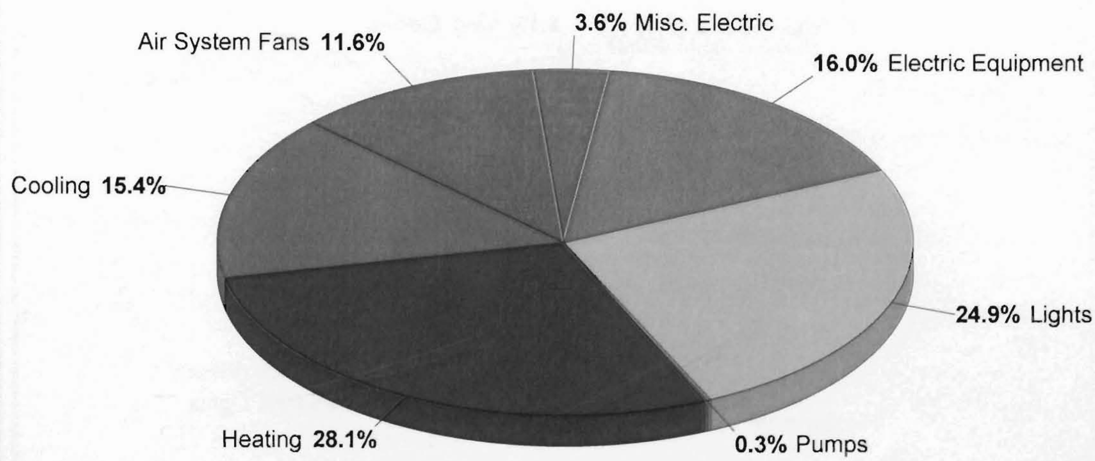
Conditioned Floor Area .... **7219.0** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - IMA_Building (Flat Rate)

02_IMA_Ryerson University 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	29,211	4.046	11.6
Cooling	38,988	5.401	15.4
Heating	71,064	9.844	28.1
Pumps	834	0.116	0.3
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**140,097**	**19.407**	**55.5**
Lights	62,926	8.717	24.9
Electric Equipment	40,484	5.608	16.0
Misc. Electric	8,969	1.242	3.6
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**112,379**	**15.567**	**44.5**
Grand Total	**252,476**	**34.974**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **7219.0** m²

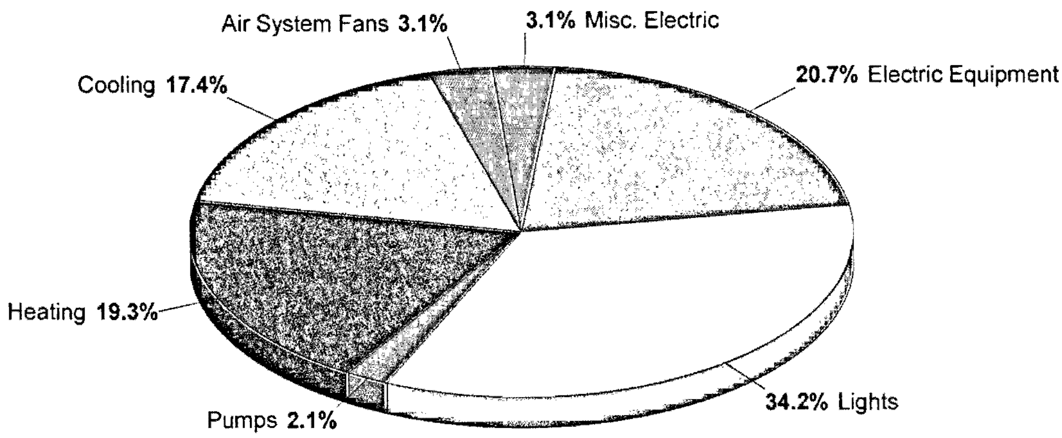
Conditioned Floor Area .... **7219.0** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - VIC_Building (Flat Rate)

03_VIC_Ryerson University 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	9,078	0.928	3.1
Cooling	51,090	5.220	17.4
Heating	56,663	5.789	19.3
Pumps	6,106	0.624	2.1
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**122,938**	**12.560**	**42.0**
Lights	100,320	10.249	34.2
Electric Equipment	60,536	6.185	20.7
Misc. Electric	9,209	0.941	3.1
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**170,064**	**17.375**	**58.0**
Grand Total	**293,002**	**29.935**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

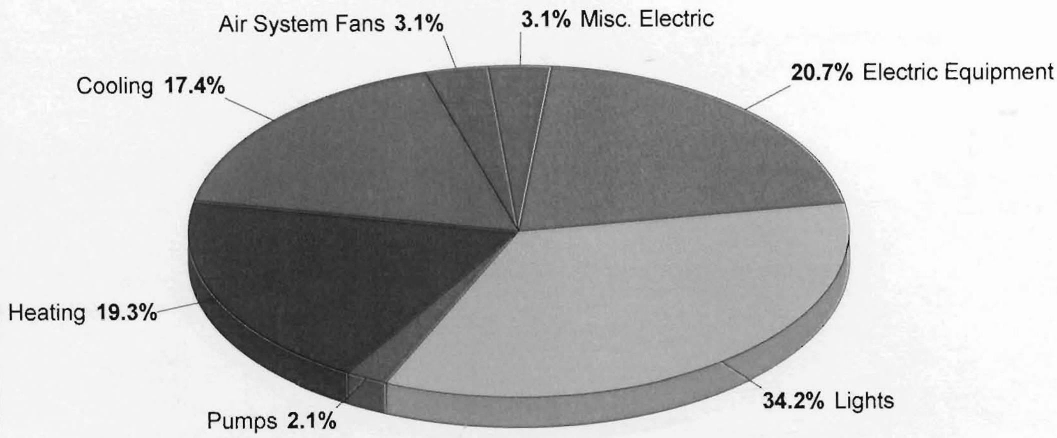
Gross Floor Area .... **9788.0** m²
Conditioned Floor Area .... **9788.0** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - VIC_Building (Flat Rate)

03_VIC_Ryerson University 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	9,078	0.928	3.1
Cooling	51,090	5.220	17.4
Heating	56,663	5.789	19.3
Pumps	6,106	0.624	2.1
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**122,938**	**12.560**	**42.0**
Lights	100,320	10.249	34.2
Electric Equipment	60,536	6.185	20.7
Misc. Electric	9,209	0.941	3.1
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**170,064**	**17.375**	**58.0**
Grand Total	**293,002**	**29.935**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

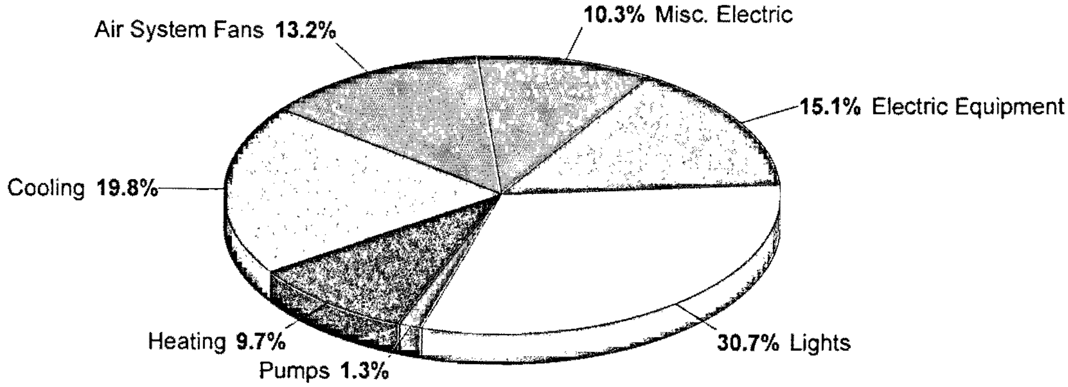
Gross Floor Area .... **9788.0** m²
Conditioned Floor Area .... **9788.0** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - JOR_Building (Flat Rate)

04_JOR_(Jorgenson Hall)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	46,998	5.755	13.2
Cooling	70,518	8.635	19.8
Heating	34,431	4.216	9.7
Pumps	4,795	0.587	1.3
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**156,743**	**19.194**	**44.0**
Lights	109,387	13.395	30.7
Electric Equipment	53,653	6.570	15.1
Misc. Electric	36,655	4.489	10.3
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**199,695**	**24.454**	**56.0**
Grand Total	**356,437**	**43.647**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

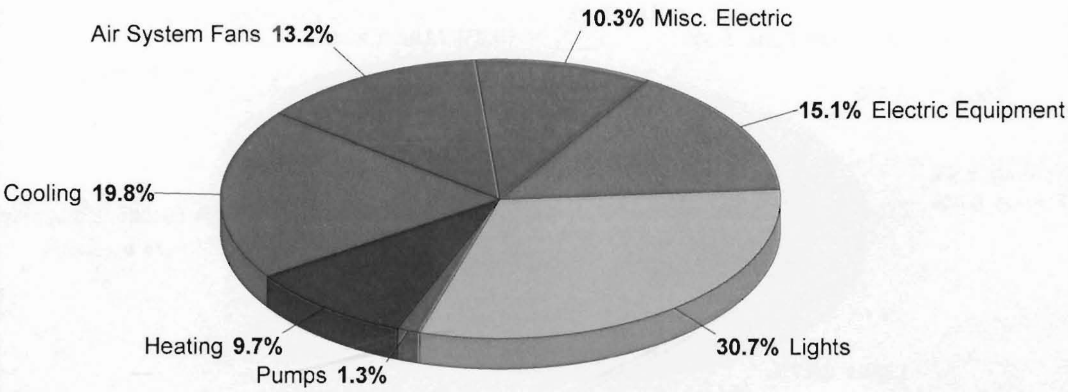
Gross Floor Area .... **8166.3** m²
Conditioned Floor Area .... **8166.3** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - JOR_Building (Flat Rate)

04_JOR_(Jorgenson Hall)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	46,998	5.755	13.2
Cooling	70,518	8.635	19.8
Heating	34,431	4.216	9.7
Pumps	4,795	0.587	1.3
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**156,743**	**19.194**	**44.0**
Lights	109,387	13.395	30.7
Electric Equipment	53,653	6.570	15.1
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Grand Total	**356,437**	**43.647**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

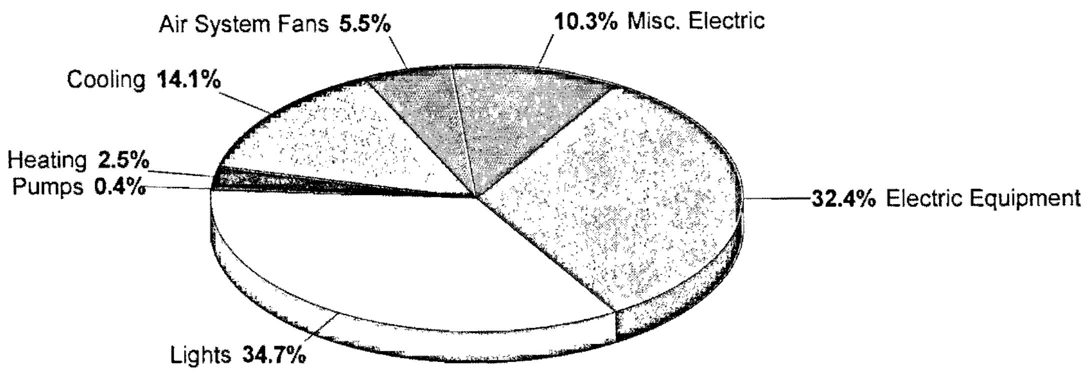
Gross Floor Area .... **8166.3** m²
Conditioned Floor Area .... **8166.3** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - LIB_Building (Flat Rate)

05_ LIB(Library Building)_RU — 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	44,102	2.859	5.5
Cooling	112,983	7.324	14.1
Heating	19,851	1.287	2.5
Pumps	3,474	0.225	0.4
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**180,410**	**11.695**	**22.6**
Lights	277,778	18.006	34.7
Electric Equipment	259,227	16.804	32.4
Misc. Electric	82,581	5.353	10.3
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**619,585**	**40.163**	**77.4**
Grand Total	**799,994**	**51.858**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

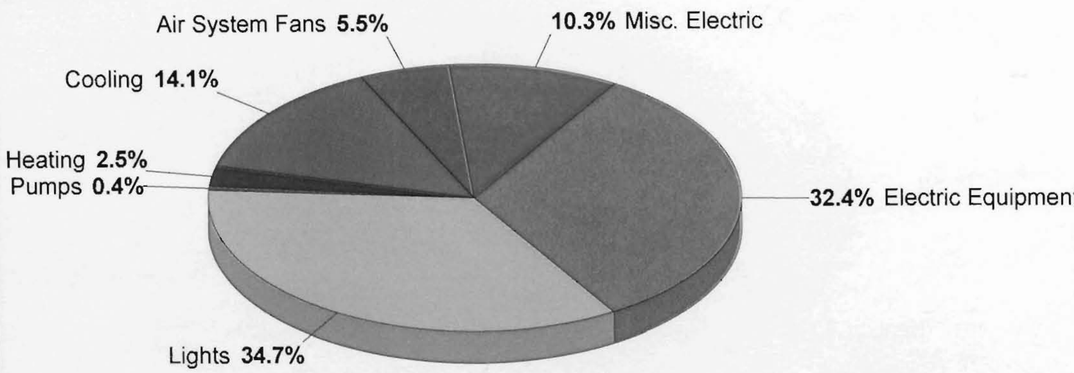
Gross Floor Area .... **15426.6** m²
Conditioned Floor Area .... **15426.6** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - LIB_Building (Flat Rate)

05_ LIB(Library Building)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	44,102	2.859	5.5
Cooling	112,983	7.324	14.1
Heating	19,851	1.287	2.5
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Non-HVAC Sub-Total	**619,585**	**40.163**	**77.4**
Grand Total	**799,994**	**51.858**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

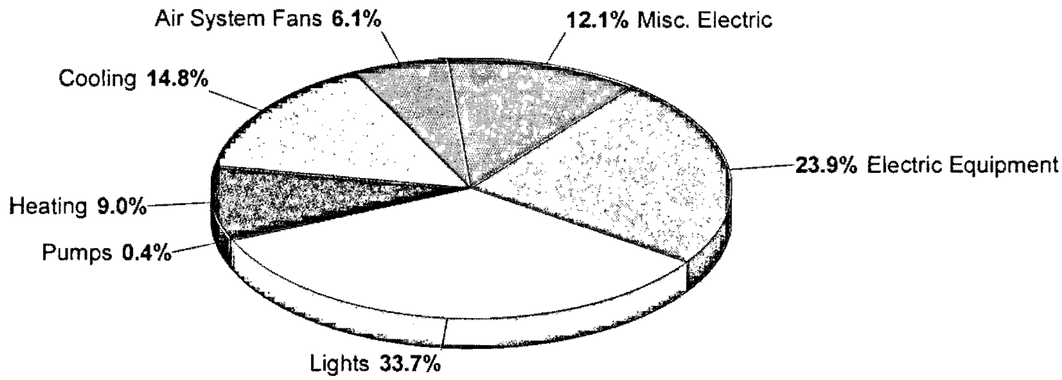
Gross Floor Area .... **15426.6** m²
Conditioned Floor Area .... **15426.6** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - POD_Building (Flat Rate)

06_POD(Podium)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	33,852	2.522	6.1
Cooling	82,277	6.130	14.8
Heating	49,919	3.720	9.0
Pumps	2,337	0.174	0.4
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**168,385**	**12.546**	**30.3**
Lights	187,141	13.944	33.7
Electric Equipment	132,617	9.881	23.9
Misc. Electric	67,317	5.016	12.1
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**387,076**	**28.841**	**69.7**
Grand Total	**555,460**	**41.387**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

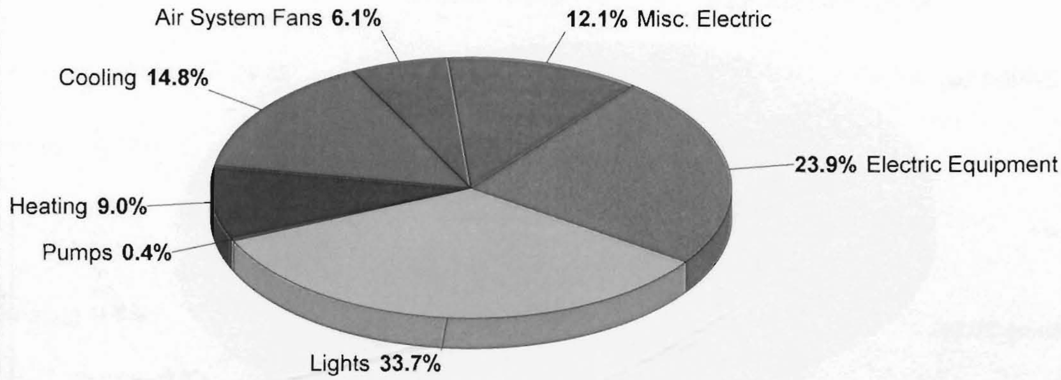
Gross Floor Area .... **13421.1** m²
Conditioned Floor Area .... **13421.1** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - POD_Building (Flat Rate)

06_POD(Podium)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	33,852	2.522	6.1
Cooling	82,277	6.130	14.8
Heating	49,919	3.720	9.0
Pumps	2,337	0.174	0.4
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Non-HVAC Sub-Total	**387,076**	**28.841**	**69.7**
Grand Total	**555,460**	**41.387**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

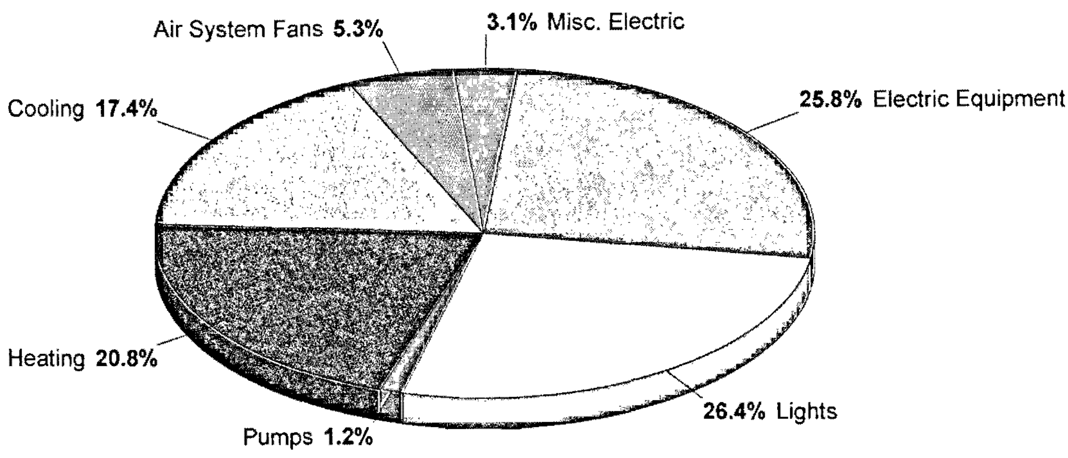
Gross Floor Area .... **13421.1** m²
Conditioned Floor Area .... **13421.1** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - ENG_Building (Flat Rate)

07_ENG(Engineering Building)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	37,547	2.135	5.3
Cooling	123,647	7.032	17.4
Heating	148,101	8.423	20.8
Pumps	8,245	0.469	1.2
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**317,541**	**18.059**	**44.6**
Lights	188,005	10.692	26.4
Electric Equipment	183,846	10.455	25.8
Misc. Electric	22,016	1.252	3.1
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**393,867**	**22.399**	**55.4**
Grand Total	**711,408**	**40.458**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

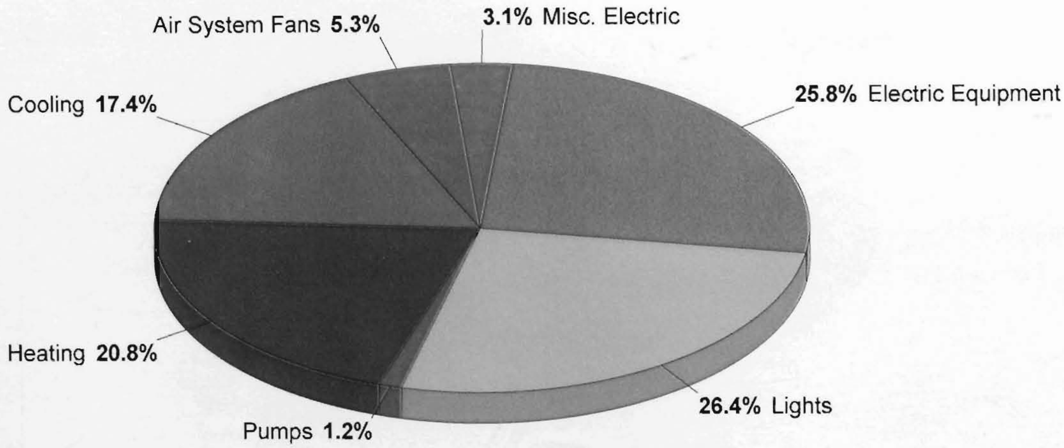
Gross Floor Area .... **17583.8** m²
Conditioned Floor Area .... **17583.8** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - ENG_Building (Flat Rate)

07_ENG(Engineering Building)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	37,547	2.135	5.3
Cooling	123,647	7.032	17.4
Heating	148,101	8.423	20.8
Pumps	8,245	0.469	1.2
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Grand Total	**711,408**	**40.458**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

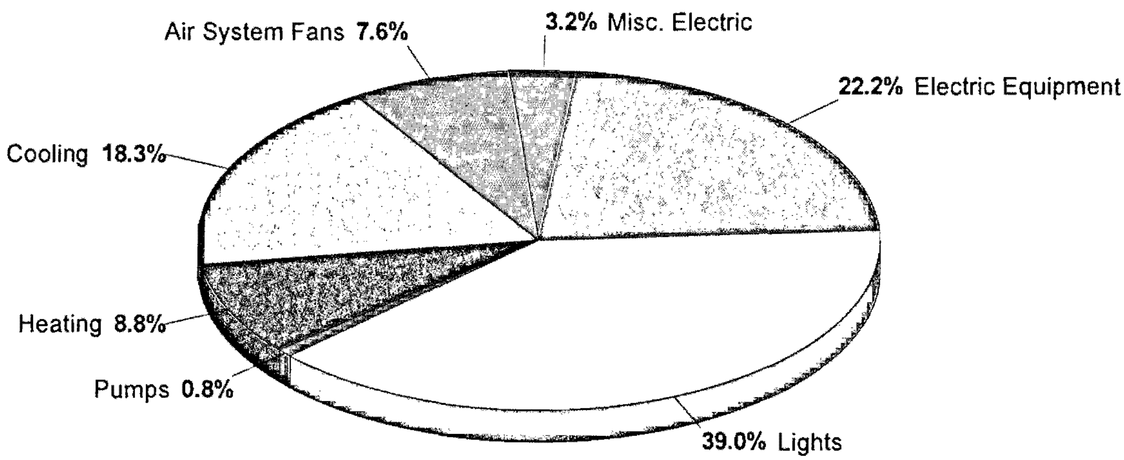
Gross Floor Area .... **17583.8** m²
Conditioned Floor Area .... **17583.8** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs – EPH and SHE_Building (Flat Rate)

08 and 09_EPH and SHE_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	40,194	2.319	7.6
Cooling	96,875	5.589	18.3
Heating	46,725	2.696	8.8
Pumps	4,082	0.236	0.8
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**187,876**	**10.838**	**35.6**
Lights	205,813	11.873	39.0
Electric Equipment	117,211	6.762	22.2
Misc. Electric	17,128	0.988	3.2
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**340,151**	**19.623**	**64.4**
Grand Total	**528,027**	**30.461**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

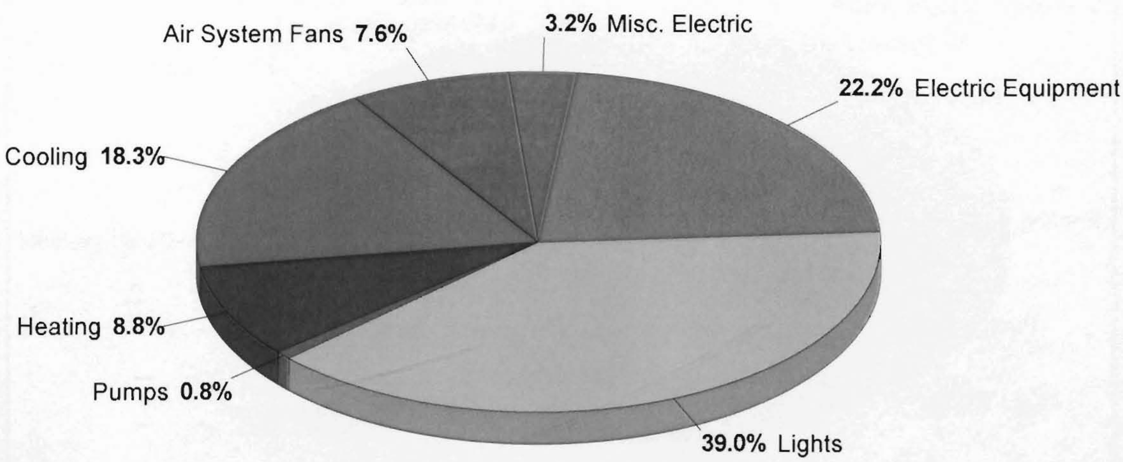
Gross Floor Area .... **17334.7** m²
Conditioned Floor Area .... **17334.7** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs – EPH and SHE_Building (Flat Rate)

08 and 09_EPH and SHE_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
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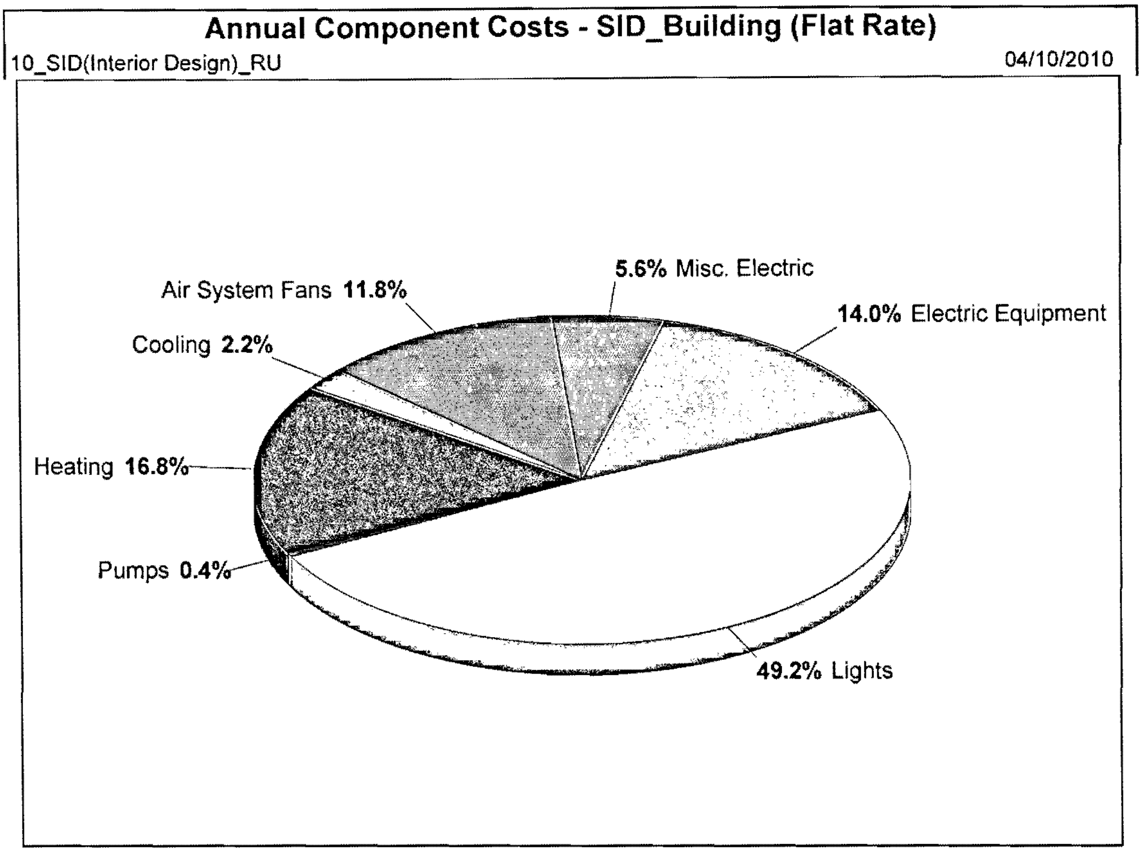
Non-HVAC Sub-Total	**340,151**	**19.623**	**64.4**
Grand Total	**528,027**	**30.461**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **17334.7** m²
Conditioned Floor Area .... **17334.7** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building



1. Annual Costs

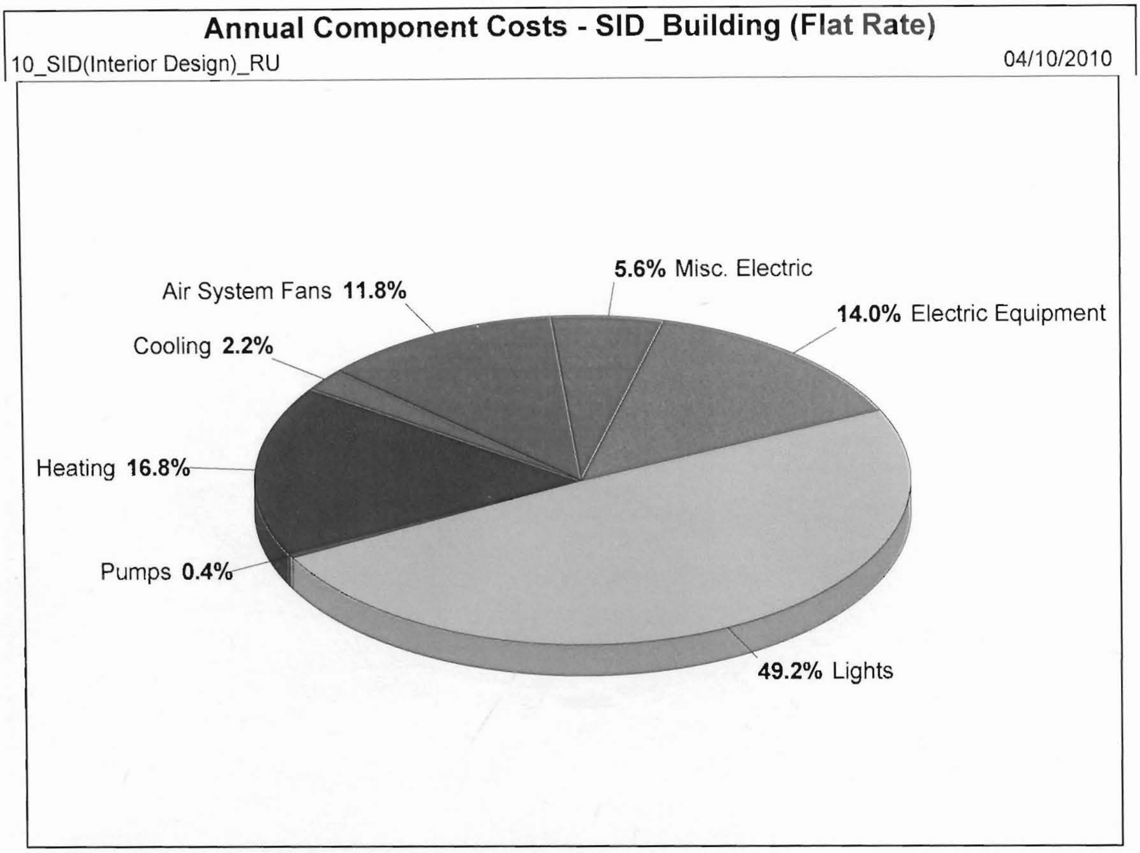
Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	5,712	1.978	11.8
Cooling	1,060	0.367	2.2
Heating	8,136	2.817	16.8
Pumps	199	0.069	0.4
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**15,106**	**5.231**	**31.3**
Lights	23,735	8.219	49.2
Electric Equipment	6,756	2.340	14.0
Misc. Electric	2,687	0.930	5.6
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**33,178**	**11.489**	**68.7**
Grand Total	**48,284**	**16.721**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **2887.7** m²
Conditioned Floor Area .... **2887.7** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building



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Note: Cost per unit floor area is based on the gross building floor area.

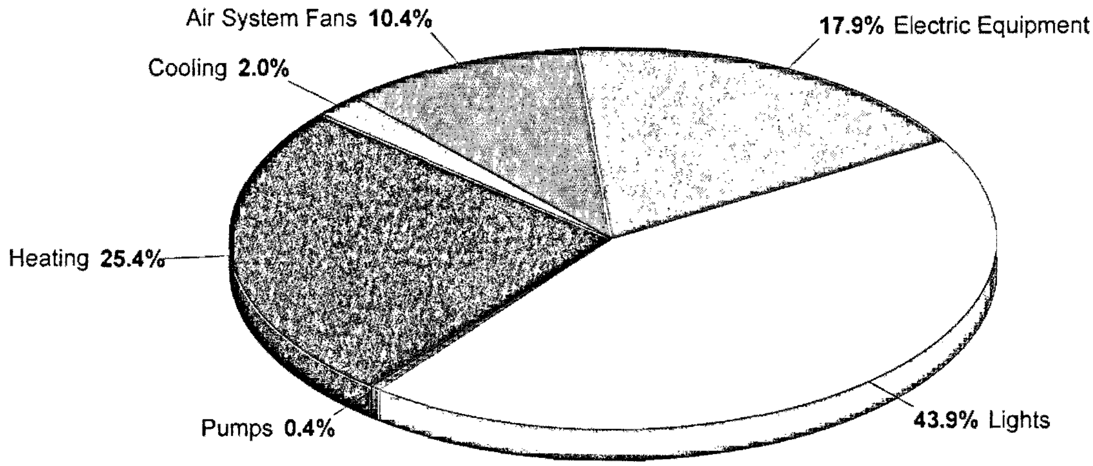
Gross Floor Area .... **2887.7** m²
Conditioned Floor Area .... **2887.7** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - SCC_Building (Flat Rate)

11_SCC (Student Campus Center)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	6,655	2.224	10.4
Cooling	1,299	0.434	2.0
Heating	16,246	5.428	25.4
Pumps	278	0.093	0.4
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**24,478**	**8.178**	**38.2**
Lights	28,145	9.403	43.9
Electric Equipment	11,435	3.820	17.9
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**39,580**	**13.224**	**61.8**
Grand Total	**64,058**	**21.402**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

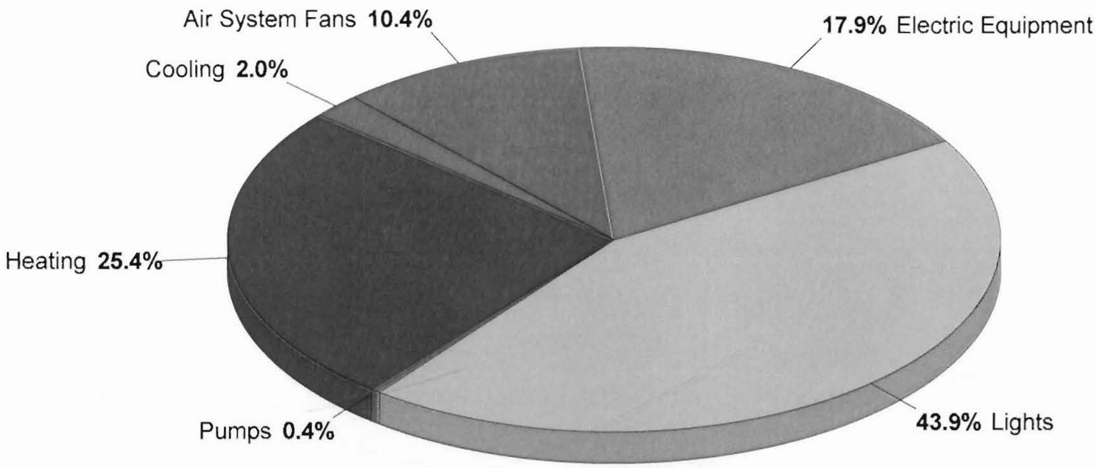
Gross Floor Area .... **2993.1** m²
Conditioned Floor Area .... **2993.1** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - SCC_Building (Flat Rate)

11_SCC (Student Campus Center)_RU 04/10/2010



1. Annual Costs

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Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**39,580**	**13.224**	**61.8**
Grand Total	**64,058**	**21.402**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

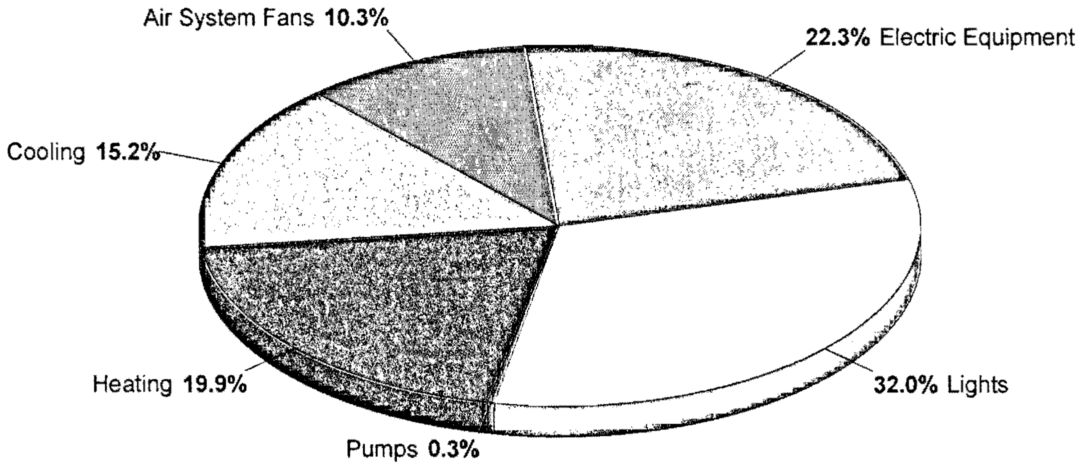
Gross Floor Area .... **2993.1** m²
Conditioned Floor Area .... **2993.1** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs – HEI-GCM_Building (Flat Rate)

12_HEI-GCM_Ryerson University 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	7,088	2.954	10.3
Cooling	10,419	4.343	15.2
Heating	13,665	5.696	19.9
Pumps	197	0.082	0.3
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**31,368**	**13.074**	**45.7**
Lights	21,984	9.163	32.0
Electric Equipment	15,347	6.397	22.3
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**37,331**	**15.560**	**54.3**
Grand Total	**68,699**	**28.634**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

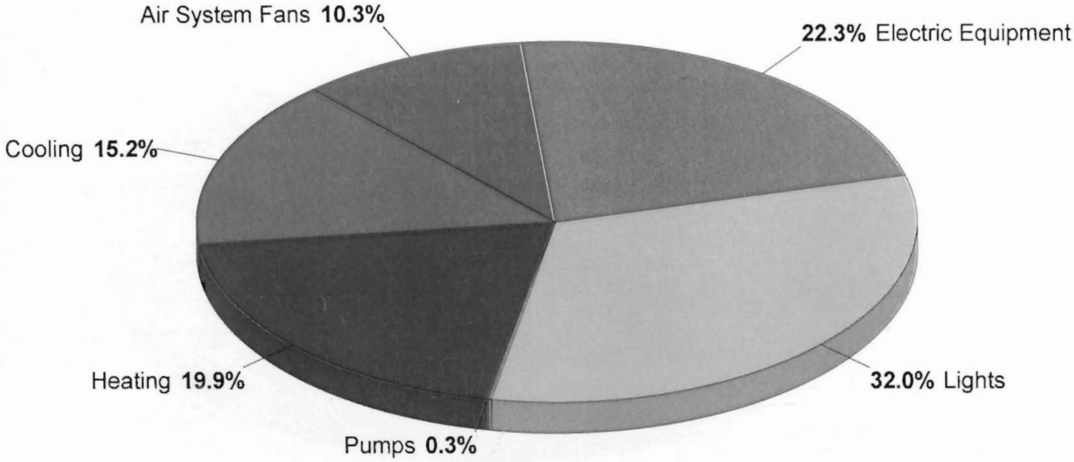
Gross Floor Area .... **2399.2** m²
Conditioned Floor Area .... **2399.2** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs – HEI-GCM_Building (Flat Rate)

12_HEI-GCM_Ryerson University 04/10/2010



1. Annual Costs

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Lights	21,984	9.163	32.0
Electric Equipment	15,347	6.397	22.3
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**37,331**	**15.560**	**54.3**
Grand Total	**68,699**	**28.634**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

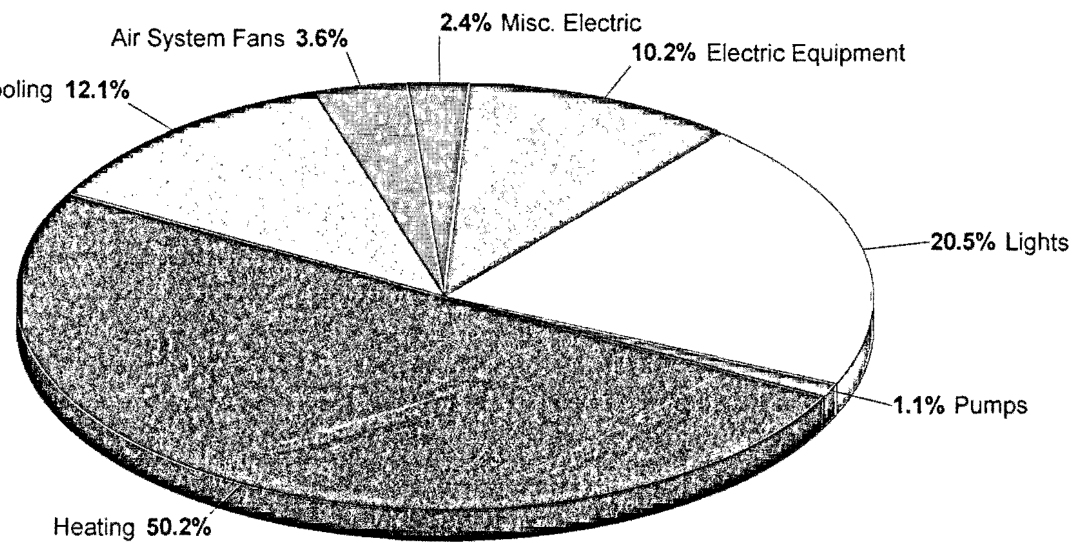
Gross Floor Area .... **2399.2** m²
Conditioned Floor Area .... **2399.2** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - KNE_Building (Flat Rate)

13a_KNE(Kerr Hall North East)_RU 04/10/2010



1. Annual Costs

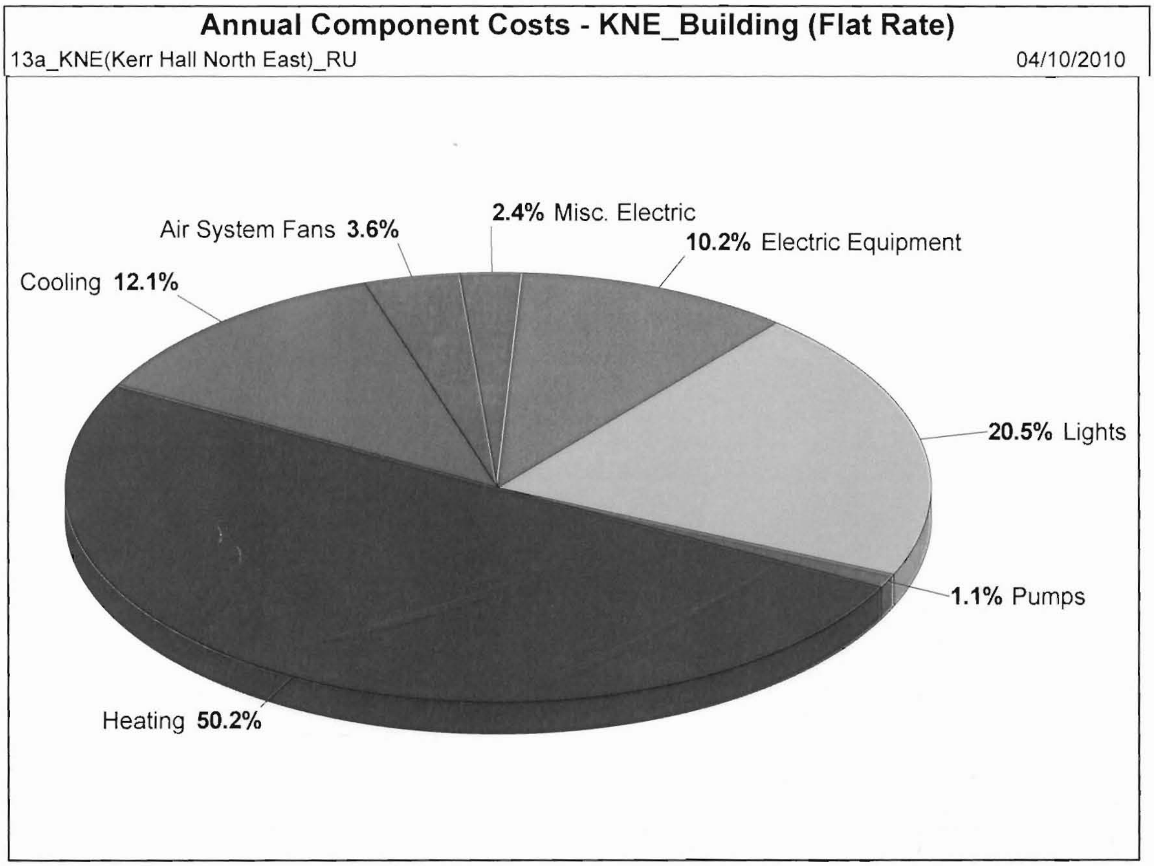
Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	8,396	2.120	3.6
Cooling	28,255	7.134	12.1
Heating	117,434	29.648	50.2
Pumps	2,531	0.639	1.1
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**156,616**	**39.541**	**66.9**
Lights	47,978	12.113	20.5
Electric Equipment	23,850	6.022	10.2
Misc. Electric	5,567	1.405	2.4
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**77,395**	**19.540**	**33.1**
Grand Total	**234,011**	**59.080**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **3960.9** m²
Conditioned Floor Area .... **3960.9** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	8,396	2.120	3.6
Cooling	28,255	7.134	12.1
Heating	117,434	29.648	50.2
Pumps	2,531	0.639	1.1
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**156,616**	**39.541**	**66.9**
Lights	47,978	12.113	20.5
Electric Equipment	23,850	6.022	10.2
Misc. Electric	5,567	1.405	2.4
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**77,395**	**19.540**	**33.1**
Grand Total	**234,011**	**59.080**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

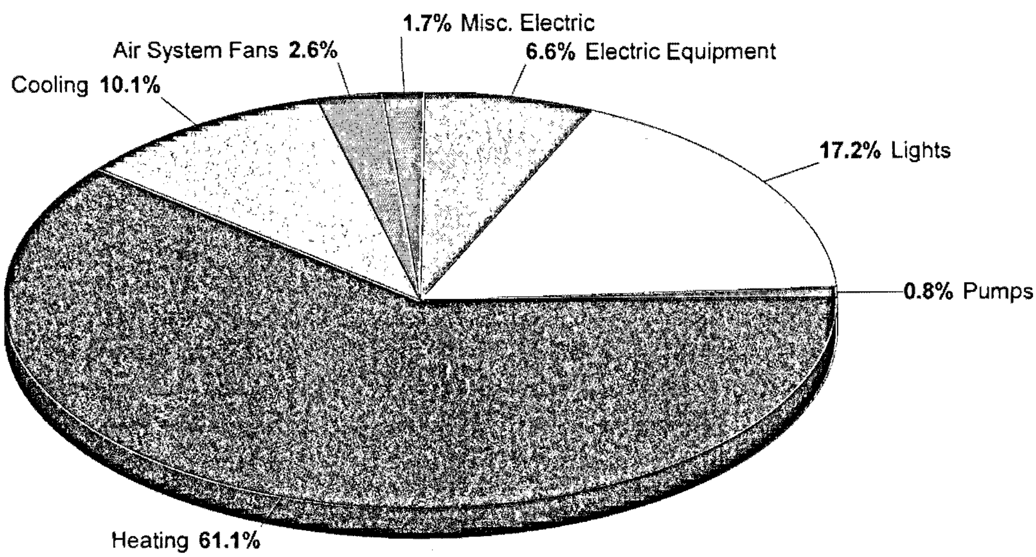
Gross Floor Area .... **3960.9** m²
Conditioned Floor Area .... **3960.9** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - KNW_Building (Flat Rate)

13b_KNW(Kerr Hall North West)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost ($)	($/m²)	Percent of Total (%)
Air System Fans	6,252	1.739	2.6
Cooling	24,374	6.780	10.1
Heating	148,092	41.197	61.1
Pumps	1,968	0.548	0.8
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**180,686**	**50.264**	**74.5**
Lights	41,732	11.609	17.2
Electric Equipment	15,901	4.423	6.6
Misc. Electric	4,053	1.128	1.7
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**61,686**	**17.160**	**25.5**
Grand Total	**242,372**	**67.424**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

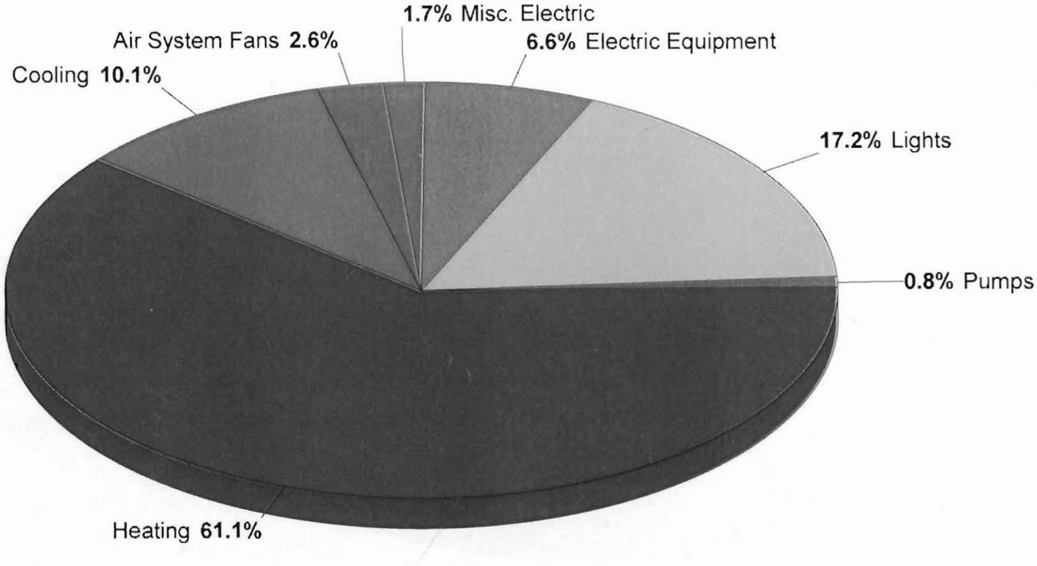
Gross Floor Area .... **3594.8** m²
Conditioned Floor Area .... **3594.8** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - KNW_Building (Flat Rate)

13b_KNW(Kerr Hall North West)_RU 04/10/2010



1. Annual Costs

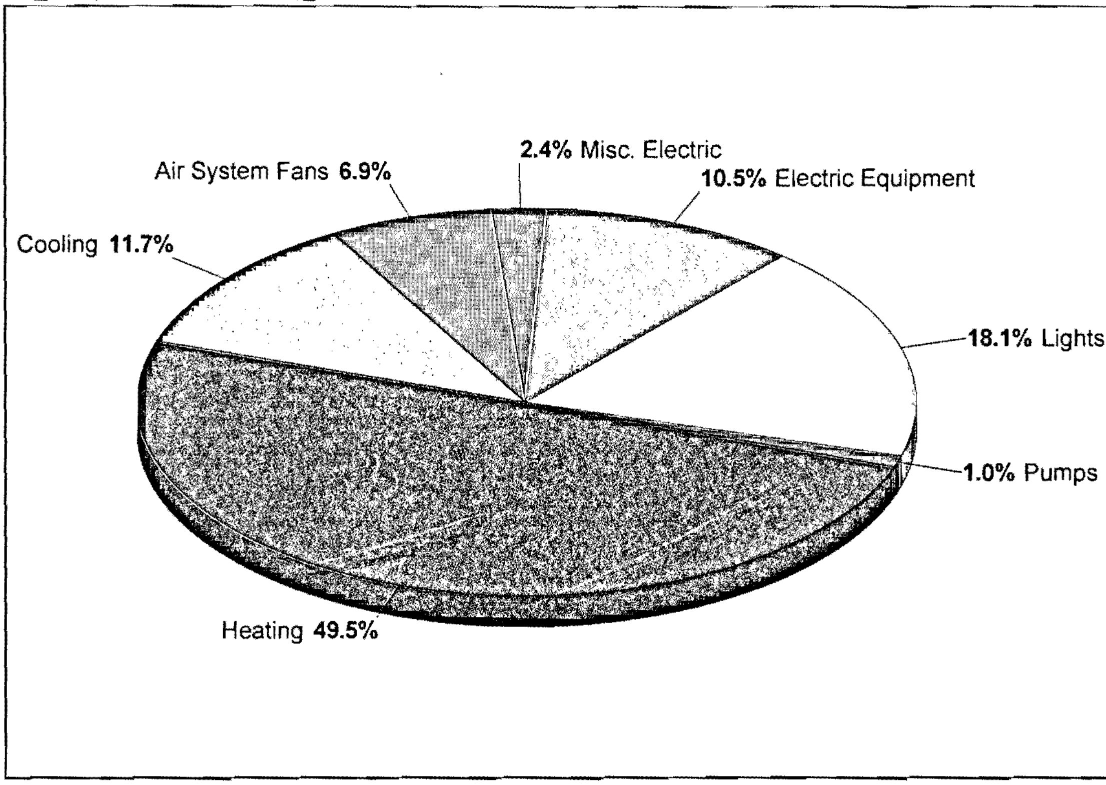
Component	Annual Cost ($)	($/m²)	Percent of Total (%)
Air System Fans	6,252	1.739	2.6
Cooling	24,374	6.780	10.1
Heating	148,092	41.197	61.1
Pumps	1,968	0.548	0.8
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**180,686**	**50.264**	**74.5**
Lights	41,732	11.609	17.2
Electric Equipment	15,901	4.423	6.6
Misc. Electric	4,053	1.128	1.7
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**61,686**	**17.160**	**25.5**
Grand Total	**242,372**	**67.424**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **3594.8** m²
Conditioned Floor Area .... **3594.8** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	56,758	4.678	6.9
Cooling	97,001	7.995	11.7
Heating	410,174	33.806	49.5
Pumps	8,004	0.660	1.0
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**571,937**	**47.138**	**69.1**
Lights	149,580	12.328	18.1
Electric Equipment	87,122	7.181	10.5
Misc. Electric	19,461	1.604	2.4
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**256,163**	**21.113**	**30.9**
Grand Total	**828,100**	**68.251**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

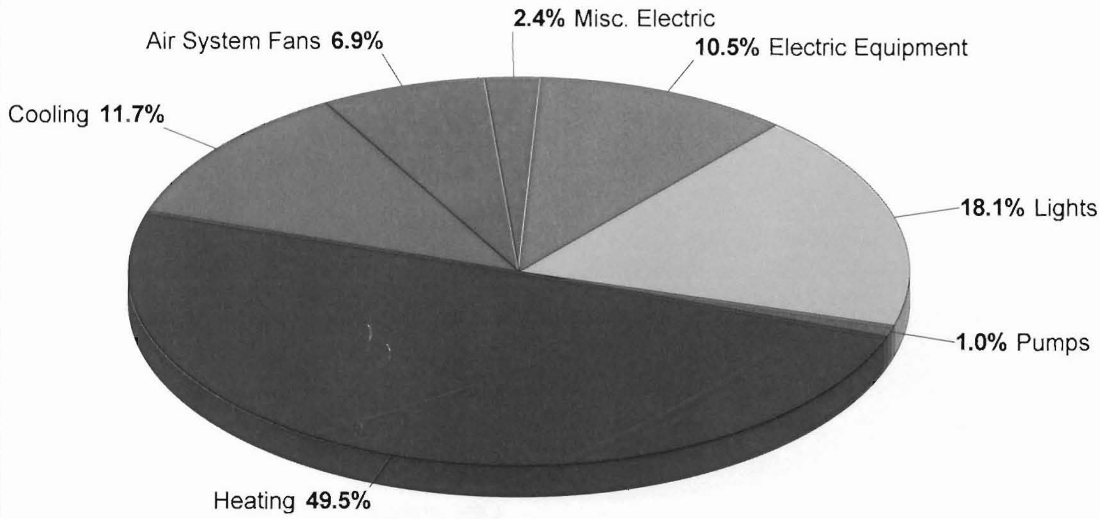
Gross Floor Area .... **12133.2** m²
Conditioned Floor Area .... **12133.2** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - KSE_Building (Flat Rate)

13c_KSE(Kerr Hall South East)_RU — 04/10/2010



1. Annual Costs

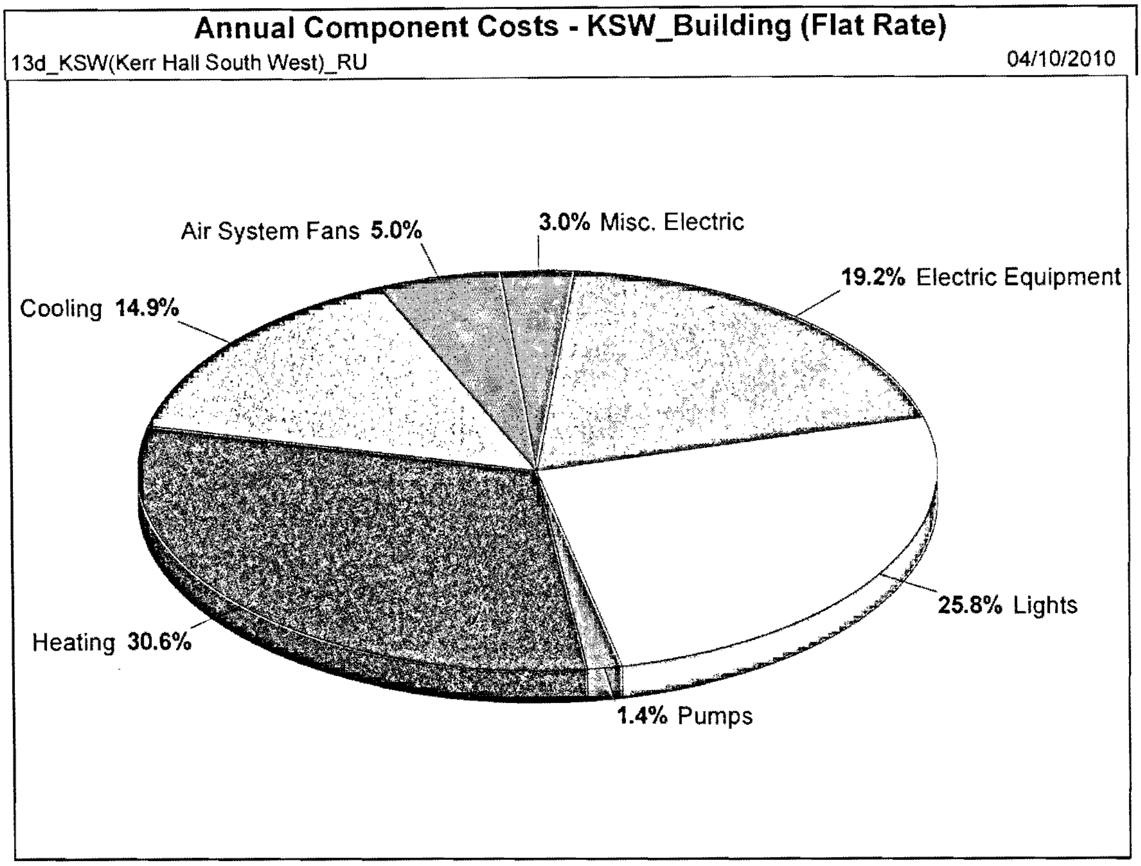
Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	56,758	4.678	6.9
Cooling	97,001	7.995	11.7
Heating	410,174	33.806	49.5
Pumps	8,004	0.660	1.0
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**571,937**	**47.138**	**69.1**
Lights	149,580	12.328	18.1
Electric Equipment	87,122	7.181	10.5
Misc. Electric	19,461	1.604	2.4
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**256,163**	**21.113**	**30.9**
Grand Total	**828,100**	**68.251**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **12133.2** m²
Conditioned Floor Area .... **12133.2** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	27,915	2.703	5.0
Cooling	82,483	7.987	14.9
Heating	159,788	16.440	30.6
Pumps	7,886	0.764	1.4
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**288,072**	**27.894**	**52.0**
Lights	142,833	13.830	25.8
Electric Equipment	106,570	10.319	19.2
Misc. Electric	16,763	1.623	3.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**266,166**	**25.773**	**48.0**
Grand Total	**554,238**	**53.666**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

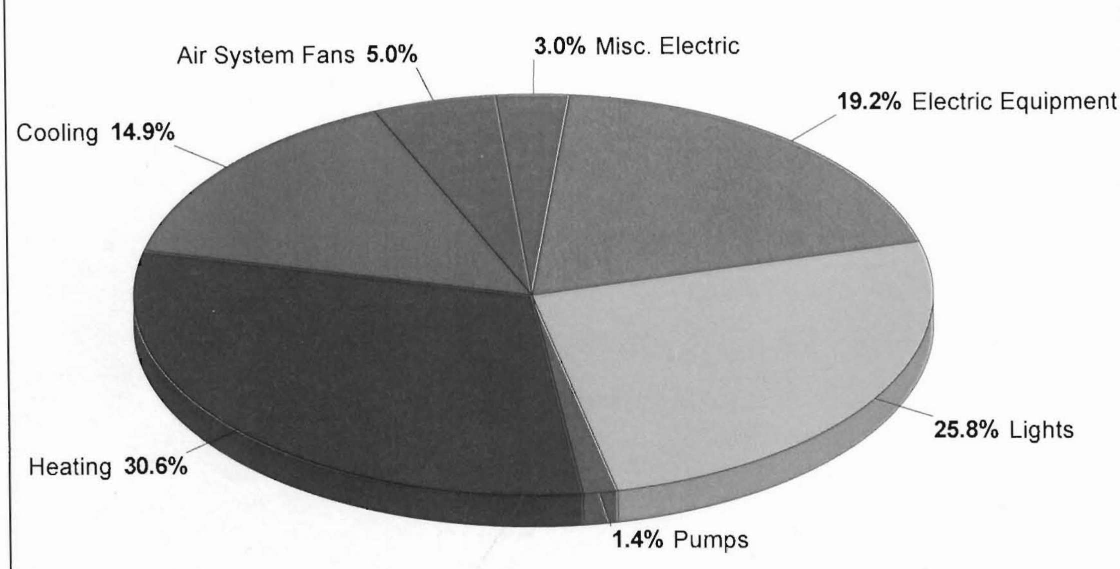
Gross Floor Area .... **10327.5** m²
Conditioned Floor Area .... **10327.5** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - KSW_Building (Flat Rate)

13d_KSW(Kerr Hall South West)_RU 04/10/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	27,915	2.703	5.0
Cooling	82,483	7.987	14.9
Heating	169,788	16.440	30.6
Pumps	7,886	0.764	1.4
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**288,072**	**27.894**	**52.0**
Lights	142,833	13.830	25.8
Electric Equipment	106,570	10.319	19.2
Misc. Electric	16,763	1.623	3.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**266,166**	**25.773**	**48.0**
Grand Total	**554,238**	**53.666**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

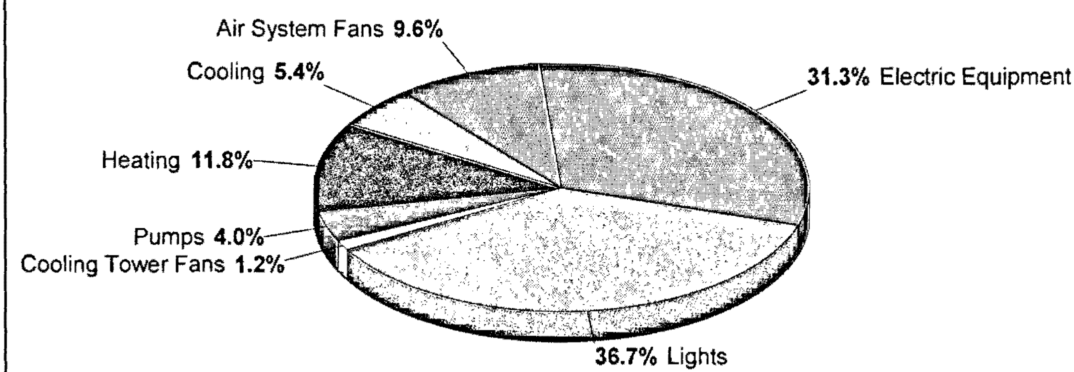
Gross Floor Area .... **10327.5** m²
Conditioned Floor Area .... **10327.5** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs -RCC_Building (Flat Rate)

14_RCC_Central Chiller_RU 04/11/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	22,337	2.055	9.6
Cooling	12,539	1.153	5.4
Heating	27,403	2.521	11.8
Pumps	9,261	0.852	4.0
Cooling Tower Fans	2,852	0.262	1.2
HVAC Sub-Total	**74,393**	**6.843**	**31.9**
Lights	85,607	7.875	36.7
Electric Equipment	73,040	6.719	31.3
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**158,647**	**14.593**	**68.1**
Grand Total	**233,039**	**21.437**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

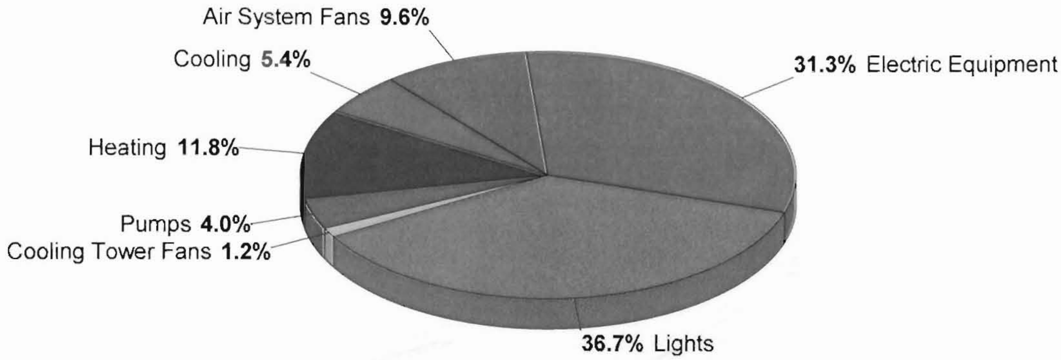
Gross Floor Area .... **10871.2** m²
Conditioned Floor Area .... **10871.2** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs -RCC_Building (Flat Rate)

14_RCC_Central Chiller_RU — 04/11/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
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Cooling	12,539	1.153	5.4
Heating	27,403	2.521	11.8
Pumps	9,261	0.852	4.0
Cooling Tower Fans	2,852	0.262	1.2
HVAC Sub-Total	**74,393**	**6.843**	**31.9**
Lights	85,607	7.875	36.7
Electric Equipment	73,040	6.719	31.3
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**158,647**	**14.593**	**68.1**
Grand Total	**233,039**	**21.437**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

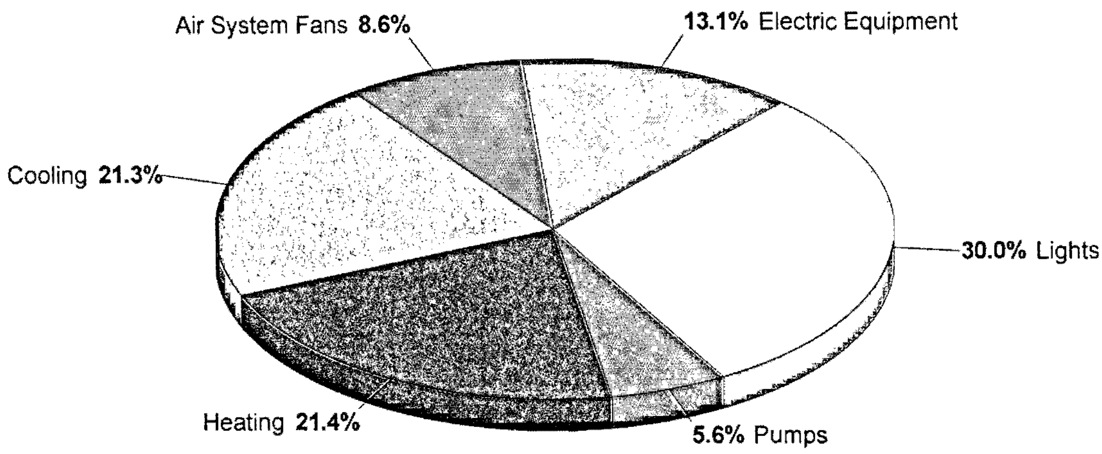
Gross Floor Area .... **10871.2** m²
Conditioned Floor Area .... **10871.2** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs -PIT_Building (Flat Rate)

15_PIT_PITMAN Building_RU 04/11/2010



1. Annual Costs

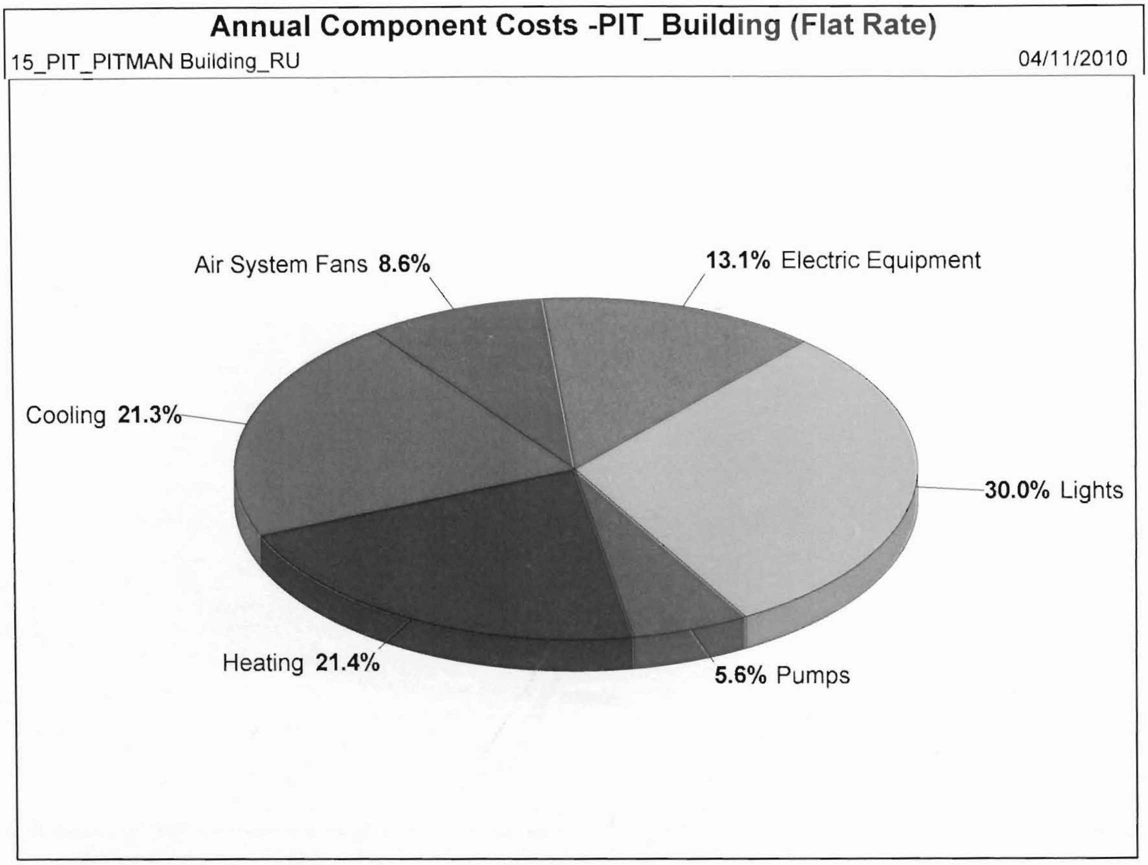
Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	5,014	2.315	8.6
Cooling	12,474	5.760	21.3
Heating	12,510	5.776	21.4
Pumps	3,267	1.509	5.6
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**33,265**	**15.359**	**56.9**
Lights	17,550	8.103	30.0
Electric Equipment	7,685	3.548	13.1
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**25,235**	**11.652**	**43.1**
Grand Total	**58,500**	**27.011**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **2165.8** m²
Conditioned Floor Area .... **2165.8** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building



1. Annual Costs

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Note: Cost per unit floor area is based on the gross building floor area.

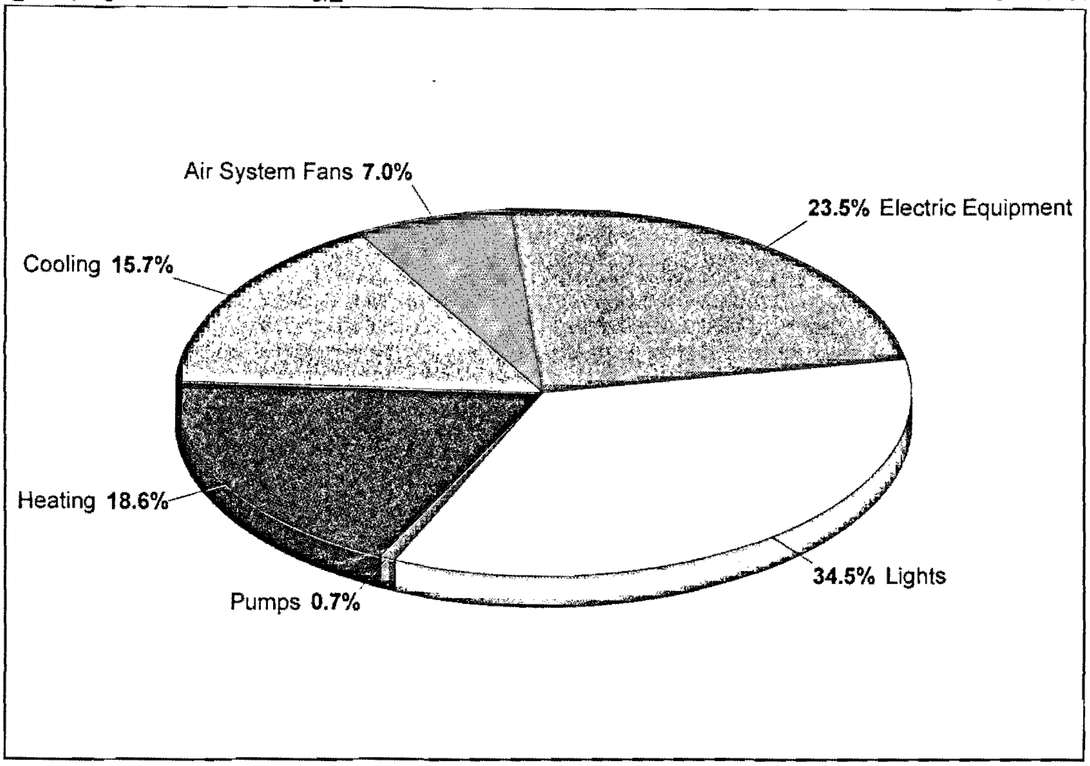
Gross Floor Area .... **2165.8** m²
Conditioned Floor Area .... **2165.8** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - RBB_Building (Flat Rate)

16_RBB(Rogers Business Building)_RU 04/11/2010



1. Annual Costs

Component	Annual Cost	($/m²)	Percent of Total
Air System Fans	42,189	2.520	7.0
Cooling	94,435	5.641	15.7
Heating	111,523	6.662	18.6
Pumps	4,158	0.248	0.7
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**252,305**	**15.071**	**42.0**
Lights	207,055	12.368	34.5
Electric Equipment	141,136	8.431	23.5
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**348,191**	**20.799**	**58.0**
Grand Total	**600,496**	**35.870**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

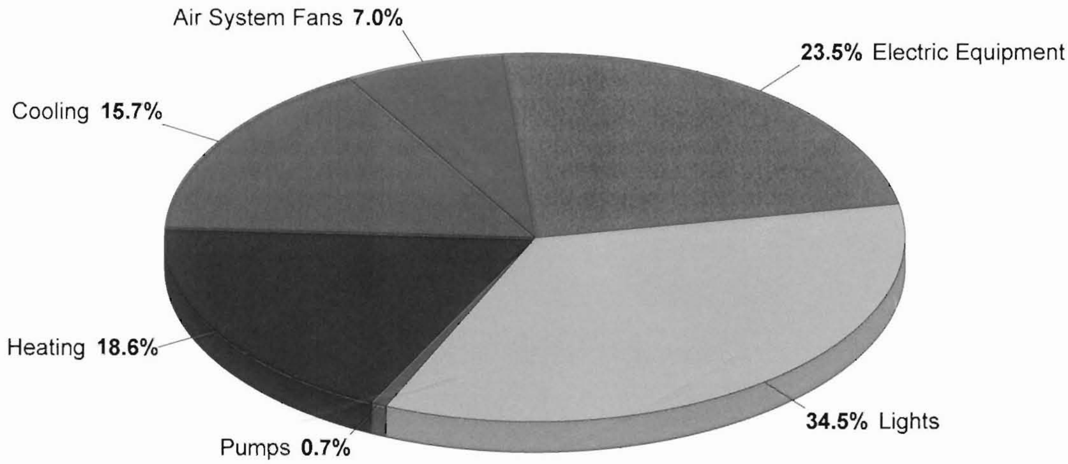
Gross Floor Area .... **16740.7** m²
Conditioned Floor Area .... **16740.7** m²

Hourly Analysis Program v.4.3

Appendix F: Annual Component Costs of Ryerson University Building

Annual Component Costs - RBB_Building (Flat Rate)

16_RBB(Rogers Business Building)_RU 04/11/2010



1. Annual Costs

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Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **16740.7** m²
Conditioned Floor Area .... **16740.7** m²

Hourly Analysis Program v.4.3