ENERGY AUDIT AND BASE CASE SIMULATION OF RYERSON BUILDINGS USING THE "CARRIER HAP" SIMULATION PROGRAM AND PRISM ANALYSIS FOR ENERGY CONSUMPTION

by

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Abstract

Modelling and simulation of energy consumption in 86% of the Ryerson campus was presented. Energy simulation models were developed with Carrier HAP for 16 Ryerson buildings. Carrier HAP, commercially available software, was used for the prediction of energy consumption and PRISM software was used for the energy consumption comparison in different locations using weather normal average temperature data. All of the possible sources and uses of energy in the building were accounted for in the modelling and simulation. From the simulation result, it showed that 26% of total energy was consumed by lighting and 19% of total energy used by plug load and 4% of total energy used by miscellaneous. Sensitivity analysis was conducted by reducing lighting schedule. As a result, annual energy savings of 10% for cooling load and 21% for hydro demand were achieved, but the heating load increased by 14%.

The other part of the energy consumption was for the Heating, Ventilation and Air Conditioning (HVAC) system, 53% of total energy was demanded in this sector for the 16 Ryerson buildings. PRISM model was developed for compared Ryerson energy consumption and also compared Ryerson campus in different locations.

The base case simulation result was compared with the campus planning actual consumption bill for the hydro, steam and DLWC cooling demand for the Ryerson campus. The result was under predicted from the actual bill. Simulation was under predicted hydro consumption by 5.7% and steam consumption by 6.26%. The average energy intensity was determined 1.04 GJ/m^2 for the 86% of total area of Ryerson campus. Also energy intensity (GJ/students) compared with different province in Canada, result shows that Ryerson University consumed less energy and this value is 10 GJ/student.

Acknowledgements

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Nomenclature

AC	Air Conditioning
ACH	Air Change per Hour
AHU	Air Handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BSPs	Building Simulation Programs
BTU	British Thermal Unit
CAD	Computer-Aided Design
CAV	Constant Air Volume
CDD	Cooling Degree Days
CEC	Commission for Environmental Cooperation
CFM	Cubic Feet per Minute
CFM/ft^2	Cubic Feet per Minute per square feet
CO	Cooling-Only
COP	Coefficient of Performance
DD	Degree Days
DX	Direct Expansion
ECO	Energy Conservation Opportunities
FCU	Fan-Coil Unit
GHG	Greenhouse Gas
HAP	Hourly Analysis Program
HC	Heating-and-Cooling
HDD	Heating Degree Days
HO	Heating-Only
HVAC	Heating, Ventilating and Air conditioning
kWh	Killo-Watt-Hour
lb	Pound
LEED	Leadership in Energy and Environmental Design
MNECB	Model National Energy Code of Canada for Buildings
NAC	Normalized Annual Consumption
NOAA	National Oceanic and Atmospheric Administration
NRTEE	National Round Table on the Environment and the Economy
PRISM	PRInceton Scorekeeping Method
RTU	Rooftop Unit
Tout	Out door temperature
Tref	Reference temperature
TU	Terminal Units
VAV	Variable Air Volume
DHW	Domestic Hot Water
DCW	Domestic Cold Water

1.0. Introduction

Energy audit gives an in-depth knowledge of the existing energy consumption profile of the audited object; it also identifies different factors affecting the energy consumption and brings up cost-effective energy saving opportunities. Energy audit makes an evaluation of the present consumption of energy, the feasible energy saving possibilities and produces the energy audit report. That is why energy audit has become an accepted first step in identification and implementation of various energy efficiency opportunities in residential, commercial, institutional and industrial facilities. The main target of the energy audit is to determine overall picture of the use and distribution of energy, its costs, energy saving potentials and the possibilities to use renewable energy sources.

The core tools in the building energy field are the whole-building energy simulation programs that provide users with key building performance indicators such as energy use and demand, temperature, humidity, and costs. There are some building simulation programs as BLAST, DOE-2.1E, eQUEST, Energy Plus, ESP-r, Carrier HAP, IES <VE>, TRNSYS etc (Chowdhury et al., 2007).

This study was to conduct detail analysis of energy audit, whole building energy simulation using computer simulation program, Carrier HAP, for the purpose of energy performance evaluation of Ryerson campus. Ryerson University has a total floor area of 281020 m^2 in 28 buildings listed in Table 1, including office buildings, educational buildings and residential buildings. ASHRAE Standard 90.1-2004 energy standard for buildings and PRInceton Scorekeeping Method (PRISM) are selected for the overall energy consumption of 86% of total Ryerson University building area listed in Table 2. This university has two central cooling plants. One of them is located in the Library building with capacity of 3100 ton which serves 66% of total area; the other one is located in the Rogers Communications Center (RCC) with capacity of 530 ton which serves 11% of total area. Deep Lake Cooling System serves 9% of total area and own/self cooling system serves 14% of total area. Figure 1 and Table 3 shows Ryerson buildings served by the different cooling systems.

Table 1: List of Ryerson buildings

Sl. No.	Name of the Buildings	Build in Year	Total Floor Area (m^2)
1	Heaslip House Continuing Education (CED)	2005	4180
2	School of Image Art (IMA)	1953	9345
3	Victoria Building (VIC)	1930	12708
4	Jorgenson Hall (JOR)	1968	10964
5	Library Building (LIB)	1971	18487
6	Podium (POD)	1969	21730
7	Engineering Building (ENG)	2005	22350
8	Eric Palin Hall (EPH)	1984	13942
9	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)	2002	7077
10	School of Interior Design (SID)	---	4373
11	Student Campus Centre (SCC)	2005	4180
12	Heidelberg Centre-School of Graphic Communications Management (HEI/GCM)	2002	2985
13	Kerr Hall (KNE, KNW, KSE, KSW)	1963	52409
14	Rogers Communications Center (RCC)	1989	13100
15	Pitman Hall Residence (PIT)	1991	17866
16	Rogers Business Building (RBB)	2004	24378
17	International Living/ Learning Centre (ILLC)	1987	9735
18	South Bond Building (SBB)	1911	6494
19	Architecture Building (ARC)	1981	7239
20	Recreation & Athletics Centre (RAC)	1987	4280
21	Monitory Time Building (MON)	---	2843
22	Oakham House (OAK)	1925	2033
23	Research and Graduate Studies (GER)	1958	2860
24	Theatre School (THR)	1971	2925
25	PRO/BND	1992	851
26	O'Keefe House	1900	848
27	ORI office	1954	732
28	Ryerson Book Store (BKS)	1988	106
	Total floor area of entire Ryerson buildings		**281,020**

Table 2: List of selected Ryerson buildings for energy audit and simulation

Sl.No.	Name of the Building	Area (m^2)
Group 1: Chiller Plant Located in the Library building		
1	School of Image Art (IMA)	9345
2	Heaslip House Continuing Education (CED)	4180
3	Victoria Building (VIC)	12708
4	George Vari Engineering and Computing Centre (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	School of Interior Design (SID)	4373
11	Student Campus Centre (SCC)	4180
12	Heidelberg Centre-School of Graphic Communications Management (HEI/GCM)	2985
13	Kerr Hall (KHN, KHS, KHE, KHW)	52409
	Total floor area served by the central chillers plant	**184,730**
Group 2: Chiller Plant Located in the RCC building		
14	Rogers Communications Centre (RCC)	13100
15	Pitman Hall Residence (PIT)	17866
	Total floor area served by the central chillers plant	**30,966**
Remote Source Chilled Water supplied by enWave		
16	Rogers Business Building (RBB)	24378
	Total Area for Audit	**240,074**

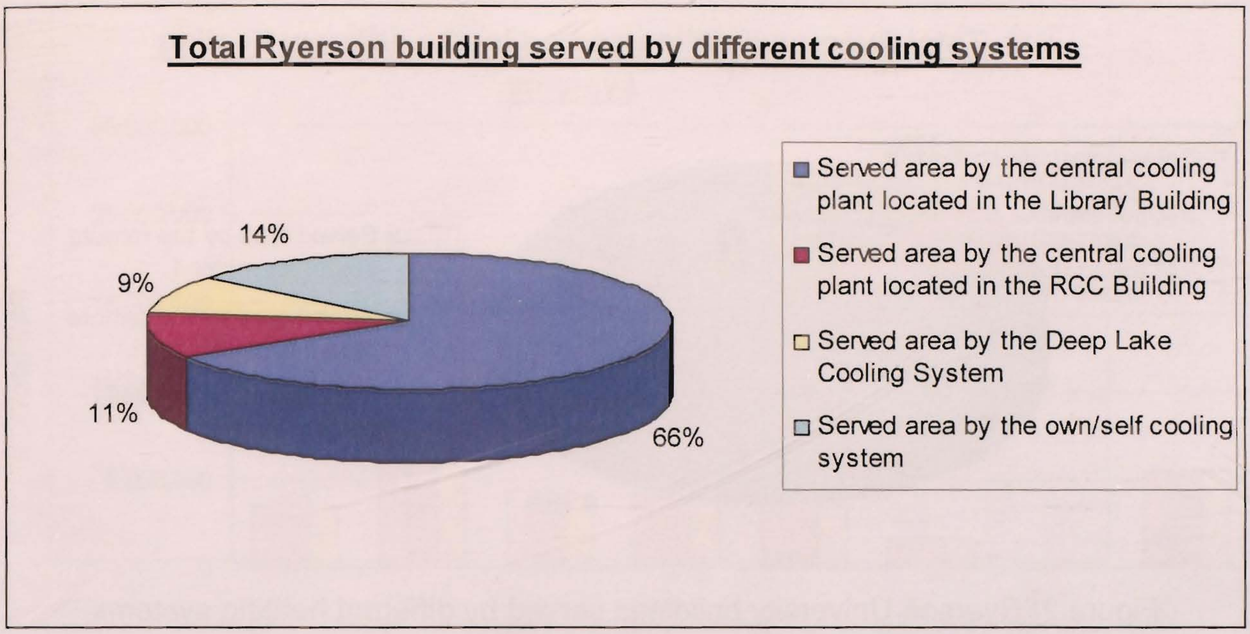

Figure 1: Ryerson University buildings served by different cooling systems

Table 3: List of different cooling systems

	Area (m^2)	(%)
Group 1: Chiller Plant Located in the Library building	184730	66
Group 2: Chiller Plant Located in the RCC building	30966	11
Rogers Business Building served by Deep Lake cooling system	24378	9
Self cooling (Roof Top Unit)	40946	14
Total Ryerson university area	**281,020**	**100**

This university has two meters for steam consumption to satisfy space heating demand, cooling demand (absorption chiller) and hot water demand supplied by the enWave. One of them serves the Rogers Business Building (RBB), having 9% of total area and other one serves 20 individual buildings, 79% of total area. Self heating system (Boiler or Heat Pump) served for 12% of total area. Figure 2 and Table 4 show Ryerson buildings served by different heating systems.

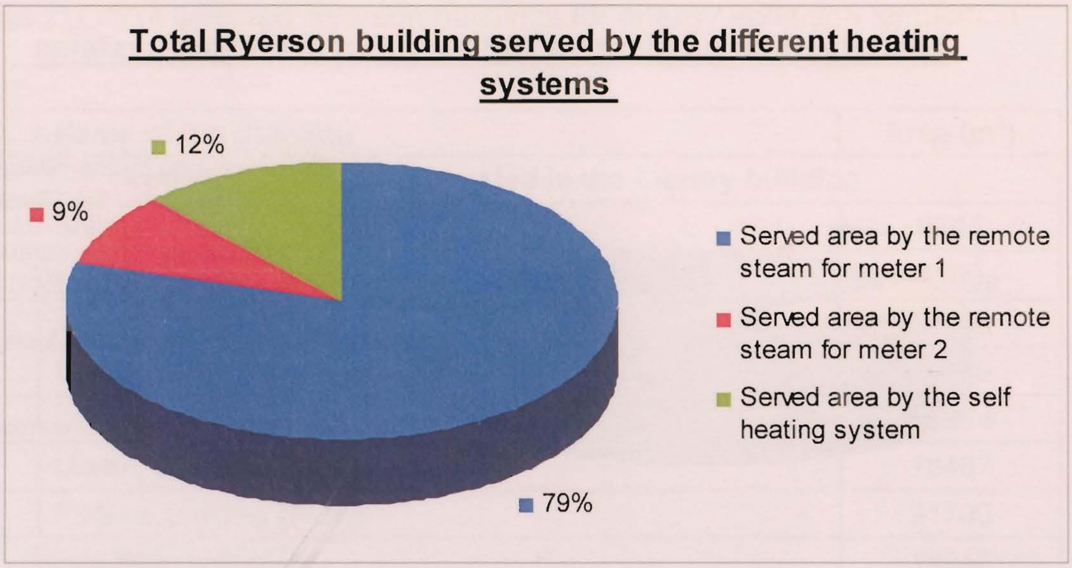

Figure 2: Ryerson University buildings served by different heating systems

Table 4: List of different heating systems

	Area (m^2)	(%)
Served area by the remote steam for meter 1	223127	79
Served area by the remote steam for meter 2	24378	9
Served area by the self heating system	33515	12
Total Ryerson building served by the different heating systems	**281,020**	**100**

1.1. Energy consumption of selected Ryerson buildings

This report describes hydro and steam consumptions for Ryerson buildings which are listed in Table 2. Energy consumption data collected for three-year period listed in Table 5 and consumption per unit area listed in Table 6 (Appendix A). Figure 3 shows electricity consumption for Ryerson University in different years according to the space used and Table 7 indicates cooling degree days (CDD) and heating degree days (HDD) for the corresponding years. Two central chiller plants electricity bills included in the Library building and RCC building.

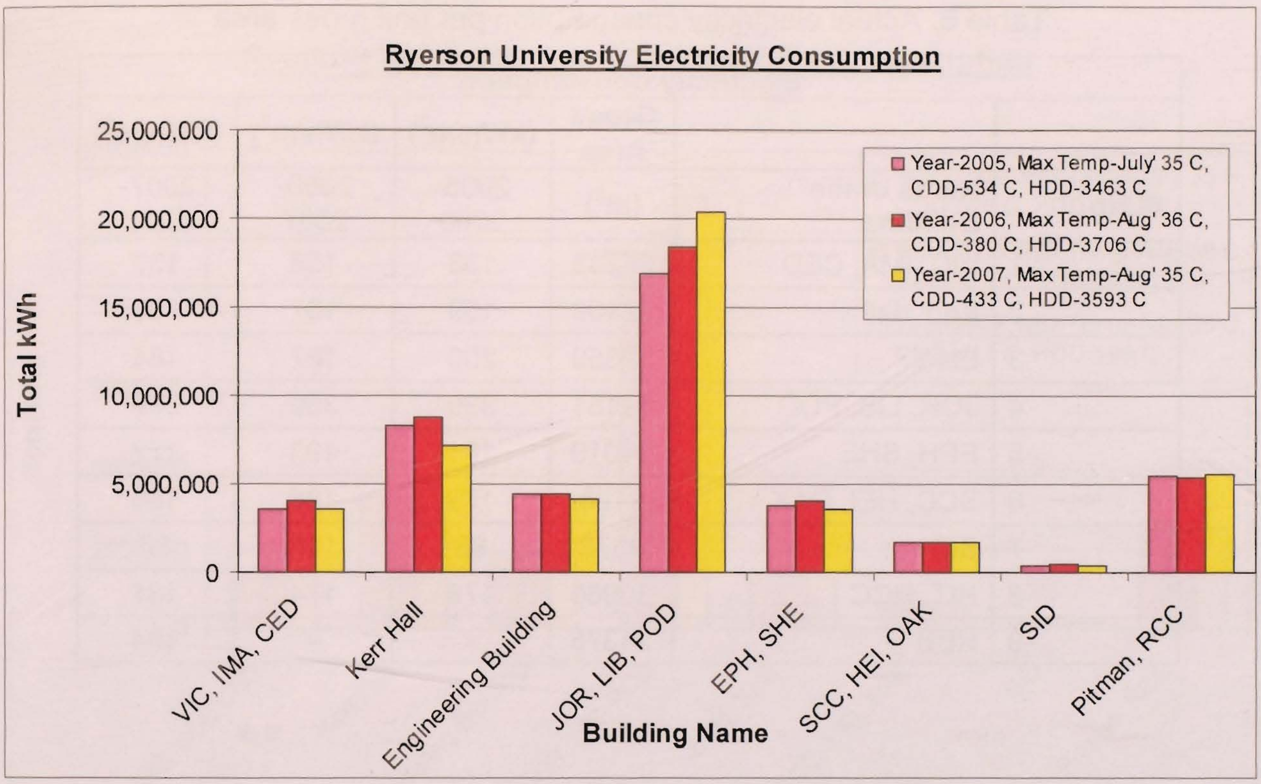

Figure 3: Annual electric consumption for Ryerson University buildings

Table 5: Electricity consumption

		Electricity Consumption		
		Total (kWh)	Total (kWh)	Total (kWh)
Sl.No.	Name of the Building/Year	2005-2006	2006-2007	2007-2008
1	VIC, IMA, CED	3,608,472	4,067,896	3,599,652
2	Kerr Hall	8,306,896	8,771,259	7,130,113
3	ENG	4,472,078	4,408,548	4,111,201
4	JOR, LIB, POD	16,895,386	18,376,049	20,399,668
5	EPH, SHE	3,813,068	4,057,548	3,609,473
6	SCC, HEI, OAK	1,650,957	1,705,010	1,732,166
7	SID	364,543	435,840	373,760
8	PIT, RCC	5,500,402	5,397,903	5,607,650
	Total	44,611,802	47,220,053	46,563,683
9	RBB	-	-	4,001,970

Table 6: Actual electricity consumption per unit gross area

Electricity Consumption					
		Gross Area	(kWh/m²)	(kWh/m²)	(kWh/m²)
Sl.No.	Name of the Building	(m²)	2005-2006	2006-2007	2007-2008
1	VIC, IMA, CED	26233	138	155	137
2	Kerr Hall	52409	159	167	136
3	ENG	22350	200	197	184
4	JOR, LIB, POD	51181	330	359	399
5	EPH, SHE	21019	181	193	172
6	SCC, HEI, OAK	9198	179	185	188
7	SID	4373	83	100	85
8	PIT, RCC	30966	178	174	181
9	RBB	24378	-	-	164

Table 7: CDD and HDD in different years

Year (May-April)	CDD (°C)	HDD (°C)	CDD+HDD (°C)
2005-2006	534	3463	3996
2006-2007	380	3706	4087
2007-2008	433	3593	4026

Annual electricity consumption can be divided into two parts as summer consumption and winter consumption. Figure 4 presents electricity consumption in summer season (May to September) and Figure 5 presents electricity consumption in winter season (October to April). Heating degree days (HDD) and cooling degree days (CDD) are calculated for the summer season from May to September listed in Table 8 and data from October to April for winter season are listed in Table 9.

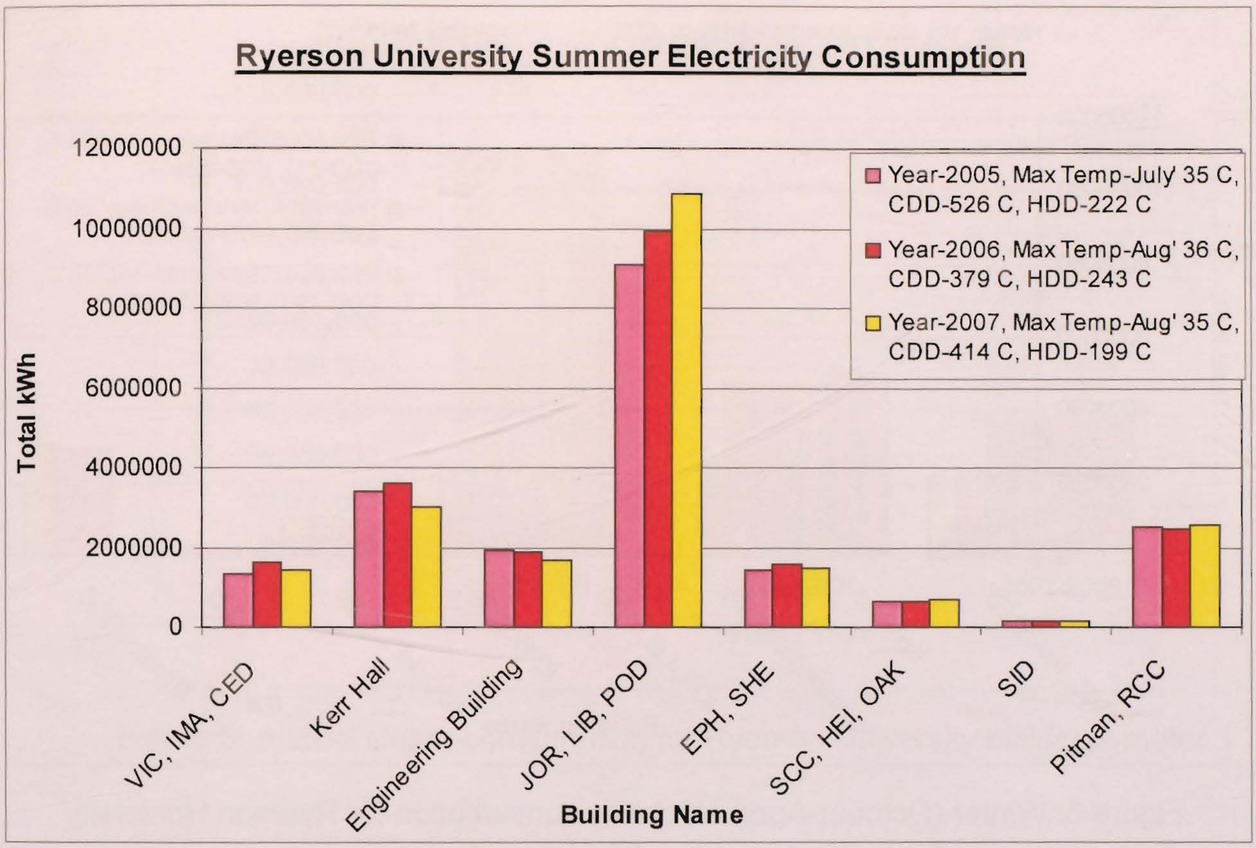

Figure 4: Summer (May-September) electricity consumption for Ryerson University

Table 8: Summer CDD and HDD in different years

Year (May-Sept)	CDD (°C)	HDD (°C)	DD (CDD+HDD) (°C)
2005	526	222	748
2006	379	243	622
2007	414	199	613

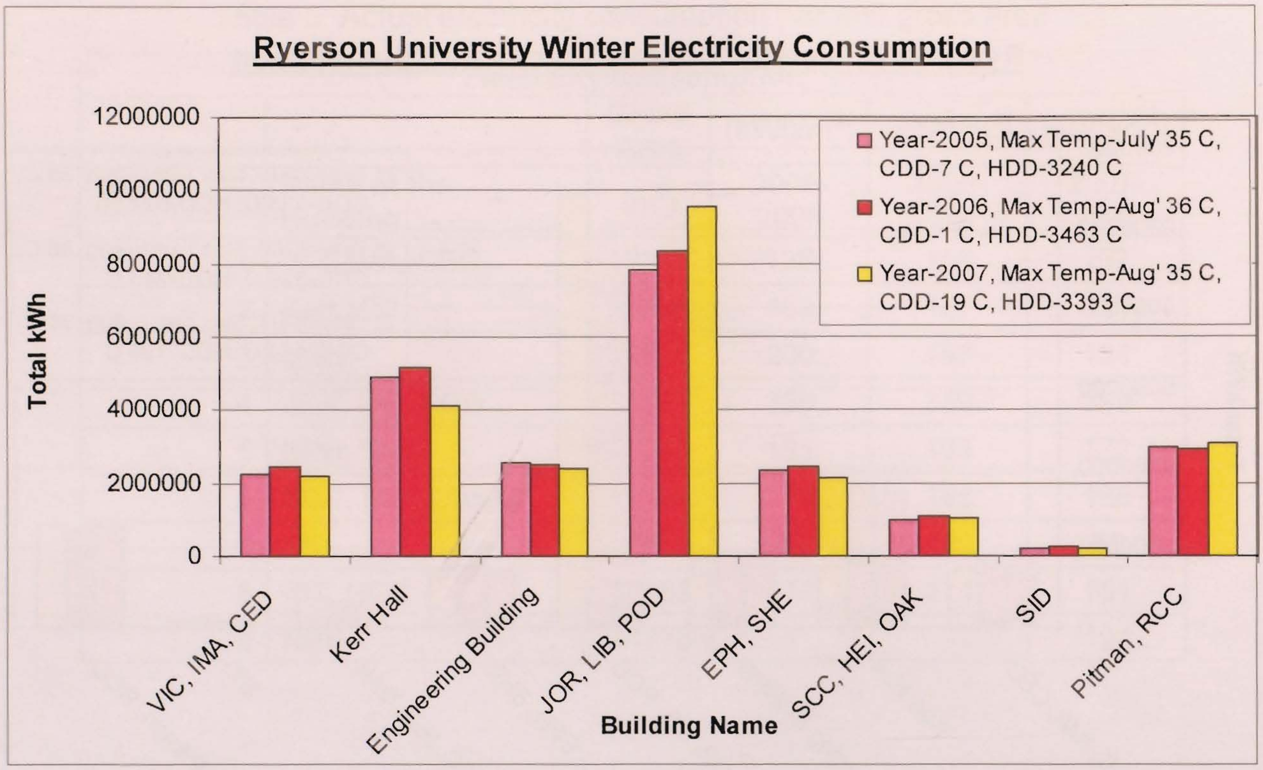

Figure 5: Winter (October-April) electricity consumption for Ryerson University

Table 9: Winter CDD and HDD in different years

Year (Oct-April)	HDD (^oC)	CDD (^oC)	DD (CDD+HDD) (^oC)
2005-2006	3240	7	3248
2006-2007	3463	1	3464
2007-2008	3393	19	3412

Figure 6 shows (meter 1) steam consumption for Ryerson University in different years and Figure 7 shows (meter 2) steam consumption for RBB in different years. CDD and HDD are listed in Table 10. The extreme minimum temperature is listed in Table 11. Total electric energy consumptions for different buildings are given in Appendix-A.

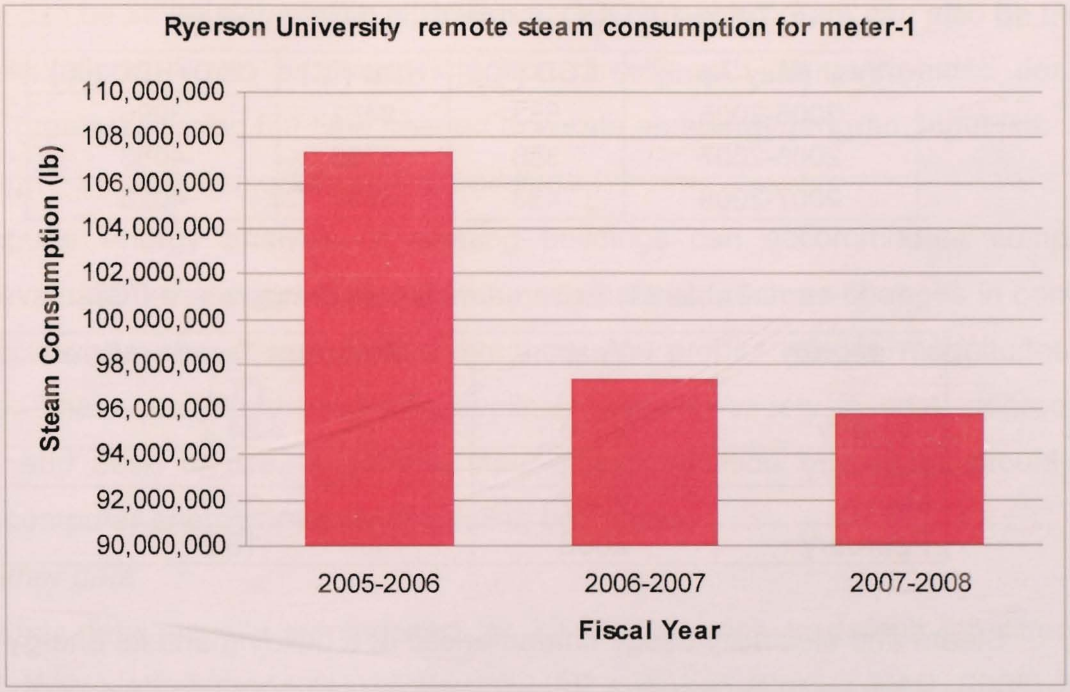

Figure 6: Annual steam consumption for Ryerson University buildings meter 1

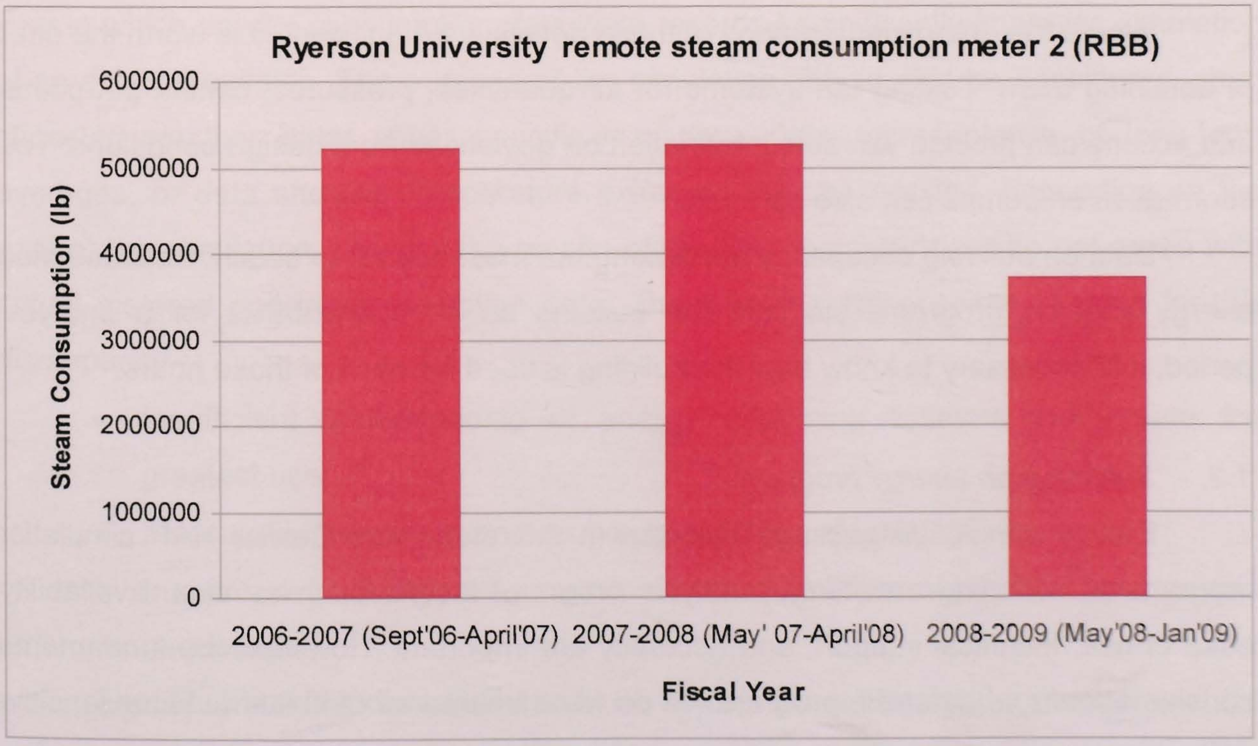

Figure 7: Annual steam consumption for Ryerson University buildings meter 2

Table 10: CDD and HDD in different years

Year (May-April)	CDD (°C)	HDD (°C)	CDD+HDD (°C)
2005-2006	533	3462	3996
2006-2007	380	3706	4086
2007-2008	433	3592	4026

Table 11: Extreme minimum temperature (°C)

Month	Year	Minimum Temperature (°C)
January	2005	-24.2
February	2006	-14.5
March	2007	-22.1
February	2008	-18.2

Steam and electricity usage characteristic of a building and its energy-consuming systems as a time-varying function of ambient conditions. Most computer programs can use as much detailed information about the building and its mechanical and electrical system as is available.

Where the energy implications of these details are significant, it is worth the effort of obtaining them. Testing fan systems for air quantities, pressures, control set points, and actions can provide valuable information on deviations from design conditions. Test information on pumps can also be useful.

Data on building occupancy are among the most difficult to obtain. Because most energy analysis programs simulate the building on an hourly basis for a one-year period, it is necessary to know how the building is used for each of those hours.

1.2. Selecting an energy program

Energy simulation package selected in this study was Carrier HAP simulation program. In selecting an energy analysis program, factors such as cost, availability, ease of use, technical support, and accuracy are important. However, the fundamental consideration is whether the program will do what is required of it. It should be sensitive to the parameters of concern, and its output should include necessary data.

Time can be saved if the initial input files for an energy program can also be used for load calculations. Some programs interface directly with computer-aided design (CAD) files, greatly reducing the time needed to create an energy program input file.

1.3. *Energy programs to model existing buildings*

Computer energy analysis of existing buildings can accommodate complex situations; evaluate the energy effects of many alternatives, such as changes in control settings, occupancy, and equipment performance; and predict relative magnitudes of energy use. There are many programs available, varying widely in cost, degree of complexity, and ease of use. A general input-data acquisition procedure should be followed in computer energy analysis of existing buildings.

1.4. *Weather data*

Weather data, usually summarized for 30-year average in default for different locations in the weather properties of Carrier HAP software (Carrier HAP, 2006) and minimum one year of daily average data is required for PRISM analysis for corresponding year energy consumption (Fels, 1986). The actual weather data for the year in which energy consumption data were recorded significantly improves simulation of an existing building. The purpose of the simulation should also be considered when choosing weather data: either specific-year data, data representative of long-term averages, or data showing temperature extremes may be needed, depending on the goal of the simulation. Usually, the results of the first computer runs do not agree with actual metered energy consumption data. The following are possible reasons for this discrepancy

- Insufficient understanding of energy-consuming systems that create the greatest use,
- Inaccurate information on occupancy and time of building use,
- Inappropriate design information on air quantities, set points, and control sequences.

The input building description must be adjusted and trial runs continued until the results approximate actual energy use. Matching the metered energy consumption precisely is difficult; in any month, results within 10% are considered adequate (Carrier HAP, 2006).

1.5. *Methodology*

Figure 8 describes the methodology used for the base case model for Ryerson University buildings using energy simulation program Carrier HAP and PRISM analysis for energy consumption.

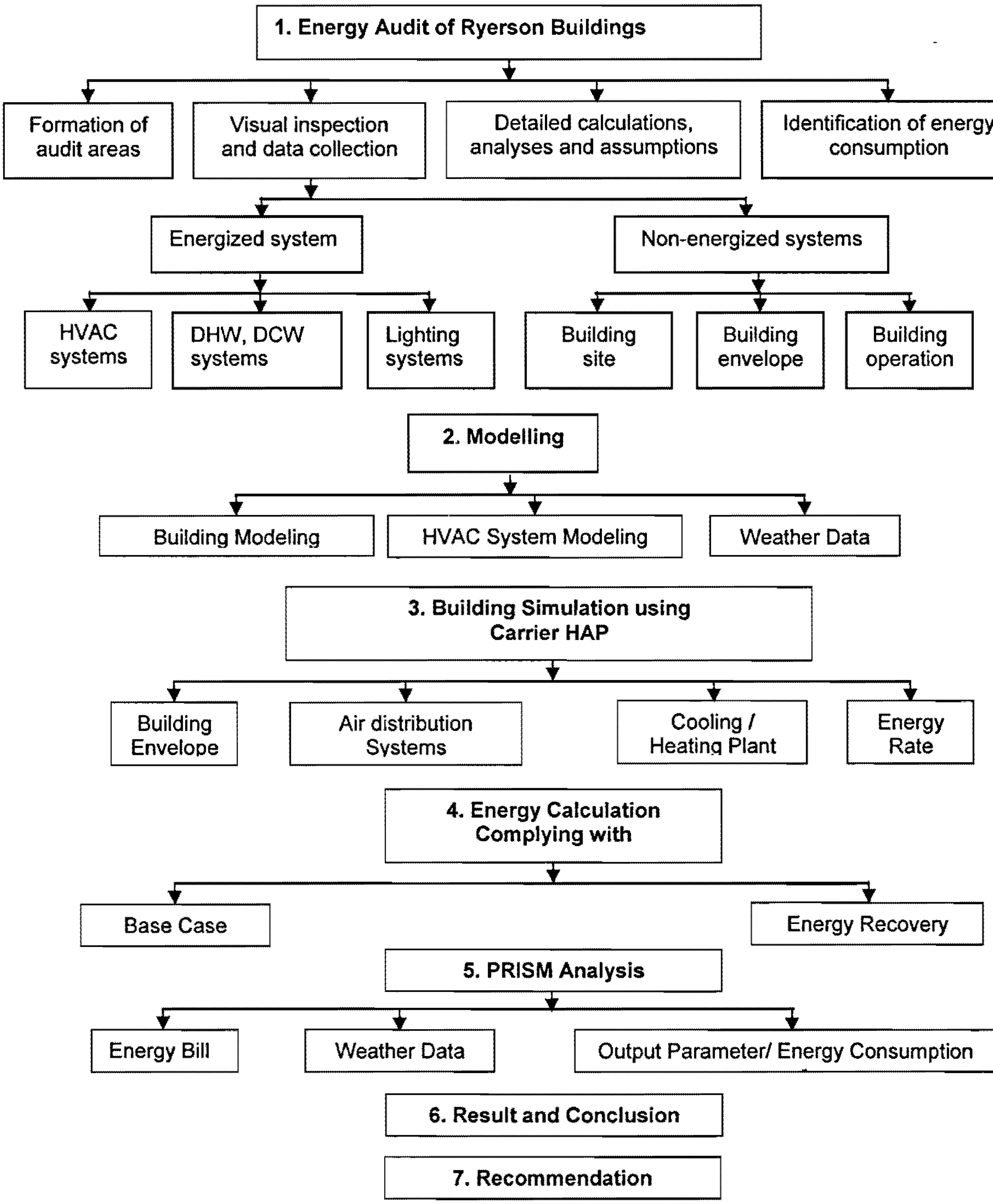

Figure 8: Flow chart of modeling the Ryerson University buildings

1.6. The Objective of the Study

The main objectives and goals of the study are energy audit, building simulation and PRISM analysis of Ryerson buildings

Specific details are:

- Determine and analyze hourly heat loss and heat gain for the 16 individual Ryerson buildings,
- Determine and evaluate the energy demand and cost of Ryerson buildings using Carrier HAP whole building energy simulation program,
- Determine cooling degree-days (CDD), heating degree-days (HDD), and normalized annual consumption (NAC) using PRISM analysis software,
- Study energy consumption in different fiscal year and provide recommendations for long-term goals of energy efficiency,
- Study and conduct sensitivity analysis to determine potential energy savings to changed lighting schedule.

2.0. Building energy audit

An energy audit and survey are parts of the energy management process in buildings. Energy management in buildings defined as the control of energy use and its cost while maintaining indoor environmental conditions to meet comfortable and functional needs. The goal of energy management is to reduce energy expenses to the lowest level as possible without sacrificing comfort, productivity, or functionality. The specific processes by which building owners and operators control energy consumption and costs are as variable as their building types. Many buildings, such as residences and small retail businesses, usually involve the efforts of one person. On the other hand, very large and complex facilities, such as hospitals or university campuses, industrial complexes, or large office buildings, usually require a team effort and process as represented in Figure 9.

The objectives of an energy analysis or audit are to identify and develop modifications to reduce energy use and/or cost of operating a building. The results should be presented in a format that provides the information needed by an owner/operator to decide if any, some, or all of the recommended modifications should be implemented (ASHRAE, 2007).

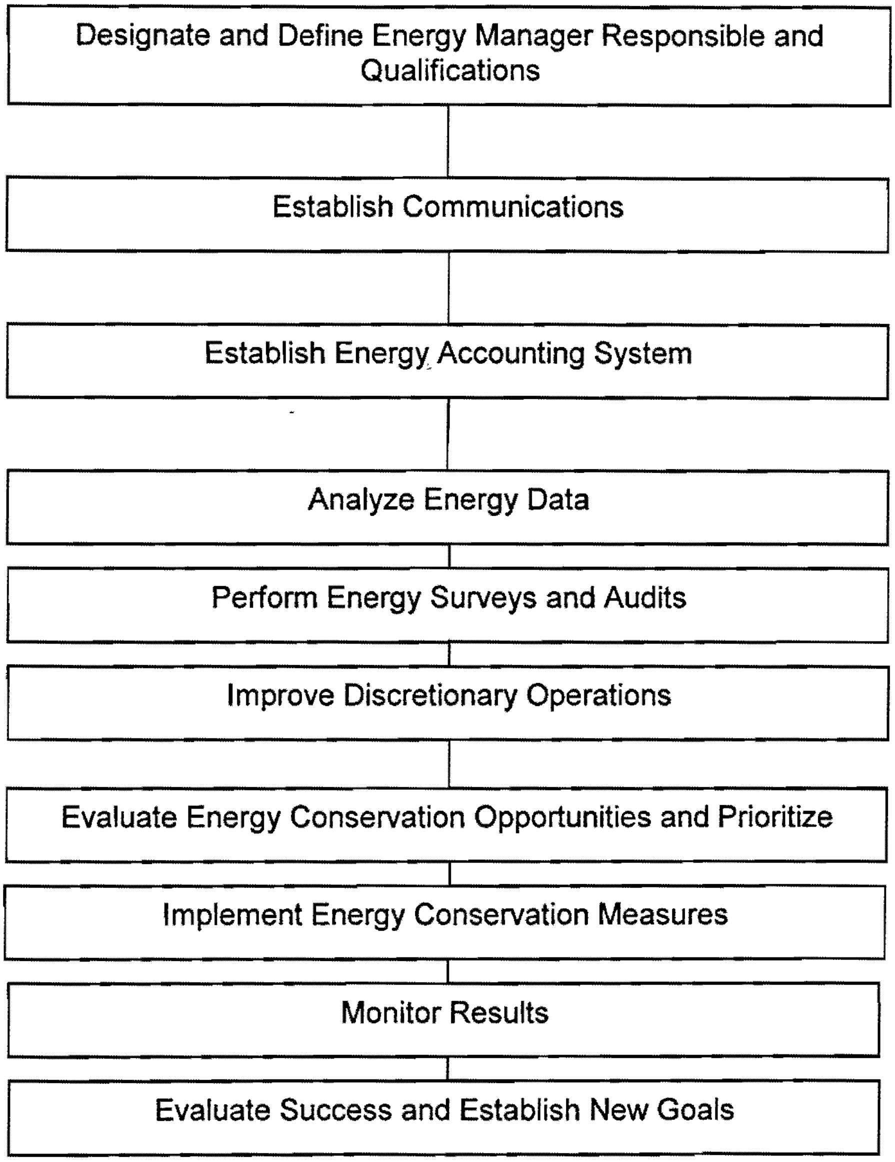

Figure 9: The Energy Management Process (ASHRAE, 2007)

Energy audit is the first phase of an energy study which includes the collection of information and data, and a preliminary analysis. This report described the detail energy audit for the selected Ryerson University buildings (listed in the Table 12) operated by central chillers plant located in the Library building and Rogers Communications Center (RCC) and Deep Lake Cooling System (DLCS) for Rogers Business Building (RBB).

Table 12: List of energy audit and base case simulation of Ryerson buildings

Sl.No.	Name of the Building	Street No.	Street Name
Meter-1: Chiller Plant Located in the Library building			
1	School of Image Art (IMA)	122	Bond Street
2	Heaslip House Continuing Education (CED)	297	Victoria Street
3	Victoria Building (VIC)	285	Victoria Street
4	George Vari Engineering and Computing Centre (ENG)	243	Church Street
5	Jorgenson Hall (JOR)	380	Victoria Street
6	Library Building (LIB)	350	Victoria Street
7	Podium Building (POD)	350	Victoria 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
Meter-2: Chiller Plant Located in the RCC building			
14	Rogers Communications Centre (RCC)	80	Gould Street
15	Pitman Hall Residence (PIT)	160	Mutual Street
Remote Source Chilled Water supplied by enWave			
16	Rogers Business Building (RBB)	55	Dundas Street West

2.1. *Types of energy audit*

Most energy audits fall into three categories. Depending on the physical and energy use characteristics of a building and the owner's needs and resources, one or more of the three different categories of effort can be used.

i. Walk-Through Assessment:

Walk-through is the least costly, preliminary stage audit. It is basically a visual inspection and a quick review of general energy data. It is usually done to determine the need for a more detail audit. The walk-through process could be relatively straightforward if the blueprints and other preliminary information available describes the building and its operation accurately. The process could begin with a walk around the building to study the building envelope. Building features such as building wall colour, external sun-shading devices, window screens and tint, and so on are noted as possible energy conservation opportunities (ECOs). If a model analysis is included in the study, the building must be divided into zones for analysis. The survey inside the building would include confirmation that the air-conditioning system is as indicated on plans. Additions and alterations would be noted. The type and condition of the windows, effectiveness of window seals, typical lighting and power requirements, occupancy and space usage are noted. System and plant data could be obtained by a visit to the mechanical rooms and plant room. Nameplate data could be compared against those in the building's documents, and spot readings of the current indicating panels for pumps and chillers recorded for estimating the load on the system. This involves assessing a building's energy cost and efficiency by analyzing energy bills and briefly surveying the building, accompanied by the building operator.

This level audit is most applicable when there is some doubt about the energy savings potential of a building, or when an owner wishes to establish which buildings in a complex have the greatest potential for energy savings. The results can be used to develop a priority list for buildings that are recommended for a Mini-audit or Maxi-audit.

ii. 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.

iii. 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.

Detailed energy audit procedure can be shown in Figure 10 as flow diagram.

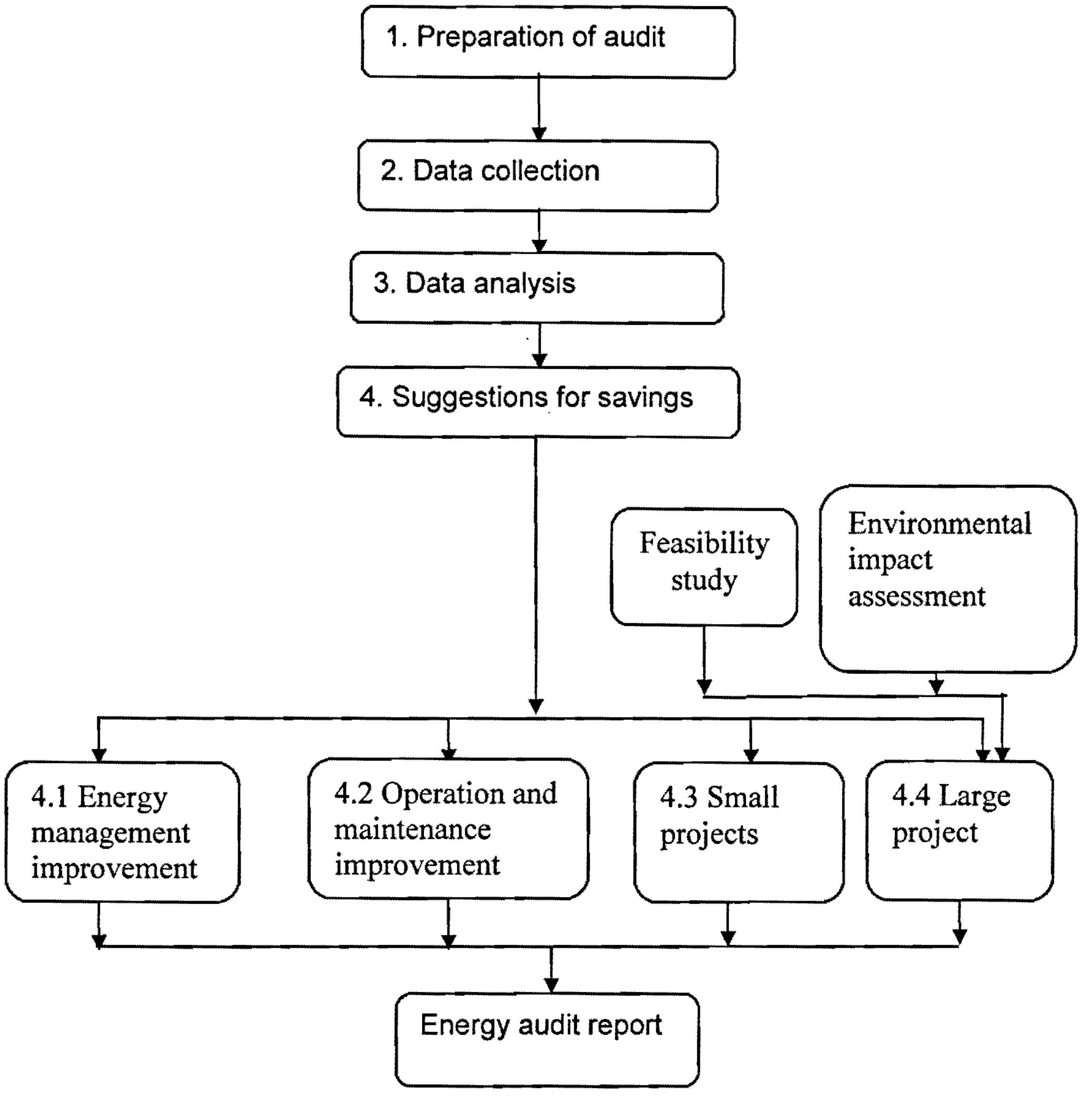

Figure 10: Steps of detailed Energy Audit

2.2. *Energy audit procedure*

During the energy audit following procedures will be helped for data collection as well as proper energy audit. Energy audits include some or all of the following (ASHRAE, 2007).

1. Energy uses data collection and analysis
    - Review more than one year of energy bills. It is preferable to have three to five years data
    - Review billing rate class options with utility as flat rate or time of uses (TOU)
    - Review monthly patterns for irregularities

- Compare the building's energy utilization index (EUI) with publicly available indices of similar buildings
- Derive target goals for energy, demand, and cost indices for a building with similar characteristics

2. Study the building and its operational characteristics
   - Acquire a basic understanding of the mechanical and electrical operating systems. Perform a walk-through survey of the facility to become familiar with its construction, equipment, operation, and maintenance
   - Meet with owner/operator and occupants to learn of special problems or needs of the facility
   - Identify any required repairs to existing systems and equipment
3. Identify potential modifications to reduce energy use and/or cost identify low-cost/no-cost changes to the facility or to operating and maintenance procedures
   - Identify potential equipment retrofit opportunities
   - Outline effect on occupant service requirements
   - Identify any training required for operating staff to maintain measures
   - Perform a rough estimate to determine the approximate breakdown of energy use for significant end-use categories
4. Perform an engineering and economic analysis of potential modifications
   - For each practical measure, determine resultant savings
   - Estimate effects on building operations and maintenance costs
   - Review effect on non energy operating costs
   - Prepare a financial evaluation of estimated total potential investment using appropriate techniques and criteria
5. Prepare a rank-ordered list of appropriate modifications
   - List all possible energy savings modifications
   - Select those that may be considered practical by the building owner
   - Assume that modifications with highest operational priority and/or best return on investment will be implemented first
   - Provide preliminary implementation costs and savings estimates

6. Prepare a report to document analysis process and results
   - Provide description of building and its requirements, and an inventory of major energy-using equipment,
   - Clearly state savings from each modification and assumptions on which each is based,
   - Discuss existing situation and why it is using excess energy,
   - Review list of practical modifications with the owner, and select those to be pursued,
   - Prioritize modifications in order of implementation,
   - If necessary, recommend measurement and verification methods to determine effectiveness of measures implemented.

2.3. *Building simulation*

Building simulation began in the 1960s and became the hot topic of the 1970s within the energy research community (Hong et al., 2000). During these two decades, most of the research activities were devoted to studies of fundamental theory and algorithms of load and energy estimation. The beginning of the 1990s saw the growing global concern to protect the environment. In the building sector, the challenge to professionals is to create a healthy and comfortable built environment with less energy consumption and reduced negative impact on the environment. The demand for green buildings has made the application of building simulation a must, rather than a need. Thus, Building Simulation Programs (BSPs) have gained acceptance as routine analysis and design tools.

The building sector, one of the fastest growing in terms of energy consumption, National Round Table on the Environment and the Economy (NRTEE) shows that nearly half a million commercial and institutional buildings in Canada provide the spaces for education, healthcare, government, and business services. But they also consume significant amounts of energy and produce carbon emissions. So it is clear that buildings are a primary contributor to global warming and ozone depletion (NRTEE, 2009).

The Commission for Environmental Cooperation (CEC) released a North American report in spring 2008 revealing that commercial and residential buildings are responsible for 33% of all energy used and 35% of greenhouse gas (GHG) emissions in Canada.

Research also shows that significant energy efficiency potential from existing technology in the commercial building sector. It is estimated that substantial energy savings can be achieved from a conventionally designed building through careful planning for energy efficiency. It is identified that heating, ventilating and air conditioning (HVAC) and lighting account for the major part of a building's energy use (NRTEE, 2009).

2.4. Energy simulation

Unlike peak load calculation programs, building energy simulation programs integrate loads over time (usually a year), consider the systems serving the loads, and calculate the energy required by the equipment to support the system. Most energy programs simulate the performance of existing systems, although programs are now available that make selections formerly left to the designer, such as equipment sizes, system air volume, and fan power. Energy programs are necessary for making decisions about building energy use and, along with life-cycle costing routines, quantify the effect of proposed energy conservation measures during the design phase. In new building design, energy programs help determine the appropriate type and size of building systems and components; they can also be used to explore the effects of design tradeoffs and evaluate the benefits of innovative control strategies and the efficiency of new equipment.

Energy programs that track building energy use accurately can help determine whether a building is operating efficiently or wastefully. They have also been used to allocate costs from a central heating/cooling plant among customers of the plant. However, such programs must be adequately calibrated to measured data from the building under consideration. Furthermore, energy simulation is necessary because of recent work on computer energy simulation studies and field surveys reveal that air conditioning represents 37-60% of total electricity use in office buildings, in accordance with building's functions (Zhou et al., 2007)

2.4.1. Characteristics of building energy simulation

Most programs simulate a wide range of buildings, mechanical equipment, and control options. However, computational results differ substantially across programs. The choice of weather data also influences the load calculation.

Depending on the requirements of each program, various weather data are used:

- Typical hourly data for one year only, from averaged weather data,
- Typical hourly data for one year, as well as design conditions for typical design days,
- Reduced data, commonly a typical day or days per month for the year,
- Typical reduced data, non serial or bin format,
- Actual hourly data, recorded on site or nearby, for analysis where the simulation is being compared to actual utility billing data or measured hourly data.

Simulation programs differ significantly in the methods they use to simulate the mass effects of buildings, ground, and furniture. How accurate these methods are and how well they delay peak heating and cooling can lead to significant uncertainty in predicting building heating and cooling needs, sizing equipment to meet those loads, and predicting system energy needs.

Both air-side and energy conversion simulations are required to handle the wide variations among central heating, ventilation, and air-conditioning systems. To properly estimate energy use, simulations must be performed for each combination of system design, operating scheme, and control sequence.

2.4.2. Simulation techniques

Two methods are used in computer simulation of energy systems:

- The fixed schematic technique and
- The component relation technique.

The fixed-schematic-with-options technique, the first and most prevalent method, involves writing a calculation procedure that defines a given set of systems. The schematic is then fixed, with the user's options usually limited to equipment performance characteristics, fuel types, and the choice of certain components.

The component relation technique is organized around components rather than systems. Each component is described mathematically and placed in a library. User input includes the definition of the schematic, as well as equipment characteristics and capacities.

Once all components have been identified and a mathematical model for each has been formulated, they may be connected and information may be transferred between them. Although its generality leads to certain inefficiencies, the component relation technique does offer versatility in defining system configurations (ASHRAE, 2007)

2.5. PRISM analysis

Steam consumption for space heating and cooling, domestic hot water and also electricity consumption for air handling unit, lighting, plug load, pump, and exhaust fan for the Ryerson buildings are analyzed using the PRInceton Scorekeeping Method (PRISM). An objective of this study is to explain in physical terms the components of annual as well as monthly steam consumption and hydro consumption, and to discuss how physical parameters and their changes can be observed in the data (Fels, 1986).

2.5.1. PRISM overview

The original version of PRISM (PRInceton Scorekeeping Method) was released in 1986. PRISM, developed at Princeton University, uses utility bills from before and after retrofit installation, together with average daily temperature from a nearby weather station for the same time periods, to determine a weather-adjusted index of consumption, Normalized Annual Consumption (NAC), for houses or buildings. PRISM has been used by utilities, private companies, government agencies, and universities to estimate energy savings from conservation programs. The PRISM which was first developed to study the energy use in single-family houses with heating systems making use of the monthly billing data as well as the normalized daily outdoor temperature.

For further development advanced PRISM project at Princeton University was funded by the Electric Power Research Institute, the Wisconsin Center for Demand-Side Research, and eight utilities, and it focused on "model tuning and data pruning." Model tuning mean adding such features as a Heating-and-Cooling model, a Robust model, and an Aggregate version, while data pruning includes improving the reliability and usefulness of the data with functions like automated data correction and "outlier" detection. The main improvement was done on PRISM methodology in order to make the best possible use of the information available in billing data (Fels et al., 1995)

The Advanced Version of PRISM makes it easier than ever to transform run-of-the-mill billing data into statistically sound savings estimates. With PRISM, utilities and energy analysts can systematically estimate total savings from a conservation or demand-side management program, for large samples of houses or buildings participating in the program, and for comparison groups as well.

PRISM is a statistical procedure that processes a year of monthly billing data from a house or building to produce a weather-adjusted Normalized Annual Consumption (NAC) index, along with other physically meaningful parameters and extensive reliability statistics. A key feature of the method is its estimation of best reference temperature to which heating and cooling degree-days in the model are computed. PRISM is generally run on the pre- and post-weatherization periods for all buildings in a sample to produce distributions of savings across the sample. With the new PRISM, participant and control groups are easily compared, in graphical and tabular forms.

To run the PRISM following data is required:

- individual-building consumption data, including exact meter reading dates, for approximately one year in each period of interest,
- average daily temperature data, for the periods of interest, from a nearby weather station.

PRISM gives results in terms of:

- heating consumption versus heating degree-days,
- cooling consumption versus cooling degree-days,
- building's reference temperature for heating or cooling.

Figure 11 shows the inputs and outputs for the PRISM program.

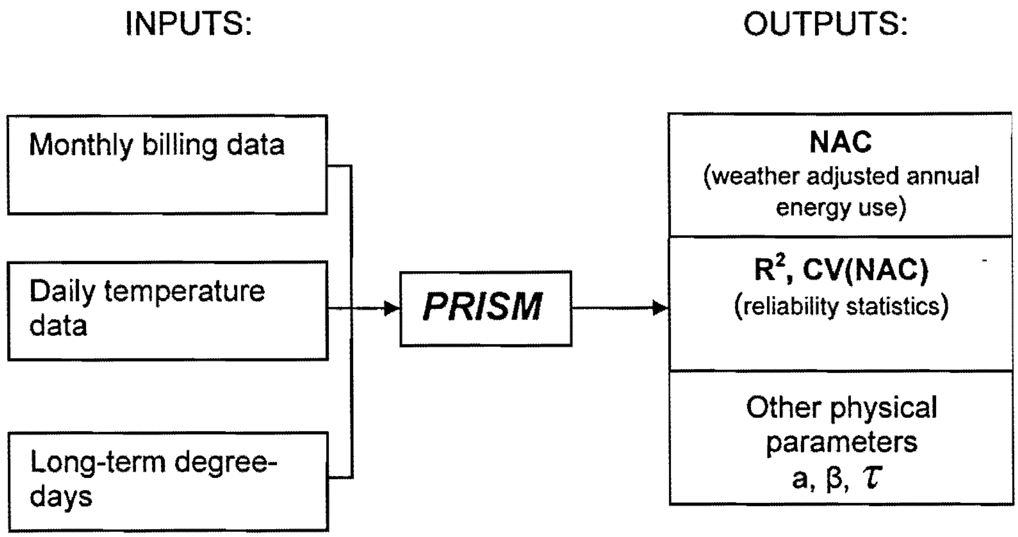

Figure 11: Schematic diagram showing the data requirements for the PRISM (Fels and Reynolds, 1992)

The advanced PRISM analysis model has worked for Heating-Only (HO) for heating fuel, Cooling-Only (CO) use electricity for air conditioning and Heating-and-Cooling (HC) model for combined heating and cooling in the analysis of buildings that use the same fuel for both.

The main equation used for the calculation of Normalized Annual Consumption (NAC):

$$NAC = \underbrace{365 * a}_{BaseLevel} + \underbrace{d_h * \beta_h * H_o(\tau_h)}_{HeatingPart} + \underbrace{d_c * \beta_c * C_o(\tau_c)}_{CoolingPart} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots (1)$$

Where,

a = base-level consumption (kWh/day)

β_h = heating slope (kWh/°C-day)

β_c = cooling slope (kWh/°C-day)

τ_h = heating reference temperature (°C-day)

τ_c = cooling reference temperature (°C-day)

$d_h = 1$ for the HO analysis and $d_c = 0$

$d_c = 1$ for the CO analysis and $d_h = 0$

$d_h = 1$ and $d_c = 1$ for the HC analysis

This report analysed electric energy consumption and steam consumption for both heating and cooling demands. In both cases energy consumption depends on degree days. Degree days are essentially a simplified representation of outside air temperature data. They are widely used in the energy industry for calculations relating to the effect of outside air temperature on building energy consumption.

Degree days calculated from the sum of heating degree day and cooling degree day. Heating degree days (HDD) is a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific base or reference/balance temperature. They are used for calculations relating to the energy consumption required to heat buildings. Cooling degree days (CDD) is a measure of how much (in degrees), and for how long (in days), outside air temperature was higher than a specific base temperature. They are used for calculations related to the energy consumption required to cool buildings.

3.0. Energy audit of Ryerson buildings

This report conducted max-audit for 86% of total area of Ryerson University; which is a part of the detail energy study and can be described step by step as follows:

3.1. Formation of audit areas

Audit area in this report has selected for the Ryerson University and located in the geographical coordinate on 43°40' North and 79°25' West, Toronto, Ontario, Canada (http://boating.ncf.ca/latlong.html). There are 28 buildings in this university. Audit area selected based on the remote source chilled water supplied by the central chiller plant located in the Library Building and Rogers Communications Center (RCC) for 15 buildings and remote source chilled water supplied by the enWave for Rogers Business Building (RBB) (listed in Table 2).

3.2. Visual inspection and data collection

Visual inspection and data collection process for the selected audit buildings were divided in to two categories as energized system and non-energized system. The data collection procedures for those systems have collected according to the simulation program Carrier HAP used in this report. Data on all sources and uses of energy, operation of mechanical systems, electrical devices, and building envelopes were collected from campus planning department, maintenance department and site inspection.

3.2.1. Energized system

Energized system of the building can be considered the equipments or electrical devices which are using electricity for operation. This system could be described for the HVAC system, domestic hot water system, domestic cold water system, miscellaneous plug load and lighting system. This report well described for the major part of HVAC system and lighting system.

3.2.1.1. HVAC system

HVAC system of Ryerson University selected buildings listed in Table 4 are served by the central chiller plant located in the Library building and Rogers Communications Centre for cooling, remote source steam supplied by the enWave for heating and deep lake cooling system served for the Rogers Business building. Air conditioning system is provided by chilled water in different buildings. Each building has own central air handling units (AHU). The air distribution system for the individual building is shown in Table 13

Table 13: Air distribution system for Ryerson buildings

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

The capacities of two central chiller plants are listed in Table 14 (based on the information from Campus Planning maintenance department).

Table 14: List of central chiller plant of Ryerson University

Chiller	
Make	**Capacity**
Plant Located in the Library building	
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**
Plant Located in the RCC building	
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	
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 Technologies	NC-240859-A1

HVAC data was collected for all of these buildings according to the requirements of Carrier HAP modelling. Data collection procedure for Heaslip House Continuing Education (CED) is listed below and data for the other buildings is listed in Appendix-B.

Air-conditioning systems for CED:

AHU Schedule

Table 15: AHU schedule

AHU	Make	System	Served Area (sq ft)	Supply Fan Capacity (CFM)	Supply Fan (BHP)	Supply Fan (kW)	Supply Fan Type	Return Fan Capacity (CFM)	Return Fan (BHP)	Return Fan (kW)	Return Fan Type	Cooling Coil EAT (DB) (^{0}F)	Cooling Coil LAT (DB) (^{0}F)	Reheat Coil EAT (DB) ((^{0}F)	Reheat Coil LAT (DB) (^{0}F)
AHU-1	HAAKON	VAV		40000	33.4	37.3	VFD	34500	9.5	11.2	VFD	78	53	55.4	71.6

Exhaust Fan Schedule

Table 16: Exhaust fan schedule

Exhaust Fan	Served area	Capacity (CFM)	Motor (kW)	Type
EF-1	Sanitary	2775	0.75	Cont
EF-2	General	2100	0.56	Cont
EF-3	CCS Exh	310	1.5A	Cont
EF-4	Elect. Room	310	1.5A	Cont
EF-5	Base Gen Exh.	215	2.3A	Cont

Heat Exchanger Schedule

Table 17: Heat exchanger schedule

HEX #	Service	IN	Out
		(^{o}C)	(^{o}C)
HEX-1	AHU-1 Glycol Preheat Coil	48.9	82.2
HEX-2	AHU-2 Heating Water	71.1	82.2

Heater Schedule

Table 18: Heater schedule

Heater (UH/FFH)	Type	Capacity	Motor kW	Wet Side	Wet Side	Air Distribution
		Area		EWT	LWT	System
		ft^2		°C	°C	
UH-1	Horizontal Unit			82.2	71.1	VAV-FPB
FFH-1	Recessed Cabinet	4.8	0.075	82.2	71.1	VAV-FPB
FFH-2	Recessed Cabinet	9.4	0.075	82.2	71.1	VAV-FPB
FFH-3	Surface Mount	7.6	0.075	82.2	71.1	VAV-FPB

Pump Schedule

Table 19: Pump schedule

Pump #	Service	Motor	Total Head
		(kW)	(m)
P-1	Heating Water	2.24	16.5
P-2	Heating Water	2.24	16.5
P-3	Heating Glycol	0.56	12.2
P-9	Steam Condensate Return Pump	0.25	10.6
P-12	Condenser Glycol Pump	0.11	4.9

3.2.1.2. DHW, DCW systems

Pump Schedule

Table 20: DHW, DCW pump schedule

Pump #	Service	Motor	Total Head
		(kW)	(m)
P-4	Fire Pump	14.9	40.8
P-5	Jockey Pump	0.75	45.9
P-6A & B	Domestic cold Water Booster Pump	2.24	24.7
P-7A & B	Storm Sump Pump	0.33	4.4
P-8A & B	Sanitary Sump Pump	0.33	4.4
P-10	DHW Recirculation Pump	0.12	3.1
P-11	DHW Circulation Pump	0.12	3.1

3.2.1.3. Lighting systems

Lighting load is a very important part for the overall energy consumption. Lighting load was calculated from the electrical drawing based on the lamp types, fixtures, total number of lamp used in the specific area, types of exit lights and plug load assumed for the computers, printers and electrical appliances. Some of these buildings' lighting loads were assumed from the ASHRAE 90.1-2004 standard because lack of lighting information. All of these information were then input in Carrier HAP to estimate electrical energy consumption for lighting and plug load.

3.2.2. Non-energized systems

Non-energized system of the building can be considered as building site, building envelope and building operation which did not use any electricity for operation.

3.2.2.1. Building site

Ryerson buildings are located in geographical coordinate of 43°40' N and 79°25' W. Figure 12 shows entire Ryerson campus in down town (http://luna.ccs.ryerson.ca/stlhe2010/downloads/campus_map.pdf).

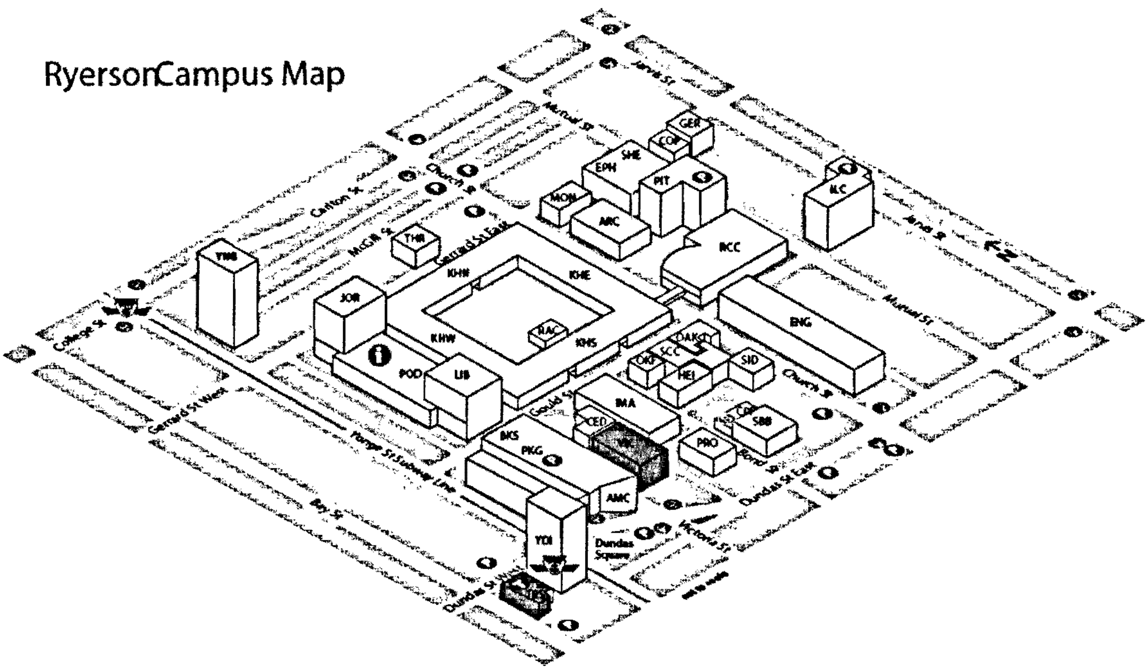

Figure 12: Ryerson campus map

3.2.2.2. Building envelope

The building envelope consists of those parts of the building that separate the controlled indoor environment from the uncontrolled outdoor environment. It typically includes the foundation, floors, walls, fenestration (windows and doors), and roof. Heat flow through the building envelope is mainly associated with the energy performance of buildings. In order to establish building energy simulation program for the Ryerson buildings, data was collected from architectural drawings and structural drawings for the building envelope including exposure as:

- Wall assembly
    - Exterior wall assembly layers defined as inside to outside
    - Interior wall assembly
- Window
    - Types of window depends on glass used
- Door
    - Types of door like sliding, entrance, revolving
- Floors
    - Above conditioned space
    - Above unconditioned space
    - Slab floor on grade
    - Slab floor below grade
- Roof
    - Roof assembly layers defined as inside to outside
- Skylight

Energy audit was conducted for the 86% of total Ryerson campus. There were 16 number of high rise buildings audited and simulated in this report. All buildings envelope data were collected for the requirements of Carrier HAP software. One of these buildings (CED building) envelope data collection process is described below from the architectural and structural drawings and remaining buildings' envelope data are listed in Appendix B. Figure 13 represents different wall types construction used in the CED building.

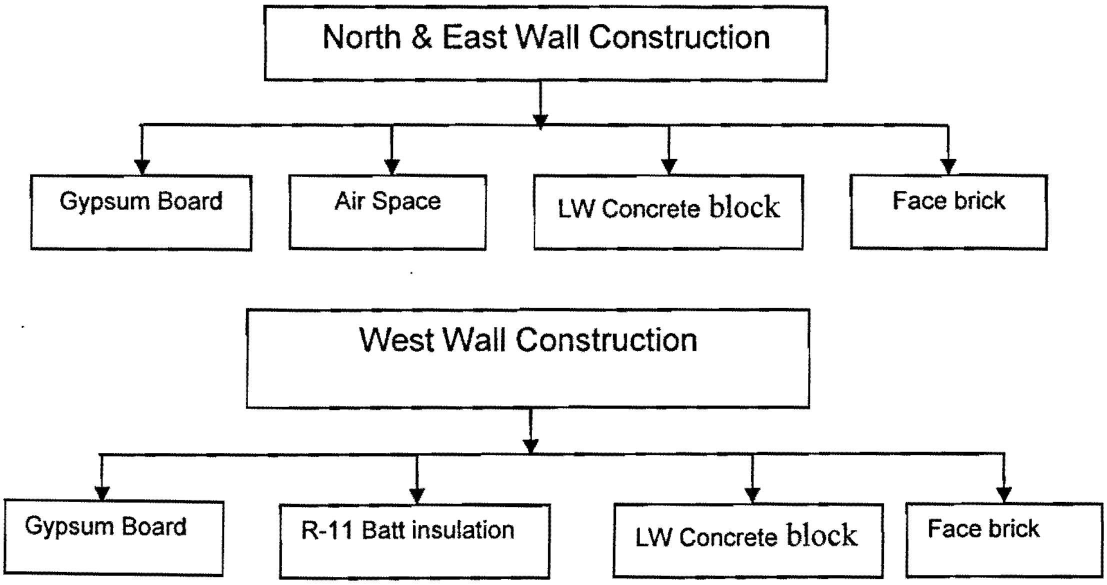

Figure 13: Types of wall construction (layer inside to outside)

Figure 14 presents different window types construction used in the CED building.

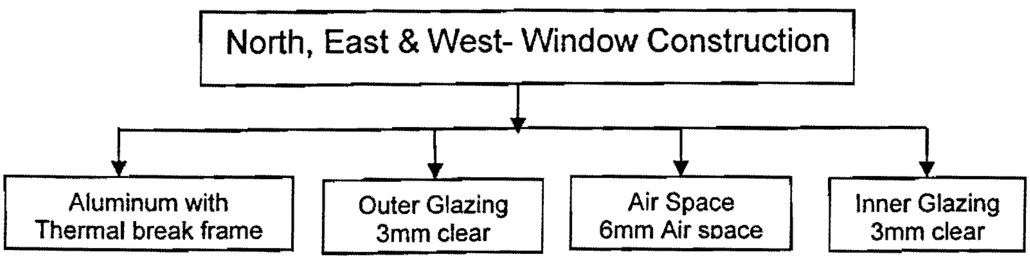

Figure 14: Types of window construction

Figure 15 presents roof used in the CED building.

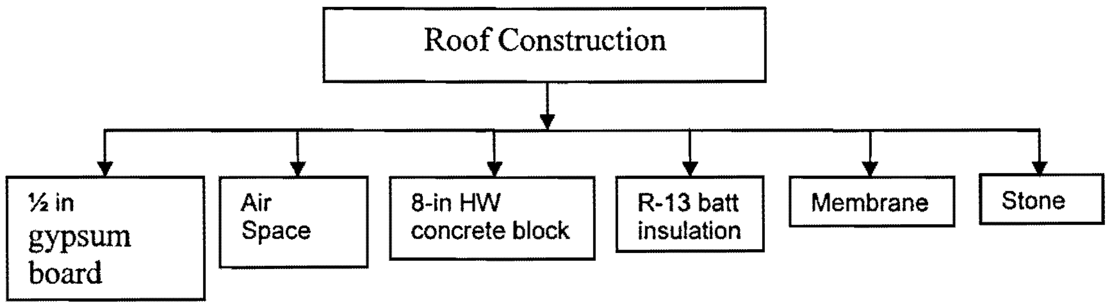

Figure 15: Roof construction

Figure 16 presents door used in the CED building

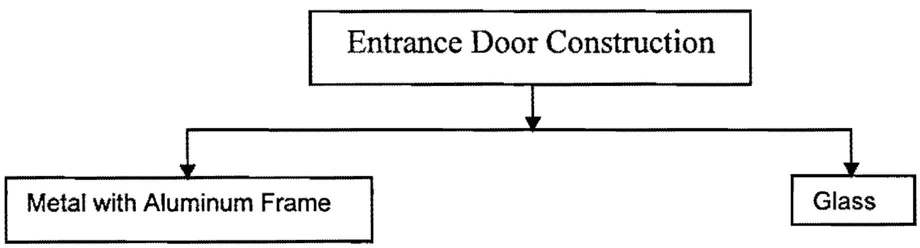

Figure 16: Door construction

4. Modelling

Modelling is a major part of building simulation software. It includes building model, HVAC system model and weather data. In building model it is necessary to consider building static and dynamic behaviour, occupancy loads, comfort requirements and control strategies like air quality, air temperature, and humidity. For HVAC system model could be described as air conditioning process, HVAC system components like terminal units, air handling units, and water, air, steam distribution systems. Figure 14 presents building model and HVAC system.

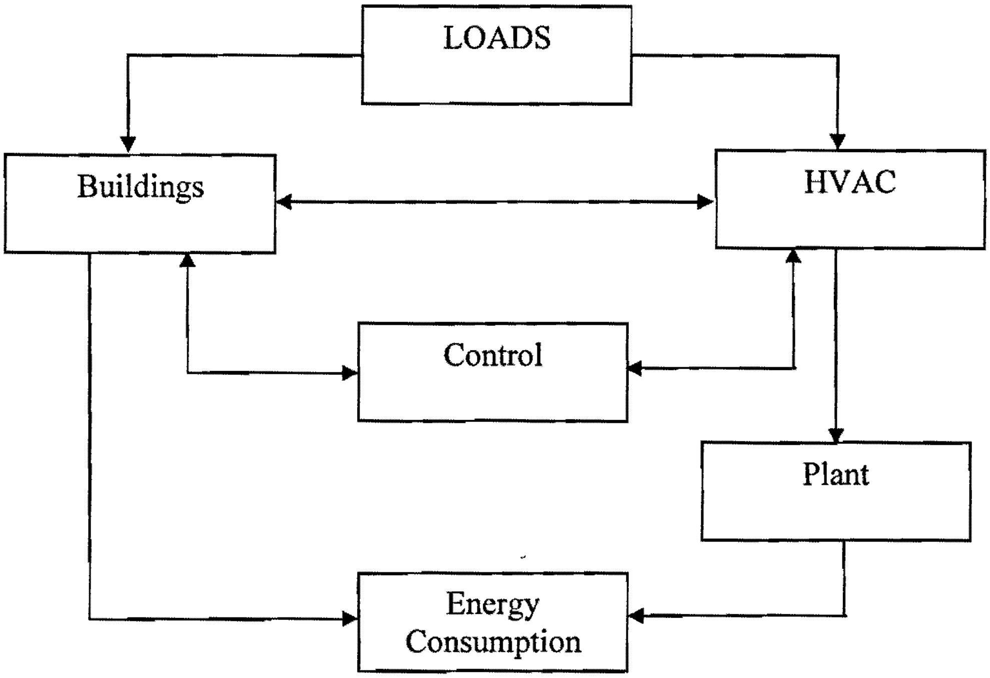

Figure 17: Model block diagram

4.1. Building modeling

The dynamic behaviour of the building like transient heat transfer through walls, energy storage in slabs, internal generated heat gains, and solar heat gains through windows, infrared losses, ventilation and heating/cooling devices are actually taken into account in order to compute heating and cooling load demands. Most of the Ryerson buildings can be modeled as large occupancy zone due to institutional building, surrounded by some of them external glazed and opaque walls.

4.2. HVAC system modeling

HVAC system model, including Constant Air Volume (CAV), Variable Air Volume (VAV), Air Handing Unit (AHU), some local heating and/or cooling Terminal Units (TU) and a heating and cooling plant, is shown in Figure 18.

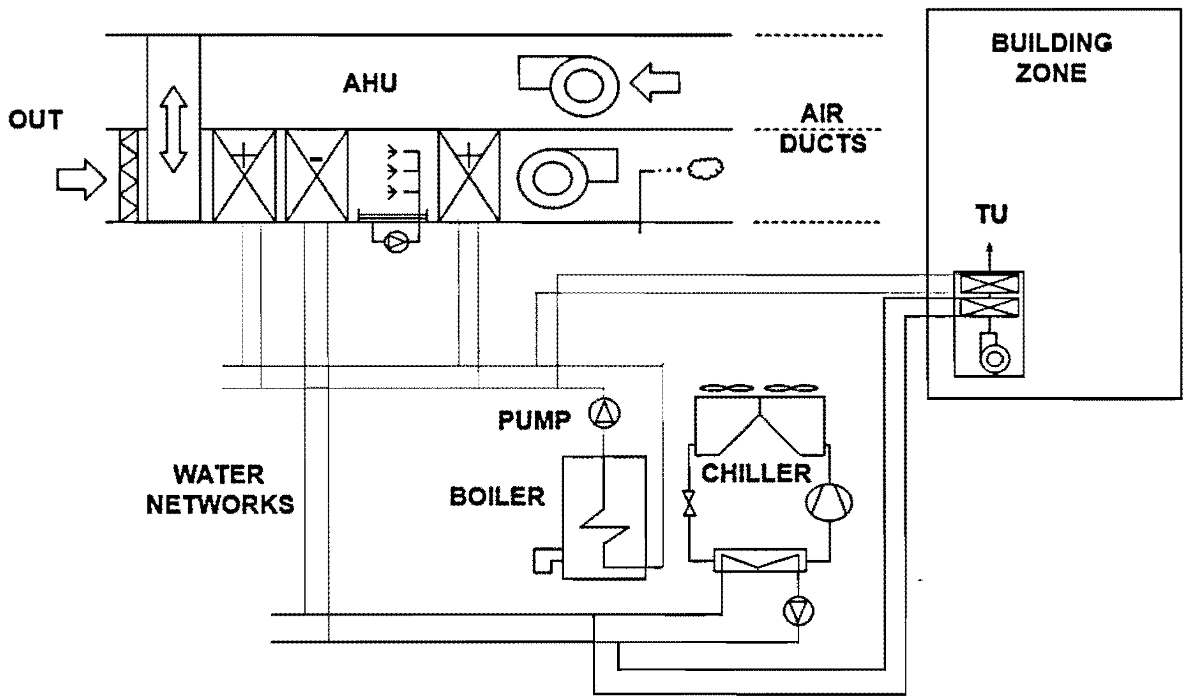

Figure 18: HVAC system modelling (Bertagnolio & Lebrun, 2008)

HVAC is the major part of the energy consumption for buildings. This study was estimated that HVAC systems consume about 53% of the total energy used in buildings. The study also was conducted in Montreal and it is estimated that 50% of the total energy consume in HVAC systems (Huang et al., 2006)

The AHU model, including recovery system, economizer, filter, preheating coil, adiabatic humidifier, cooling coil, post heating coil, steam humidifier, main fan and return fan, is shown in Figure 19.

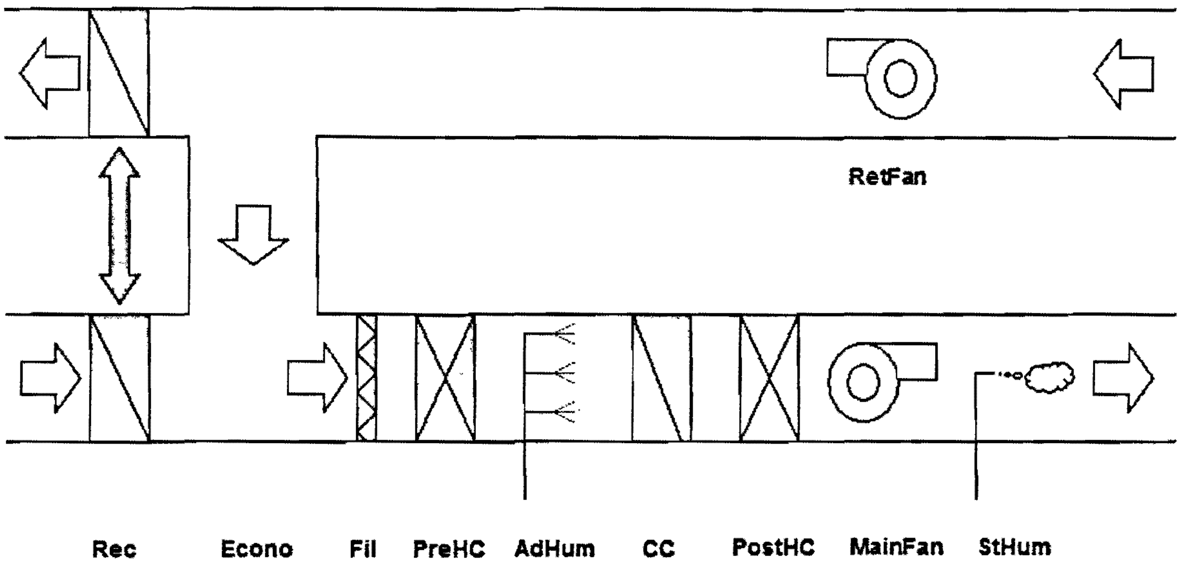

Figure 19: AHU components (Bertagnolio & Lebrun, 2008)

4.3. Weather data

Weather Data refers to the temperature, humidity and solar radiation conditions experienced by the building and its HVAC equipment. Weather data has a significant effect on building loads and equipment operation. Weather data plays a key role in load calculations and system performance calculations. This project conducted building energy simulation for Ryerson University buildings using hourly analysis program Carrier HAP. Carrier HAP also used to refer to information about the geographical location of the building, the nature of local time and local soil properties. Ryerson University is located in Toronto, Ontario, Canada. Figure 20 presents design parameters for weather properties used in Carrier HAP.

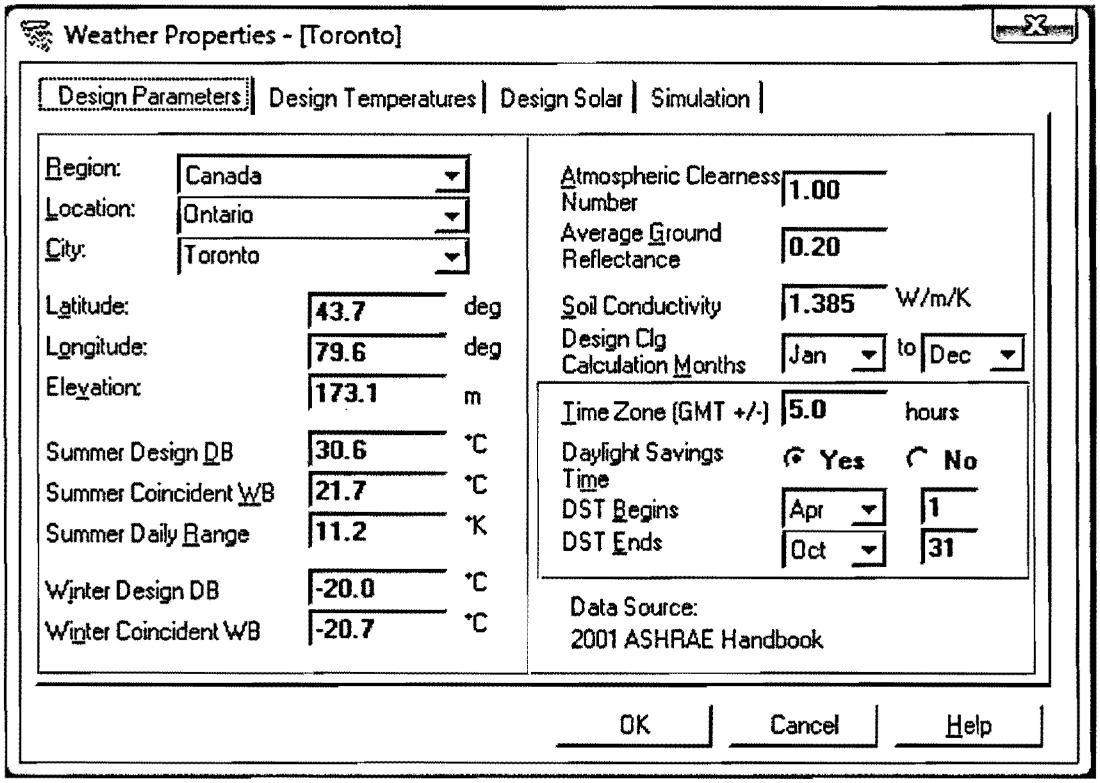

Figure 20: Carrier HAP weather properties (Carrier HAP, 2006)

HAP deals with two distinct kinds of weather data:

- Design Weather Data is used to perform cooling and heating design load estimates.
- Simulation Weather Data is required when performing 8,760 hour energy simulations.

Simulation weather data refers to the 8,760 hour 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.

5.0. Building simulation using Carrier HAP

5.1. Carrier HAP Overview

The purpose of this project is to application of Carrier HAP whole building energy simulation program to analyses hourly energy consumption for the Ryerson University buildings.

Carrier's hourly analysis program (HAP) by Carrier Corporation provides two powerful 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. It also simulates 8760-hr building energy performance to derive annual energy use and energy costs (Carrier, 2006).

HAP uses six different calculation methods:

- The Loads engine uses the ASHRAE Transfer Function Method to analyze dynamic heat transfer in the building, producing space cooling and heating loads,
- The Systems engine simulates the thermo-mechanical operation of air side systems,
- The Sizing engine integrates with both the loads and systems engines to determine required sizes for diffusers, air terminals, fans, coils and humidifiers,
- The Plant engine simulates the operation of chilled water and hot water plants,
- The Building engine collects energy and fuel consumption data from the system and plant calculations and combines them with utility rate specifications to produce energy meter consumption totals and energy costs, and
- Life-cycle engine in a separate, but integrated program combines energy costs from HAP with purchase, installation and maintenance costs to derive life-cycle costs.

The program is a powerful tool for designing systems and sizing system components.

HAP can easily handle projects involving:

- Small to large commercial buildings,
- Systems including packaged rooftops, packaged and built-up central air handlers, fan coils,
- Many types of constant volume and 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 and
- New design, retrofit or energy conservation work.

HAP provides following extensive features for configuring and controlling air-side HVAC systems and terminal equipment.

- Part-load performance models are provided for split DX units, packaged DX units, heat pumps, chillers and cooling towers,
- Hydronic loops can be simulated with primary-only and primary/secondary configurations, using constant speed or variable speed pumps,
- Energy costs can be calculated with simple or complex utility rates, the latter including energy and demand charges, time of day and year pricing, and demand determination clauses such as ratchets,

Although HAP is powerful simulation software it has following limitation:

- Air system has a limit of 100 zones,
- Spaces up to 50 per zone,
- Up to 100 plants,
- Spaces up to 2500 per project,
- Maximum Wall constructions 8, window constructions 16, door constructions 8, and 16 shade geometrics per space,
- Systems up to 250 per project,
- Plants up to 100 per project,
- Buildings up to 100 per project,

5.2. *Carrier HAP structure:*

Carrier HAP program uses an explorer type of graphical user interface (GUI) to provide quick and efficient access to the project data. The user-friendly graphical interface of Carrier HAP makes the entry of data quick and easy. Carrier HAP methodology can be presented in Figure 21 in order to create an input data file for the base case building.

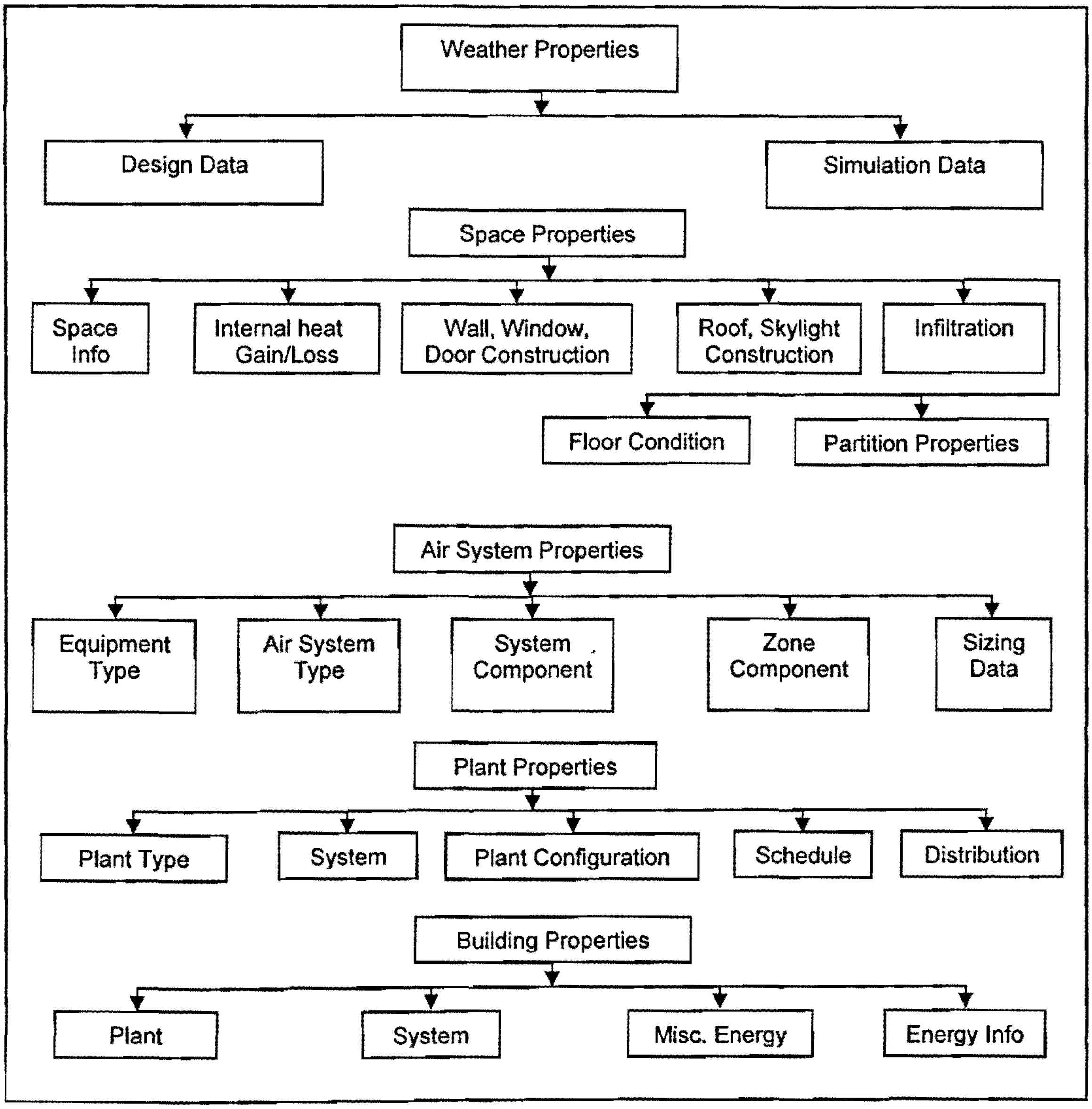

Figure 21: Carrier HAP data input structure

5.3 *Building envelope*

The building envelope is one of the major parts of space properties in Carrier HAP.

Space properties section consists of:

- General space information for space uses, floor area, ceiling height, building weight, outdoor air requirements,
- Internal heat gain for light, plug load, occupancy, people activity, schedule, sensible and latent heat gain,
- Wall, window and door construction, exposure area, shade type,
- Roof and skylight construction, exposure,
- Infiltration air in terms of CFM, CFM/ft^2, ACH,
- Floor type, area, U-value,
- Partition type, area, U-value, maximum and minimum temperature.

Figure 22 shows space input data for the CED building

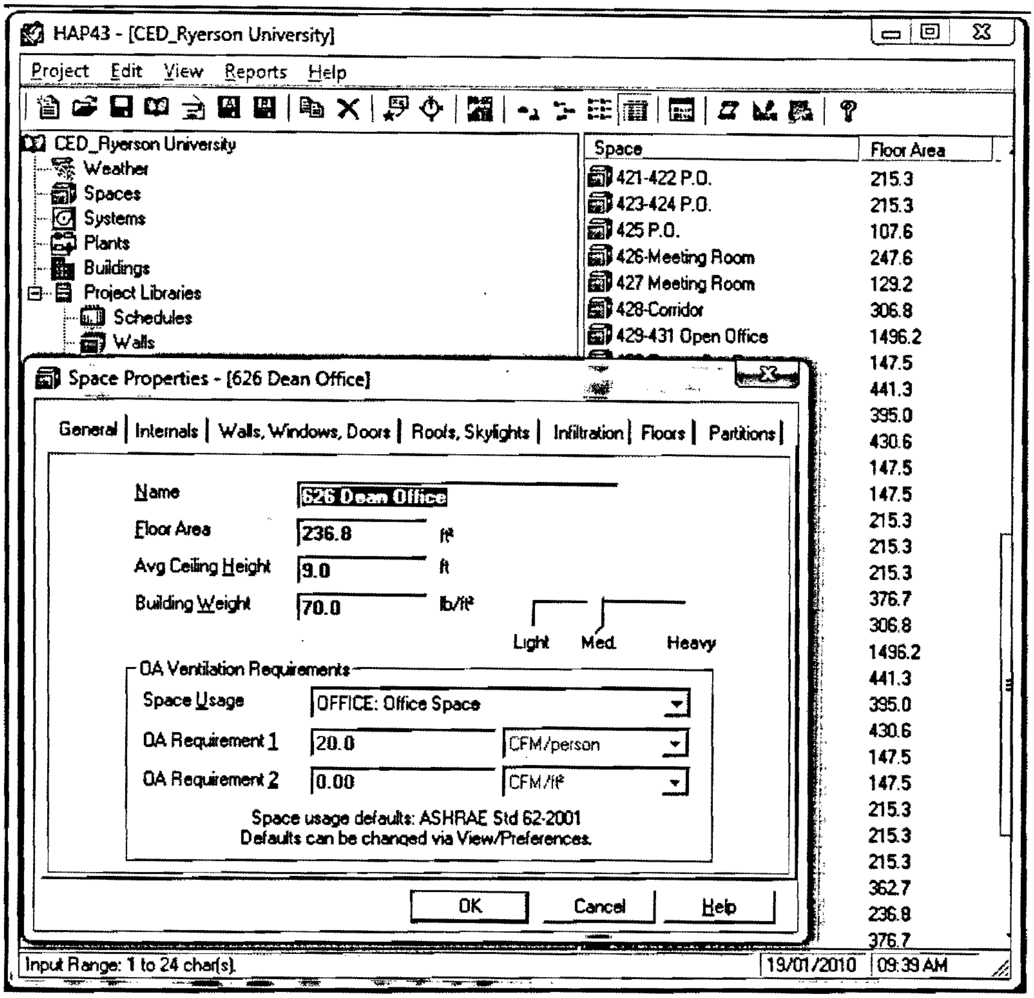

Figure 22: Space (Zone) Input Data Form

Total number of space created for CED building is 71, three types of wall assembly, four types of window assembly, one entrance door, and one roof assembly.

Wall constructions are used:

1. East Wall Assembly (Exterior Wall) Exposed to outside environment

   Overall Heat Transfer Coefficient: U-Value= 0.377 W $/m^2/K$
2. West Wall Assembly (Exterior Wall) Exposed to outside environment

   Overall Heat Transfer Coefficient: U-Value= 0.354 W $/m^2/K$
3. North Wall Assembly (Exterior Wall) Exposed to outside environment

   Overall Heat Transfer Coefficient: U-Value= 0.310 W $/m^2/K$

Window constructions are used:

1. East Glass Assembly

   Overall Heat Transfer Coefficient: U-Value= 3.601 W /m^2/K

2. North Glass Assembly

   Overall Heat Transfer Coefficient: U-Value= 3.617 W /m^2/K

   North Window Assembly

   Overall Heat Transfer Coefficient: U-Value= 3.629 W /m^2/K

3. West Window Assembly

   Overall Heat Transfer Coefficient: U-Value= 3.629 W /m^2/K

Entrance Door:

Overall Heat Transfer Coefficient: U-Value= 1.703 W /m^2/K

Roof Assembly:

Overall Heat Transfer Coefficient: U-Value= 0.322 W /m^2/K

5.4. Air distribution system:

An air distribution system is the equipment and controls which provide cooling and heating to a region of a building. An air system serves one or more zones; each zone is a group of one or more spaces having a single thermostatic control. There are 63 zones created in the CED building in order to well describe an air distribution system. Figure 23 shows an air system properties data sheet for Carrier HAP.

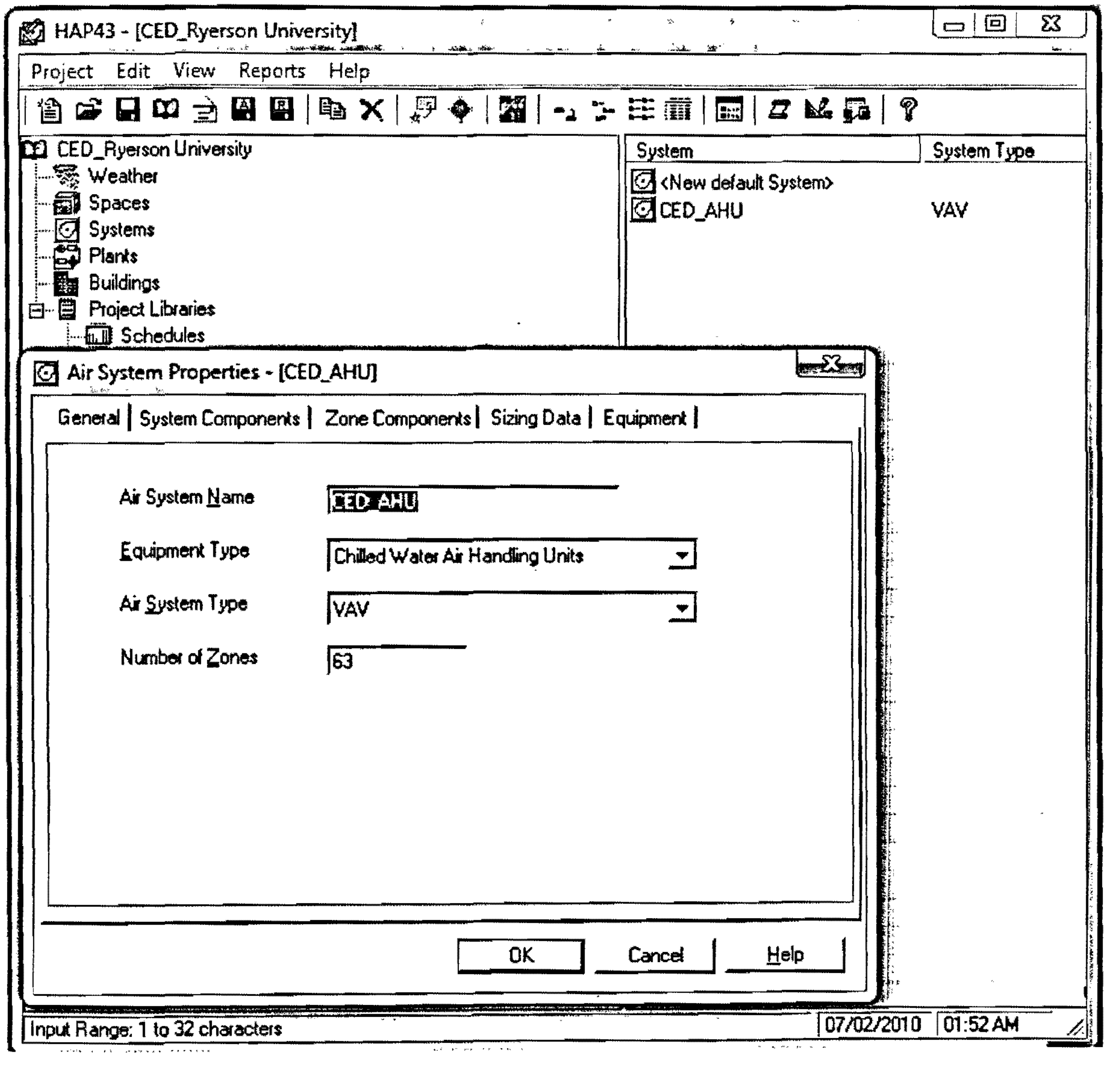

Figure 23: Air system properties data form for Carrier HAP

Carrier HAP air distribution system consists of following parameters:

Equipment types include:

- Packaged Rooftop Units
- Self-Contained Units
- Split DX Air Handling Units
- Chilled Water Air Handling Units
- Packaged and Split DX Fan Coils
- Hydronic Fan Coils

- Water Source, Ground Source, and Groundwater Source Heat Pumps
- Water Source, Ground Source, and Groundwater Source Heat Pumps

CED building uses air handling unit for cooling and heating purpose using chilled water cooling coil and remote steam heating coil. Most of the Ryerson buildings use VAV system types including VAV with reheat, fan powered mixing boxes. And some of them are CAV with terminal reheat. Different types of air systems are listed in Table 13. There are different types of control system as:

System types include:

- Single Zone CAV
- CAV with Terminal Reheat
- Multizone CAV
- Bypass Multizone CAV
- Dual Duct CAV
- 4-Pipe Induction
- Tempering Ventilation
- VAV and VAV with Reheat, Series Fan Powered Mixing Boxes, Parallel Fan Powered Mixing Boxes, or mixed terminals
- 1-Fan Dual Duct VAV
- 2-Fan Dual Duct VAV
- VVT

Systems are configurable with many controls and components including:

- Supply air temperature reset
- Ventilation airflow control
- Outdoor air economizers
- Ventilation air heat reclaim devices
- Humidistats and humidifiers
- Preheat and precool coils
- Central cooling and central heating
- Duct system
- Supply fan and return fan

Figure 24 shows different parameters required for the system components

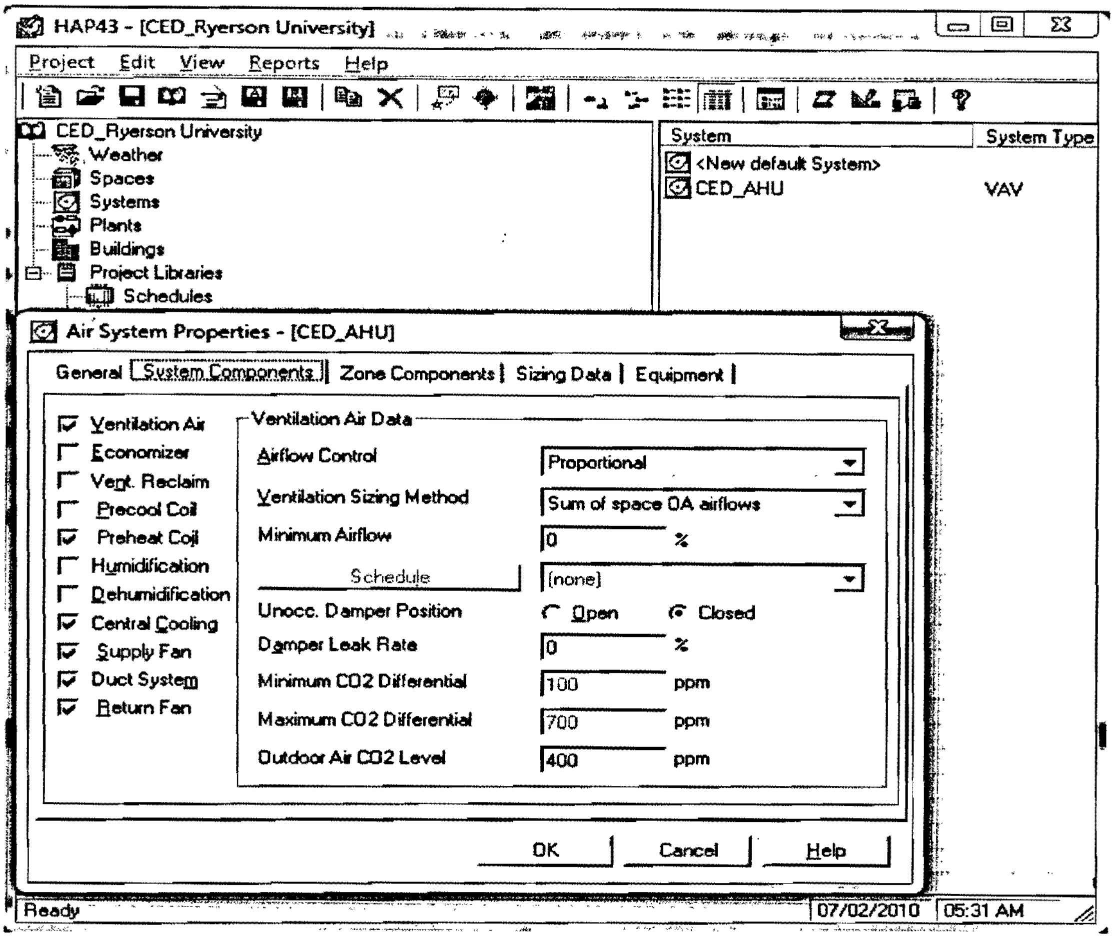

Figure 24: Parameters for the system components in Carrier HAP

CED and most of the buildings using proportional airflow control model of uncontrolled or partially controlled ventilation air for variable volume systems and constant airflow control model for CAV systems and Engineering Building uses demand control ventilation (DCV) system, defined by CO_2 differential.

Proportional airflow method control the ventilation airflow rate as the supply airflow varies. This ventilation airflow rate is calculates by the sum of space OA airflow ventilation sizing method. This method calculated the design ventilation airflow by summing the space outdoor airflow requirements for all spaces served by the system. Certain ventilation standards and codes use this process. This system is also typically used when the building is not subject to a ventilation standard or code.

CO_2 sensors are used in each zone to control ventilation air for the demand controlled ventilation (DCV) models. Since occupants are the primary source of CO_2 in most buildings, measuring CO_2 is a means of indirectly measuring the number of occupants present in a zone. Outdoor ventilation air can then be adjusted as CO_2 levels change so the proper ventilation per occupant is maintained, while at the same time minimizing ventilation air and therefore the corresponding cooling and heating loads due to ventilation. In this system CO_2 data will be collected to establish a control profile which relates a zone CO_2 levels to ventilation airflow rates. The Carrier HAP program performs a CO_2 balance calculation to estimate CO_2 levels at all points in the system. The zone CO_2 levels and the control profile together determine the amount of ventilation air introduced into the system.

Outdoor air economizer is the factory default builds up in every air handling unit. An economizer is used to vary the flow of outdoor air into the system to reduce or eliminate the need for mechanical cooling or heating. There are different types of control used in the economizer, some of them include:

- integrated enthalpy control,
- integrated dry-bulb control,
- non-integrated dry-bulb control,
- upper cutoff, and
- lower cutoff

As shown in Figure 25, most of the buildings at Ryerson University air distribution system can be described. In this system a portion of the room return air (RA) is exhausted (exhaust air, EA), and the rest is mixed with outdoor air (OA). The mixed air is cooled in the cooling coil (CC) for cooling demand or heated in the heating coil (HC) for heating demand and circulated via the supply fan, return fan, air distribution duct and VAV box arrangement. In response to the demand for cooling or heating from the zone thermostat, the supply air (SA) volume flow rate is varied by modulating the damper by controller. Similarly, controller maintains the supply air temperature near its set point value by modulating the chilled water valve. Also, the OA is controlled by modulating the outdoor air damper by another controller.

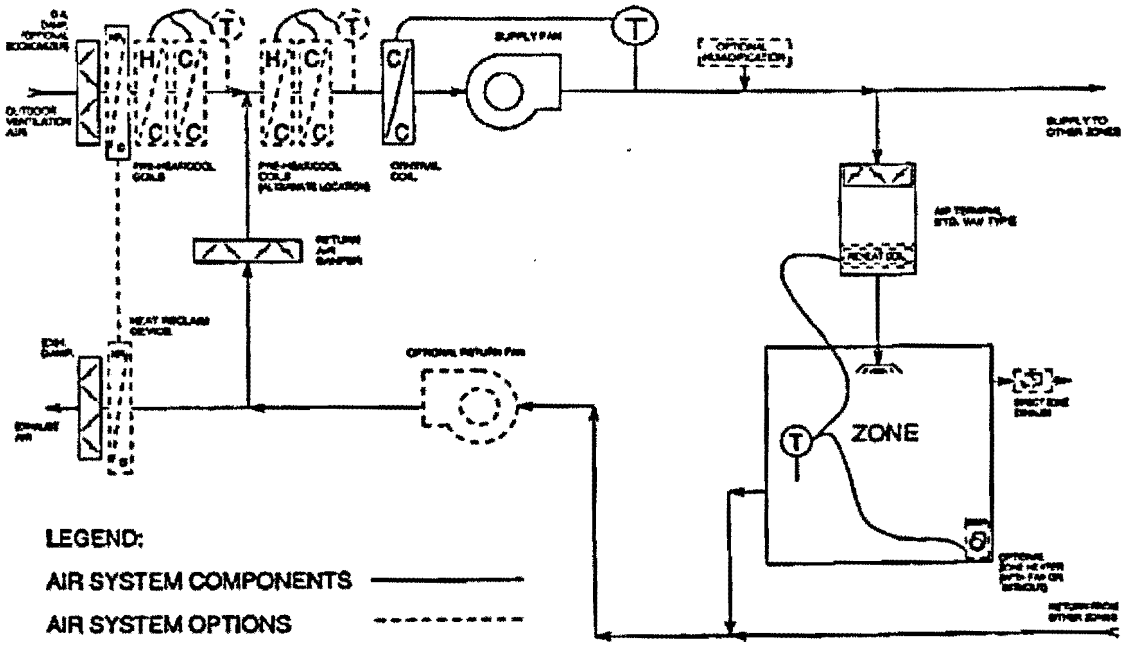

Figure 25: VAV with terminal reheats air distribution system (Carrier HAP, 2006)

The Zone Components contains information about components located in or adjacent to zones served by the system. This includes supply terminals, thermostats, supplemental heating units and the spaces included in the zone. The Thermostats data view contains information about zone thermostat controls, the zone diversity factor and direct exhaust air. Figure 26 shows information required to establish zone components in Carrier HAP.

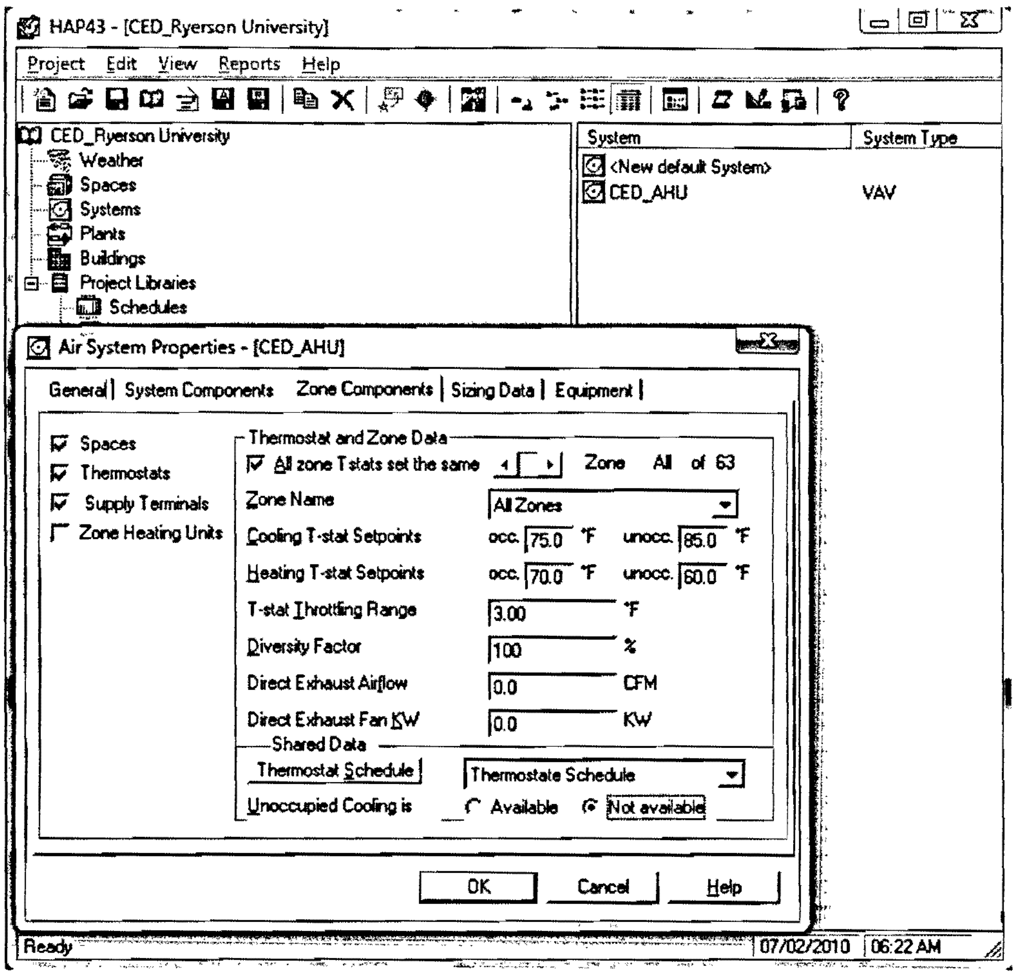

Figure 26: Zone components data form

In zone component thermostat data can be set one set of data to all zones or data will be defined on a zone-by-zone basis. In the Figure 26, data for the CED building zone is shown. In this case all zone T-stats set the same, that's why the zone name appear as "All Zones" indicating common data for all zones is shown. The Thermostat Schedule defines the daily "occupied" and "unoccupied" system operating periods. In CED building thermostat schedule selected as unoccupied cooling is not available to the whole system. There are three types of Fan/Thermostat schedule used for this system. Figure 27 shows weekday, weekend and holiday thermostat schedule.

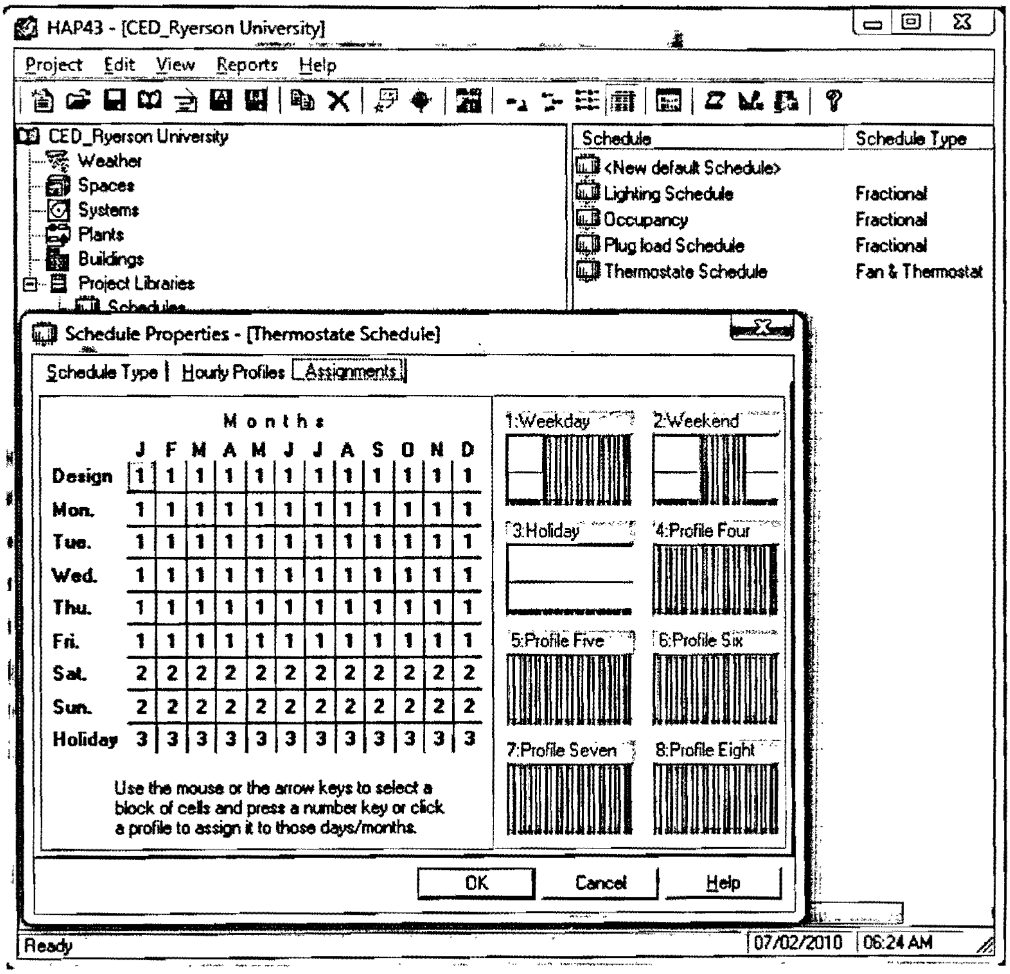

Figure 27: Thermostat schedule (weekday, weekend and holiday)

5.5. *Cooling and heating plant*

Cooling and heating plant are the equipment and controls, which provide chilled water to cooling coils and hot water or steam to heating coils in one or more air systems. Ryerson campus chilled water is supplied by the central chillers plant for 15 buildings and remote steam supplied by the enWave. Chillers plant data and remote steam information were collected from the campus planning and entered to the Carrier HAP software in order to generate plant sizing and energy uses. This report described the chillers plant and cooling towers information, which were located in the Library building and Rogers Communication Centre building. Based on the information was gathered from the Campus Planning Table 21 through Table 24 describe detail information for the chillers plant and Table 25 present cooling tower information.

Table 21: McQuay 1200 ton double effect absorption water chiller specification

Chiller Plant: Double Effect Absorption Water Chiller 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 4220.2 kW
COP	-	1.46
Fuel or Energy Type	-	Steam
Fuel Consumption	lbs/hr	11760
Entering Cooling Water Temperature	°F	85
Leaving Cooling Water Temperature	°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

Table 22: Carrier 500 ton centrifugal water cooled chiller specification

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 1758.4 kW
Fuel or Energy Type	-	Electric
Full Load Power	kW/Ton	0.597
Entering Chilled Water Temperature	°F	85
Leaving Chilled Water Temperature	°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 Armstrong(4300TC)	HP or kW	15 HP / 11.22 kW

Table 23: Trane 275 ton centrifugal water cooled chiller specification

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 Temperature	^oF	85
Leaving Chilled Water Temperature	^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

Table 24: York 100 ton air cooled scroll chiller specification

Chiller Plant: Electric		
Field	Units	
Chiller Name: York		
Chiller Type		Air-Cooled Scroll Chiller
Refrigerant Type		
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	^oF	85
Leaving Chilled Water Temperature	^oF	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

Table 25: Marley cooling tower specification

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 Efficiency	%	80
Condenser pumps Electrical Efficiency	%	94
Hot water	°F	95
Cold water	°F	85
Design Approach	°F	10
Full Load Fan	HP	50
Chilled Water set point	°F	85
Set Point Control		Variable Speed Fan

Figure 28 shows sample chiller plant schematic diagram for central air conditioning system.

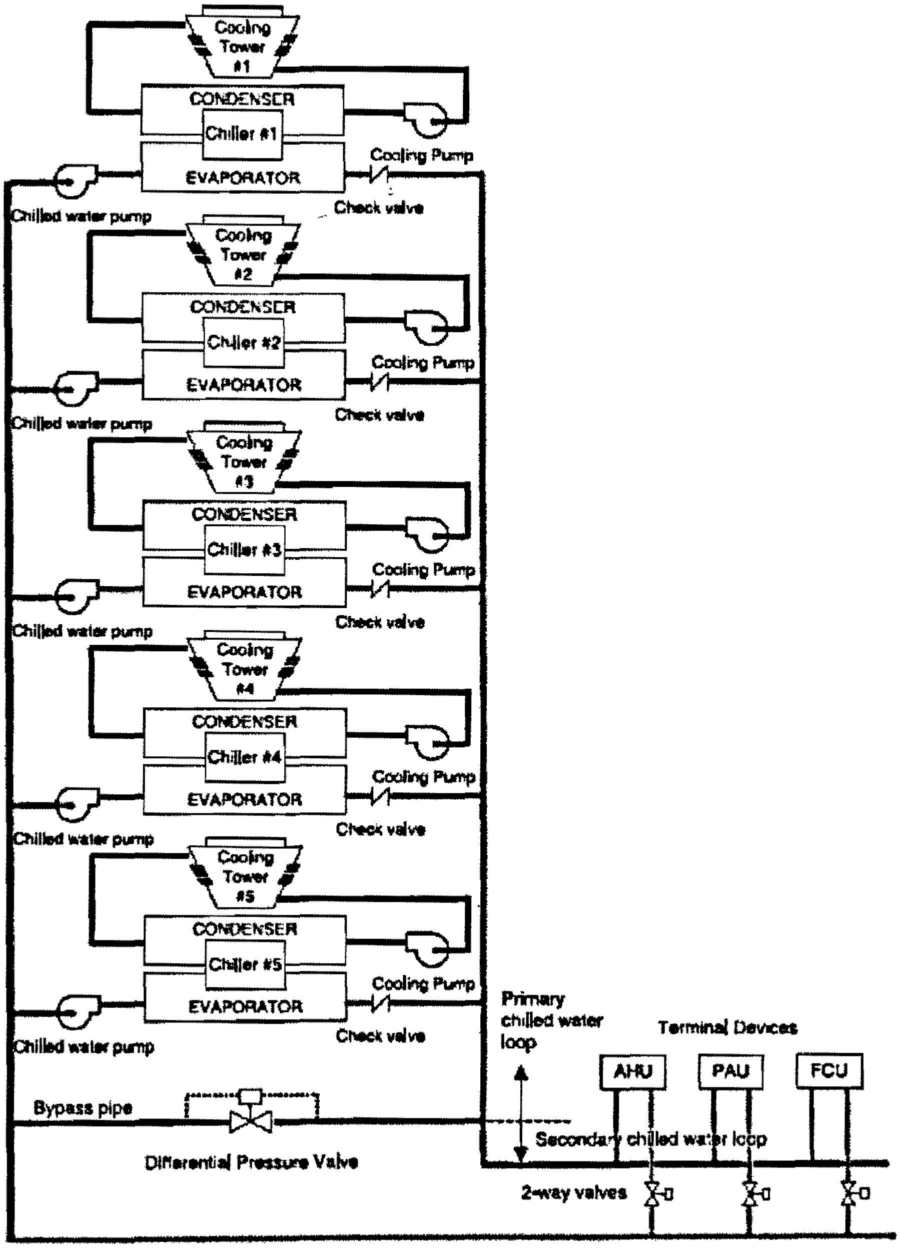

Figure 28: Sample chiller plant schematic diagram (Yu & Chow, 2007)

Figure 29 shows the detail input data in Carrier HAP chiller properties for the McQuay Absorption Chiller

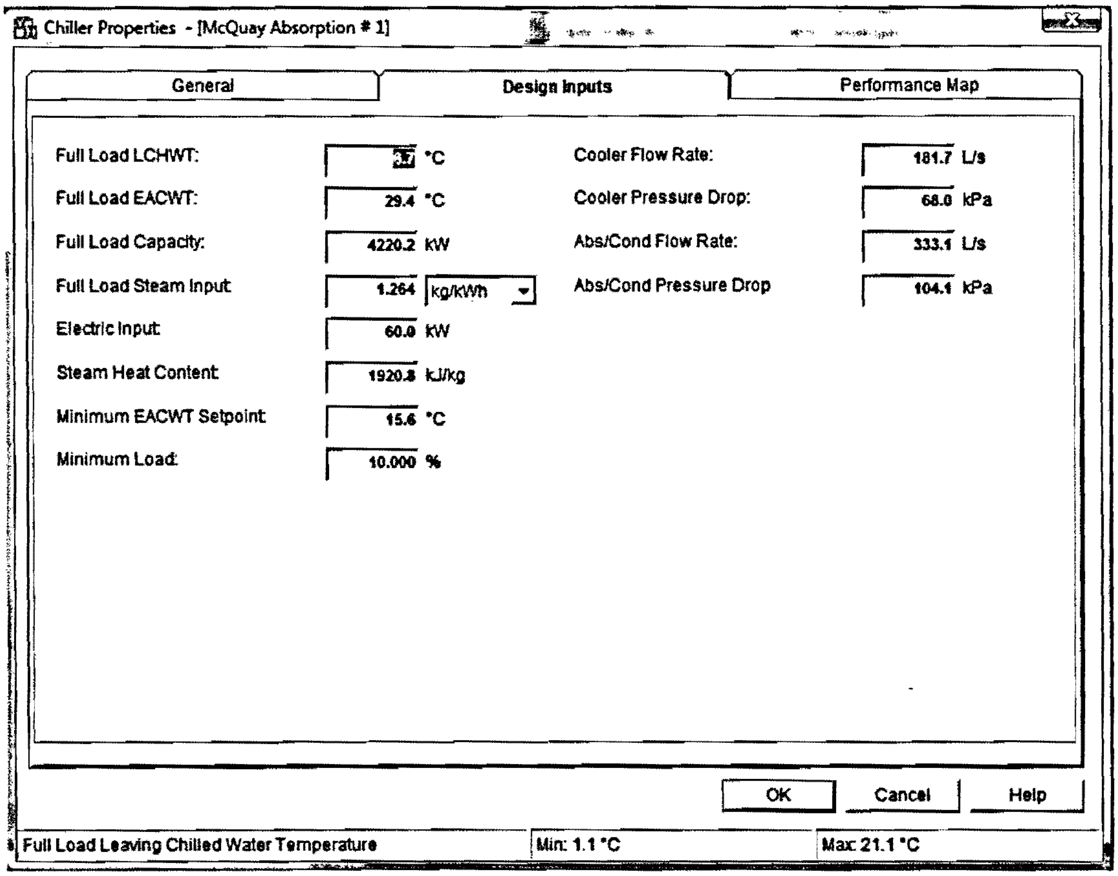

Figure 29: Chiller input data form (Carrier HAP, 2006)

Air distribution system for these chillers plant selected as variable speed secondary type. One constant speed pump is paired with each chiller in the system. These constant speed pumps maintain a constant flow through the individual chiller or boiler legs in the primary portion of the system. Therefore, each primary pump operates at its design point. A separate variable speed pump, or group of variable speed pumps in parallel, drives flow in the secondary portion of the system. Two-way valves regulate flow through air system coils. A differential pressure sensor measuring pressure between the supply and return legs of the secondary system controls the secondary pump speed to maintain a constant differential pressure. As a result, the secondary pump rides the system curve as flow varies. This configuration is shown in Figure 30 below and Figure 31 shows the required data for the plant properties in the distribution system.

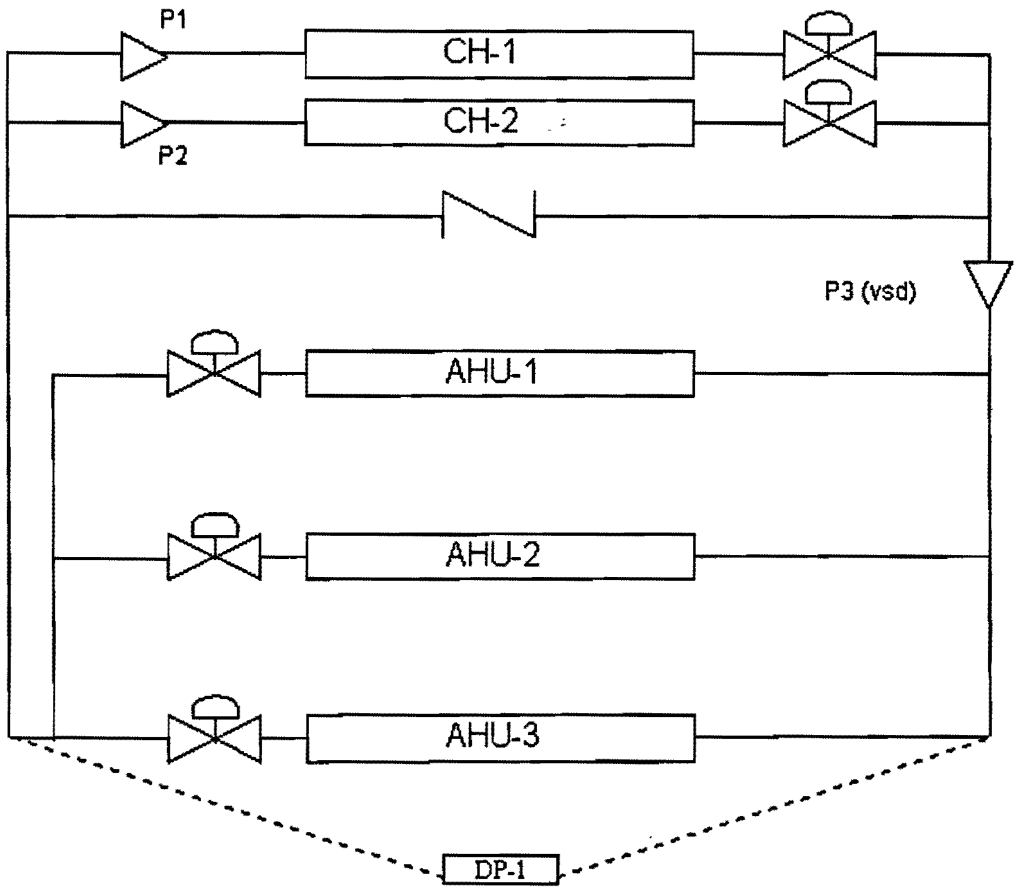

Figure 30: Primary/Secondary, Variable speed secondary of air distribution system (Carrier HAP, 2006)

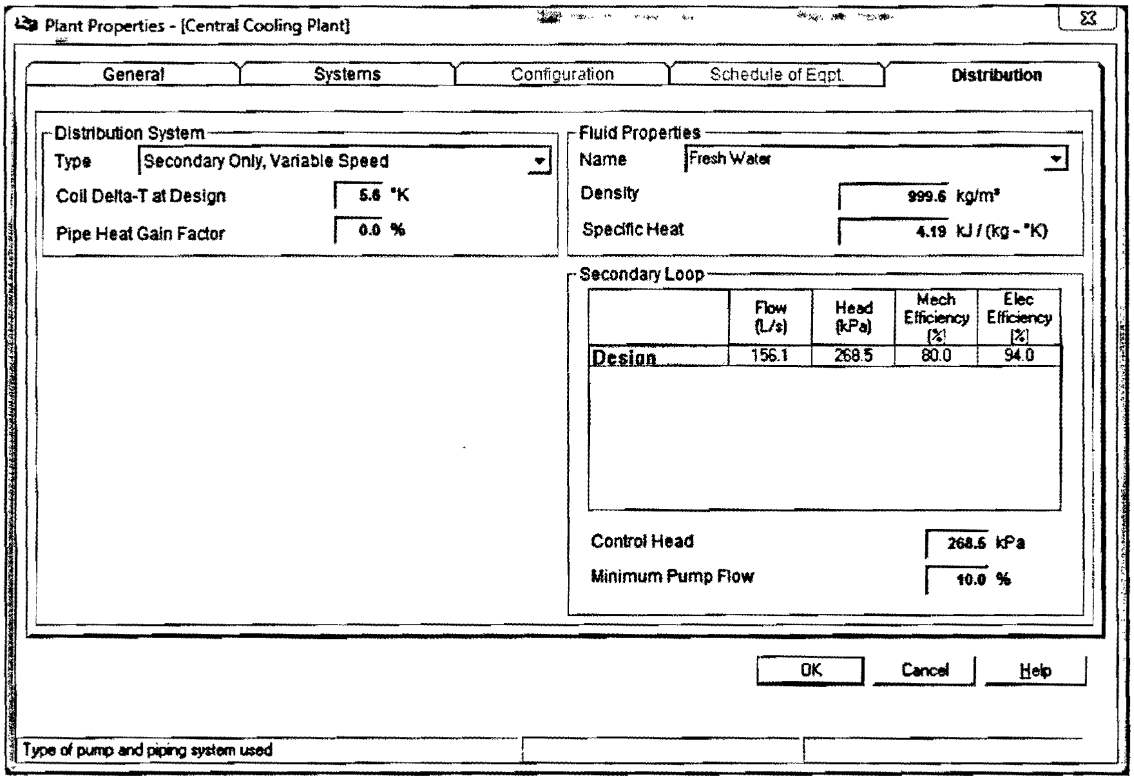

Figure 31: Plant distribution system data form (Carrier HAP, 2006)

5.6. *Energy rate*

The flat rate of chilled water ($0.23/ton-hr) was calculated from the conceptual model of central chiller plant output data, located in the Library Building. This price was used all HAP model for calculation annual chilled water energy cost. The detail calculation is given in Appendix C. In order to lack of sufficient information from the Campus Planning, flat rate were assumed for steam $0.025/lb and for hydro $0.10/kWh.

6.0. Energy calculation and simulation

Buildings are built to provide a safe and comfortable internal environment despite variations in external conditions. Building energy calculation and simulation based on the energy uses in the building for different purposes, i.e. cooling, heating, lighting, plug load, etc. Generally heat loss and heat gain by conduction, convection and radiation is the main part of energy calculation process. Heat transfer through a solid material, referred to as conduction, which involves energy exchange at the molecular level. Radiation, on the other hand, is a process that transports energy by way of photon propagation from one surface to another. Convection heat transfer depends upon conduction from a solid surface to an adjacent fluid and the movement of the fluid along the surface or away from it. These heat transfer processes considered for heat balance method to determined building loads.

6.1. Base case simulation of Ryerson buildings using carrier HAP

As a base model for energy audit simulation study, 16 buildings at Ryerson University have been considered. The climate conditions for Toronto are 43.7 degree latitude and 79.6 degree longitude, high dry and wet bulb temperatures are 30.6°C and 21.7°C, the daily range is 11.2°C and CWEC weather location data was used (Carrier HAP, 2006). The heating and cooling load of the air system of the base case building depends on the actual schedules of occupancy schedule, lighting schedule, equipment schedule, fan/thermostat schedule and ventilation requirements.

Energy simulation result obtained from Carrier HAP of the Ryerson base case buildings were compared with the Campus Planning energy bills for hydro consumption, remote steam consumption and maximum plant cooling load.

6.1.1. *Simulation results of the Ryerson buildings*

Building simulation reports contain energy consumption and energy cost data produced by the building energy simulation program Carrier HAP. This report contained simulation result for the followings:

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

6.1.2. *Lighting and plug load simulation result*

From Carrier HAP simulation result it is estimated that 49% of electrical energy consumption is due to lighting, plug load and miscellaneous uses. Figure 32 presents annual components electrical energy consumption in Ryerson buildings. From this figure it shows that 26% hydro consumption is for lighting, 19% hydro consumption is for equipment and 4% hydro consumption is for miscellaneous electric. So when attempting energy savings, lighting is the first area in a facility to look for savings because changes are usually easy and inexpensive. Table 26 presents' percentages of annual components hydro energy consumption and Table 27 presents annual components hydro energy consumption per square meter.

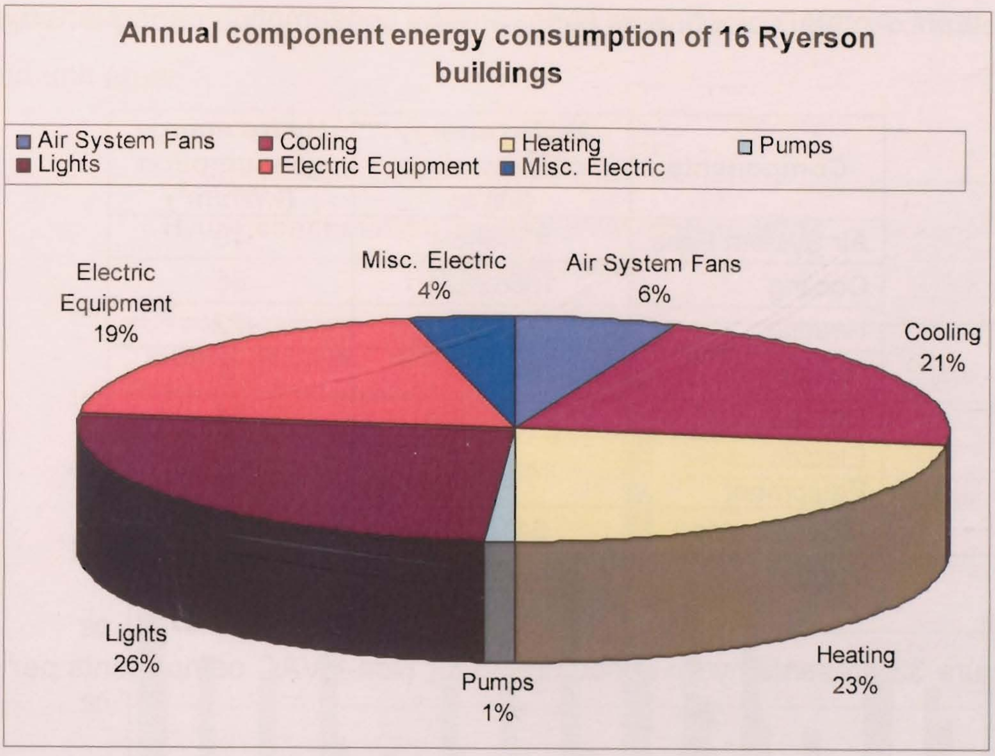

Figure 32: Annual components energy consumption

Table 26: Percentage of annual components energy consumption

Components	**Total energy consumption (%)**
Air System Fans	6
Cooling	21
Heating	23
Pumps	1
Lights	26
Electric Equipment	19
Misc. Electric	4
Total	**100**

Table 27: Annual components hydro energy consumption per square meter

Components	Hydro energy consumption (kWh)	Hydro energy consumption (kWh/m^2)
Air System Fans	4338489	18
Cooling	15868834	66
Heating	17257792	72
Pumps	619044	3
Lights	20273333	84
Electric Equipment	14681308	61
Misc. Electric	3418056	14
Total	**76,456,856**	318

Figure 33 presents hydro consumption for Non-HVAC components per gross unit area

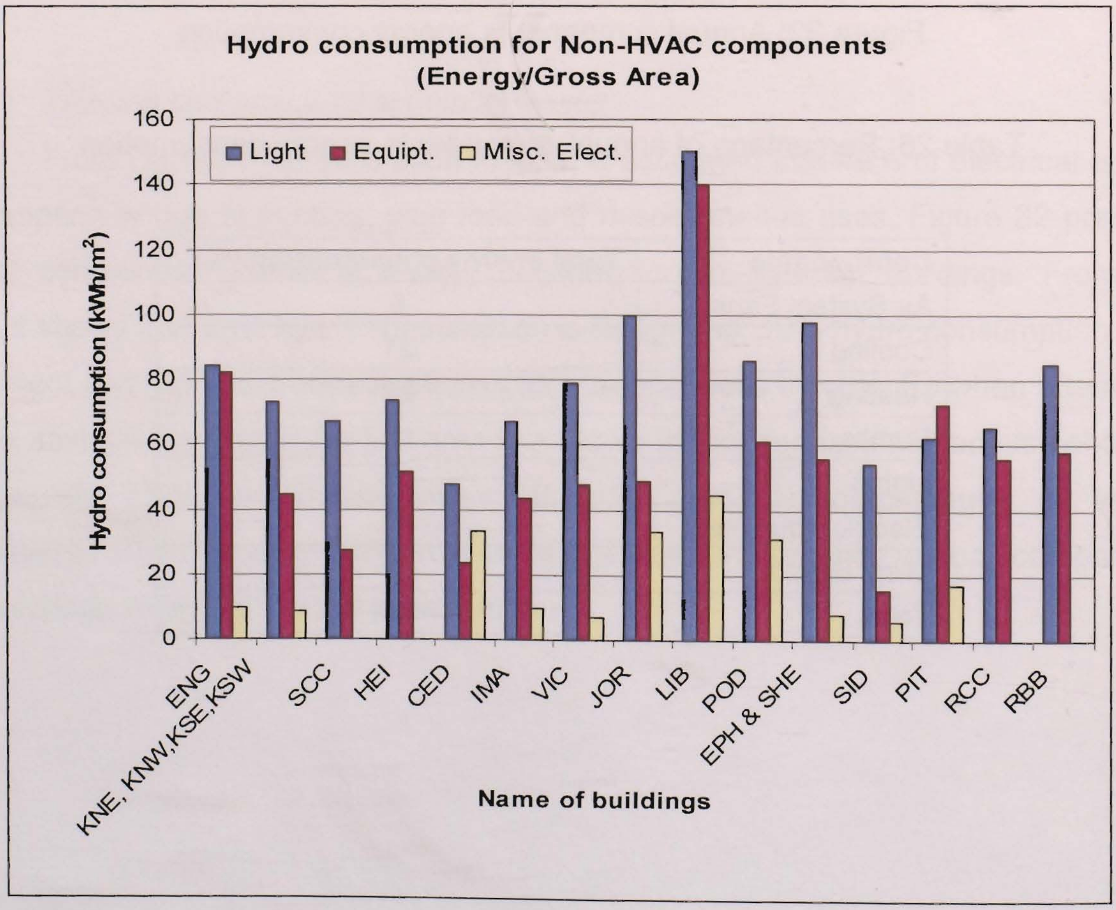

Figure 33: Hydro consumption for Non-HVAC components (gross area)

Figure 34 presents hydro consumption for Non-HVAC components per conditioned unit area

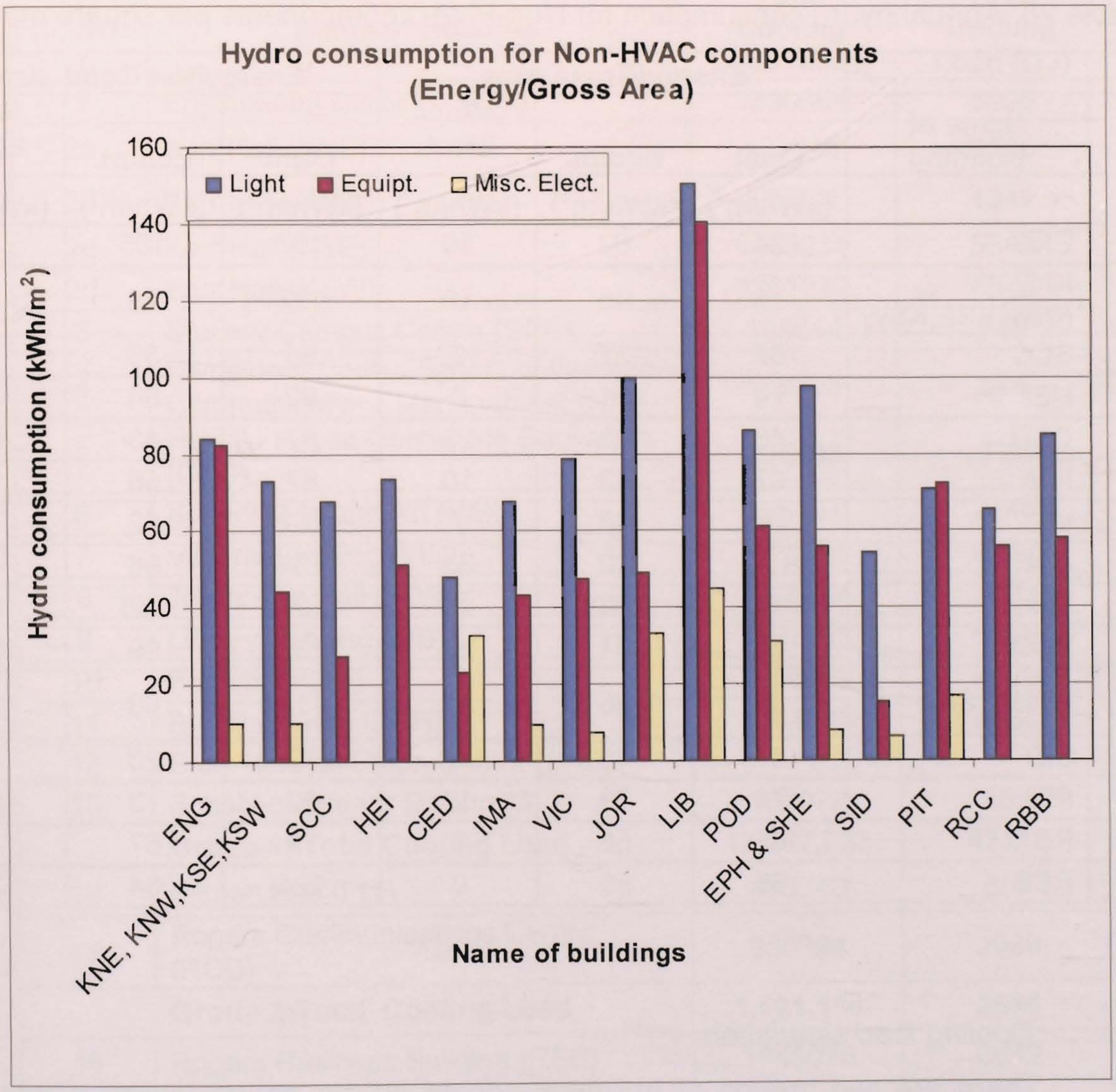

Figure 34: Hydro consumption for Non-HVAC components (conditioned area)

Table 28 presents Carrier HAP simulation result for the annual hydro consumption per unit area of Non-HVAC components for each building

Table 28: Annual hydro consumption for Non-HVAC components per square meter

		Energy/Gross Area			Energy/Net Cond. Area		
Sl. NO.	**Name of Building**	**Light**	**Equipt.**	**Misc. Elect.**	**Light**	**Equipt.**	**Misc. Elect.**
		(kWh/m^2)	**(kWh/m^2)**	**(kWh/m^2)**	**(kWh/m^2)**	**(kWh/m^2)**	**(kWh/m^2)**
1	ENG	84	82	10	107	105	13
2	KNE, KNW,KSE,KSW	73	45	10	127	78	15
3	SCC	67	27	0	94	38	0
4	HEI	74	51	0	92	64	0
5	CED	48	23	33	87	43	61
6	IMA	67	43	10	87	56	12
7	VIC	79	48	7	102	62	9
8	JOR	100	49	33	134	66	45
9	LIB	150	140	45	180	168	54
10	POD	86	61	31	139	99	50
11 & 12	EPH & SHE	98	56	8	119	68	10
13	SID	54	15	6	82	23	9
14	PIT	71	73	17	62	73	17
15	RCC	65	56	0	79	67	0
16	RBB	85	58	0	124	84	0

6.1.3. Cooling load simulation

There are two groups of buildings served by the central chiller plants for cooling and remote steam for heating. Group 1 central chiller plant located in the Library building has a total capacity of 10903kW and Group 2 central chiller plant located in the Rogers Communications Center building has a total capacity of 1864 kW. Table 29 presents annual total cooling load demand for 16 Ryerson buildings. Figure 35 and Table 30 present annual cooling load demand for individual buildings per square meter.

Table 29: Total annual cooling load demand for individual building of Ryerson University

Sl. NO.	Name of Building	Total Cooling Load (kWh)	Total Cooling Load (GJ)
1	Engineering Building (ENG)	1890651	6806
2a	Kerr Hall (KNE)	432045	1555
2b	Kerr Hall (KNW)	372691	1342
2c	Kerr Hall (KSE)	1483211	5340
2d	Kerr Hall (KSW)	1261217	4540
3	Student Campus Centre (SCC)	198614	715
4	Heidelberg Centre-School of Graphic Communications Management (HEI)	159308	574
5	Heaslip House Continuing Education (CED)	205136	738
6	School of Image Art (IMA)	596157	2146
7	Victoria Building (VIC)	781200	2812
8	Jorgenson Hall (JOR)	1078274	3882
9	Library Building (LIB)	1727593	6219
10	Podium (POD)	1258069	4529
11	Eric Palin Hall (EPH)	1481285	5333
12	Sally Horsfall Eaton Centre (SHE)		
13	School of Interior Design (SID)	162072	583
	Group 1: Total Cooling Load	**13,087,523**	**47115**
14	Pitman Hall (PIT)	190740	687
15	Rogers Communications Centre (RCC)	830394	2989
	Group 2:Total Cooling Load	**1,021,134**	**3676**
16	Rogers Business Building (RBB)	1845076	6642
Total Cooling Load for Audit Area		**15,953,733**	**57,433**

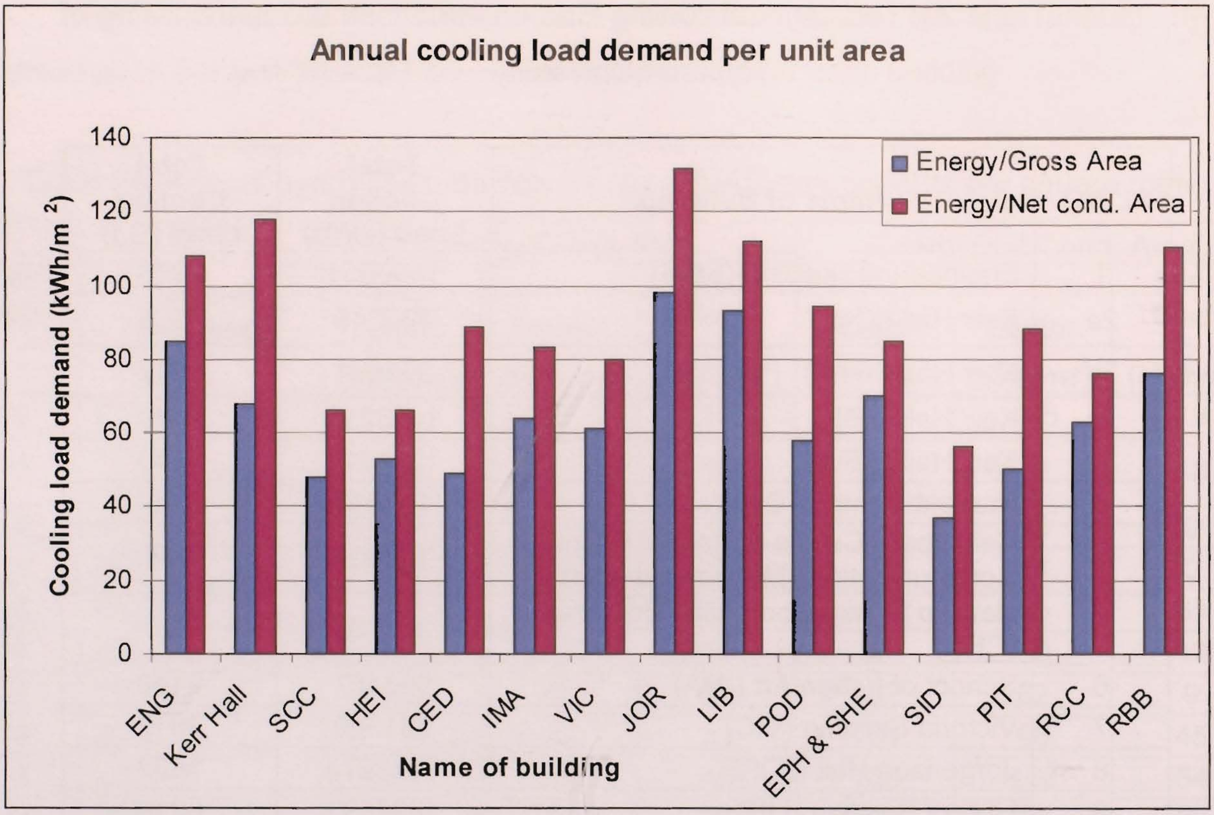

Figure 35: Annual cooling load demand per unit area

Table 30: Cooling load for individual building per square meter

Sl. NO.	Name of Building	Gross Floor Area	Net Conditioned Area	Energy/Gross Floor Area	Energy/Net Cond. Area
		(m^2)	(m^2)	(kWh/m^2)	(kWh/m^2)
1	Engineering Building (ENG)	22350	17583	85	108
2	Kerr Hall (NE, NW,SE,SW)	52409	30125	68	118
3	Student Campus Centre (SCC)	4180	2993	48	66
4	Heidelberg Centre-School of Graphic Communications Management (HEI)	2985	2399	53	66
5	Heaslip House Continuing Education (CED)	4180	2302	49	89
6	School of Image Art (IMA)	9345	7219	64	83
7	Victoria Building (VIC)	12708	9788	61	80
8	Jorgenson Hall (JOR)	10964	8188	98	132
9	Library Building (LIB)	18487	15426	93	112
10	Podium Building (POD)	21730	13421	58	94
11	Eric Palin Hall (EPH)	21019	17334	70	85
12	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)				
13	School of Interior Design (SID)	4373	2888	37	56
14	Pitman Hall (PIT)	3828	2165	50	88
15	Rogers Communications Centre (RCC)	13100	10871	63	76
16	Rogers Business Building (RBB)	24378	16740	76	110
	Total	**226,036**	**159,442**	**70**	**100**

Maximum cooling load demand was determined from 8760 hour cooling load analysis from the carrier HAP output. Table 31 shows from Carrier HAP result that maximum plant cooling load for 13 buildings for central chiller plant located in the library building is 10809 kW compared with the central chiller plant maximum capacity of 10903 kW.

Table 31: Maximum cooling plant load for individual building

Sl. No	Name of Building	Max Plant Load
		(kW)
Group 1: Maximum cooling plant load occur on July 7th at 1700		
1	Engineering Building (ENG)	1981
2a	Kerr Hall (KNE)	324
2b	Kerr Hall (KNW)	287
2c	Kerr Hall (KSE)	934
2d	Kerr Hall (KSW)	899
3	Student Campus Centre (SCC)	202
4	Heidelberg Centre-School of Graphic Communications Management (HEI)	154
5	Heaslip House Continuing Education (CED)	221
6	School of Image Art (IMA)	535
7	Victoria Building (VIC)	786
8	Jorgenson Hall (JOR)	682
9	Library Building (LIB)	1189
10	Podium Building (POD)	1032
11	Eric Palin Hall (EPH)	1399
12	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)	
13	School of Interior Design (SID)	184
	Total Max Plant Cooling Load	**10,809**
Group 2: Maximum cooling plant load occur on July 7th at 1600		
14	Pitman Hall (PIT)	212
15	Rogers Communications Centre (RCC)	858
	Total Max Plant Cooling Load	**1070**
Maximum cooling plant load occur on July 9th at 1200		
16	Rogers Business Building (RBB)	**2538**

The peak load for space cooling usually occurs under very hot and sunny conditions, although it depends not only on outside weather conditions (temperature, wind, etc) but also on other parameters such as the thermal mass of the building, orientation of the building, and infiltration rate. Table 32 shows the peak cooling load occurs in different month and time for the different building.

Table 32: Peak cooling load for individual building

<table>
<tr><th>Sl. No</th><th>Name of Building</th><th>Peak Cooling Load</th><th colspan="3">Load Occurs</th></tr>
<tr><th></th><th></th><th>(kW)</th><th>Month</th><th>Day</th><th>Hour</th></tr>
<tr><td>1</td><td>Engineering Building (ENG)</td><td>1981</td><td>July</td><td>7</td><td>1700</td></tr>
<tr><td>2a</td><td>Kerr Hall (KNE)</td><td>359</td><td>August</td><td>5</td><td>1400</td></tr>
<tr><td>2b</td><td>Kerr Hall (KNW)</td><td>362</td><td>August</td><td>5</td><td>1400</td></tr>
<tr><td>2c</td><td>Kerr Hall (KSE)</td><td>1123</td><td>August</td><td>5</td><td>1400</td></tr>
<tr><td>2d</td><td>Kerr Hall (KSW)</td><td>981</td><td>August</td><td>5</td><td>1400</td></tr>
<tr><td>3</td><td>Student Campus Centre (SCC)</td><td>202</td><td>July</td><td>7</td><td>1700</td></tr>
<tr><td>4</td><td>Heidelberg Centre-School of Graphic Communications Management (HEI)</td><td>154</td><td>July</td><td>7</td><td>1700</td></tr>
<tr><td>5</td><td>Heaslip House Continuing Education (CED)</td><td>221</td><td>July</td><td>7</td><td>1700</td></tr>
<tr><td>6</td><td>School of Image Art (IMA)</td><td>535</td><td>July</td><td>7</td><td>1700</td></tr>
<tr><td>7</td><td>Victoria Building (VIC)</td><td>786</td><td>July</td><td>7</td><td>1700</td></tr>
<tr><td>8</td><td>Jorgenson Hall (JOR)</td><td>737</td><td>August</td><td>5</td><td>1400</td></tr>
<tr><td>9</td><td>Library Building (LIB)</td><td>1372</td><td>August</td><td>4</td><td>1200</td></tr>
<tr><td>10</td><td>Podium Building (POD)</td><td>1067</td><td>August</td><td>4</td><td>1200</td></tr>
<tr><td>11</td><td>Eric Palin Hall (EPH)</td><td rowspan="2">1466</td><td rowspan="2">July</td><td rowspan="2">7</td><td rowspan="2">1600</td></tr>
<tr><td>12</td><td>Sally Horsfall Eaton Centre for Studies in Community Health (SHE)</td></tr>
<tr><td>13</td><td>School of Interior Design (SID)</td><td>185</td><td>July</td><td>7</td><td>1800</td></tr>
<tr><td colspan="2">Total Peak Cooling Load</td><td>11,531</td><td colspan="3"></td></tr>
<tr><td>14</td><td>Pitman Hall (PIT)</td><td>222</td><td>August</td><td>5</td><td>1400</td></tr>
<tr><td>15</td><td>Rogers Communications Centre (RCC)</td><td>858</td><td>July</td><td>7</td><td>1200</td></tr>
<tr><td colspan="2">Total Peak Cooling Load</td><td>1080</td><td></td><td></td><td></td></tr>
<tr><td>16</td><td>Rogers Business Building (RBB)</td><td>2538</td><td>July</td><td>9</td><td>1200</td></tr>
</table>

6.1.4. Heating load simulation

Maximum heating plant load is the sum of total heating load required for group of buildings operated under a meter. The peak heating load for space heating usually occurs under very cold conditions. It occurs only for a limited time of the year-usually during very cold spell. Ryerson University used remote steam for heating demand. Most of the Ryerson buildings have humidifier for humidification of air which uses direct steam injection in the air distribution system. Table 33 shows peak heating load for Ryerson buildings.

Table 33: Peak heating load for individual building

<table>
<tr><th>Sl. No</th><th>Name of Building</th><th>Peak Heating Load</th><th colspan="3">Load Occurs</th></tr>
<tr><th></th><th></th><th>(kW)</th><th>Month</th><th>Day</th><th>Hour</th></tr>
<tr><td>1</td><td>Engineering Building (ENG)</td><td>1792</td><td>January</td><td>27</td><td>800</td></tr>
<tr><td>2a</td><td>Kerr Hall (KNE)</td><td>471</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>2b</td><td>Kerr Hall (KNW)</td><td>621</td><td>January</td><td>27</td><td>500</td></tr>
<tr><td>2c</td><td>Kerr Hall (KSE)</td><td>1333</td><td>January</td><td>25</td><td>2200</td></tr>
<tr><td>2d</td><td>Kerr Hall (KSW)</td><td>1021</td><td>January</td><td>2</td><td>1200</td></tr>
<tr><td>3</td><td>Student Campus Centre (SCC)</td><td>128</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>4</td><td>Heidelberg Centre-School of Graphic Communications Management (HEI)</td><td>93</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>5</td><td>Heaslip House Continuing Education (CED)</td><td>136</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>6</td><td>School of Image Art (IMA)</td><td>463</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>7</td><td>Victoria Building (VIC)</td><td>464</td><td>January</td><td>27</td><td>600</td></tr>
<tr><td>8</td><td>Jorgenson Hall (JOR)</td><td>425</td><td>January</td><td>27</td><td>800</td></tr>
<tr><td>9</td><td>Library Building (LIB)</td><td>232</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>10</td><td>Podium Building (POD)</td><td>375</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>11</td><td>Eric Palin Hall (EPH)</td><td rowspan="2">510</td><td rowspan="2">January</td><td rowspan="2">27</td><td rowspan="2">700</td></tr>
<tr><td>12</td><td>Sally Horsfall Eaton Centre for Studies in Community Health (SHE)</td></tr>
<tr><td>13</td><td>School of Interior Design (SID)</td><td>113</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>14</td><td>Pitman Hall (PIT)</td><td>168</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td>15</td><td>Rogers Communications Centre (RCC)</td><td>362</td><td>January</td><td>27</td><td>700</td></tr>
<tr><td colspan="2">Total Peak Heating Load</td><td>8707</td><td></td><td></td><td></td></tr>
<tr><td>16</td><td>Rogers Business Building (RBB)</td><td>1076</td><td>January</td><td>15</td><td>200</td></tr>
</table>

The result shows that in January 27th maximum steam was used for space heating. Table 34 shows maximum plant heating load for 15 buildings.

Table 34: Maximum plant heating load of 16 Ryerson buildings

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

Annual steam consumption obtained from the Carrier HAP simulation result for the 16 buildings, total steam consumption and calculated equivalent energy uses in GJ are listed in Table 35 and steam consumption per gross unit area are listed in Table 36. Figure 36 shows the bar chart for the annual steam demand per unit area. The conversion factor of 0.0036 is used for kWh to GJ.

Table 35: Annual remote steam consumption

Sl. No	**Name of Building**	**Total Heating Load**	**Total Energy Uses**
		(kWh)	**(GJ)**
1	Engineering Building (ENG)	1736162	6250
2	Kerr Hall (NE, NW, SE, SW)	9849907	35460
3	Student Campus Centre (SCC)	190450	686
4	Heidelberg Centre-School of Graphic Communications Management (HEI)	160195	577
5	Heaslip House Continuing Education (CED)	183831	662
6	School of Image Art (IMA)	833069	2999
7	Victoria Building (VIC)	664253	2391
8	Jorgenson Hall (JOR)	403630	1453
9	Library Building (LIB)	232707	838
10	Podium Building (POD)	585197	2107
11	Eric Palin Hall (EPH)	547752	1972
12	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)		
13	School of Interior Design (SID)	95374	343
14	Pitman Hall (PIT)	146650	528
15	Rogers Communications Centre (RCC)	321243	1156
16	Rogers Business Building (RBB)	1307372	4707
	Total Steam Load	**17,257,792**	**62,129**

Table 36: Annual remote steam consumption per unit area

Sl. No	Name of Building	Gross Floor Area	Net Conditioned Area	Load/Gross Floor Area	Load/Net Cond. Area
		(m^2)	(m^2)	(kWh/m^2)	(kWh/m^2)
1	Engineering Building (ENG)	22350	17583	78	99
2	Kerr Hall (NE, NW, SE, SW)	52409	30125	188	327
3	Student Campus Centre (SCC)	4180	2993	46	64
4	Heidelberg Centre-School of Graphic Communications Management (HEI)	2985	2399	54	67
5	Heaslip House Continuing Education (CED)	4180	2302	44	80
6	School of Image Art (IMA)	9345	7219	89	115
7	Victoria Building (VIC)	12708	9788	52	68
8	Jorgenson Hall (JOR)	10964	8188	37	49
9	Library Building (LIB)	18487	15426	13	15
10	Podium Building (POD)	21730	13421	27	44
11	Eric Palin Hall (EPH)	21019	17334	26	32
12	Sally Horsfall Eaton Centre for Studies in Community Health (SHE)				
13	School of Interior Design (SID)	4373	2888	22	33
14	Pitman Hall (PIT)	3828	2165	38	68
15	Rogers Communications Centre (RCC)	13100	10871	25	30
16	Rogers Business Building (RBB)	24378	16740	54	78
	Total Steam Load (kWh)	**226,036**	**160,442**	**76**	**107**

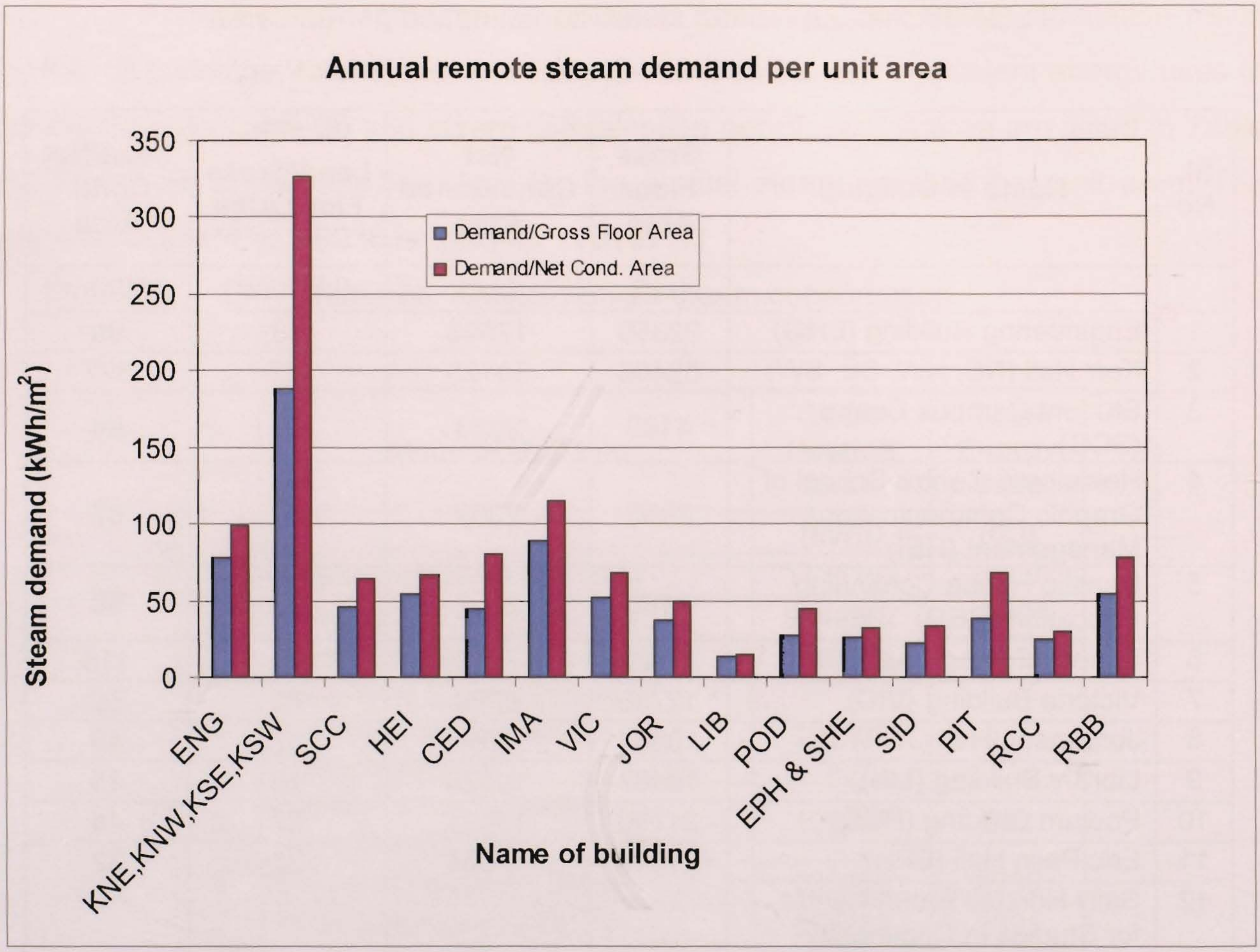

Figure 36: Annual steam demand each building per unit area

Ryerson University remote steam is used for a total area of 245842 m^2 including Rogers Business Building (RBB). There are two meters for steam consumption. Meter one serves total area of 223127 m^2 (20 Buildings) including central chillers plant (for absorption chillers) located in the Library building and meter two is connected to RBB. The audit area for the 15 buildings (201658 m^2) covers equivalent of 90.3% from the actual campus planning steam consumption bill of meter one. The calculation for this steam service area is listed in Appendix C. Table 37 shows annual steam consumption bill for 2006 from Campus Planning and compared with steam consumption obtained from Carrier HAP simulation program. Remote steam is supplied at a pressure of 250 psig, at this pressure the enthalpy for this steam is 825.8 BTU/lb. The conversion factor of 3.412 is used for kWh to kBTU.

Table37: Steam consumption comparison with Carrier HAP

Meter-1 (90.3% of actual steam)	(kWh)	(kBTU)	(lb)	(%)
15 buildings steam consumption	15950420			
Chiller plant steam consumption	5751754			
Total steam consumption	21702174	74047818	89667980	
Campus Planning bill			95656508	
Difference (under predict)				**6.26**
Meter-2				
Rogers Business Building (RBB)	1307372	4460753	5401736	
Campus Planning bill			5804648	
Difference (under predict)				**6.94**

6.1.5. Hydro simulation

Hydro consumption for the individual building depends on the space uses. The main components of the hydro energy consumptions are air system fans, cooling tower fans, cooling and heating loads, pumps (domestic hot water pump, domestic cold water pump, chilled water supply pump, condenser pump, heating glycol pump, sanitary sump pump, storm pump, fire pump, jockey pump, etc), lighting, equipments, and miscellaneous electric. Table 38 shows hydro consumption was calculated from Carrier HAP simulation for chiller plant model located in the Library Building and RCC Building.

Table 38: Annual chiller plant hydro consumption

	Chiller Plant in the Library Building	**Chiller Plant in the RCC Building**
Chiller Electricity	**(kWh)**	**(kWh)**
Chiller Input	1229193	146555
Chiller Misc. Electric	394722	-
Chilled water pump	863513	67860
Cooling Tower Fan	664352	30272
Total	**3,151,780**	**244,687**

Hydro consumption was estimated from the Carrier HAP simulation program for the 16 individual buildings. Table 39 shows annual hydro demand for individual building of Ryerson campus.

Table 39: Annual hydro demand from simulation program

Sl. NO.	Building	Annual Hydro Consumption	Annual Hydro Consumption/ Gross Area	Annual Hydro Consumption/ Cond. Area
	Name	(kWh)	(kWh/m^2)	(kWh/m^2)
1	ENG	4396600	197	250
2	Kerr Hall	7863450	150	261
3	SCC	465118	111	155
4	HEI	446131	149	186
5	CED	517,658	124	225
6	IMA	1424168	152	197
7	VIC	1852390	146	189
8	JOR	2514762	229	307
9	LIB	6671607	361	432
10	POD	4232528	195	315
11 & 12	EPH & SHE	3844099	183	222
13	SID	390869	89	135
14	PIT	2954134	182	221
15	RCC	1811528	157	167
16	RBB	3945188	162	236
	Total	**43,330,230**	**180**	**250**
	LIB_Chiller	3151780		
	RCC_Chiller	244687		
Total		**46,726,697**		

Figure 37 presents annual hydro consumption per unit area (gross area and net conditioned area). From this figure it shows that comparatively Library building hydro demand is high. The reason for this high hydro consumption of Library building is to operate maximum hour of the year comparatively with others building, high plug load (computers, printers, cafeteria and other equipments) used in the study area, especially on the third floor (study area) of the building.

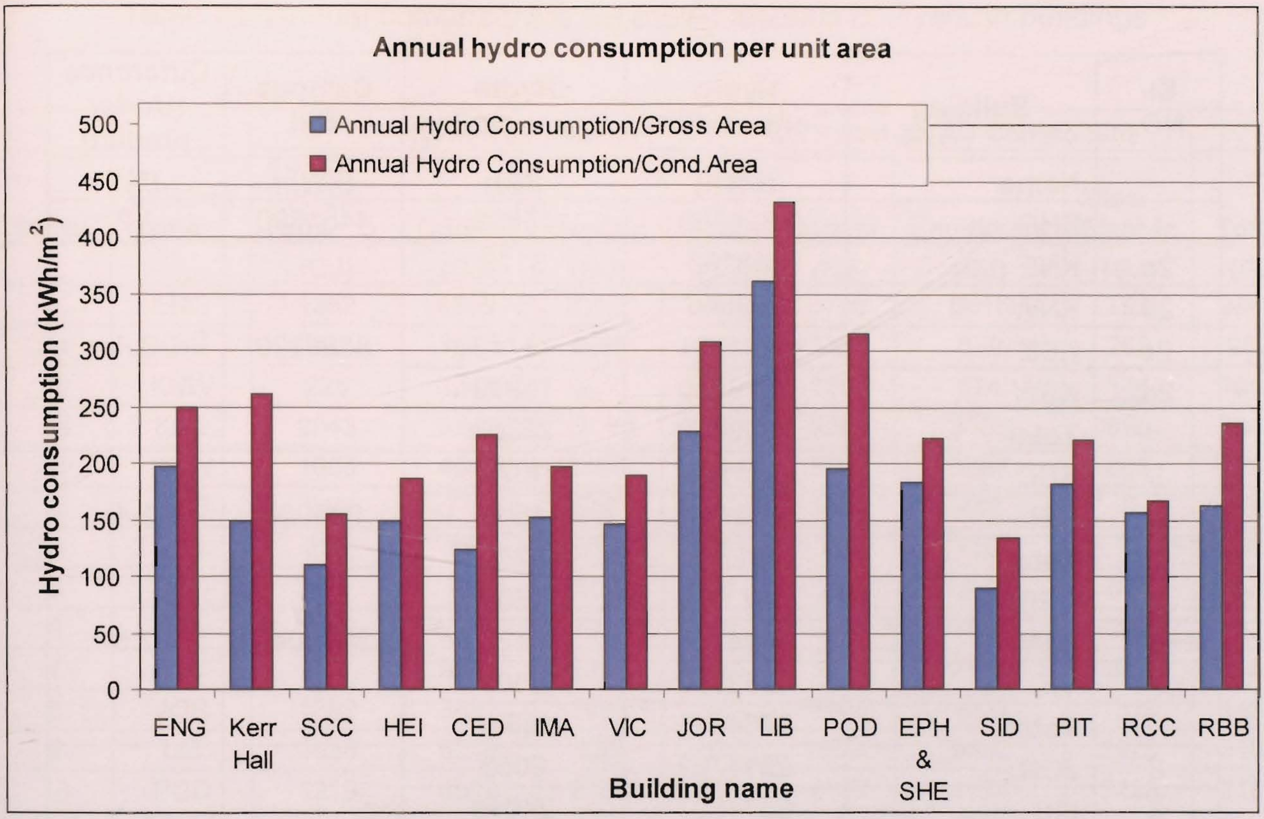

Figure 37: Annual hydro demand each building per unit area

Hydro consumption for the central chiller plant was calculated based on the conceptual design of chiller model to equivalent of maximum cooling plant load of 10903kW. Hydro bill for Jorgenson Hall, Library Building and Podium Hall is one single bill and it includes the hydro consumption of chiller plant located in the Library building. Table 40 shows the simulated hydro consumption comparison for 15 buildings with the Campus Planning bill for 2006 (January to December) and for RBB hydro consumption bill for 2007 (January to December).

Table 40: Hydro bill comparison

Sl. NO.	Building	Hydro Consumption	Hydro Consumption	Campus Bill	Difference (Under predict)
	Name	(kWh)	(GJ)	(kWh)	(%)
1	ENG	4396600	15828	4451690	1.2
2a	KNE	883183	3179	8590220	8.4
2b	KNW	699046	2517		
2c	KSE	3261691	11742		
2d	KSW	3019530	10870		
	Total	**7863450**	**28308**		
3	SCC	465118	1674	924080	1.4
4	HEI	446131	1606		
	Total	**911249**	**3280**		
5	CED	517,658	1864	3893040	2.5
6	IMA	1424168	5127		
7	VIC	1852390	6669		
	Total	**3794216**	**13660**		
8	JOR	2514762	9053	17960970	7.7
9	LIB	6671607	24018		
10	POD	4232528	15237		
	Chiller Plant	3151780	11346		
	Total	**16570677**	**59654**		
11 & 12	EPH & SHE	3844099	13839	3974560	3.3
13	SID	390869	1407	400000	2.3
14	PIT	2954169	10635	5360462	6.5
15	RCC	1811528	7403		
	Chiller	244687			
	Total	**5010384**	**18038**		
16	RBB	3945188	14203	4001970	1.4
	Total	**46,726,697**	**168,216**	**49,556,992**	**5.7**

Building energy consumption in various purposes like central chiller plant, air system fan, heating load, lighting load, plug load and miscellaneous uses of electricity were obtained from the Carrier HAP simulation program for 86% of total area of the Ryerson campus. Table 41 presents annual component energy consumption related to the building energy systems.

Table 41: Annual component energy consumption of Ryerson buildings

		HVAC Component				Non-HVAC Component			
Sl. No.	Building Name	Air System Fans	Cooling	Heating	Pumps	Lights	Equipment	Misc. Electric	Total
		(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)	(GJ)
1	ENG	1352	6806	6250	297	6768	6618	793	28884
2a	KNE	302	1555	4956	91	1727	859	200	9690
2b	KNW	225	1342	6250	71	1502	574	144	10108
2c	KSE	2043	5340	17088	288	5385	3136	890	34170
2d	KSW	1005	4540	7165	284	5142	3837	603	22576
3	SCC	240	715	686	10	1013	412	0	3076
4	HEI	255	574	577	7	791	552	0	2756
5	CED	254	738	662	31	722	353	504	3264
6	IMA	1052	2146	2999	30	2265	1457	323	10272
7	VIC	327	2812	2391	220	3612	2179	331	11872
8	JOR	1692	3882	1453	173	3938	1932	1319	14389
9	LIB	1588	6219	838	125	10000	9332	2973	31075
10	POD	1219	4529	2107	84	6737	4774	2423	21873
11 & 12	EPH & SHE	1447	5333	1972	147	7409	4220	616	21144
13	SID	206	583	343	7	854	243	97	2333
14	PIT	181	524	528	118	4583	4665	1089	11688
15	RCC	713	2846	1156	97	3082	2629	0	10523
16	RBB	1519	6642	4707	150	7454	5081	0	25553
Total :		**15,620**	**57,126**	**62,128**	**2,230**	**72,984**	**52,853**	**12,305**	**275,246**

Energy audit and simulation was done for the 16 Ryerson buildings using Carrier HAP software. After the simulation program running successfully, hourly analysis was done for chilled water demand, steam energy demand for heating and cooling (absorption chiller) and also hydro consumption for all heating, cooling and Non-HVAC demand. Table 42 and Figure 38 present annual total energy demand and demand for per square meter for the 86% of total area of Ryerson campus.

Table 42: Annual total energy demand per gross unit area

Sl. NO.	Building Name	Hydro/m² (kWh/m²)	Heating/m² (kWh/m²)	Cooling/m² (kWh/m²)	TEC/m² (kWh/m²)	TEC/m² (GJ/m²)
1	ENG	197	78	85	359	1.29
2	KNE,KNW,KSE,KSW	150	188	68	389	1.40
3	SCC	111	46	48	204	0.74
4	HEI	149	54	53	256	0.92
5	CED	124	44	49	217	0.78
6	IMA	152	89	64	305	1.10
7	VIC	146	52	61	260	0.93
8	JOR	229	37	98	365	1.31
9	LIB	361	13	93	467	1.68
10	POD	195	27	58	280	1.01
11 & 12	EPH & SHE	183	26	70	279	1.01
13	SID	89	22	37	148	0.53
14	PIT	182	38	50	270	0.97
15	RCC	157	25	63	245	0.89
16	RBB	162	54	76	291	1.05
	Total	181	70	77	328	1.18

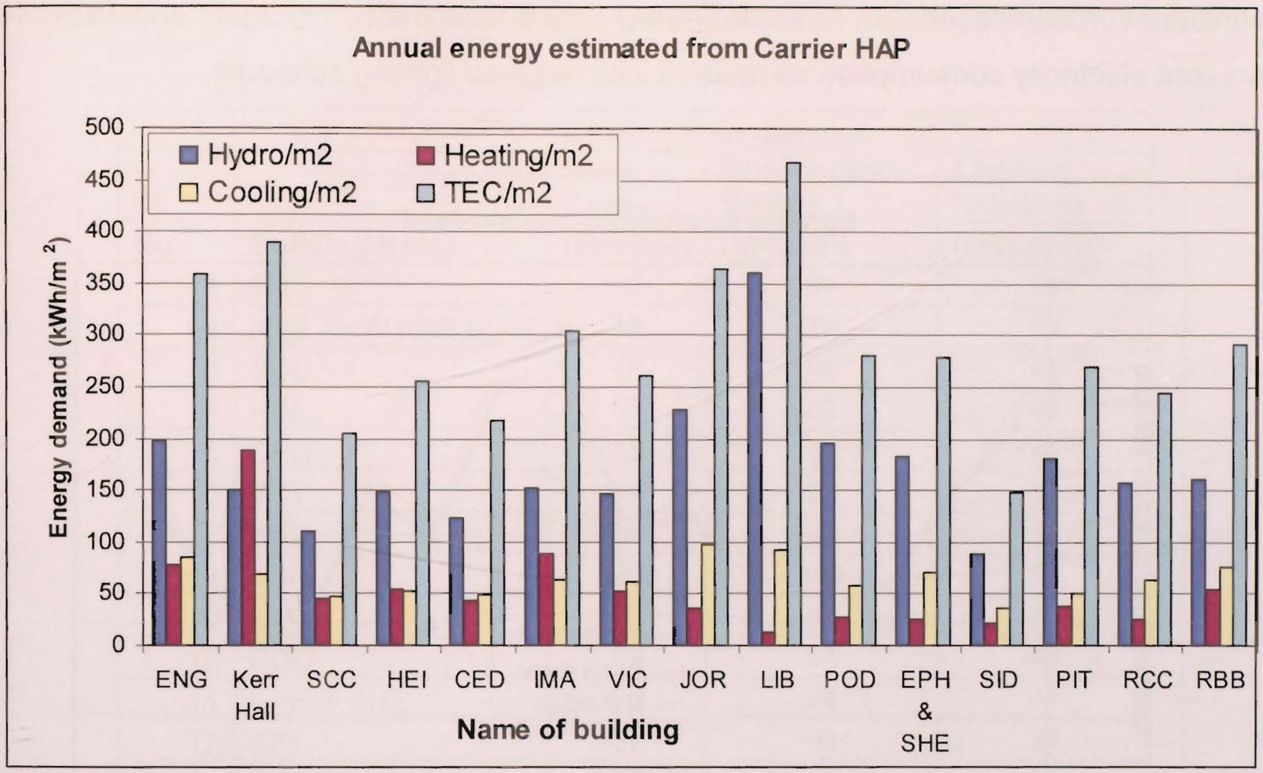

Figure 38: Annual total energy demand per unit area of Ryerson campus

6.1.6. Sensitivity analysis

From the energy audit and simulation it is clear that major part of energy consumption in a building is for lighting, equipments and HVAC systems. Energy can be saved from HVAC system by reducing HVAC system operation when building or space is unoccupied. It can be done by rescheduling for the HVAC operating hours, eliminating HVAC usages in vestibules and unoccupied space, adjusting areas that are too hot or too cold, reducing unnecessary heating or cooling, implementing heat recovery system. Also changes of lighting schedule have significant effect on total energy cost. Figure 39 presents the comparison of cooling load consumption (kWh/m^2) with base case economizer setting from integrated enthalpy to integrated dry bulb control and base case lighting schedule reduction by 20%. This comparison shows that economizer control change to the integrated dry bulb control have significant effect on cooling load. In this case cooling load consumption increased from the base case result. Cooling load also depends on the lighting schedule. If the lighting energy consumption increases, cooling energy will be increased. Figure 39 and Table 43 present cooling consumption decreased with reduced lighting schedule and also Figure 40 and Table 44 present electricity consumption decreased with reduced lighting schedule.

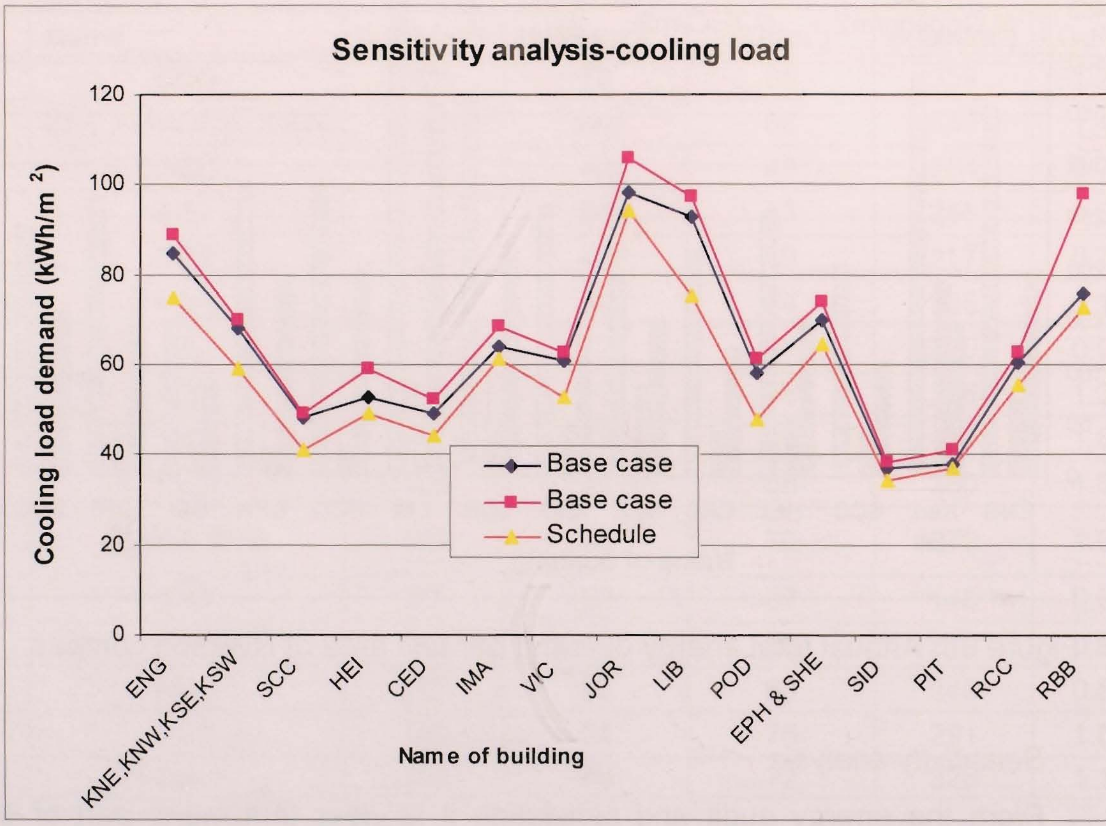

Figure 39: Effects of economizer setting and reduced lighting schedule on cooling load

Table 43: Comparison base case consumption with economizer setting and reduced lighting schedule

		Cooling load demand		
Sl.		Base Case	Economizer Setting	Lighting Schedule
No.	Building Name	(kWh/m^2)	(kWh/m^2)	(kWh/m^2)
1	ENG	85	89	75
2	KNE,KNW,KSE,KSW	68	70	59
3	SCC	48	49	41
4	HEI	53	59	49
5	CED	49	52	44
6	IMA	64	68	61
7	VIC	61	63	53
8	JOR	98	106	94
9	LIB	93	97	75
10	POD	58	61	48
11	EPH & SHE	70	74	64
12	SID	37	39	34
13	PIT	38	41	37
14	RCC	60	63	56
15	RBB	76	98	73
	Savings (%)		**-7.39**	**9.89**

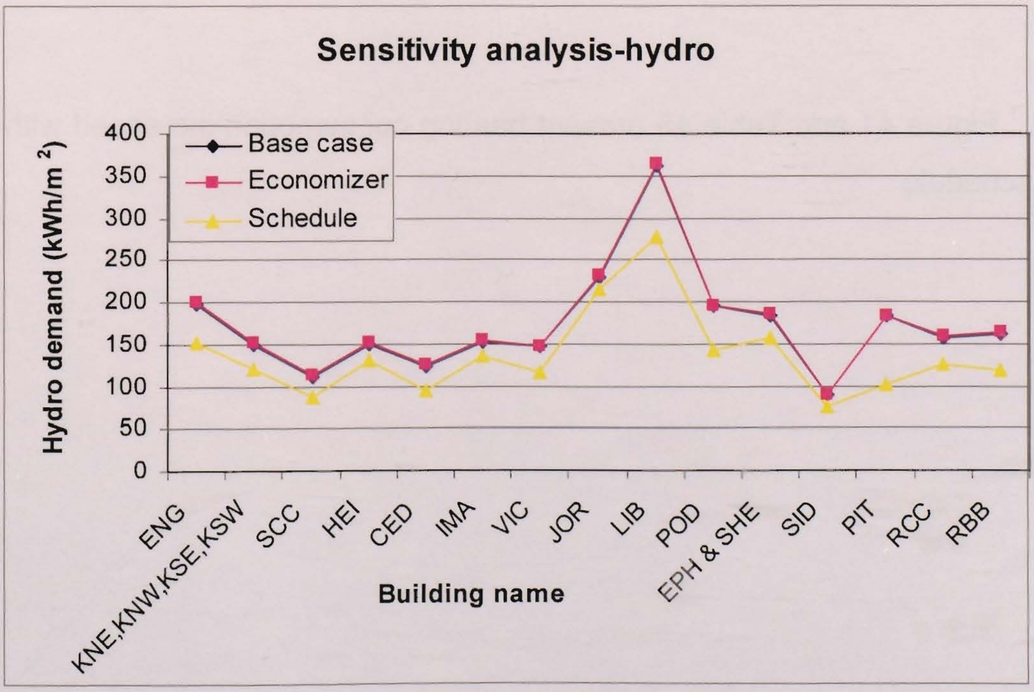

Figure 40: Effects of economizer setting and reduced lighting schedule on hydro

Table 44: Comparison base case consumption with economizer setting and reduced lighting schedule

		Hydro load Consumption		
Sl.		Base Case	Economizer Setting	Lighting Schedule
No.	Building Name	(kWh/m^2)	(kWh/m^2)	(kWh/m^2)
1	ENG	197	199	152
2	KNE,KNW,KSE,KSW	150	153	121
3	SCC	111	113	86
4	HEI	149	151	129
5	CED	124	125	93
6	IMA	152	155	135
7	VIC	146	146	115
8	JOR	229	232	215
9	LIB	361	363	277
10	POD	195	196	142
11	EPH & SHE	183	185	157
12	SID	89	90	74
13	PIT	182	184	101
14	RCC	157	158	124
15	RBB	162	164	117
	Savings (%)		**-1.04**	**21.24**

Figure 41 and Table 45 present heating consumption increased with reduced lighting schedule

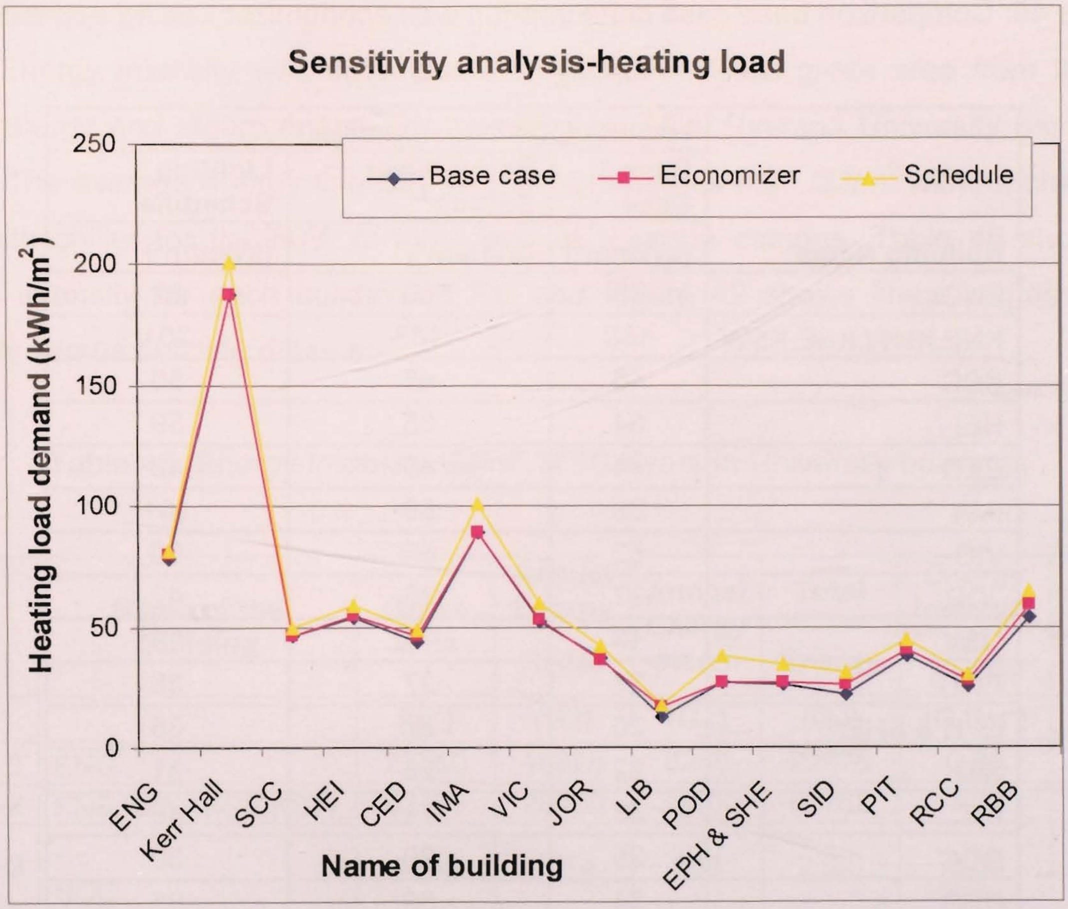

Figure 41: Effects of economizer setting and reduced lighting schedule on heating load

Table 45: Comparison base case consumption with economizer setting and reduced lighting schedule

	Heating load Consumption		
	Base Case	**Economizer Setting**	**Lighting Schedule**
Building Name	**(kWh/m^2)**	**(kWh/m^2)**	**(kWh/m^2)**
ENG	78	80	82
KNE,KNW,KSE,KSW	188	188	201
SCC	46	46	50
HEI	54	55	59
CED	44	46	49
IMA	89	89	101
VIC	52	53	60
JOR	37	36	42
LIB	13	17	18
POD	27	27	38
EPH & SHE	26	27	35
SID	22	26	31
PIT	38	71	45
RCC	25	28	30
RBB	54	59	65
Savings (%)		**-7**	**-14**

6.1.7. Energy Intensity

Energy intensity was determined based on the total gross area from the total hydro energy and steam energy consumption in GJ of Ryerson University per square meter. The average energy intensity was determined as 0.91 GJ/m^2 without chiller and 1.04 with chiller for the 86% of total area of Ryerson campus. Table 46 shows the energy intensity for each building of RU and Figure 42 shows linear regression for intensity versus building gross area.

Table 46: Energy Intensity GJ/m^2 of 16 Ryerson University buildings

Sl. No.	Name of the Building	Gross Area	Annual Energy Hydro	Annual Energy steam	Total Energy	Energy Intensity W/O Chiller	Energy Intensity With Chiller
		(m^2)	(GJ)	(GJ)	(GJ)	(GJ/m^2)	(GJ/m^2)
1	ENG	22350	15828	6250	22078	0.99	1.16
2	KNE,KNW,KSE,KSW	52409	28308	35460	63768	1.22	1.39
3	SCC	4180	1674	686	2360	0.56	0.74
4	HEI	2985	1606	577	2183	0.73	0.90
5	CED	4180	1864	662	2526	0.60	0.78
6	IMA	9345	5127	2999	8126	0.87	1.04
7	VIC	12708	6669	2391	9060	0.71	0.89
8	JOR	10964	9053	1453	10506	0.96	1.13
9	LIB	18487	24018	838	24856	1.34	1.52
10	POD	21730	15237	2107	17344	0.8	0.97
11 & 12	EPH & SHE	21019	13839	1972	15811	0.75	0.92
13	SID	4373	1407	343	1750	0.40	0.57
14	PIT	17866	10635	528	11163	0.73	0.75
15	RCC	13100	6522	1156	7678	0.59	0.65
16	RBB	24378	14203	4707	18910	0.78	0.78
	Total	**240,074**	**155,990**	**62,129**	**218,119**	**0.91**	**1.04**
	LIB Chiller Plant				32052	0.17	
	RCC Chiller				881	0.06	

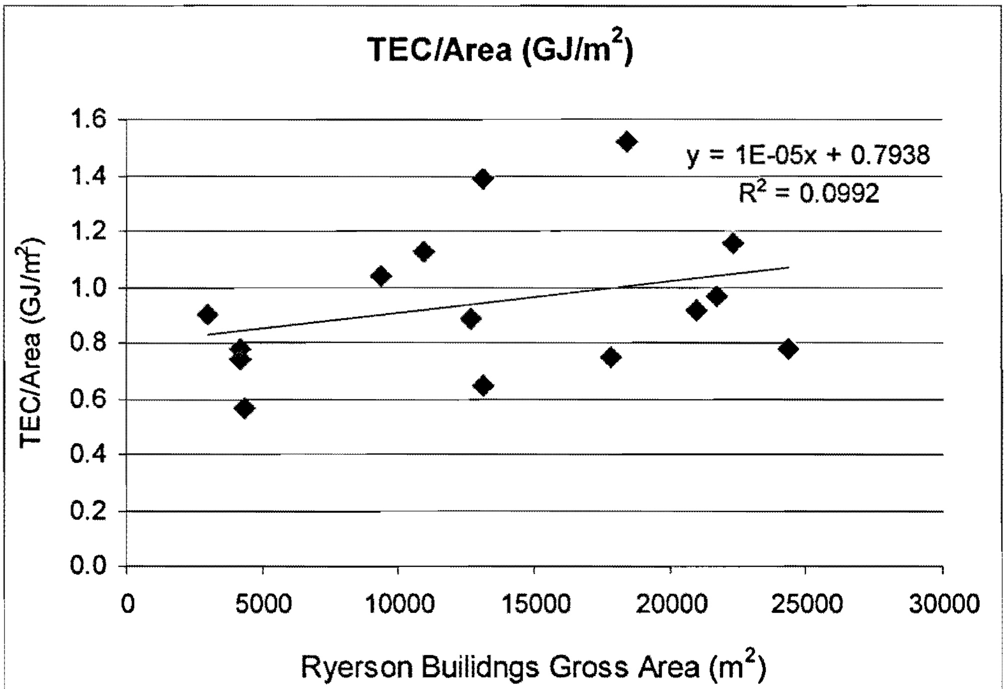

Figure 42: Intensity versus building gross area.

6.2. PRISM analysis

The objective of this section was to assess the validity and usefulness of available energy consumption data in Ryerson University. This analysis includes steam and hydro consumptions for heating and cooling demands. The PRISM analysis conducted was based on the model of Heating-Cooling (HC).

6.2.1 Energy Bill

Energy bill for electricity and steam consumptions are collected from the Campus Planning department for 44 months (May' 2005-December' 2008). This project covered 90.3% of total steam consumption based on the area analyzed. Energy bill information is listed in Appendix C.

6.2.2. Weather Data

Daily temperature data were collected from the National Climate Data and Information Archive website and Carrier HAP simulation weather data. Data was selected for nearby weather station Toronto Pearson International Airport, Ontario, Canada. The list of data was prepared in Excel file and attached in Appendix D.

6.2.3. Output parameters and energy consumptions

The output parameters from the PRISM were obtained in terms of building's reference (base) temperature based on 18°C for heating and cooling, heating degree days (HDD), cooling degree days (CDD), reliability statistic (R^2), cooling/heating slope, annual energy use, base-level versus heating consumption and base-level versus cooling consumption.

Table 47 shows the degree days information for 44 months billing period with reference temperature of 18°C.

Table 47: Sum of heating degree days over billing periods for a reference temperature of 18°C

Billing Period		Sum of Heating Degree Days (°C)	Sum of Cooling Degree Days (°C)	Sum of Degree Days (°C)
Month	**Year**			
May	2005	190.0	0.8	190.7
June	2005	9.0	145.8	154.8
July	2005	0.0	187.9	187.9
August	2005	0.3	140.1	140.3
September	2005	22.9	51.7	74.5
October	2005	221.1	7.6	228.6
November	2005	388.6	0.0	388.6
December	2005	664.9	0.0	664.9
January	2006	551.8	0.0	551.8
February	2006	604.0	0.0	604.0
March	2006	516.5	0.0	516.5
April	2006	294.0	0.0	294.0
May	2006	137.6	25.9	163.5
June	2006	19.7	73.1	92.7
July	2006	0.0	166.7	166.7
August	2006	4.3	100.9	105.2
September	2006	81.5	12.7	94.2
October	2006	289.2	1.1	290.3
November	2006	383.0	0.0	383.0
December	2006	501.1	0.0	501.1

Table 47: Sum of heating degree days over billing periods for a reference temperature of 18°C (Continue)

Billing Period		Sum of Heating Degree Days (°C)	Sum of Cooling Degree Days (°C)	Sum of Degree Days (°C)
Month	Year			
January	2007	647.3	0.0	647.3
February	2007	739.4	0.0	739.4
March	2007	546.7	0.0	546.7
April	2007	356.9	0.0	356.9
May	2007	136.9	22.3	159.2
June	2007	16.7	98.7	115.4
July	2007	3.4	105.3	108.7
August	2007	5.3	140.5	145.7
September	2007	37.2	47.3	84.5
October	2007	138.1	19.4	157.5
November	2007	463	0.0	463.0
December	2007	630.4	0.0	630.4
January	2008	623.4	0.0	623.4
February	2008	674.3	0.0	674.3
March	2008	610.2	0.0	610.2
April	2008	254.4	0.0	254.4
May	2008	194.2	2.5	196.7
June	2008	23.0	71.4	94.4
July	2008	1.1	110.3	111.4
August	2008	12.9	63.4	76.3
September	2008	59.6	26.4	85.9
October	2008	279.4	0.0	279.4
November	2008	452.2	0.0	452.2
December	2008	654.4	0.0	654.4

The method used in this analysis is called PRInceton Scorekeeping Method (PRISM) emphasized on the Heating-Cooling (HC) model. The method essentially performs a linear regression analysis between the outdoor temperature parameter and the billing energy consumption.

The PRISM test was conducted for heating-cooling (HC) model for weather data from i) Carrier HAP weather simulation, ii) Toronto weather data iii) four years energy consumption data, iv) individual year from 2005 to 2008 data, v) every two years data and vi) one year overlapping data for both steam consumption and hydro consumption. The result of these analyses are listed in Appendix D. Based on these analyses for steam energy demand the best linear regression analysis of HC model was selected. This model was used 2005-2008 Toronto weather data and 2005-2008 steam consumption data. PRISM model was selected for hydro demand based on the 2006 weather data and 2006 hydro consumption. Once the parameters (a, β_h, β_c, τ_h, τ_c) were selected then Normalized Annual Consumption (NAC) could be calculated using Equation (1). The parameters of those selected models are listed in Table 48 to Table 50.

The main equation used for the calculation of Normalized Annual Consumption (NAC):

$$NAC = \underbrace{365 * a}_{BaseLevel} + \underbrace{d_h * \beta_h * H_o(\tau_h)}_{HeatingPart} + \underbrace{d_c * \beta_c * C_o(\tau_c)}_{CoolingPart} \quad \ldots \quad \ldots \quad \ldots \quad \ldots(1)$$

Where,

a = base-level consumption (kWh/day)

β_h = heating slope (kWh/°C-day)

β_c = cooling slope (kWh/°C-day)

τ_h = heating reference temperature (°C-day)

τ_c = cooling reference temperature (°C-day)

d_h = 1 for the HO analysis and d_c = 0

d_c = 1 for the CO analysis and d_h = 0

d_h = 1 and d_c = 1 for the HC analysis

6.2.4. Model selection

PRISM model was selected for steam energy demand and hydro demand from the analysis of PRISM software (PRISM Advanced Version 1.0) output parameters. The first step for this software requires to creation of the temperature file and meter file. After successfully running the temperature file (degree days calculation-DDCalc) for the required meter file will be needed to obtained the PRISM output. The output parameters include heating reference temperature, cooling reference temperature, heating slope, cooling slope, base level consumption, reliability statistics (R^2) and the coefficient of variation of NAC (CV(NAC)). Figure 43 shows temperature file output from PRISM software.

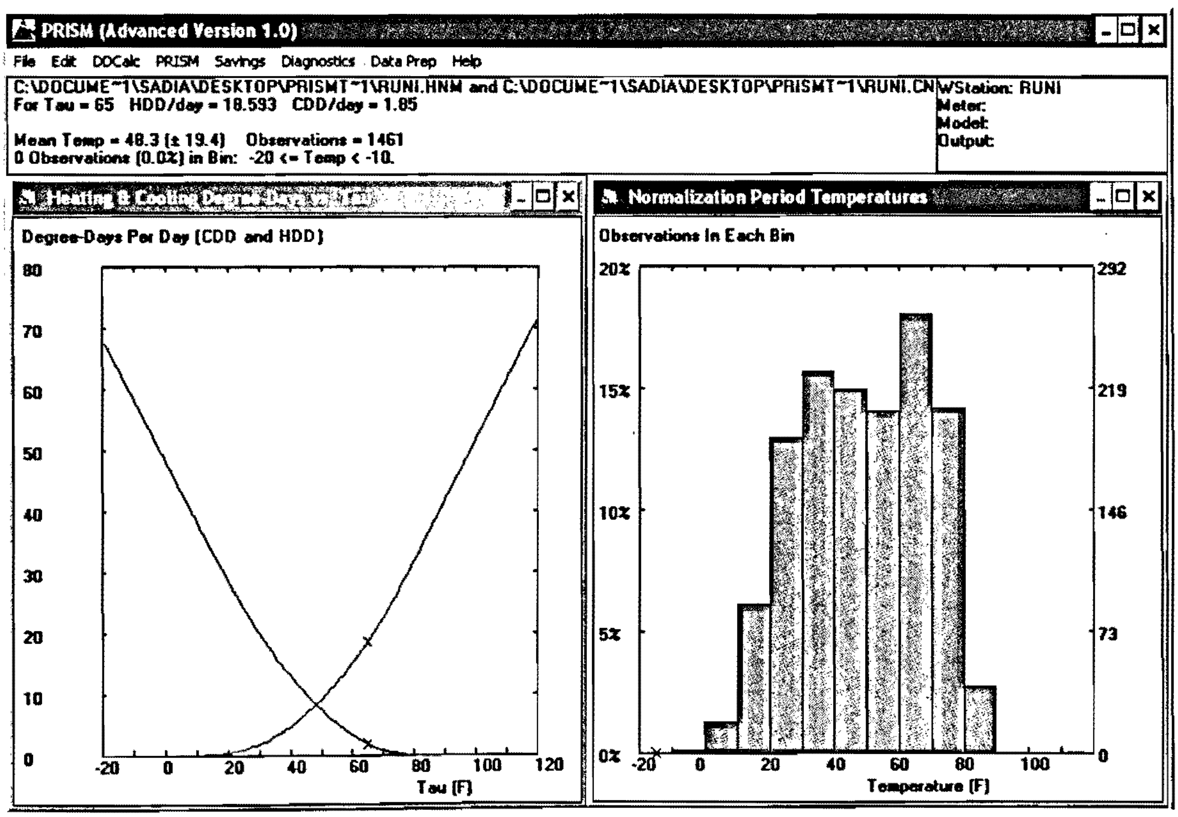

Figure 43: Degree days versus average temperature (T_{av})

Heating-cooling model (HC) PRISM analyses were run for combined 15 buildings and individual Rogers Business Building (RBB) for an initial assessment of the quality of the data.

Two indicators of the goodness of fit from PRISM are CV(NAC), the coefficient of variation, which ideally is very small, and the model's R^2-statistics, whose closeness to 1.0 (its maximum value) measures the extent to which consumption correlates linearly with degree-days (computed to the "best" reference temperature determined by PRISM) (Fels & Reynolds, 1992).

Figure 44 to 47 present PRISM output for energy consumption versus heating degree-days and consumption versus cooling degree-days for the model.

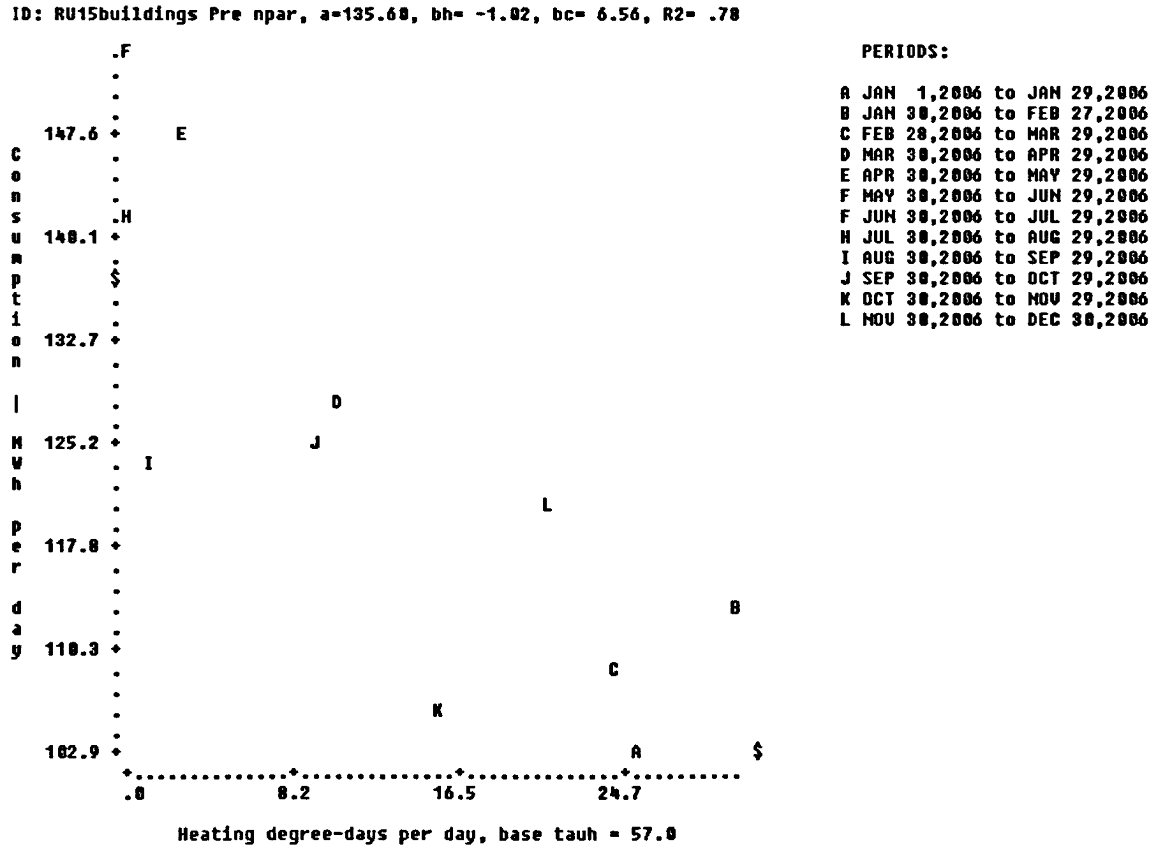

Figure 44: Hydro consumption versus heating degree-days (HC Model) for 15 buildings

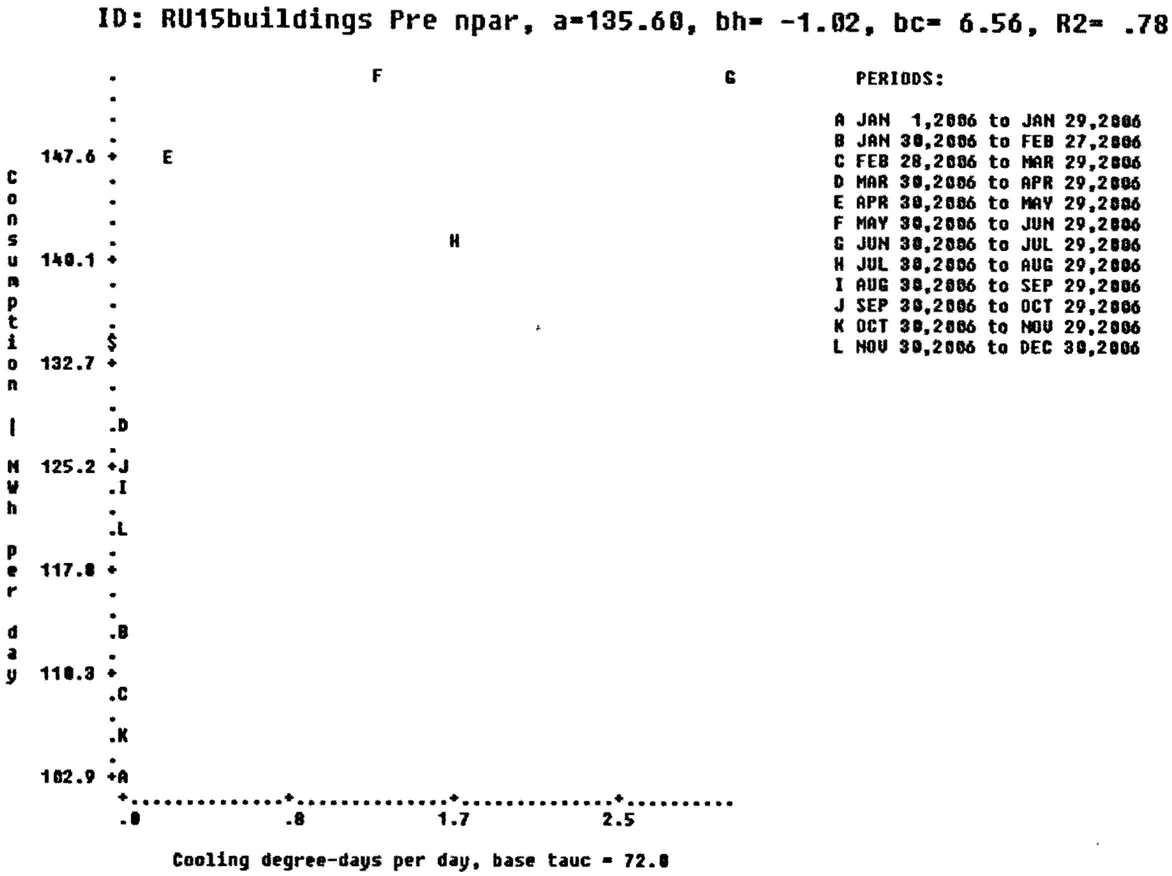

Figure 45: Hydro consumption versus cooling degree-days (HC Model) for 15 buildings

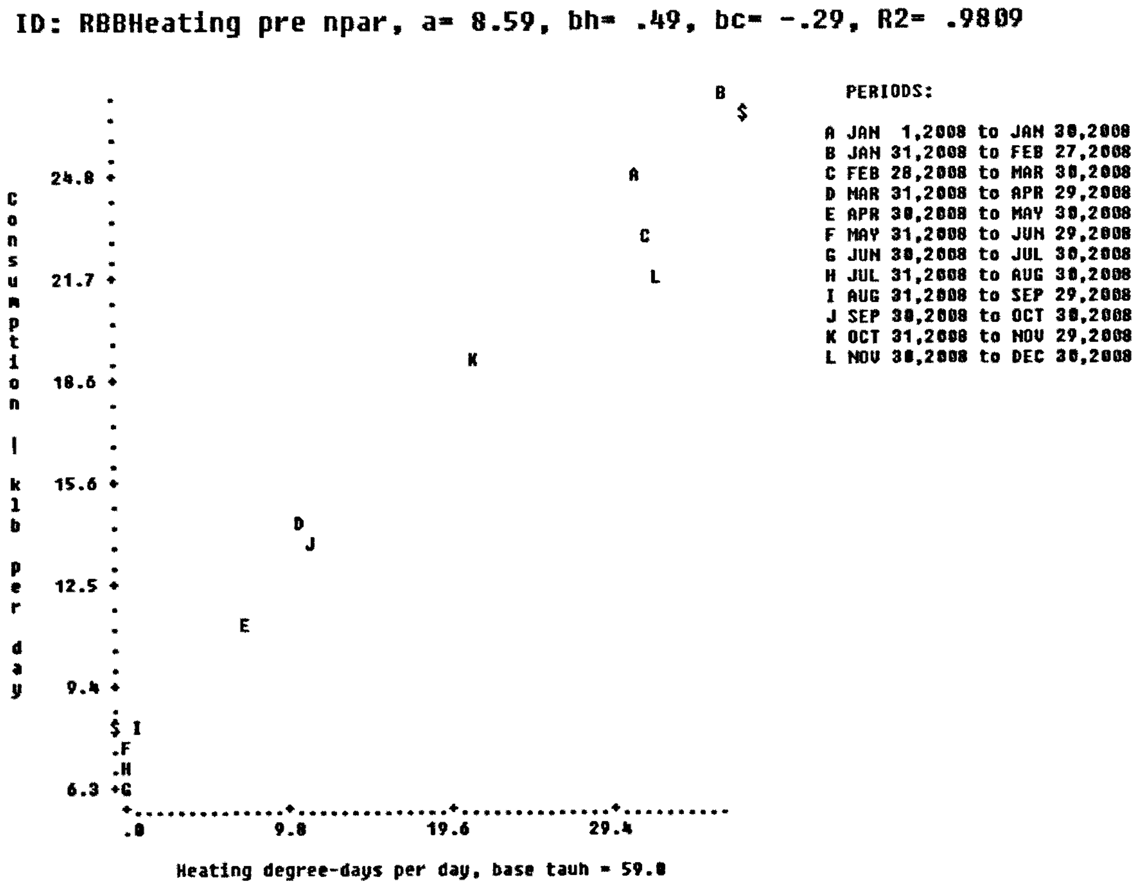

Figure 46: Steam consumption versus heating degree-days (HC Model) for RBB

ID: RBBHeating pre npar, a= 8.59, bh= .49, bc= -.29, R2= .9809

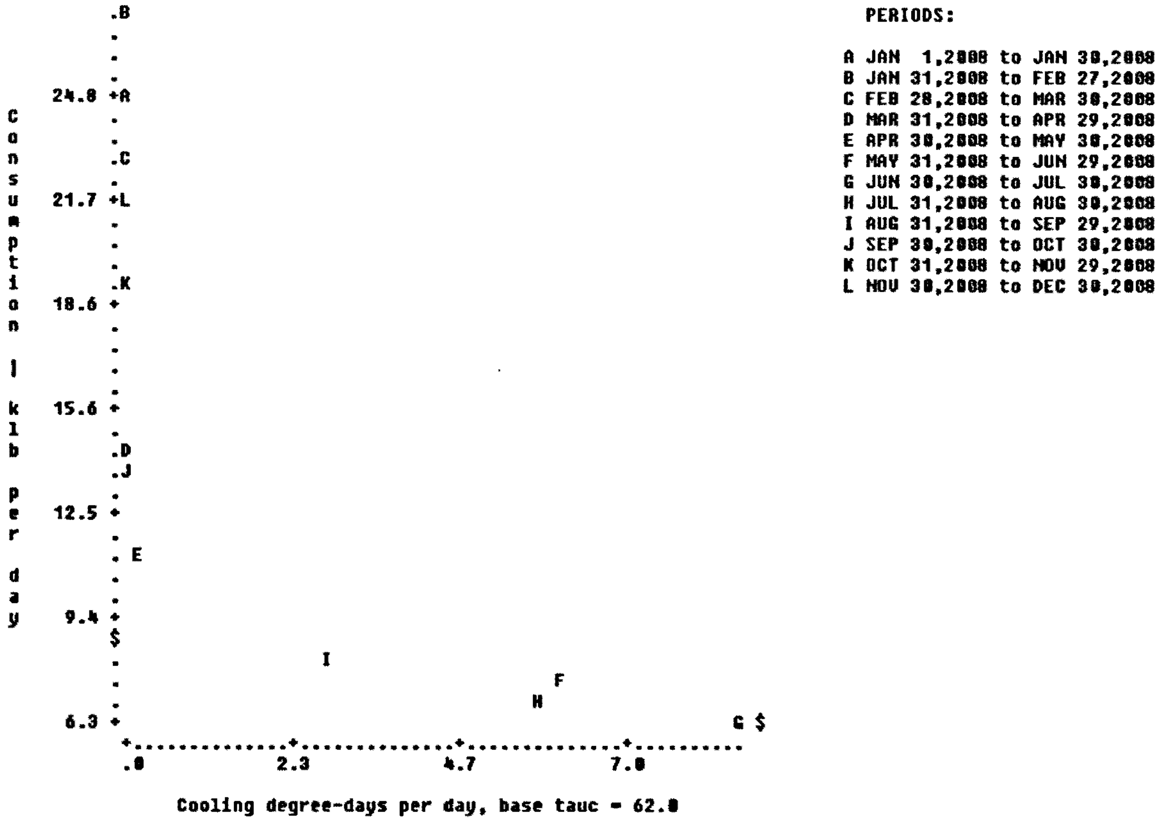

Figure 47: Steam consumption versus cooling degree-days (HC Model) for RBB

Based on the reliability statistics (R^2) and base level consumption PRISM model were selected for steam consumption and hydro consumption (Appendix D). Table 48 shows PRISM model for steam energy demand (temperature and meter file of 2005-2008) and Table 49 shows PRISM model for hydro demand (temperature and meter file of 2006) for combined 15 Ryerson buildings. Table 50 presents steam PRISM model for RBB for the meter and temperature file of 2008. Hydro PRISM model did not select for RBB due to insufficient data and very low value of R^2 (R^2=0.2843 for HO model, 0.3728 for CO model, and 0.4 for HC model)

Table 48: PRISM (HC) model parameters for steam energy demand

Model (HC)	Unit	PRISM Model	Original Consumption
Base Level (a)	(lb X 1000/Day)	24.90	
Heating Ref. Temp (τ_h)	(^OF)	68.00	
Cooling Ref. Temp (τ_c)	(^OF)	68.00	
Heating Slope (β_h)		10.60	
Cooling Slope (β_c)		6.30	
HDD	(HDD/Day)	20.90	
CDD	(CDD/Day)	1.10	
CV (NAC)	(%)	3.50	
R^2		0.89	
Normalized Annual Consumption (NAC)	(lb X 1000/Year)	92,480	95,656
Difference (%)	Under predict		3.3

Table 49: PRISM (HC) model parameters for hydro demand

Model (HC)	Unit	HC	Original Consumption
Base Level (a)	(MWh/Day)	135.60	
Heating Ref. Temp (τ_h)	(^OF)	57.00	
Cooling Ref. Temp (τ_c)	(^OF)	72.00	
Heating Slope (β_h)		-1.02	
Cooling Slope (β_c)		6.56	
HDD	(HDD/Day)	11.57	
CDD	(CDD/Day)	0.53	
CV (NAC)	(%)	2.30	
R^2		0.78	
Normalized Annual Consumption (NAC)	(MWh/Year)	46,455	45,555
Difference (%)	Over predict		-9.2

Table 50: PRISM (HC) model parameters for steam demand (RBB)

Model (HC)	Unit	PRISM Model	Original Consumption
Base Level (a)	(lb X 1000/Day)	8.59	
Heating Ref. Temp (τ_h)	(^{0}F)	59.00	
Cooling Ref. Temp (τ_c)	(^{0}F)	62.00	
Heating Slope (β_h)		0.49	
Cooling Slope (β_c)		-0.29	
HDD	(HDD/Day)	14.99	
CDD	(CDD/Day)	1.96	
CV (NAC)	(%)	2.30	
R^2		0.98	
Normalized Annual Consumption (NAC)	(lb X 1000/Year)	5,609	5,567
Difference (%)	Under predict		0.7

6.2.5. Comparison of PRISM model (HC) for different geographic locations

Energy consumption in high-rise buildings depends on age of the building, number of stories, floor area, geographical location, types of energy used for heating, cooling, lighting, domestic water heating, number of occupancy etc. All of these factors were considered for energy audit and base case simulation for most of the buildings at Ryerson University. Energy demand also depends on the outdoor air temperature to maintain comfort air zone for the buildings. If the outdoor air temperature increases in the cooling season more hydro and steam energy will be required. On the other hand if outside air temperature decreases in the heating season more steam energy will be required to maintain comfort air temperature inside the buildings. Heating degree-days and cooling degree-days are the main parameters for determining energy demand for heating and cooling. These two parameters depend on the base reference temperature and outdoor air temperature and they also differ from geographical locations. PRISM model could predict energy demand for heating and cooling in different geographic locations for the same buildings. In this case the total area of Ryerson University is assumed constant, all other energy used for lighting load; plug load and miscellaneous electricity are also constant.

The expected energy consumption for the Ryerson University in four different geographic locations were estimated and compared. The geographic coordinates of the selected locations were found using GeoCoding process from GeoCoder.ca that assigns a latitude-longitude coordinates to a valid address. The weather normals for different locations were collected from the National Climate Data and Information Archive website (http://climate.weatheroffice.gc.ca/climateData/canada_e.html) is listed in Table 51 and Figure 48.

Table 51: Canadian Climate Normal (1971-2000) (Environment Canada, 2010)

	Average Temp (°C)			
Month/City	Edmonton	Vancouver	Fredericton	Toronto
January	-13.5	3.3	-9.8	-6.3
February	-10.5	4.8	-8.2	-5.4
March	-4.5	6.6	-2.4	-0.4
April	4.3	9.2	4.3	6.3
May	10.4	12.5	11.1	12.9
June	14.1	15.2	16.2	17.8
July	15.9	17.5	19.3	20.8
August	15.1	17.6	18.4	19.9
September	10.1	14.6	13.1	15.3
October	4.3	10.1	7.0	8.9
November	-5.7	6.0	1.1	3.2
December	-11.3	3.5	-6.3	-2.9

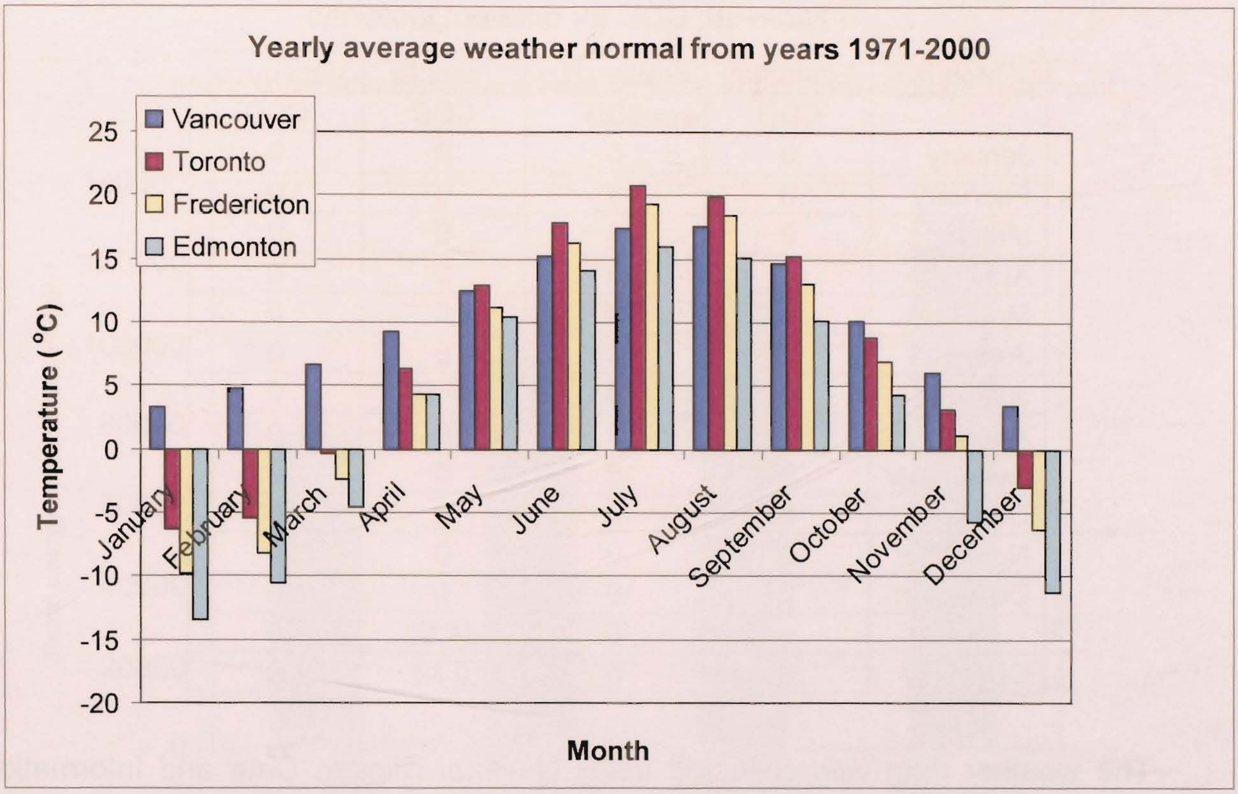

Figure 48: Yearly average weather normal from years 1971-2000

The heating degree days (HDD) and cooling degree days (CDD) at the base temperature of 68 °F (using temperature data: Canadian Climate Normal, 1971-2000) for the different locations are listed in Table 52 and Table 53.

Table 52: HDD for different locations

City	**Edmonton**	**Fredericton**	**Toronto**	**Vancouver**
Month	**HDD**	**HDD**	**HDD**	**HDD**
January	1869	1663	1468	932
February	1537	1421	1280	766
March	1367	1250	1138	748
April	848	848	740	583
May	536	497	396	419
June	319	205	119	259
July	229	39	0	140
August	273	89	6	134
September	535	373	254	292
October	876	725	619	552
November	1388	1021	907	756
December	1747	1468	1278	921
Total HDD	**11524**	**9599**	**8205**	**6502**
HDD/Day	**31.57**	**26.30**	**22.48**	**17.81**

Table 53: CDD for different locations

Month	Edmonton	Fredericton	Toronto	Vancouver
	CDD	CDD	CDD	CDD
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	44.60	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	0
	0	0	44.60	0
CDD/Day	0	0	0.12	0

The weather data was collected using National Climate Data and Information Archive. Table 54, Table 56, Figure 49 and Figure 50 show energy demand in these locations using PRISM model HC.

Table 54: Steam energy demand in different locations

Model	**(HC)**	**Edmonton**	**Fredericton**	**(RU) Toronto**	**Vancouver**
Base Level (a)	(lb X 1000/Day)	24.9	24.9	24.9	24.9
Heating Ref. Temp (τ_h)	(^oF)	68.0	68.0	68.0	68.0
Cooling Ref. Temp (τ_c)	(^oF)	68.0	68.0	68.0	68.0
Heating Slope (β_h)		10.6	10.6	10.6	10.6
Cooling Slope (β_c)		6.3	6.3	6.3	6.3
HDD	(HDD/Day)	31.6	26.3	22.5	17.8
CDD	(CDD/Day)	0	0	0.12	0
DD	(HDD+CDD)	31.6	26.3	22.6	17.8
CV (NAC)	(%)	3.5	3.5	3.5	3.5
R^2		0.9	0.9	0.9	0.9
Normalized Annual Consumption (NAC)	(lb X 1000)/yr	131,349	110,843	96,417	77,957

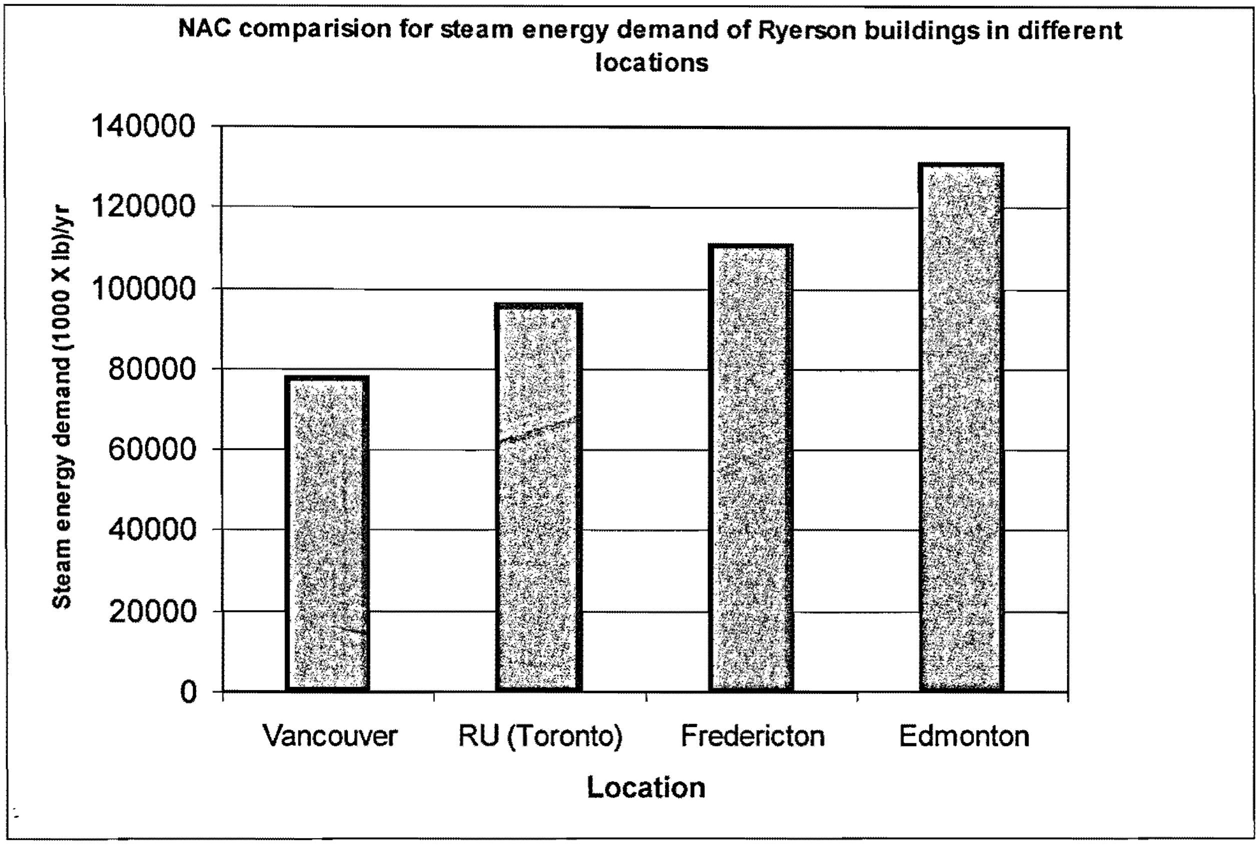

Figure 49: Steam energy demand in different locations

Heating reference temperature 57°F and cooling reference temperature 72°F were obtained from PRISM HC model for hydro demand. Table 55 shows HDD and CDD for heating and cooling reference temperature.

Table 55: HDD and CDD

		57°F	72°F
Location	NAC (MWh/yr)	HDD/Day	CDD/Day
Edmonton	41,642	21.09	0
Fredericton	43,105	17.16	0
Toronto	44,237	14.12	0
Vancouver	46,430	8.23	0

Table 56: Hydro demand in different locations

Model	(HC)	Edmonton	Fredericton	Toronto	Vancouver
Base Level (a)	(MWh/Day)	135.60	135.60	135.60	135.60
Heating Ref. Temp (τ_h)	(°F)	57.00	57.00	57.00	57.00
Cooling Ref. Temp (τ_c)	(°F)	72.00	72.00	72.00	72.00
Heating Slope (β_h)		-1.02	-1.02	-1.02	-1.02
Cooling Slope (β_c)		6.56	6.56	6.56	6.56
HDD	(HDD/Day)	21.09	17.16	14.12	8.23
CDD	(CDD/Day)	0.00	0.00	0.00	0.00
DD		21.09	17.16	14.12	8.23
CV (NAC)	(%)	2.30	2.30	2.30	2.30
R^2		0.78	0.78	0.78	0.78
Normalized Annual Consumption (NAC)	(MWh/yr)	41,642	43,105	44,237	46,430

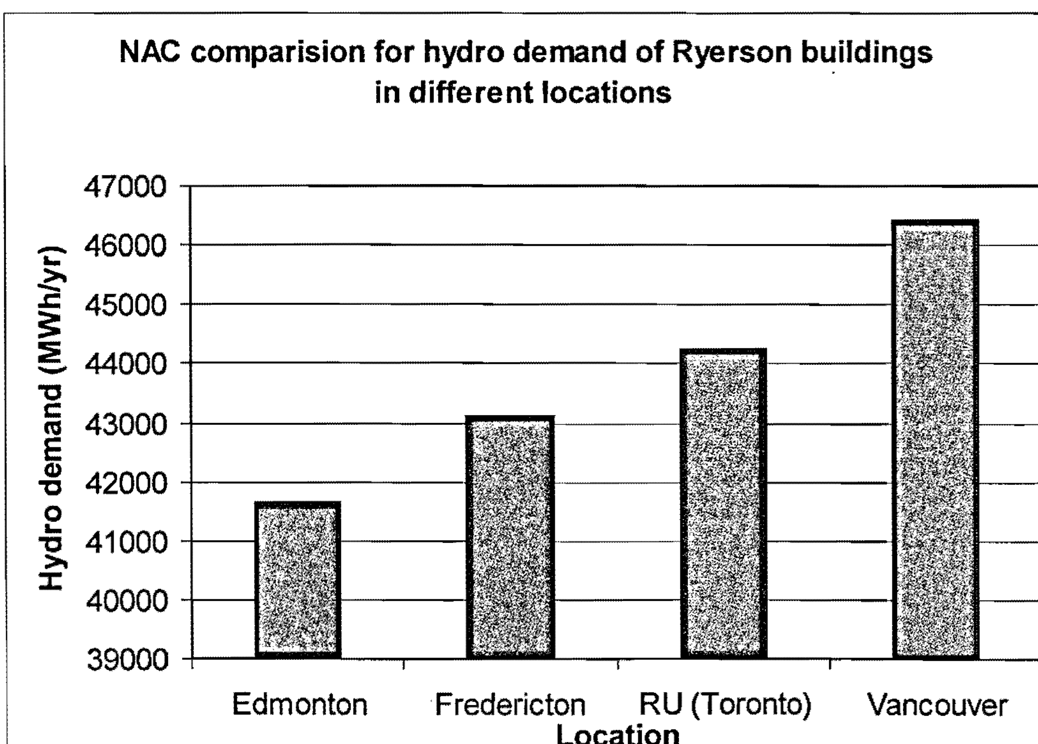

Figure 50: Hydro demand in different locations

From Table 54 and Table 56, it is clear that if the base level consumption is constant then energy demand will depends on the heating degree-days and cooling degree-days only. Figure 49 shows that steam energy demand is higher for Edmonton due to total degree days for the Edmonton location is higher than in other locations at 68°F reference temperature. Figure 50 shows that hydro demand is higher for Vancouver due to heating slope is negative and total degree days is lower than in other locations at reference temperature.

Table 57 and Table 58 show Carrier HAP average temperature and PRISM (HC) model result for 15 buildings and Table 59 shows PRISM model for RBB.

Table 57: Steam demand using HAP temperature

Model (HC)	Unit	PRISM Result	HAP Model	Original Consumption
Base Level (a)	(lb X 1000/Day)	24.90		
Heating Ref. Temp (τ_h)	(°F)	68.00		
Cooling Ref. Temp (τ_c)	(°F)	68.00		
Heating Slope (β_h)		10.60		
Cooling Slope (β_c)		6.30		
HDD	(HDD/Day)	23.63		
CDD	(CDD/Day)	0.54		
CV (NAC)	(%)	3.50		
R^2		0.898		
Normalized Annual Consumption (NAC)	(lb X 1000/yr)	101,755	92,320	95,656
Difference (%)		-6.4	3.5	

Table 58: Hydro demand using HAP temperature

Model (HC)	Unit	PRISM HC	HAP Model	Original Consumption
Base Level (a)	(MWh/Day)	135.60		
Heating Ref. Temp (τ_h)	(°F)	57.00		
Cooling Ref. Temp (τ_c)	(°F)	72.00		
Heating Slope (β_h)		-1.02		
Cooling Slope (β_c)		6.56		
HDD	(HDD/Day)	15.04		
CDD	(CDD/Day)	0.18		
CV (NAC)	(%)	2.30		
R^2		0.78		
NAC	(MWh/Year)	44,326	47,738	45,555
Difference (%)		2.7	-4.8	

Table 59: Steam demand using HAP temperature (RBB)

Model (HC)	Unit	PRISM Model	Original Consumption
Base Level (a)	(lb X 1000/Day)	8.59	
Heating Ref. Temp (τ_h)	(°F)	59.00	
Cooling Ref. Temp (τ_c)	(°F)	62.00	
Heating Slope (β_h)		0.49	
Cooling Slope (β_c)		-0.29	
HDD	(HDD/Day)	16.46	
CDD	(CDD/Day)	1.60	
CV (NAC)	(%)	2.30	
R^2		0.98	
Normalized Annual Consumption (NAC)	(lb X 1000/Year)	5,910	5,567
Difference (%)		Over predict (5.9)	

6.3. Energy consumption summary

Ryerson University annual total energy consumption summary for the 16 buildings are listed in Table 60.

Table 60: Energy comparison

Source	From base case HAP simulation	From PRISM model (HAP weather data)	From actual bill
Steam (lb) (15 buildings and RBB)	95,069,716	107,492,000	101,461,156
Difference (%)	Under predict (6.3)	Over predict (5.9)	
Hydro (kWh) (15 buildings)	42,781,509	44,335,000	45,555,022
Difference (%)	Under predict (6.1)	Under predict (2.7)	

According to the information of Ryerson University website, total number of staff is 1700, continue education students are 19039, undergraduate students are 22926, and graduate students are 1085. It is assumed that university staff works on a full time basis (8 hours/day, 5 days a week), undergraduate students have class 4.5 hours/day (5 days a week), graduate and continue education students have class 3 hours/week. If the academic staff will be considered full time basis, then annually total number of people can be counted as 16105. If the undergraduate student will be considered full time basis then annually total number of student can be counted as 25609.Table 61 shows total energy uses at Ryerson University for the selected audit area.

Table 61: Annual total energy uses

Total Energy Consumption (GJ)	251,052	
Total Energy Consumption (GJ/m^2)	1.04	
Energy consumption (GJ/person) or (GJ/student)	15.59 (Staff & Student)	9.80 (Student)
Number of person /m^2	14.91	
Energy consumption (GJ/(person/ m^2))	16,838	

Figure 51 and Table 62 shows energy intensity (GJ/student) in different locations in Canada (NRCan, 2005).

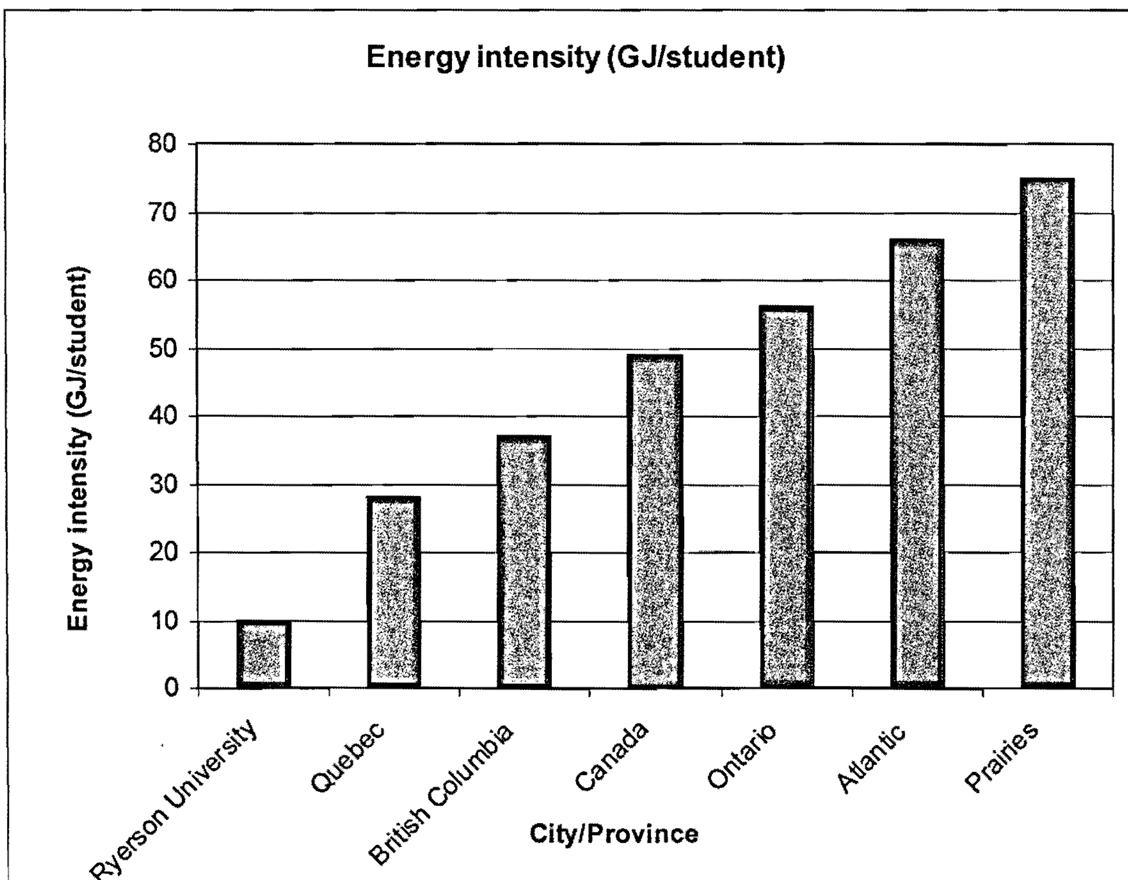

Figure 51: Energy intensity in different locations in Canada

Table 62: Energy intensity (NRCan, 2005)

Location	Energy Intensity (GJ/student)
Ryerson University	10
Quebec	28
British Columbia	37
Canada	49
Ontario	56
Atlantic	66
Prairies	75

7.0. Conclusion

Energy audit and simulation for most of the buildings (86% of area) in Ryerson University has been carried out. Energy simulation was done using Carrier HAP software. This study was conducted to balance total energy consumption for chilled water balance from the chillers plant. Steam energy balance and electricity consumption were calculated and compared to the actual bill for Campus Planning. For performing accuracy necessary data and information of the buildings has been collected and measured on site as the input of the model. Also this report conducted energy analysis and compared energy consumption for the Ryerson University in different location using PRISM software.

Sources of the heat gain, heat loss and typical effect on the whole building have been predicted. The energy consumption profile of the buildings illustrates that 51% energy used is for HVAC system and 49% energy is used for Non-HVAC system. For the HVAC system, 25% of the energy used during the summer season and 26% of the energy was used during the winter season. Annually, 26% of the hydro energy was used for lighting, 19% was used for equipment and 4% was used for miscellaneous. The three types of energy demands: chilled water demand, steam demand and hydro demand, were analysed in this report.

From the analysis it showed that the Engineering building, Kerr Hall, Jorgenson Hall, Library Building and Rogers Business Building required more cooling demand in the summer season compared to other buildings. Because Kerr Hall has a different air distribution system, Library Building operates for the longer hours, and Engineering Building and RBB have lots of exposed area consisting of glass, their cooling are expected to be higher. This is because lots of internal heat gain and heat gain through envelope system. The data also shows that comparatively Kerr Hall needs higher heating demand. It is identified that having air distribution of constant air volume (CAV), Kerr Hall and IMA need more air supply. So both heating and cooling systems require more energy. Engineering Building, Kerr Hall, and Library Building have lots of equipments, lab equipments, computer that lead to higher electricity consumption. In addition, this will result in higher cooling load but lower heating load.

This report also performed a sensitivity analysis in two cases. One of these was on HVAC system and other one was on lighting schedule. The HVAC system for the economizer was switched to integrated dry bulb system. The present economizer setting is an integrated enthalpy system. This analysis shows that the present economizer setting is the most desirable system. The potential saving could be done from electricity uses. The entire audit area (86%) of Ryerson campus consumes about 26% of electricity in lighting system. So when attempting energy savings, lighting is probably the first place in a facility to look for savings because changes are usually easy, inexpensive. The second sensitivity analysis was done for the lighting schedule. In this case the program was run for the 16 Ryerson buildings by reducing lighting schedule. The output from the program shows significant saving in this case. It shows that by rescheduling lighting schedule, lighting electricity consumption reduced by 21% as well as 10% cooling demand decreased, but 14% heating load increased.

PRISM HC model was established based on the Toronto weather data for hydro demand and steam demand. The results from these models were compared to the actual bills for Campus Planning, base case simulation from Carrier HAP model and PRISM model was established from HAP weather data. This model was also applied for the Ryerson campus in three different locations namely as Edmonton, Vancouver and Fredericton. This model shows that for steam consumption Ryerson University is the second highest and for hydro consumption Ryerson University is the second lowest position. This report also estimated energy intensity for the Ryerson campus. Result shows that Ryerson University in Toronto consumed less energy compared to other universities.

8.0. Recommendations

Performing building energy simulation needs to account for many of things related to the building environment, occupancy behaviour, building thermal performance, building operating schedule. It also needs to identify the factors of wastes energy. This project was done based on the information gathered from the Campus Planning about the building operation and schedule with some assumption on the plug load and miscellaneous energy uses in the buildings.

This project was completed 86% of the entire Ryerson campus, it is highly recommended that for further improvement of this analysis it is required to complete the remaining area for energy audit and find out potential savings from the analysis. It is also recommended to collect actual data for the plug load, electricity consumption for different types of equipment to determine accurate electricity consumption for entire Ryerson campus.

The analysis showed that Constant Air Volume (CAV) air distribution system required more electricity for continuous recirculation of air. As a result in this system required more cooling load demand and heating load demand compared to Variable air Volume (VAV) system. Kerr Hall, Victoria Building, Jorgenson Hall and one part of School of Image Art have CAV air distribution system. It is recommended that for the potential savings CAV air distribution system must be replaced with the VAV air distribution system for those buildings.

This report performed PRISM modeled and analysis for combined 15 buildings energy consumption (steam and hydro) and RBB only for steam consumption. For better result it is good practise to do PRISM model for individual building. To performed individual analysis for PRISM model, it is more important individual building metering data for different end-uses.

9.0. References

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Appendix A: Bill information

Hydro bill from campus planning

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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

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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	400,821	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

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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	11,380	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	328,853	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

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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			

Table 63: Steam consumption bill for Meter-1

2005	Steam Consumption (lb/hr)
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**

2006	Steam Consumption (lb/hr)
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**

2007	Steam Consumption (lb/hr)
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**

2008	Steam Consumption (lb/hr)
May_2008	7,249,496
June_2008	3,026,709
July_2008	2,260,656
August_2008	2,296,366
Sept_2008	2,138,684
Oct_2008	6,694,544
Nov_2008	12,669,623
Dec_2008	15,965,697
Jan_2009	19,176,725
Feb_2009	0
March_2009	0
April_2009	0
Total	**71,478,500**

Table 63: Steam consumption bill for Meter-2 (RBB)

2006	Steam Consumption (lb/hr)
May_2006	0
June_2006	0
July_2006	0
August_2006	0
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	0
Total	**4,786,006**

2007	Steam Consumption (lb/hr)
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**

2008	Steam Consumption (lb/hr)
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	0
March_2009	0
April_2009	0
Total	**3,722,299**

Appendix B: Building envelope

Table 64: Building envelope data

Sl. No.	Building Name	Types	Overall U-value	Overall U-value	Shade Coefficient
			W/m2/K	W/m2/K	
1	ENG	Wall Assembly-1	0.376		
		Wall Assembly-2	0.323		
		Wall Assembly-3	0.407		
		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	
		Roof Assembly-1	0.549		
		Roof Assembly-2	0.358		
2a	KNE	Wall Assembly	0.32		
		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	
		Roof Assembly	0.317		
2b	KNW	Wall Assembly	0.361		
		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	
		Roof Assembly	0.305		

2c	KSE	Wall Assembly	0.186		
		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	
		Roof Assembly	0.317		

Sl. No.	Building Name	Item	Overall U-value	Overall U-value	Shade Coefficient
			W/m2/K	W/m2/K	
2d	KSW	Wall Assembly	0.351		
		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	
		Roof Assembly	0.317		
3	SCC	East Wall Assembly	0.33		
		North Wall Assembly	0.339		
		South Wall Assembly	0.321		
		West Wall Assembly	0.321		
		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
		Door Assembly	1.703	3.293	
		Roof Assembly	0.348		
4	HEI	North Wall Assembly	0.253		
		South Wall Assembly	0.233		
		East Wall Assembly	0.27		
		West Wall Assembly	0.285		
		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	
		Roof Assembly	0.379		
5	IMA	Wall Assembly	0.402		
		Window Assembly A	3.062		
		Window Assembly B	3.064		
		Window Assembly C	3.612		
		Window Assembly D	3.657		
		Window Assembly E	3.628		

Sl. No.	Building Name	Item	Overall U-value	Overall U-value	Shade Coefficient
			W/m2/K	W/m2/K	
6	VIC	Wall Assembly	0.478		
		Window Assembly	2.69		0.641
		Door properties Assembly	1.703	3.293	
		Roof Assembly	0.317		
7	JOR	East Wall Assembly	0.327		
		North Wall Assembly	0.403		
		South Wall Assembly	0.403		
		West Wall Assembly	0.316		
		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	
		Roof Assembly	0.476		
8	LIB	East Wall Assembly	0.347		
		North Wall Assembly	0.348		
		South Wall Assembly	0.348		
		West Wall Assembly	0.348		
		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	
		Roof Assembly	0.352		
9	POD	East Wall Assembly	0.344		
		South Wall Assembly	0.344		
		West Wall Assembly	0.344		
		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	
		Roof Assembly	0.379		

Sl. No.	Building Name	Item	Overall U-value	Overall U-value	Shade Coefficient
			W/m2/K	W/m2/K	
10	EPH	East Wall Assembly	0.384		
		North Wall Assembly	0.363		
		South Wall Assembly	0.363		
		West Wall Assembly	0.329		
		Window Assembly	3.668		0.747
11	SHE	East Wall Assembly	0.385		
		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		
12	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
		Door Assembly	1.073	3.293	
		Roof Assembly	0.505		
13	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	

Sl. No.	Building Name	Item	Overall U-value	Overall U-value	Shade Coefficient
			W/m2/K	W/m2/K	
14	RCC	North Wall Assembly	0.203		
		South Wall Assembly	0.244		
		East Wall Assembly	0.348		
		West Wall Assembly	0.2		
		Type-A Window Assembly	3.662		0.74
		Type-B Window Assembly	3.635		0.74
		Door Assembly	1.703	3.293	
		Roof Assembly	0.497		
15	RBB	North Wall Assembly	0.285		
		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	1.703	0.751
		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		
		Roof Assembly A	0.235		
		Roof Assembly B	0.203		
		Roof Assembly C	0.237		
		Roof Assembly D	0.383		
		Roof Assembly E	0.383		
		Roof Assembly F	0.388		
		Roof Assembly G	0.292		
		Roof Assembly H	0.309		
		Roof Assembly I	0.323		

Appendix C: Calculation

Central Chiller Plant Model

Chiller Output (kWh)	13231280
Chiller Output, Chilled water (kBTU)	45145127
Remote steam load (kWh)	5814941
Remote steam load (kBTU)	19840579
Steam cost $ (0.025 $/lb)	496014

Electricity consumption	(kWh)
Chiller Input, Electricity	1229193
Misc. Electric	394722
Primary Chilled Water pump	229645
Secondary Chilled Water pump	99414
Condenser Pump	633868
Cooling Tower Fan	664352
Total	**3251194**

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**

Steam demand calculation for Meter-1

Sl. No.	Name of building	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 Communications Management (HEI/GCM)	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	**223,127**

Audit area serves for Meter-1

Sl. No.	Name of building	Area
		(m²)
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
14	Rogers Communications Center (RCC)	13100
15	Pitman Hall Residence (PIT)	3828
	Total audit area for Meter-1	**201,658**

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

Steam demand for Fiscal year 2006

Fiscal Year-2006	
Steam Consumption	**(lb)**
January	17,905,233
February	17,267,436
March	15,882,044
April	10,224,038
May	7,651,590
June	2,719,484
July	2,532,838
August	1,554,106
September	2,997,085
October	6,567,065
November	10,503,550
December	10,127,434
Total	**105,931,903**
Steam Used for selected buildings (90.3%)	**95,656,508**

Appendix D: Necessary data for PRISM model

Canadian Climate Normals 1971-2000

(http://climate.weatheroffice.gc.ca/climate_normals/index_e.html)

Month/City	Edmonton	Toronto	Fredericton	Vancouver
	(°F)	(°F)	(°F)	(°F)
January	8	21	14	38
February	13	22	17	41
March	24	31	28	44
April	40	43	40	49
May	51	55	52	55
June	57	64	61	59
July	61	69	67	64
August	59	68	65	64
September	50	60	56	58
October	40	48	45	50
November	22	38	34	43
December	12	27	21	38

PRISM (HC) model result for steam demand of 15 Ryerson buildings

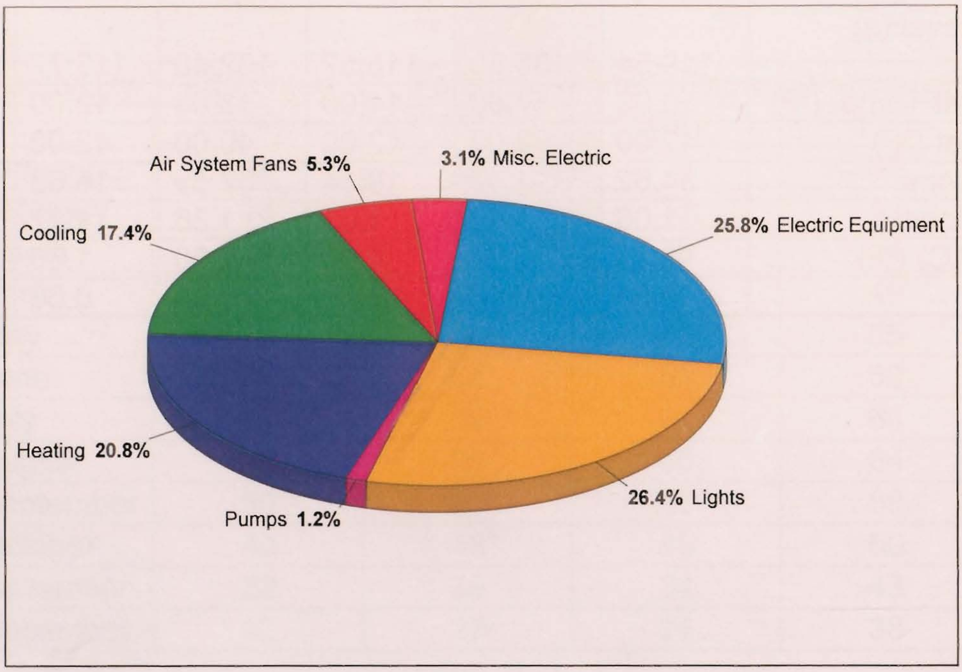
Model (HC)	May'05-Dec'08	Jan-Dec 2006	Jan-Dec 2007	Jan-Dec 2008	Jan'06-Dec'07	Jan'07-Dec'08
Base Level (a) (lb X 1000)	24.91	-78.11	117.07	-3.66	-2.49	49.69
Heat Ref Temp. (°F)	68.00	73.97	47.65	69.00	70.00	63.00
Cool Ref (°F)	68.00	74.00	61.00	69.00	71.00	69.00
Heat Slope	10.58	12.86	14.22	11.73	10.63	11.05
Cool Slope	6.28	67.36	-4.80	23.95	20.75	5.85
CV (NAC) (%)	3.50	6.90	9.90	3.60	6.50	5.20
R^2	0.90	0.91	0.86	0.98	0.84	0.89

PRISM (HC) model result for hydro demand of 15 Ryerson buildings

Model (HC)	May'05-Dec'08	Jan-Dec 2006	Jan-Dec 2007	Jan-Dec 2008	Jan'06-Dec'07	Jan'07-Dec'08
Base Level (a) (MWh)	110.54	135.60	115.57	102.40	113.77	110.56
Heat Ref Temp. (°F)	10.00	57.00	11.00	13.00	12.00	18.00
Cool Ref (°F)	42.00	72.00	42.00	40.00	42.00	40.00
Heat Slope	34.62	-1.02	19.34	67.59	16.63	7.12
Cool Slope	1.06	6.56	1.03	1.36	1.17	1.08
CV (NAC) (%)	2.20	2.29	2.80	2.60	1.80	1.90
R^2	0.53	0.78	0.57	0.66	0.66	0.58

Appendix E: Carrier HAP simulation result for each building

1. Engineering Building Annual Component Costs



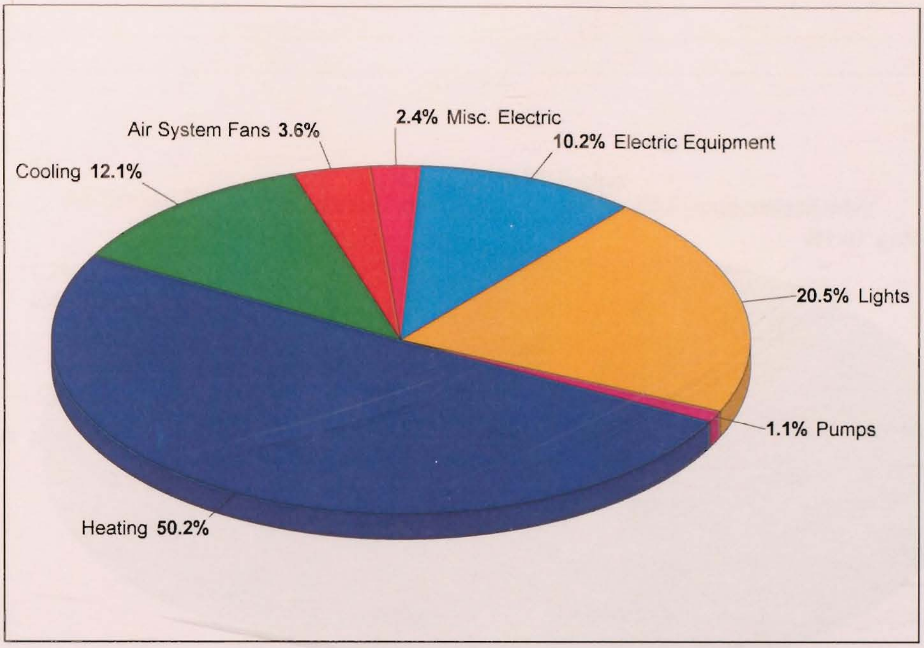
1. Annual Costs

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 m^2
Conditioned Floor Area 17583.8 m^2

2.a. Kerr Hall (KNE) Annual Component Costs



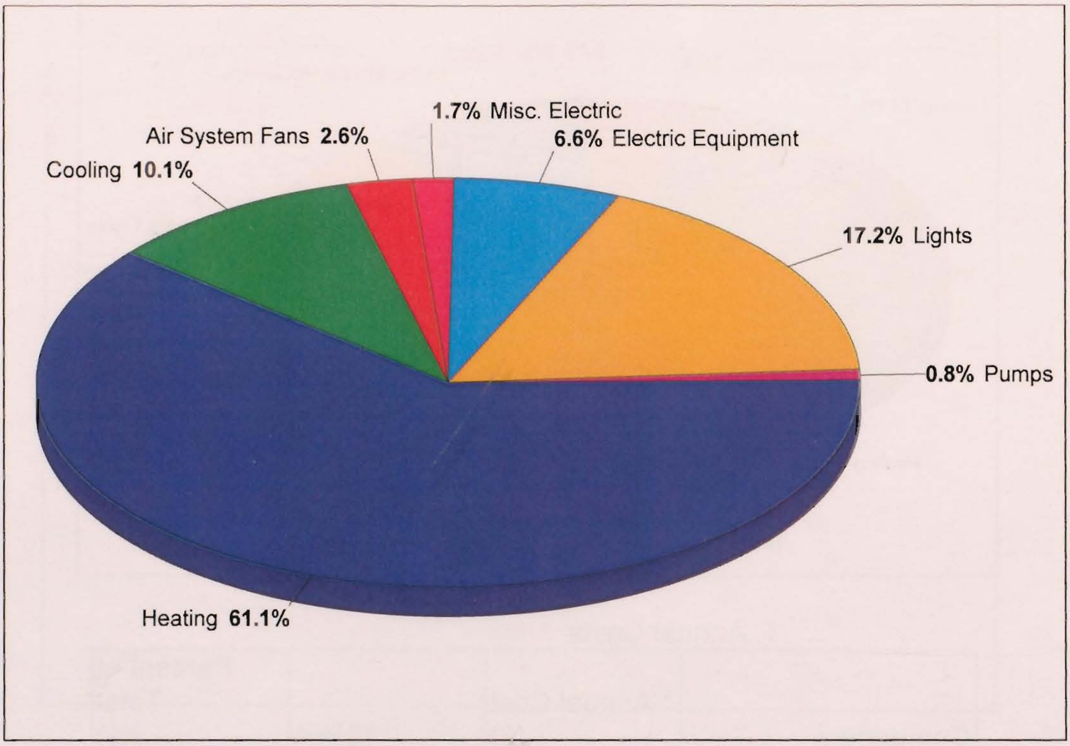
1. Annual Costs

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

2.b. Kerr Hall (KNW) Annual Component Costs



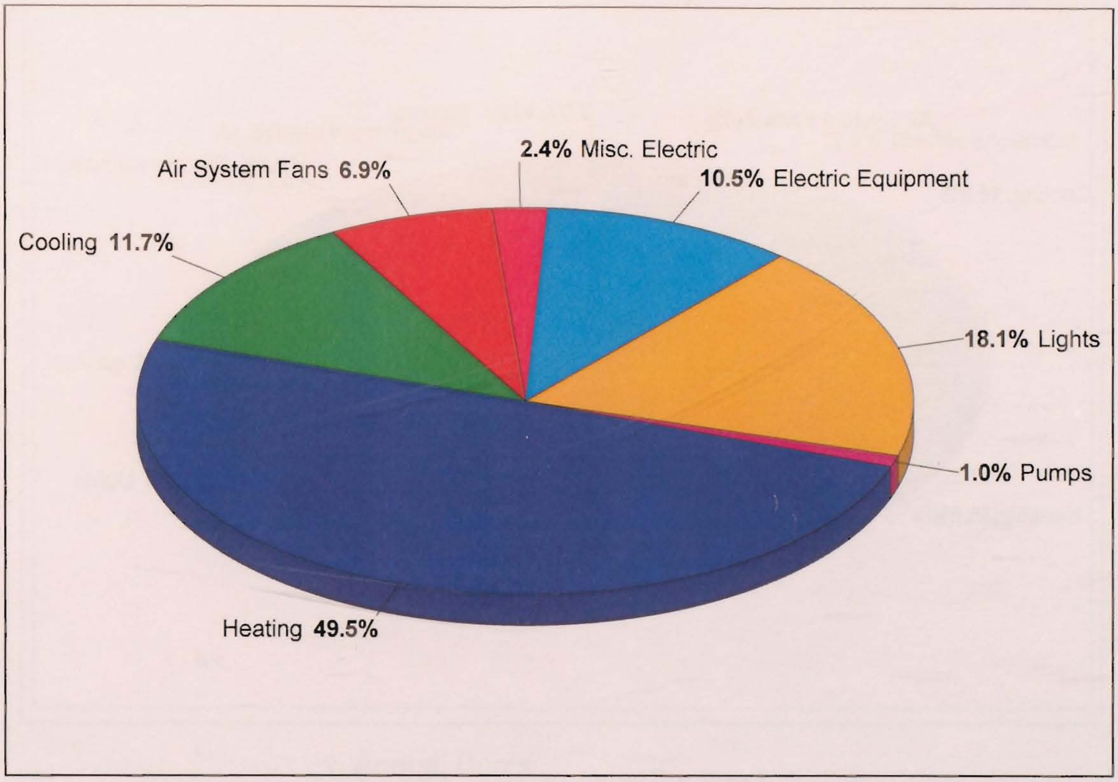
1. Annual Costs

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

2.c. Kerr Hall (KSE) Annual Component Costs



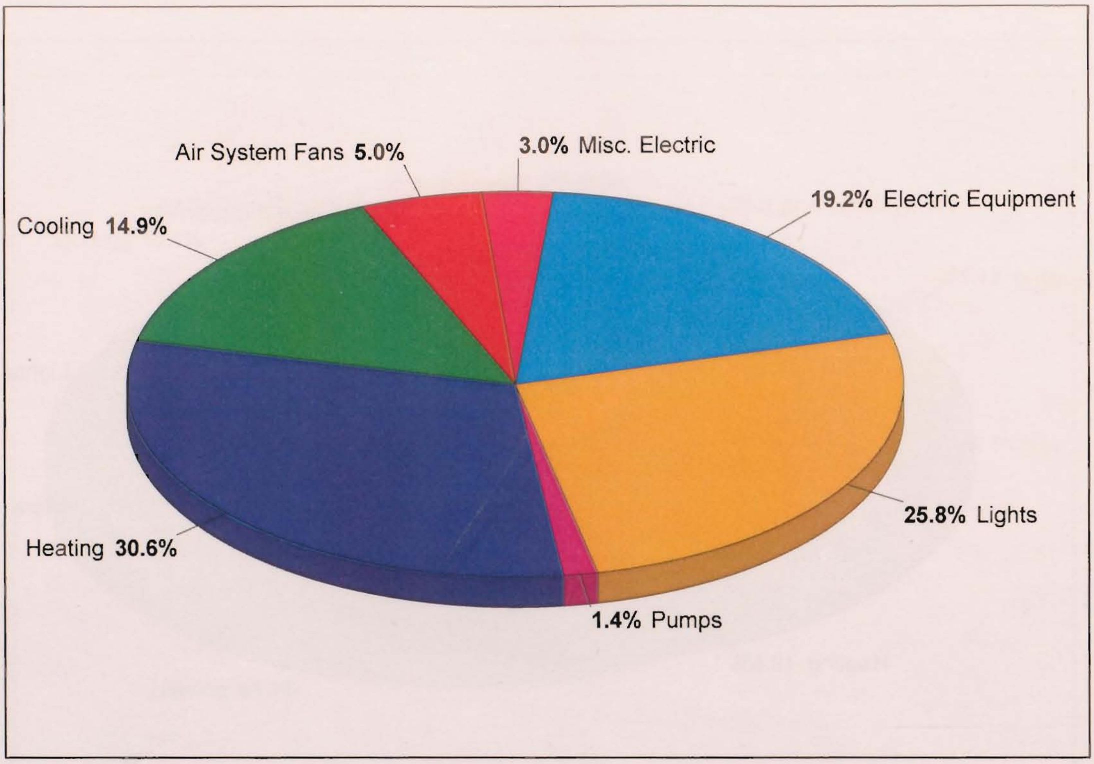
1. Annual Costs

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

2.d. Kerr Hall (KSW) Annual Component Costs



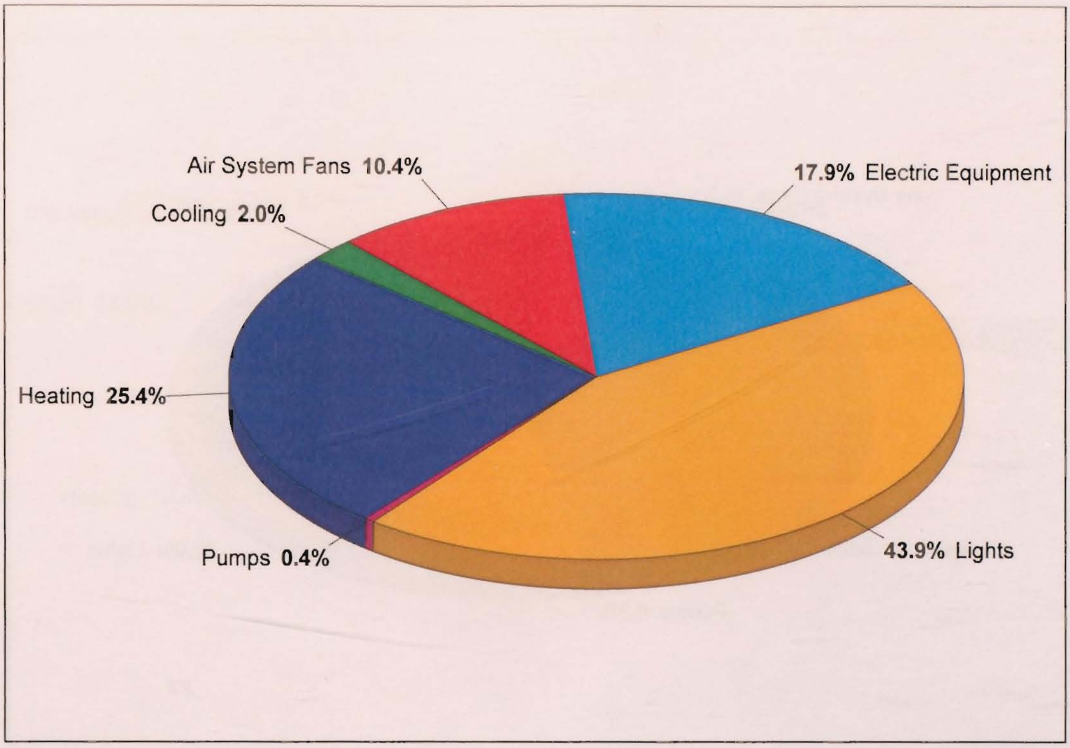
1. Annual Costs

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

3. SCC Annual Component Costs



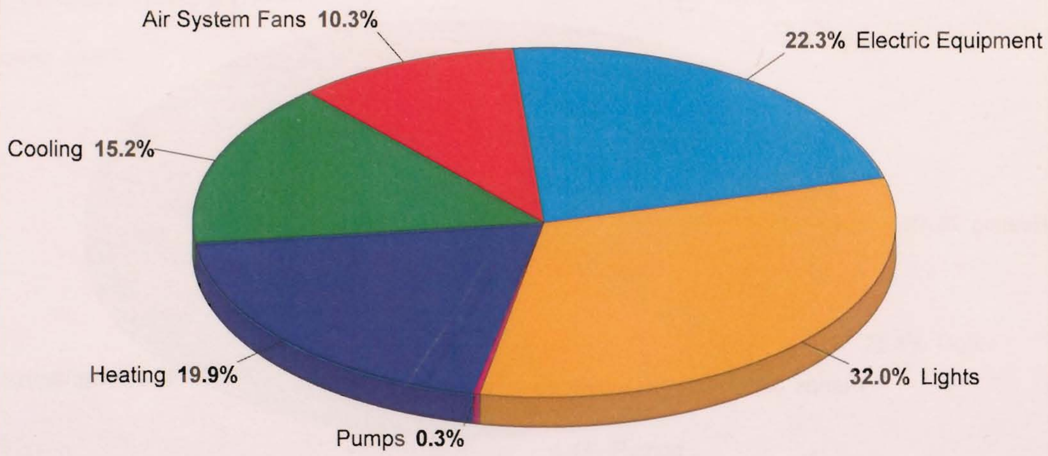
1. Annual Costs

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

4. HEI Annual Component Costs



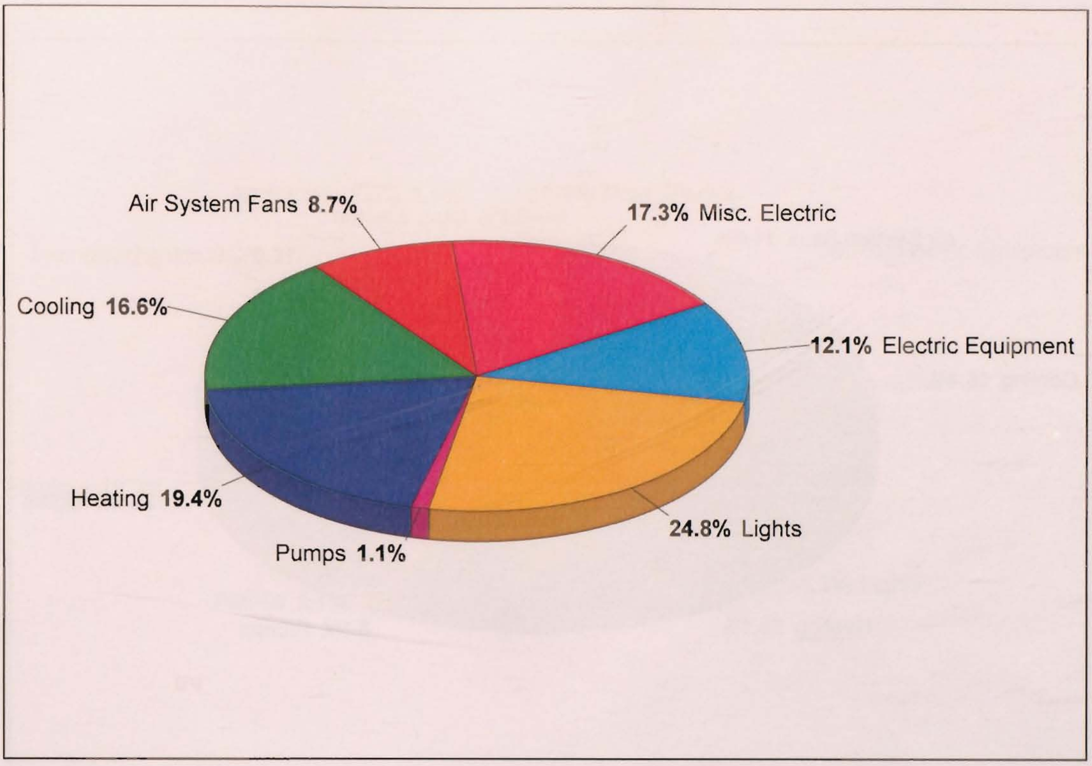
1. Annual Costs

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

5. CED Annual Component Costs



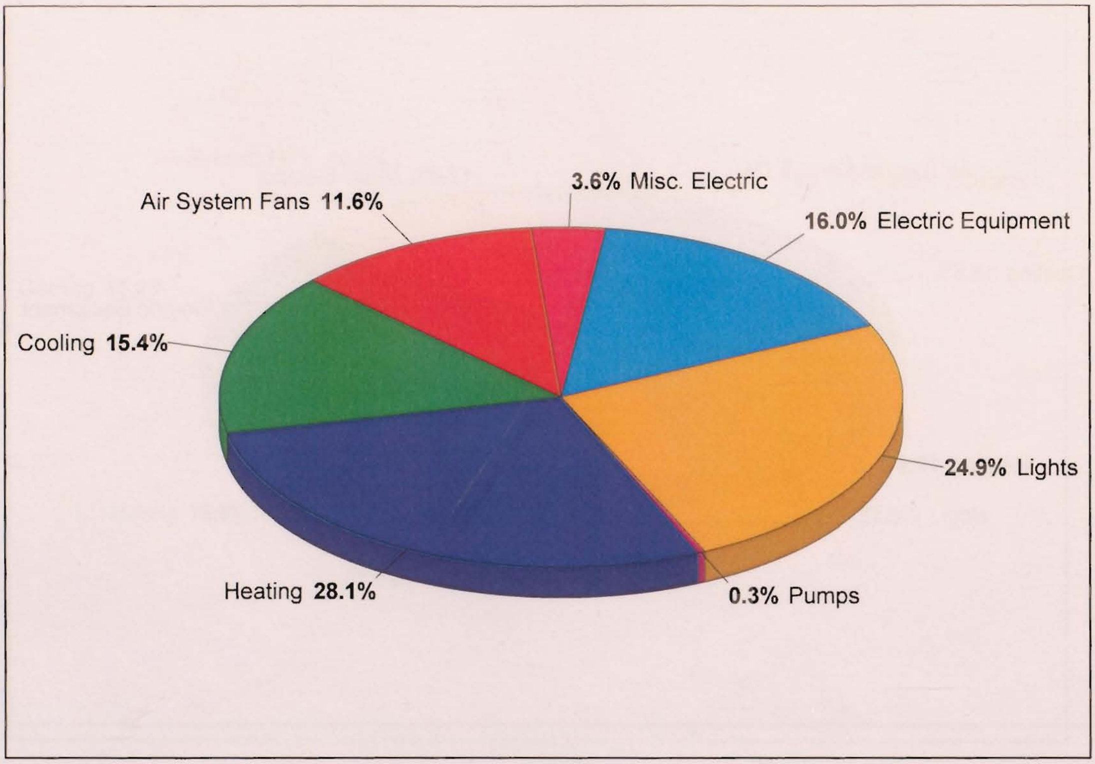
1. Annual Costs

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

6. IMA Annual Component Costs



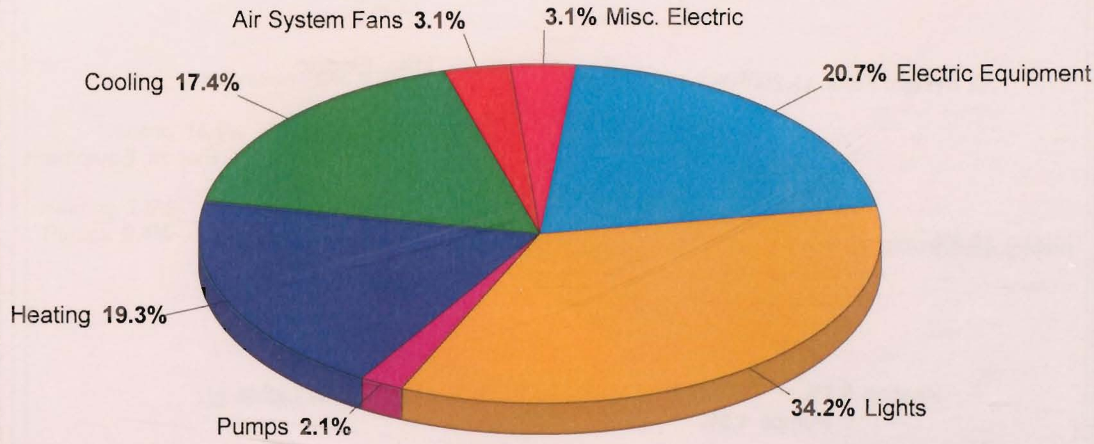
1. Annual Costs

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

7. VIC Annual Component Costs



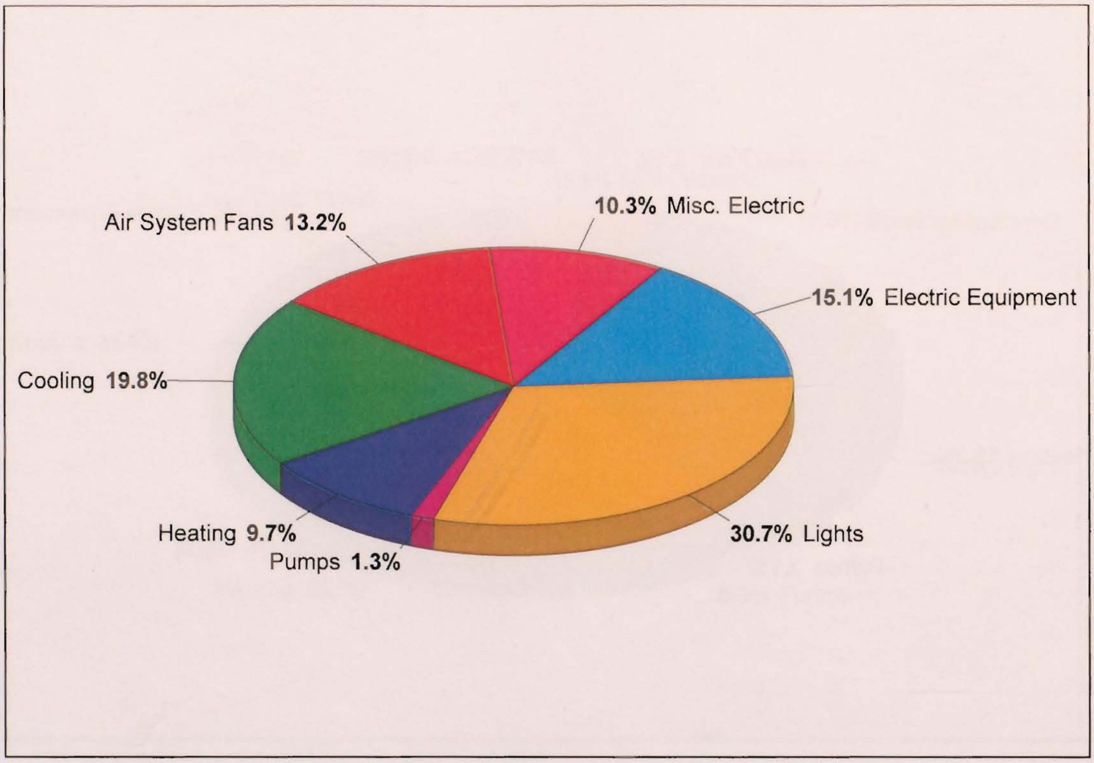
1. Annual Costs

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

8. JOR Annual Component Costs



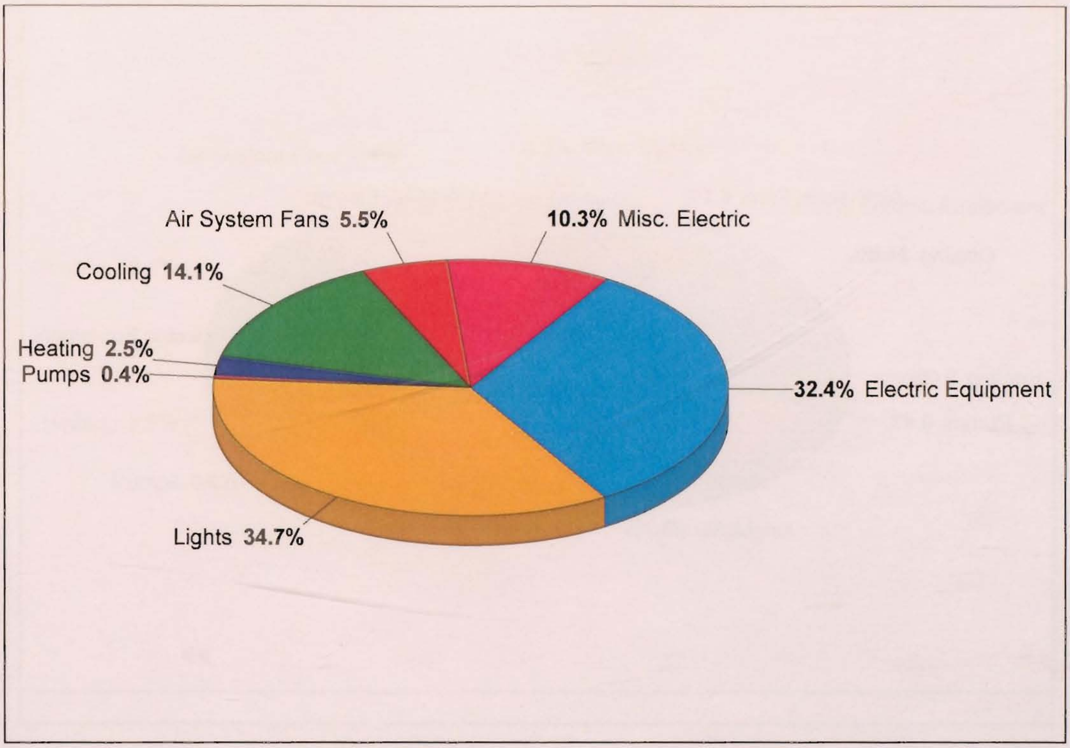
1. Annual Costs

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

9. LIB Annual Component Costs



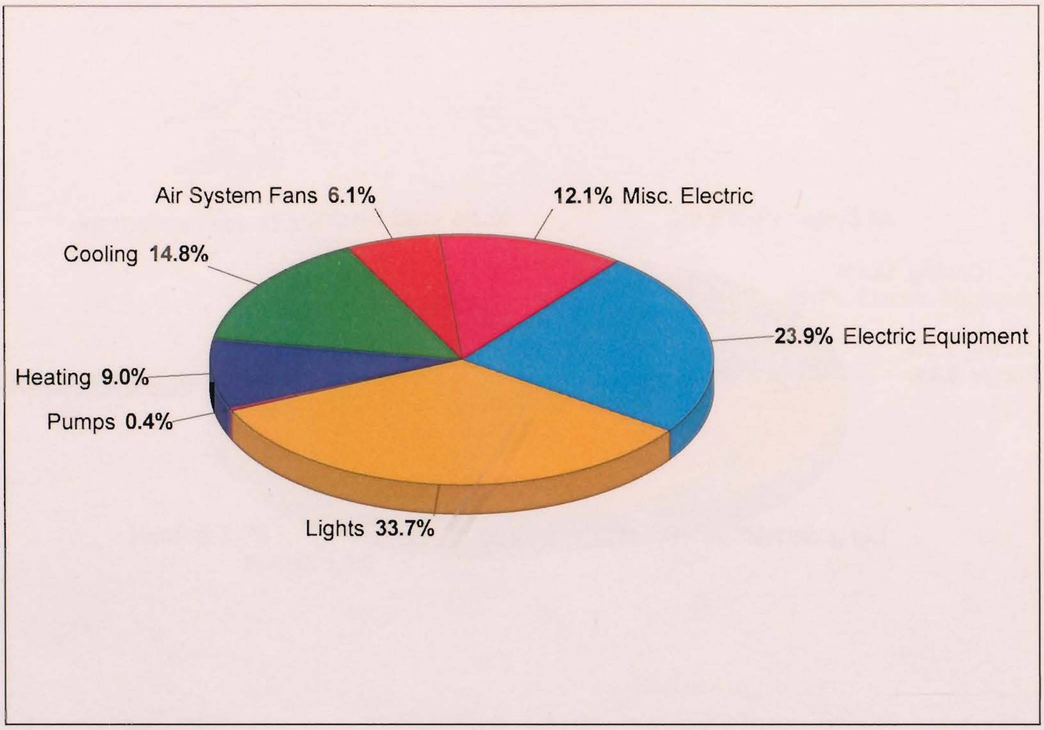
1. Annual Costs

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

10. POD Annual Component Costs



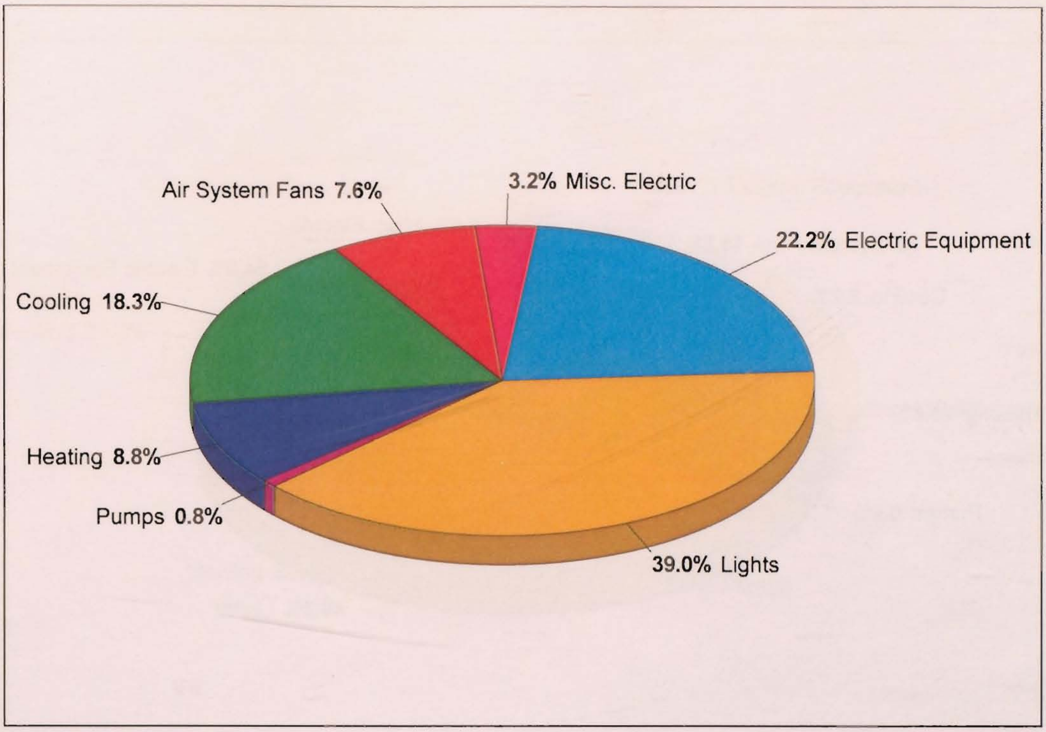
1. Annual Costs

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

11 & 12. EPH & SHE Annual Component Costs



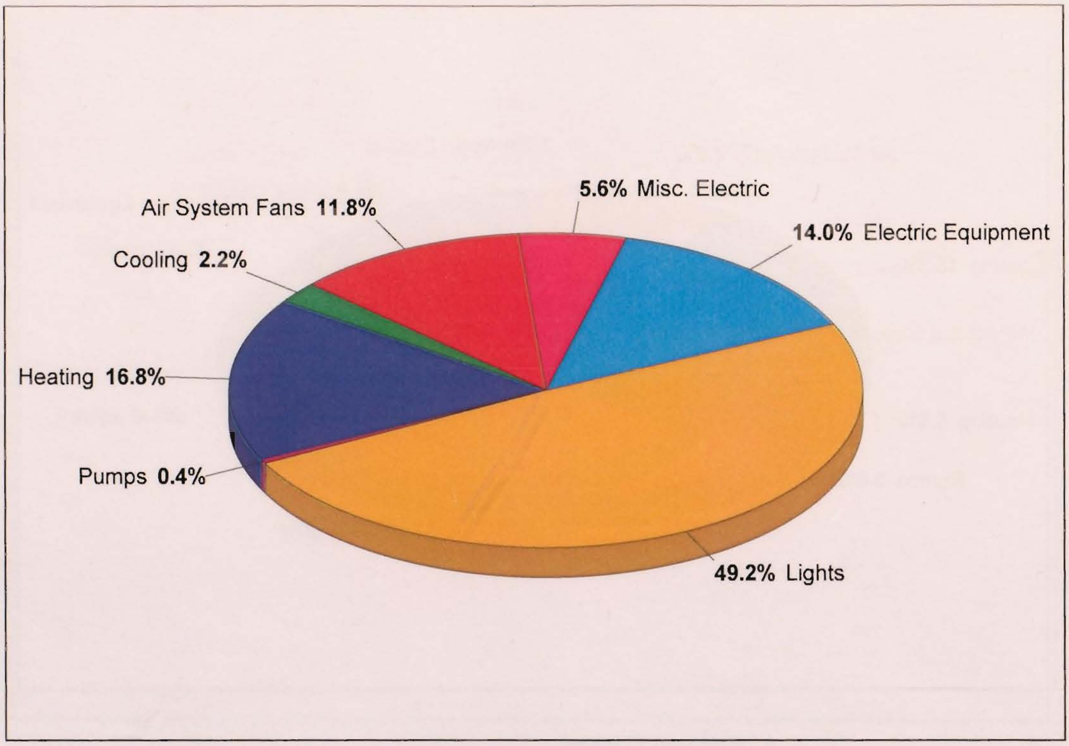
1. Annual Costs

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

13. SID Annual Component Costs



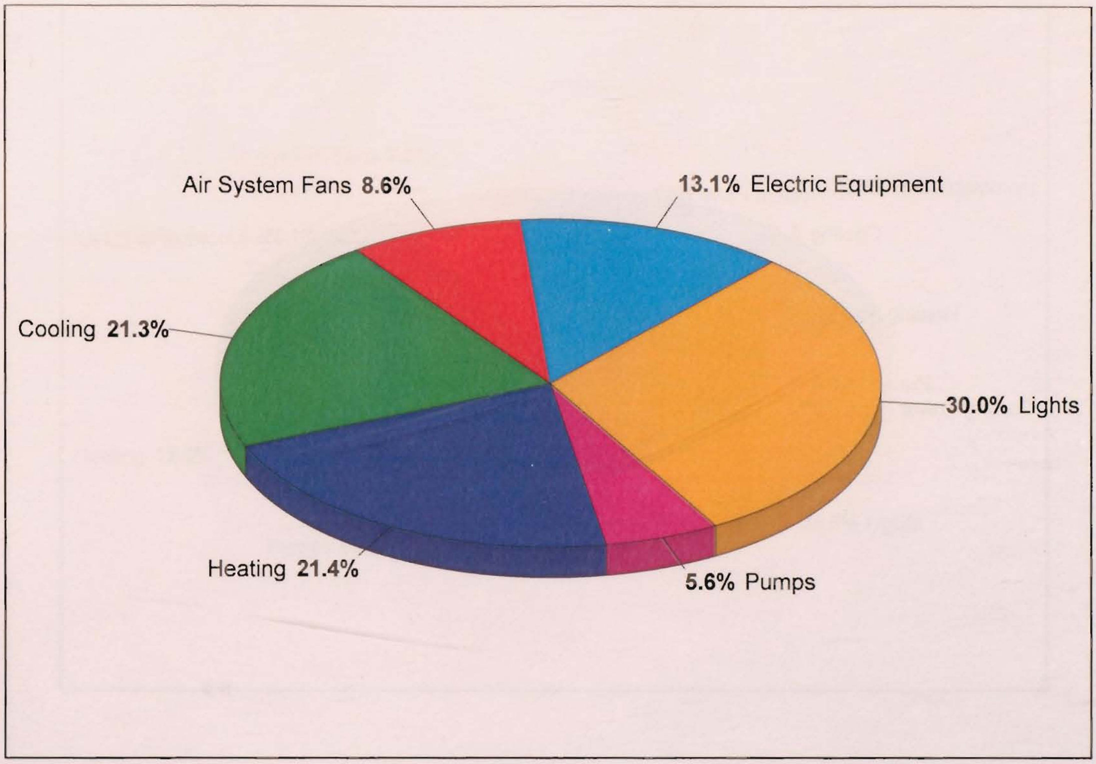
1. Annual Costs

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 m^2
Conditioned Floor Area 2887.7 m^2

14. PIT Annual Component Costs



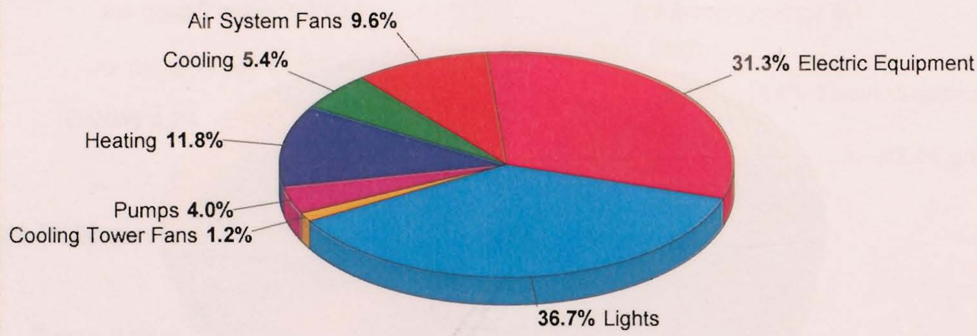
1. Annual Costs

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

15. RCC Annual Component Costs



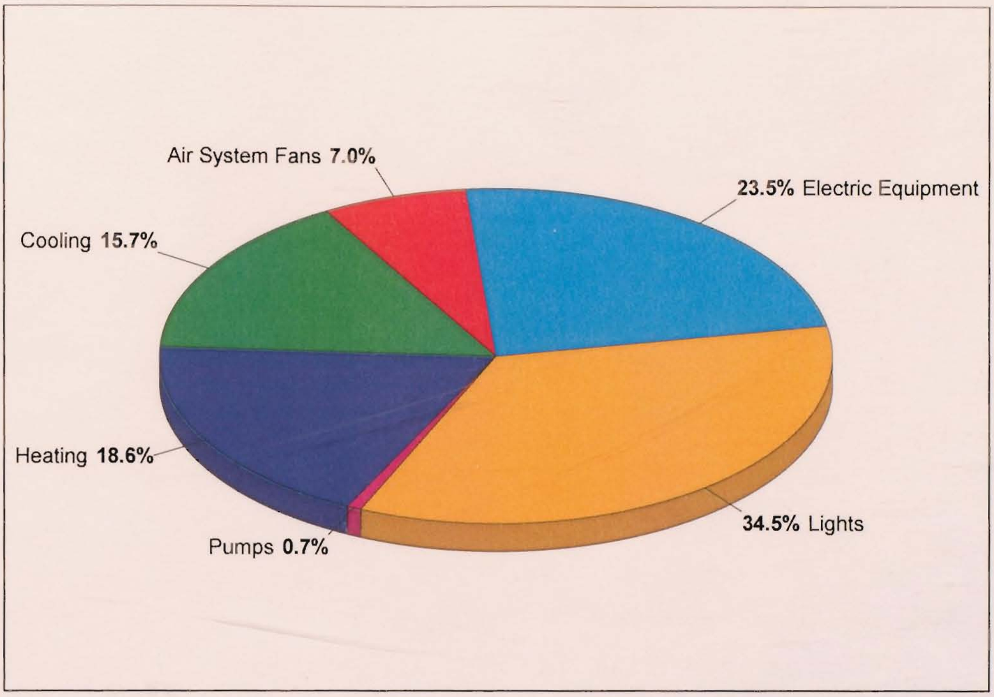
1. Annual Costs

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

16. RBB Annual Component Costs



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 m^2
Conditioned Floor Area 16740.7 m^2