RETROFITTING A HIGH-RISE RESIDENTIAL BUILDING TO REDUCE ENERGY USE BY A FACTOR OF 10

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By
Chris Richards

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ABSTRACT

This thesis details the ways in which energy is consumed in an existing Canadian high-rise apartment building and outlines a strategy to reduce its consumption of grid purchased energy by 90%. Grid purchased energy is targeted because the building is located in Saskatchewan where energy is predominantly generated from fossil fuels that release greenhouse gas emissions into the environment. Greenhouse gas emissions are targeted because of the growing consensus that human activities are the cause of recent global climate destabilization and the general trend towards global warming. Energy consumption is also a concern because of anticipated resource shortages resulting from increases in both global population and average per capita consumption. Many researchers are beginning to claim that a factor 10 reduction in energy use by industrialized nations will be required in order for our civilization to be sustainable.

The building that was studied is an 11 story seniors high-rise with a total above ground floor area of 8,351 m^2. It was constructed in 1985, in Saskatoon, SK, and it is an average user of energy for this region of the world and for a building of its size and type. Numerous field measurements were taken in the building, both during this study and previously by the Saskatchewan Research Council. These measurements were used to create a computer model of the building using EE4. After the computer model of the building was created different energy saving retrofits were simulated and compared.

Over 40 retrofits are presented and together they reduce the annual grid purchased energy of the building from 360 kWh/m^2 (based on above ground floor area) to 36 kWh/m^2, a factor 10 reduction. Natural gas consumption was reduced by approximately 94% and grid purchased electrical consumption was reduced by approximately 81%. As a result of these energy savings, a factor 6.6 reduction (85%) in greenhouse gas emissions was also achieved. The goal of factor 10 could not be achieved only through energy conservation and the final design includes two solar

water heating systems and grid-connected photovoltaic panels. These systems were modeled using RETScreen project analysis tools.

Capital cost estimates and simple payback periods for each retrofit are also presented. The total cost to retrofit the building is estimated to be $3,123,000 and the resulting utility savings from the retrofits are approximately $150,000 per year. This is a factor 6 reduction (83%) in annual utility costs in comparison to the base building. While the typical response to proposing a "green" building is that financial sacrifices are required, there is also research available stating that operating in a more sustainable manner is economically advantageous. This thesis adds to the "green building economics" debate by detailing savings and costs for each retrofit and ranking each retrofit that was proposed. The most economically advantageous mechanical system that was added to the building was energy recovery in the outdoor ventilation air. It should also be noted that there was already a glycol run-around heat recovery system in the building and even greater savings would have been obtained from installing the energy recovery system had this not been the case.

While the goal of factor 10 required economically unjustifiable retrofits to be proposed, the majority of the retrofits had simple payback periods of less than 20 years (30 out of 49). This research shows that certain retrofits have highly desirable rates of return and that when making decisions regarding investing in auditing a building, improving energy efficiency, promoting conservation, or utilizing renewable energy technologies, maintaining the status quo may be economically detrimental. This would be especially true in the case of new building construction.

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NOMENCLATURE

ACRONYMS:

AHU	Air Handling Unit
AFUE	Annual Fuel Utilization Efficiency
BEM	Building Energy Management
CBIP	Commercial Building Incentive Program
CFL	Compact Fluorescent Lamps
CMHC	Canadian Mortgage and Housing Corporation
COP	Coefficient of Performance
DHW	Domestic Hot Water
DJSI	Dow Jones Sustainability Index
KEP	King Edward Place
ELA	Equivalent Leakage Area
ER	Energy Rating
GPE	Grid Purchased Energy
GUI	Graphical User Interface
HDD	Heating Degree Days
LEED	Leadership in Energy and Environmental Design
MNECB	Model National Energy Code for Buildings
MSCI	Morgan Stanley Capital International
NRC	National Research Council of Canada
NRCan	Natural Resources Canada
PV	Photovoltaic
SHC	Saskatchewan Housing Corporation
SHGC	Solar Heat Gain Coefficient
SRC	Saskatchewan Research Council
SWH	Solar Water Heating
TMY	Typical Meteorological Year
WMAC	Window Mounted Air Conditioners

SYMBOLS:

A_{DU}	Average surface area of a human (m^2)
C	Flow coefficient ($L/(s \cdot Pa^n)$)
C_i	Steady-state indoor concentration of carbon dioxide (mg/m^3)
C_O	Steady-state outdoor concentration of carbon dioxide (mg/m^3)
Cp	Specific heat ($kJ/kg \cdot K$)
C_{EX}	Concentration of carbon dioxide in the exhaust air (mg/m^3)
C_S	Concentration of carbon dioxide in the supply air (mg/m^3)
Fr	Solar collector heat removal factor (dimensionless)
H	Height (m)
m_E	Mass flow rate of the exhaust fluid (kg/s)
m_{MIN}	Minimum mass flow rate of either the hot or cold fluid (kg/s)
M	Average tenant metabolic rate (W/m^2)
n	Number of tenants (persons)
ΔP	Pressure difference across the exterior wall (Pa)
P_{out}	Outdoor pressure (Pa)
P_{in}	Indoor pressure (Pa)
Q	Infiltration flow rate (L/s)
Q_S	Mechanical supply air rate (m^3/s)
Q_I	Infiltration rate (m^3/s)
Q_{Exh}	Mechanical exhaust air rate (m^3/s)
Q_{Exf}	Exfiltration rate (m^3/s)
Q_t	Rate at which air enters or exits the building (m^3/s)
r	Average metabolic carbon dioxide emission rate of tenants ($L/(s \cdot W)$)
R	Carbon dioxide emission rate of tenants (mg/s)
R^2	Relative predictive power of a model
S	Total pollutant source strength (mg/s)
T_1	Supply air temperature prior to heat recovery (ºC)
T_2	Supply air temperature after heat recovery (ºC)
T_3	Exhaust air temperature prior to heat recovery (ºC)

T_4	Exhaust air temperature after heat recovery (ºC)
U	Overall coefficient of heat transfer ($W/m^2 \cdot K$)
UL	Solar collector loss coefficient ($W/m^2 \cdot K$)
W	Width (m)

GREEK SYMBOLS

α	Solar collector plate absorbance (dimensionless)
ϵ	Heat recovery effectiveness (dimensionless)
ρ_{CO2}	Density of carbon dioxide at room temperature (kg/m^3)
τ	Solar transmittance of the glazing (dimensionless)

CHAPTER 1
INTRODUCTION

1.1 OVERVIEW AND OBJECTIVES

The goal of this thesis is to show how an existing typical apartment building in Saskatoon, Saskatchewan, could be modified to achieve a factor 10 (90%) reduction in its annual consumption of grid purchased energy (GPE). The building in question is King Edward Place (KEP), an 11 story apartment building owned by the Saskatchewan Housing Corporation (SHC). Tenants in KEP are predominantly seniors.

There are three main steps to this project:

1. Create a computer model of the existing building
2. Use the computer model to examine potential energy saving retrofits
3. Present a retrofit strategy to achieve a factor 10 reduction in GPE

The retrofit strategy will include the use of renewable energy sources and provide estimates of the cost and simple payback period of each proposed retrofit. The computer model of the building will be based on measurements, literature, and observations made while studying the building.

1.2 RESEARCH NEED

Canadians represent approximately 0.5% of the world's population; yet in 2001, they produced 2.2% of the world's annual greenhouse gas emissions and approximately 80% of these emissions came from energy use [1.1]. In this same year, 20% of Canada's annual energy use came from the residential sector [1.1]. Apartment buildings are the second most prevalent form of housing in Canada, accounting for 29% of the Canadian housing stock [1.2]. In 2004, 24% of the overall annual energy use within the residential sector occurred in apartment buildings. This is approximately 4.8% of the total energy used by Canadians. With the every growing global urgency to reduce dependence on fossil fuels in an effort to promote sustainability, reducing energy use in apartment buildings should be of concern to Canadians.

KEP provides subsidized housing for seniors. The number of seniors in Canada's population is growing at a rate roughly twice that of the general population and is expected to accelerate with the aging of the baby boom generation [1.2]. Housing affordability, which is directly related to utility costs, is of obvious concern to all Canadians but especially for seniors. Approximately 53% of seniors that live alone are classified as being in core housing need [1.2]. Households in core housing need are those who currently reside in housing that is in need of major repair, does not have enough bedrooms for the size and makeup of the household, or costs 30% or more of the household's total income (or they would not be able to rent an alternative housing unit which meets these standards without paying 30% or more of their income). With a growing population of seniors, rising fuel prices, and the fact that many Canadians already face difficulties in paying for their housing [1.3], significantly reducing the cost of utilities in apartment buildings would have a large impact on many Canadians.

Although the research in this thesis focuses on the retrofit of an existing building, it is also applicable to new building design and construction. In fact, new building design may be the most applicable use of this research as it is much more cost effective to implement the changes proposed in this thesis during initial construction as opposed to during a retrofit. Construction of new multiple family dwellings increased by 28.6% in 2003; and in this same year construction in Canada reached a 15 year high with multifamily residential buildings out-pacing single-detached homes [1.2].

The following section further discusses the global environmental implications of energy consumption, resource use of industrialized countries, and the rationale behind the choice of 10 as the factor to reduce the GPE of KEP. In the past, SRC and other researchers have investigated building factor 10 residential homes [1.4-1.6] but the author does not know of such an attempt for a high-rise apartment building in a cold climate.

1.3 RATIONALE FOR FACTOR 10

The criteria "factor 10" is most strongly advocated by Prof. Friedrich Schmidt-

Bleek, founder of the Factor 10 Institute and 2001 recipient of the Takeda award for World Environmental Well-Being. He states that, "The root cause for the growing ecological crisis is the massive and frequently indiscriminate use of natural resources [1.7]." He supports this by saying that "On the average, more than 30 tons of non-renewable natural resources are invested today for every ton of goods, with increasing tendency [1.7]." Factor 10 is his recommended target for the increase in efficiency that nations must achieve in their use of energy, resources and other materials. Schmidt-Bleek advocates that industrialized nations take up the challenge of factor 10; he promotes a goal of factor 2 globally and factor 10 for industrialized nations [1.8].

A rough calculation of the number 10 is as follows:

$$\begin{gathered} \textit{Factor Required for Sustainability} = \\ \textit{Factor of Future Population Growth} \times \qquad (1.1) \\ \textit{Factor of Future Consumption Growth per Person} \times \\ \textit{Factor to Account for the Required Reduction in GHG Emissions} \end{gathered}$$

1.3.1 GLOBAL POPULATION GROWTH

The Population Reference Bureau states that "In 2000, the world had 6.1 billion human inhabitants. This number could rise to more than 9 billion in the next 50 years" [1.9]. Thus, the estimated factor of future population growth is 1.5.

1.3.2 GLOBAL RESOURCE CONSUMPTION GROWTH

An ecological footprint is a measure of how much land and water is needed to produce the resources we consume and to dispose of the waste we produce [1.10]. The 2005 Footprint of Nations report states that humanity's footprint is currently 23 hectares per person while the Earth's biological capacity is just 17 [1.11]. We are already exceeding the earth's carrying capacity and yet global consumption rates are increasing [1.12, 1.13]. An estimate of the factor for the future growth in global consumption per person is 3.3 [1.14, 1.15].

1.3.3 REQUIRED REDUCTION IN GREENHOUSE GAS EMISSIONS

The recent report from the Intergovernmental Panel on Climate Change strongly stresses the need to take action to reduce global greenhouse gas emissions [1.16]. A New York Times article covering the report's release stated: “the leading international network of climate change scientists has concluded for the first time that global warming is "unequivocal" and that human activity is the main driver, "very likely" causing most of the rise in temperatures since 1950 [1.17].” The Government of Canada stated in a 2001 Kyoto Protocol report that “If we are ever to win the long-term battle on climate change, global greenhouse gas emissions will have to be cut by more than half by the end of this century [1.18].” Thus the factor for our required reduction in GHG emissions is approximately 2.

$$\text{Factor } 10 = 1.5 \, x \, 3.3 \, x \, 2 \qquad (1.2)$$

The “factor” concept has also been introduced in the book *Factor Four - Doubling Wealth, Halving Resource Use* by Ernst von Weizsäcker, Amory Lovins, and L. Hunter Lovins [1.19]. Their book asserts that industrial nations are extremely wasteful in their use of resources (particularly in the areas of material use, energy and transportation) despite the fact that technologies and proven methods exist that could lead to dramatic reductions. The book attempts to outline methods to achieve a factor of 4 (75%) in industrialized nations during the next decade. They also argue that potential improvements are not too costly but, in fact, often reduce costs and lead to increased profits.

The economic gains that result from taking a more sustainable approach to consumption is also advocated by Dr. Bob Willard, author of *The Sustainable Advantage* [1.20]. In this book, he provides seven case studies of the benefits of moving beyond a traditional accounting framework by accounting for environmental and social performance in addition to financial performance. Dr. Willard charts the performance of companies labeled as sustainable and shows that they consistently outperform companies that do not focus on sustainability. This can be seen in Figure 1.1, which was taken from a presentation on Dr. Willard's website [1.20].

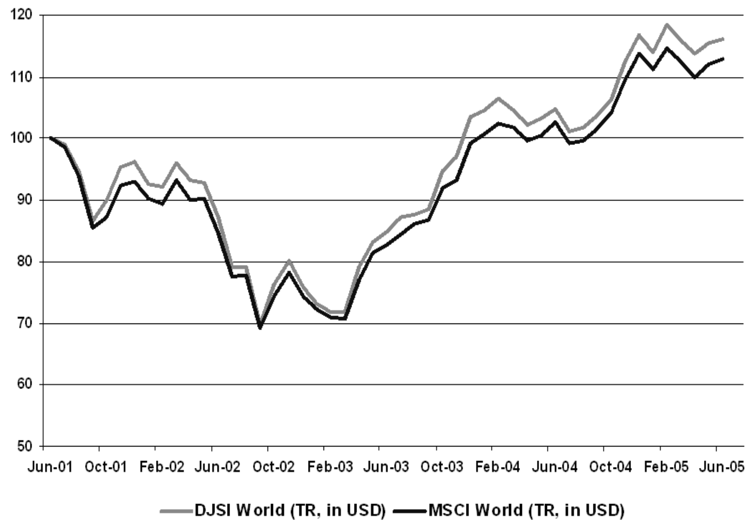

Figure 1.1: DJSI vs MSCI over a 4 year period [1.20]

Figure 1.1 shows the Dow Jones Sustainability Index (DJSI) in comparison to the Morgan Stanley Capital International (MSCI) index over a 4 year period. The DJSI tracks the financial performance of the world's leading sustainability-driven companies and the MSCI is a selection of stocks from 23 countries and is a common benchmark for global stock funds [1.21]. Figure 1.1 shows the sustainability index to be consistently higher than this global benchmark.

There appears to be two main arguments for an agenda of achieving factor 10. The first being that the earth simply cannot sustain our current rate of consumption growth and we will eventually run out of resources on a global scale. The second is that it is in fact more economically viable to operate in a more efficient and sustainable manner. It would seem then, that from both an environmental and economic standpoint, a factor of 4-10 may be best practice for building design.

1.4 COMPUTER MODELING SOFTWARE

This section briefly introduces the different computer software that was used to model the building, estimate solar energy collection, simulate energy recovery, and process weather data.

1.4.1 EE4 / DOE SIMULATION OF THE BUILDING

The computer models of KEP will be created using EE4, a building modeling tool structured around Canada's Model National Energy Code for Buildings (MNECB). The model national energy code was published in 1997 by the National Research Council of Canada (NRC) and it contains “prescriptive” energy-efficiency measures for new commercial buildings. It also allows alternative energy-efficiency measures to be substituted for prescribed measures if the substitution does not increase building energy consumption. It is a voluntary code that represents a minimum level of energy efficiency and applies only if it is adopted by the local authority of the region.

The Commercial Building Incentive Program (CBIP) was created by Natural Resources Canada (NRCan) to encourage the design and construction of energy-efficient commercial buildings. Applicants to the program are eligible for up to $60,000 in design assistance and funding if they can show that their building is designed to be at least 25% more energy efficient than if it were constructed to meet the requirements of the MNECB. In order to apply under the CBIP program, building energy consumption must be determined using NRCan's EE4 software. EE4 is also accepted as a building energy simulation tool by the Canadian Green Building Council's Leadership in Energy and Environmental Design (LEED) green building rating system. EE4 was chosen as the program for modeling the building and proposed retrofit options as it is a recognized program in Canada, designers in Canada can compare their work to the work in the thesis, there was a high potential to use EE4 in future work, and Tom McDermott, an engineer with SRC, was already familiar with EE4 and could provide both support and critiques of the model.

EE4 is a graphical user interface (GUI) developed for use with the United States Department of Energy building energy performance software DOE. DOE is a DOS based building energy performance calculator that has been developed and refined for over 25 years. The EE4 program is Windows based and uses a tree structure where building components are nested together and individual components of the building can be easily inserted, removed, and edited.

EE4 includes a “non-compliant” mode where most of the default values (which are based on MNECB values) are removed and must be entered by the user. This is the most flexible mode of EE4 and will be used in this research. Nevertheless, even in non-compliant mode the EE4 program makes many assumptions, some of which needed to be altered to accurately model KEP. Some of the building variables assumed by the EE4 program are hot water delivery temperature, piping losses, internal heat gain allocations, standby losses for equipment, boiler and chiller load/part load correlations, heat recovery control method, secondary heating and cooling loop operation, humidity control, and fan performance curves.

From the values entered into the tree structure and its own built in assumptions, EE4 creates a text input file for the DOE software. This text file is read by the DOE calculation engine and it calculates the total building energy consumption. When modeling the KEP building, some of the default values in the text file outputted by EE4 were changed in order to more accurately represent the building. Thus, when the term “the computer model” is used throughout this document, it is referring to a text file that was generated by the EE4 GUI and then manually edited and used as an input for the DOE building energy performance software.

1.4.2 RETSCREEN RENEWABLE ENERGY SIMULATION TOOLS

RETScreen International is a United Nations sponsored program that develops decision-making tools for the evaluation of the energy production, life-cycle costs and greenhouse gas emission reductions from various types of energy efficient and renewable energy technologies. Their software tools provide monthly results using average monthly data. They are essentially spreadsheet programs that allow users to enter the majority of the required variables needed to model a particular system. Each program has many built in assumptions that simplify the modeling process but also limit modeling flexibility.

The two RETScreen tools that will be used in this thesis are the solar water heating (SWH) and photovoltaic (PV) programs. The SWH program uses the f-Chart correlations which were was first published in 1976 by Klein and Beckman and are now the most widely-used correlations for calculating useful absorbed solar energy [1.22]. The correlations calculate average monthly solar energy collection and for space-heating and DHW systems the total annual results from the correlations have been found to generally match measured actual annual solar collection within ± 5% and sometimes within ± 2.2% [1.22]. The amount of collected solar energy predicted for each month, however, can vary by as much as ± 20% from measured performance of actual solar systems [1.23].

When compared to measured performance, the results from RETScreen SHW tool has been typically found to overestimate the actual annual energy delivered. This overestimation can be as high as 20% but it tends to decrease as the size of the system increases. The RETScreen engineering textbook discusses accuracy of its results in more detail [1.24].

1.4.3 TRNSYS HOURLY SIMULATION TOOL

TRNSYS is a transient energy system simulation tool. It is a commercially available software program that has been continuously updated and developed since 1975. It contains many built in simulation tools and allows the user to create hourly simulations of solar, thermal, and other processes. This software was used to generate air properties for weather files, process measured radiation, and to create an hourly model of the proposed energy recovery system in the final design.

CHAPTER 2
BUILDING OVERVIEW

2.1 GENERAL BUILDING DESCRIPTION

King Edward Place (KEP) is an 11 story senior's high-rise built in 1985. It has a total heated floor area of 8,351 m^2, and 106 one-bedroom suites, 10 two-bedroom suites and on average 125 occupants. It is a rectangular shaped building with a long North and South face. Figure 2.1 shows the North face of the building.

Figure 2.1: North face of KEP in 2003

Figure 2.2 shows the site plan for the building. The tenant parking lot on the North side of the building has 32 stalls which individual tenants pay a fixed amount to rent. The building has South and North entrances, the latter of which is predominantly used. A light grey section between the building and the parking lot on the North side can also be seen in Figure 2.2. This is a rear brick patio that is electrically heated to remove snow and ice.

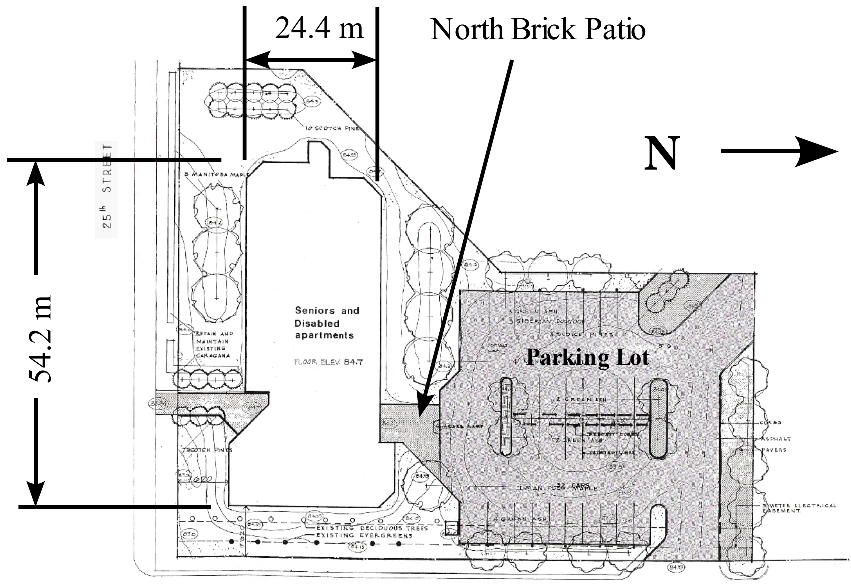

Figure 2.2: KEP site plan [2.1]

Figure 2.3 shows the East face of the building. The main floor has an area of approximately 986 m^2 and typical floors (3-10) have an area of approximately 746 m^2. The 11th floor is a mechanical room that extends the entire length of the building in the East-West direction.

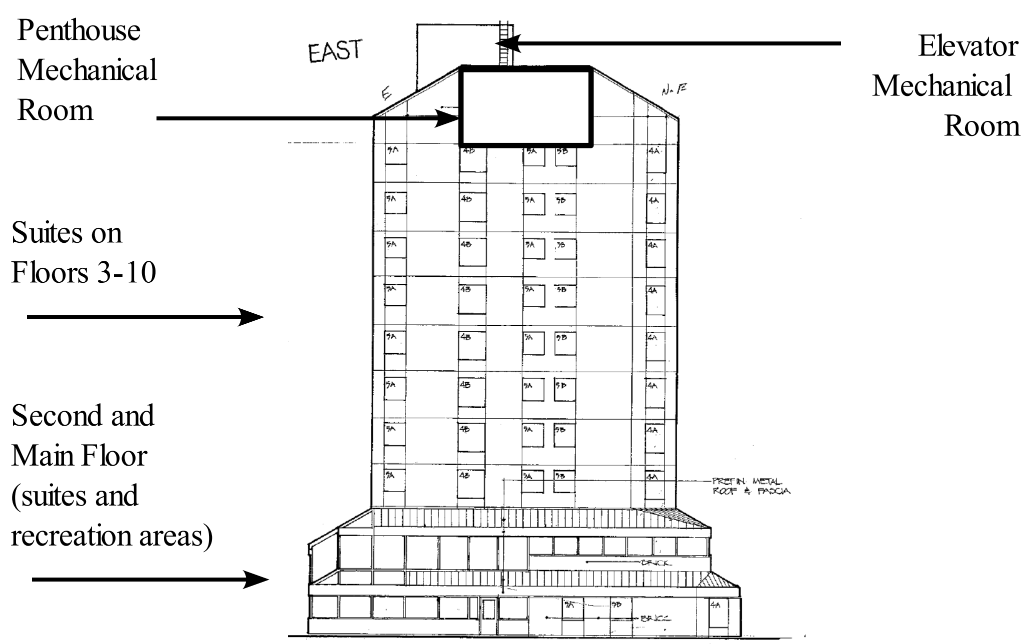

Figure 2.3: East face of KEP [2.1]

The main and second floors each contain a kitchen, recreation area, and laundry room. Both kitchens are seldom used. The recreation areas on the main and second floors are open to each other and the main floor can be viewed from the second floor by looking down over a balcony. The main floor recreation room is rarely used but it contains a salon that is open on Fridays. The second floor recreation room is extensively used by occupants for making puzzles, using the Internet, reading books, and socializing. Events such as bingo nights and evening exercises are also organized on the second floor.

Figure 2.4 shows a typical building floor. Every floor has a central corridor with suites on each side. Mechanical ventilation (100% outdoor air) is provided to the hallways on every floor. Each typical floor contains 11 single bedroom suites and one two bedroom suite. The average floor area of the suites in KEP is approximately 52 m^2.

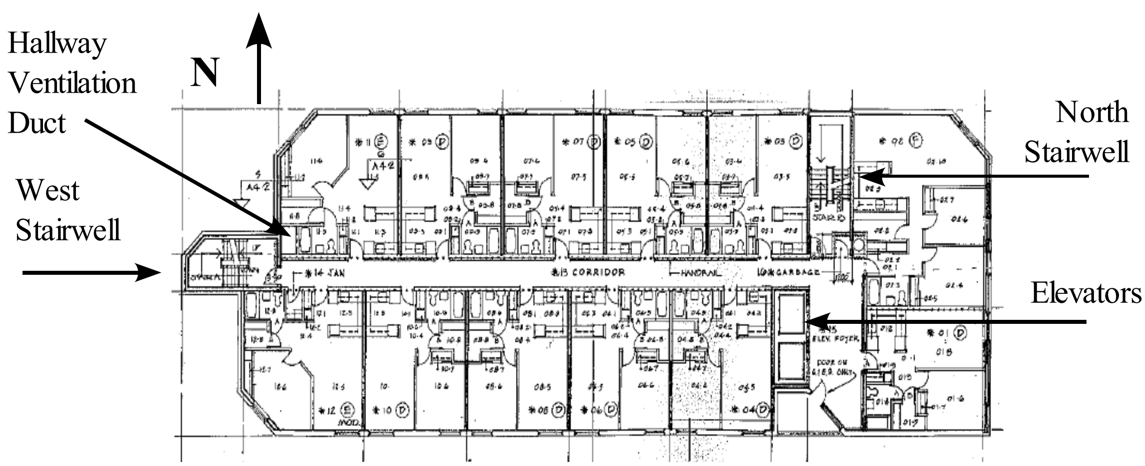

Figure 2.4: Typical floor plan [2.1]

Figure 2.5 is a plan view of the crawlspace. The area shaded in grey is finished mechanical/electrical and storage rooms. The remainder of the crawlspace is unfinished storage space with an average height of 1.7 m and a floor area of approximately 986 m^2.

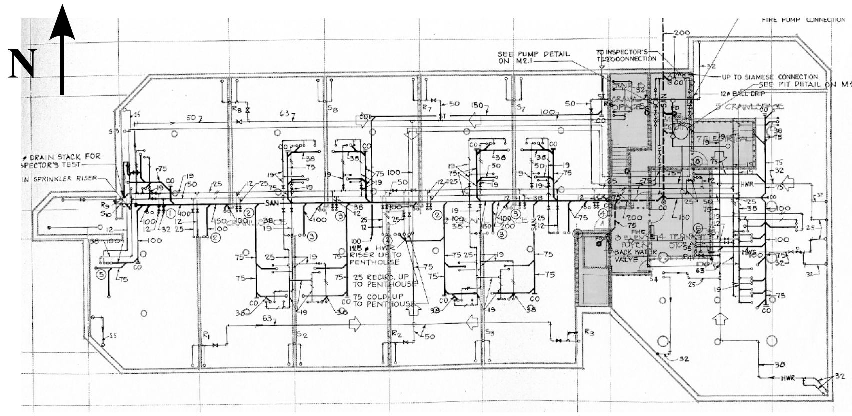

Figure 2.5: Crawlspace and foundation [2.1]

2.2 WEATHER

Hourly weather data is provided with the EE4 program for different locations throughout Canada. Saskatoon data is not included and instead the program uses typical meteorological year (TMY) data from North Battleford when Saskatoon is selected as the building site. This was a concern when attempting to match consumption calculated by the computer model to actual measured natural gas and electrical consumption as Saskatoon will receive different weather and solar radiation than North Battleford. Furthermore, TMY data will also not match the weather experienced in the years measurements were taken. Table 2.1 shows differences in heating degree days per year, cooling degree days per year, and average annual solar radiation for the default weather file and measured data from 2002-2005.

Table 2.1: Heating and cooling degree days and average annual solar radiation for Saskatoon and North Battleford TMY weather file

	[HDD/Year]	[CDD/Year]	Horizontal [W/m^2]	Direct Normal [W/m^2]
North Battleford TMY	6067	188	157	204
Saskatoon 2002	6044	298	154	187
Saskatoon 2003	5874	352	146	199
Saskatoon 2004	5872	140	133	165
Saskatoon 2005	5642	153	143	192

The number of heating or cooling degrees for a particular day is equal to the difference between each day's mean temperature and the "balance point" temperature.

The balance point temperature in Canada is chosen as 18°C and mean daily temperatures below the balance point result in heating degrees. Mean temperatures above the balance point result in cooling degrees. Higher heating degree days (HDD) per day indicate colder outdoor temperatures. The number of heating degree days for a year is the summation of the heating degrees from each day.

Figure 2.6 shows the measured monthly natural gas consumption in KEP during the years 2002 and 2003 as a function of average monthly heating degrees per day.

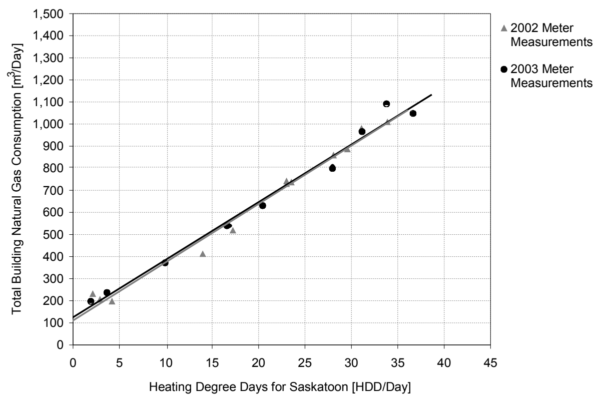

Figure 2.6: Measured natural gas consumption (2002 and 2003)

In theory, plotting measured natural gas consumption as shown in Figure 2.6 allows measured data from two different years to be compared without being concerned about variations in annual heating degree days. Figure 2.6 shows that this method works well because while the number of heating degree days in 2002 was approximately 3% greater than the number in 2003 (Table 2.1), the linear trend-lines fitted to the data from each year are nearly identical.

To obtain a more accurate evaluation of whether the two sets of data match, the slope and Y-intercept from the linear trend-lines in Figure 2.6 can be used to determine a total effective annual natural gas consumption using the following simple formula:

$$Annual\ Consumption = (Slope)\left(\frac{Average\ HDD}{Year}\right) + (Y\ Intercept)\left(\frac{365\ Days}{Year}\right) \quad (2.1)$$

One way Equation 2.1 can be used is to compare the annual consumption of a building before and after an energy saving retrofit. An example would be if a retrofit occurred in a building and the percent reduction in energy consumption resulting from the retrofit was desired. The percent difference between the effective annual consumptions calculated for the pre and post retrofit years would represent the savings obtained without needing to take into account annual weather variations that make comparing the actual total energy consumed in each year problematic.

To test if this method of comparing data was satisfactory for comparing computer models that used the default EE4 weather file for Saskatoon, a second weather file was created. This weather file contained the same solar radiation and wind conditions as the default weather file but all of the outdoor air properties (temperature, density, enthalpy, etc.) were replaced with Environment Canada weather data for Saskatoon in 2005. Properties such as enthalpy and air density which were not available in the past data were determined using a psychometric calculator built into TRNSYS. The year 2005 was chosen as it had the lowest number of annual HDD/Year of the years studied (7% lower than the default weather file) while the default weather file had the highest. It is also interesting to note that in Table 2.1 the number of HDD/Year decreases with each increasing year. Once the second weather file was created the computer model was run using both the default weather file and the modified weather file.

Modifying the default weather file to reduce its annual heating degree days per year by 7% resulted in a 0.5% decrease in the total effective annual natural gas consumption. Further experimenting with making changes to the default weather file also showed that when the default annual solar radiation was reduced by approximately 17%, the annual effective natural gas consumption increased by 1.7%. The decrease in solar radiation of 17% is the difference between the default weather file and measured radiation in 2004 (2004 had the lowest solar radiation of the years studied).

It was decided that the use of the default weather file for the simulations would not be satisfactory. To improve the accuracy of the simulations results for the years of interest (2003 and 2005) Saskatoon weather files were created for these years using hourly Environment Canada weather data and radiation data measured by SRC (Appendix A1.1).

2.3 SRC BUILDING AUDIT AND TIME LINE OF PAST RETROFITS

This project is built upon past work by SRC, particularly the Building Energy Management (BEM) audit that they performed on King Edward Place (KEP) in 2003. A BEM audit includes a facility assessment with energy benchmarking, a technical audit, an evaluation of cost-effective retrofit options, and a summary of potential energy and cost savings. Many of the variables that will be used in the computer models of the building are based upon the measurements taken by SRC during this BEM audit. Some of the retrofit options and associated energy savings that are described in this thesis are also based upon the BEM audit report.

Figure 2.7 was created from the BEM audits SRC has completed of over 40 Saskatchewan buildings. The annual energy consumption of KEP in Figure 2.7 is approximately 370 kWh/m^2. This is approximately the measured amount of energy that the building consumed in the year 2002.

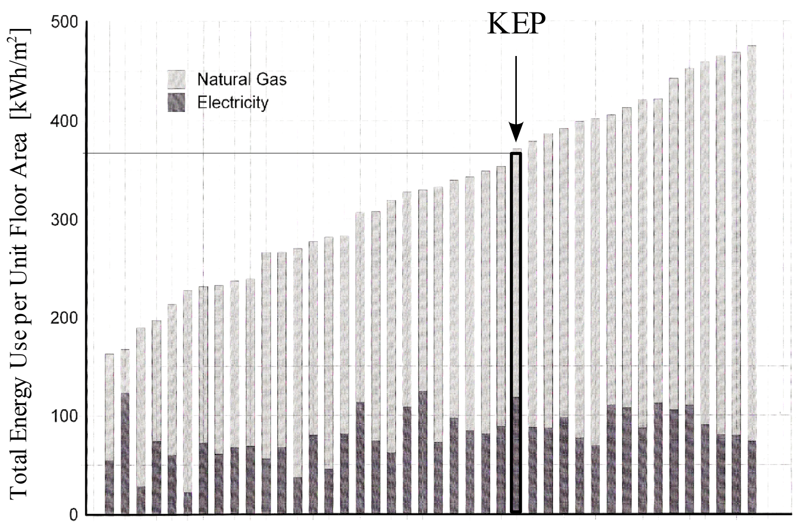

Figure 2.7: Measured energy of Saskatchewan apartments [2.2]

Over 70% of the buildings shown in Figure 2.7 are high-rise apartments but the buildings with the lowest energy consumption are typically low-rise apartment buildings. The total energy consumption of KEP is less than the Saskatchewan average of approximately 410 kWh/m^2 cited in Canadian Mortgage and Housing Corporations' (CMHC) HiStar Database [2.3]. Of the buildings audited by SRC, however, it appears to be a typical consumer of energy. Figure 2.7 shows, however, that the percentage of total energy consumption in KEP that is electricity is higher than expected.

Figure 2.8 shows the break down of the total grid purchased energy (GPE) of KEP in 2002 and Figures 2.9 shows the break down of KEPs annual utility billing in 2002. There are two electrical meters in the building, one for the suites and the other for non-suite building electrical consumption. There is only one meter for total natural gas use. Domestic hot water (DHW) energy consumption in Figure 2.8 was not directly measured. It was found from the measured total natural gas consumption using the method described in Appendix A1.4. Figure 2.8 shows that even if all of the energy consumed in the building was eliminated, with the exception of the electricity used in the suites, the goal of factor 10 still would not be achieved.

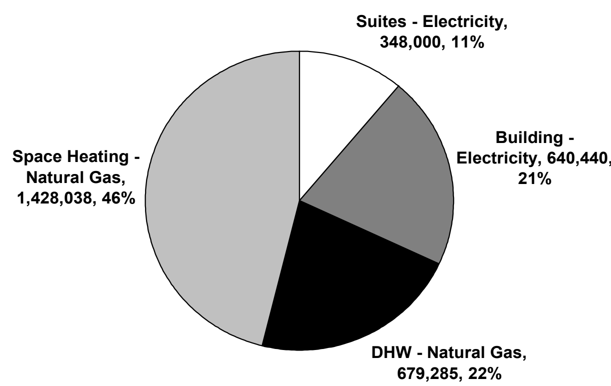

Figure 2.8: Breakdown of total annual energy use in 2002 (values are in kWh)

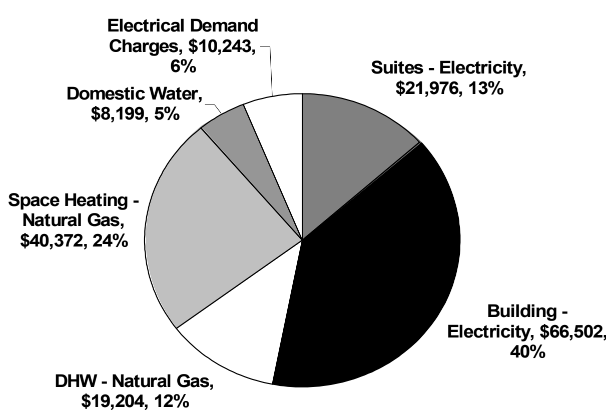

Figure 2.9: Breakdown of total annual utility costs (2002)

Creating a computer model of the building from which retrofits could be simulated required working backwards in time in order to account for energy saving retrofits performed in the building in recent years. Figure 2.10 shows a time-line of important retrofits and other events related to KEP since 2002.

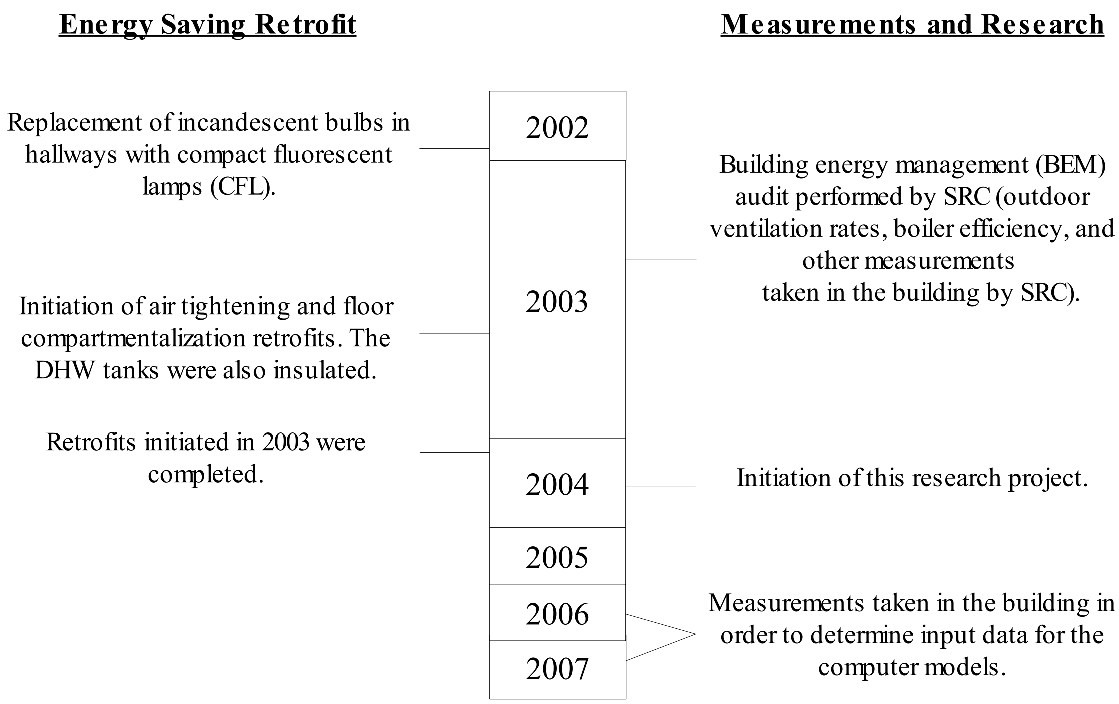

Figure 2.10: Building retrofit and research time line

Figure 2.10 shows that since 2002 there has been two energy saving retrofits undertaken in the building. The first was in December 2002 when all of the incandescent bulbs in the hallways were replaced with compact fluorescent lamps (CFL). The second was an air tightening and floor compartmentalization retrofit that SRC was contracted to manage and monitor. The goal of the air tightening and floor compartmentalization retrofits in 2003 was to reduce building infiltration by sealing air pathways between the interior and exterior of the building and also between floors in the building. This was achieved by weatherstripping the exterior doors of the building, stairwell doors and garbage chute doors, reducing the size of the opening around the elevator cables in the elevator mechanical room, sealing penetrations through floors such as electrical and pipe chases, and in general attempting to seal all potential pathways for air to travel across the exterior walls or between floors.

Monitoring the energy savings from the retrofits in 2003 required SRC to obtain meter measurements from the building during the years 2002-2005. Thus, the natural gas, water, and electrical readings used extensively throughout this thesis were either directly measured, or obtained from the utility companies, by SRC.

In order to create a "base" computer model from which proposed retrofits could be simulated, three different models were created in order to work backwards in time and account for the recent energy saving retrofits that have occurred. Models of the building during different years were also required because some of the measurements taken in the building and used to define the computer models (such as infiltration rate) were taken after energy saving retrofits had occurred. The three computer models of KEP that were created using EE4 are listed below:

1. A model of the building operating in the year 2005 (the time period when recent measurements were taken and all of the energy saving retrofits had been completed),
2. A model of the building operating in 2003 (the time period when SRC took their BEM audit measurements and prior to the insulation of the DHW heaters and the air sealing retrofits that affected infiltration rates),
3. A "base" model that represents the building operating in a typical year prior to all recent energy saving retrofits. This model accounts for the lighting retrofit in Dec. 2002 and uses annual averages for loads that will vary from year to year.

As 2002 is a year before the energy saving retrofits, the measured energy consumption during this year (370 kWh/m^2) should be similar to the annual energy consumption of the base computer model of the building. The method in which the base building model is defined as operating in a "typical" year, however, results in it having a lower annual consumption. This will be explained in greater detail in Chapter 7 where the energy consumption of the base model is introduced more fully.

The following 4 chapters describe how these 3 models were created based on literature and measurements. They are intended to provide the reader with more background on the building and its performance and also to demonstrate that the input data for the computer models matches the actual envelope, HVAC systems, and electrical equipment in the KEP building. Following these 4 chapters the "base" computer model of the building is summarized and the retrofit strategy to achieve a factor 10 reduction in GPE is presented.

CHAPTER 3
BUILDING ENVELOPE

3.1 EXTERIOR WALLS

The exterior walls of King Edward Place (KEP), not including windows, account for 3,446 m^2 (54%) of the buildings total above and below ground exterior surface area. Figure 3.1 shows a cross section of the exterior walls in KEP. The walls have a brick exterior that covers two distinct sections: a batt-insulated steel stud wall with a gypsum board interior surface and a concrete floor with rigid insulation at the perimeter.

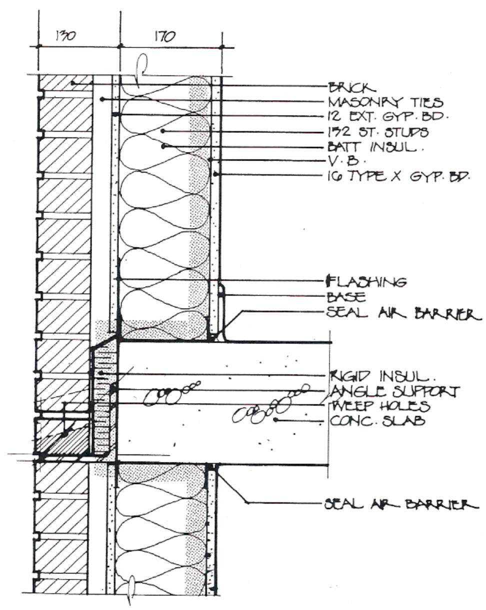

Figure 3.1: Blueprint drawing of exterior brick wall (dimensions are in mm) [3.1]

Figure 3.2 is an infrared photograph of the North exterior wall. In the figure, white denotes high temperatures and dark denotes low temperatures. The temperature of the exterior surface of the wall at the point where the cross-hairs appear in the figure was measured to be -14.5ºC (average daily temperature was -19ºC). The white pairs of rectangles are suite windows and the white horizontal bands locate the concrete floors.

Figure 3.2: Infrared photograph of the North exterior wall

Figure 3.2 shows that the windows and concrete floors have a greater surface temperature than the batt-insulated sections of the brick wall and therefore have a higher heat transfer rate. The computer model accounts for the presence of windows in exterior walls but the thermal bridging that occurs at the concrete floors needed to be considered when the exterior walls were defined in the models.

The EE4 program allows users to determine the thermal properties of a wall by choosing building components from a library of materials and placing them together in series. Each material chosen from the library is assigned a thickness and defined as either having studs or not. Studs are a source of thermal bridging across a material; and when they are present, the program calculates effective thermal resistance values that take them into account. Alternatively, a user can calculate the thermal resistance of a wall manually and enter it directly into the program.

The EE4 program's built in wall library was used to create two different wall sections, the batt-insulated steel stud wall and a concrete floor wall, in order to account for the presence of the steel studs in the batt-insulation and thermal bridging of the floor. These separate wall sections were created using the CBIP modeling guidelines, values from literature, and material data in EE4s built-in library. A total effective resistance for the whole wall was then found by manually calculating the effective resistance when the two wall sections are combined. Wall thermal resistance was then entered directly into the EE4 program. The total effective resistance of the exterior walls was found to be 1.84 m^2K/W (R 10.4). When thermal resistance values are given throughout this document 1 m^2K/W = 1 RSI and R 1 = 1 $ft^2 \cdot hr \cdot °F/BTU$ (1 RSI = R 5.678).

3.2 ROOFS

KEP has two distinct roof types. One is a flat, rigidly insulated, inverted roof with gravel ballast, and the other is a sloped metal roof with batt-insulation. There are two types of sloped roofs, one with 150 mm of batt-insulation and the second with 300 mm of batt-insulation. The total surface area of the flat roof is 329 m^2 and the total area of the sloped roofs is 724 m^2. Roofs account for 16.6% of the total above and below ground external surface area. Figure 3.3 shows the flat roof covering the 11th floor mechanical room and Figure 3.4 shows the sloped roof with 150 mm of batt-insulation. This roof type partially covers the first and second floor lounge areas and the first floor suites. There are also sloped metal roofs covering the 10th floor suites that are of a similar construction as the roof in Figure 3.4 except they have 300 mm of batt-insulation.

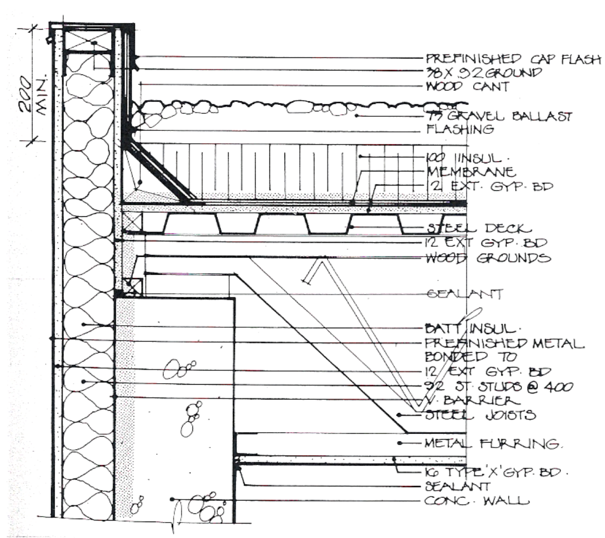

Figure 3.3: Flat 11th floor mechanical room roof (dimensions are in mm) [3.1]

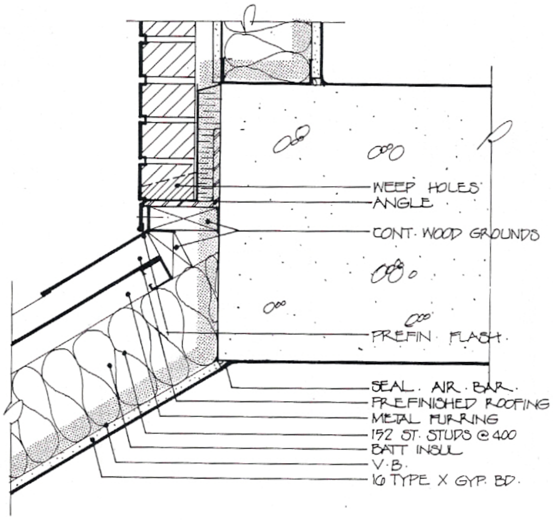

Figure 3.4: Sloped roof with 150 mm of insulation (dimensions are in mm) [3.1]

The thermal properties of the building's roofs were defined using the built in envelope construction library in EE4. The thermal resistance of the flat 11th floor mechanical room roof was found to be 3.87 m^2K/W (R 22.0). The thermal resistance of the sloped metal roof with 150 mm of insulation was found to be 1.73 m^2K/W (R 9.8) and the thermal resistance of the sloped metal roof with 300 mm of insulation was found to be 3.18 m^2K/W (R 18.1).

3.3 WINDOWS

Windows account for approximately 608 m^2 (9.5%) of the building's exterior surface. There are three main types of windows in KEP: operable suite windows, fixed suite windows, and fixed windows in the main and second floor recreation areas. The two most predominant types of windows in KEP are fixed picture windows and double-hung vertical sliding windows in the suites. They can be seen in Figure 3.5.

Figure 3.5: Living room (left) and bedroom (right) windows

Suite windows in the building are always grouped as operable/fixed pairs and each suite has one pair of windows in each of their living and bed rooms. The living room windows are larger than the bedroom windows. All windows in KEP are clear glass, with metal spacers, wooden frames, and metal exterior cladding.

The overall coefficient of heat transfer, U, and the solar heat gain coefficient (SHGC) are the variables used by the computer model to define the thermal properties of windows. Table 3.1 shows the U-values that were found for each window using methods outlined in the 1997 ASHRAE Fundamentals Handbook [3.2] (Appendix A1.2).

Table 3.1: Properties of the five window types in KEP

Location	Type	Width [m]	Height [m]	Area [m^2]	#	U [W/m^2K]	SHGC
Suite (Living Room)	Fixed	0.87	1.61	1.39	116	3.18	0.39
Suite (Living Room)	Operable	0.66	1.61	1.06	116	3.22	0.33
Suite (Bedroom)	Fixed	0.54	1.20	0.65	126	3.11	0.39
Suite (Bedroom)	Operable	0.66	1.20	0.79	126	3.21	0.33
Recreation Area or Hallway	Fixed	1.75	1.50	2.63	67	3.23	0.49

Solar heat gain coefficient (SHGC) is a dimensionless value that represents the solar heat gain properties of an entire fenestration product. It is equal to the fraction of incident irradiance that enters through the glazing and becomes heat gain. It includes both the transmitted portion and the absorbed, re-radiated, and convected portions. Typically SHGC values are given for unshaded windows but all of the windows in KEP have interior shading of some kind. Draperies and other interior shading devices have been found to have an effect on heating and cooling loads in buildings and were accounted for using the tables and methods outlined in the 1997 ASHRAE Fundamentals Handbook [3.2] (Appendix A1.2). The calculated reductions in SHGC due to shading were compared to amounts recommended by Enermodal Engineering, a Canadian energy consulting company, and found to acceptably agree [3.3].

3.4 INFILTRATION

This section describes how the infiltration rates were determined for the 2005 computer model. This model represents the current status of the building (after the air tightening retrofits SRC performed in 2003). The EE4 program requires the user to enter a constant infiltration rate based on exterior wall area. The default rate required by the CBIP program is 0.25 $L/(s \cdot m^2)$ for new building construction. Because infiltration results in approximately 14% of the natural gas energy consumption in KEP, it was decided to determine infiltration based on measurements of supply and exhaust air carbon dioxide (CO_2) concentrations, rather than use the default value.

3.4.1 CARBON DIOXIDE CONCENTRATION MEASUREMENTS

The concentrations of CO_2 in the central exhaust and supply ducts of KEP were monitored every 5 minutes for 8 days in January 2006 and 5 days in February 2006. A YES 206 Falcon infrared CO_2 monitor was used in the supply duct and a Vaisala M170 indicator with a MGP70 infrared CO_2 probe was used in the exhaust duct. Prior to performing the measurements, both were calibrated in SRC's lab according to the manufacturers specifications. The VAISALA meter specifies its accuracy to be 20 ppm + 2% of the reading. The YES Falcon meter specifies its accuracy to be 5% of the reading.

Figure 3.6 contains the measured data that shows that the concentration of CO_2 in the supply air increases dramatically, above the expected urban ambient level of 350-

375 ppm [3.2] during several days. The average supply and exhaust concentrations, for days when the supply concentration was below 500 ppm, was 386 ppm and 532 ppm respectively.

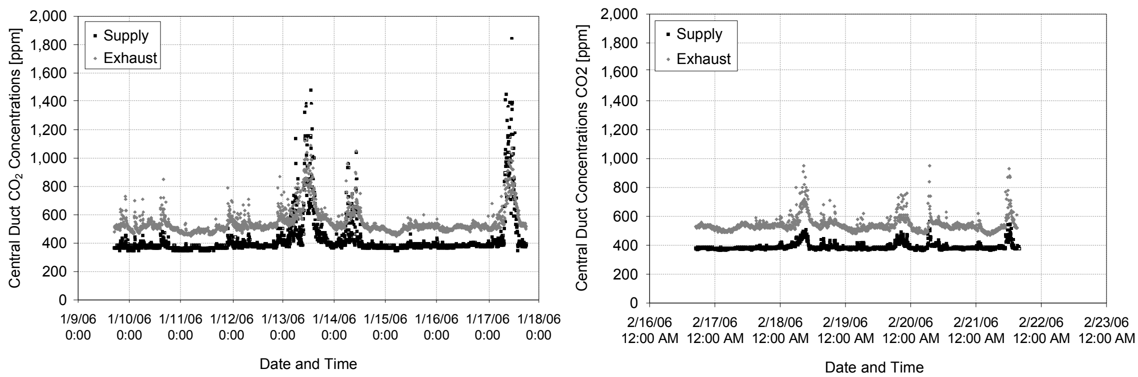

Figure 3.6: Measured January central supply and exhaust duct CO_2 concentrations during January (left) and February (right) 2006

One potential reason for the large increase in outdoor air CO_2 concentrations are weather inversions. An inversion of atmospheric air occurs when the temperature of the atmosphere increases as altitude increases as opposed to the typical decrease in temperature as altitude increases. A low level inversion will trap the air below it, limiting the dispersion of pollutants such as exhaust from vehicles. In some locations inversions result in smog accumulation over industrial and urban areas.

KEP is adjacent to a busy street and buses frequently stop in front of the South entrance. Traffic on this street during rush hour can back up for several blocks and, in 2000, the supply air intake was moved from the side of the building to the roof because tenants complained that they could smell vehicle exhaust air in the building. Upon further investigation it was observed by the building managers that litter caught in the wind by the bus stop would travel in a spiral up the side of the building and pass by the original air intake. It was apparent that under certain conditions an updraft would occur in the space between KEP and the adjacent building (to the West). Moving the supply air intake to the roof of the building has likely reduced the intake of vehicle emissions but when an inversion occurs the rooftop intake may sometimes still drawn in exhaust from vehicles and other sources as indicated by the CO_2 measurements in the supply duct.

Figure 3.7 shows, for each hour of the day, the measured concentrations in the central supply and exhaust air ducts as well as the average difference between exhaust and supply concentrations. Each point for each hour is from a different day. To create these graphs the data in Figure 3.7 were filtered in order to only use days in which the outdoor CO_2 concentration was relatively stable and below 500 ppm (January 11, 15, & 16, and February 16, 17, 19, & 20).

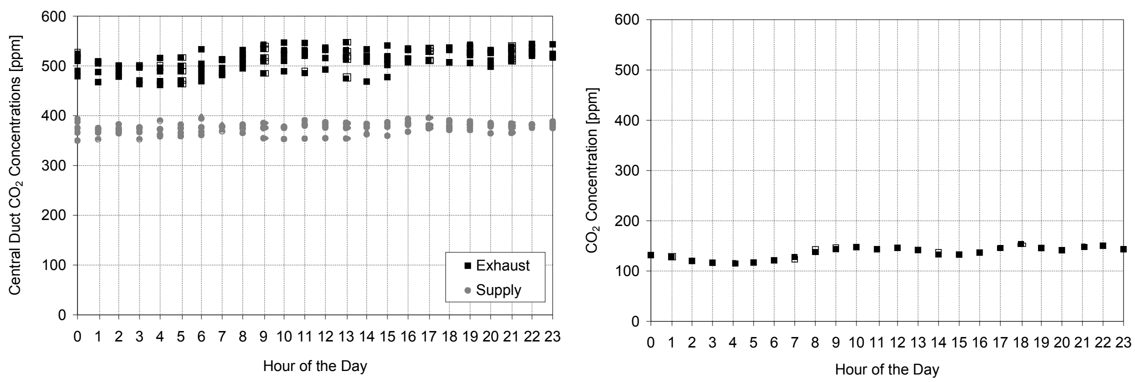

Figure 3.7: Measured hourly CO_2 concentrations for selected days (left) and average (Exhaust – Supply) concentrations for each hour

The difference in CO_2 concentration drops during the night (between midnight and 6am), in the early afternoon (between 1:00 pm and 3:00 pm), and in the evening (between 7:00 pm and 9:00 pm). Assuming that the difference in CO_2 concentrations is greatest when the CO_2 emission of the tenants is greatest, the most likely cause of the decrease in CO_2 concentration during the night is the lower metabolic rate of the tenants while sleeping. In the afternoon and evening the decreases are most likely due to people leaving the building. The difference in the CO_2 concentrations between the supply and exhaust air streams peaks at noon, 6 pm, and 10 pm, all hours when tenants are most likely to be in the building preparing meals or retiring for the evening. Also, when it peaks at these times, it does so at approximately the same concentration.

3.4.2 CALCULATION OF INFILTRATION

The steady-state indoor pollutant concentration of a building can be determined from the mass balance:

$$(Q_S+Q_I)C_o+S=(Q_{Exh}+Q_{Exf})C_i \tag{3.1}$$

where C_i is the steady-state indoor concentration (mg/m^3), C_O is the steady-state outdoor concentration (mg/m^3), S is the total pollutant source strength (mg/s), Q_S is the mechanical supply air rate (m^3/s), Q_I is the infiltration rate (m^3/s), Q_{Exh} is the mechanical exhaust air rate (m^3/s), and Q_{Exf} is the exfiltration rate (m^3/s). If it is assumed that changes in density are negligible then the volume flow rate entering the building ($Q_S + Q_I$) must equal the volume flow rate leaving the building ($Q_{exh} + Q_{exf}$) and the rate at which air enters or leaves the space, Q_t, will be:

$$Q_t=(Q_S+Q_I)=(Q_{Exh}+Q_{Exf}) \tag{3.2}$$

With carbon dioxide as the pollutant, and assuming that the occupants were the only source of CO_2 in the building, the equation becomes:

$$Q_t C_{EX}=Q_t C_S+nR \tag{3.3}$$

where C_{EX} is the concentration of CO_2 in the exhaust air (mg/m^3), C_S is the concentration of CO_2 in the supply air (mg/m^3), n is the number of tenants (persons), and R is the CO_2 emission rate of tenants (mg/s). This rate, R, was defined as:

$$R = r\, M\, A_{DU}\, \rho_{CO2} \tag{3.4}$$

where r is the average metabolic CO_2 emission rate of the tenants (L/(s·W)), M is the average tenant metabolic rate (W/m^2), A_{DU} is the average surface area of a human (m^2), and ρ_{CO2} is the density of CO_2 at room temperature (kg/m^3).

With the exception of the laundry rooms, which are directly exhausted to the outdoors at a rate of 57.5 L/s, the above ground floors of KEP are mechanically ventilated using central exhaust and central supply ducts. The central supply system provides air to the hallways and the central exhaust system draws air from the bathrooms. Chapter 5, Section 2, discusses how central supply and exhaust rates were measured in 2006 to be 3,307 L/s and 3,270 L/s, respectively, and that fan speed was found to be relatively constant throughout the year. In order to determine the infiltration rate, Q_t was defined as $(Q_S + Q_I)$ and Equation 3.3 was solved for Q_I.

Equation 3.4 shows that CO_2 production from the occupants can be estimated based on their metabolic rate. Based on values in the 1997 ASHRAE Fundamentals Handbook, the average daily metabolic rate for an average adult male is approximately 1.3 Met [3.2]. Human metabolic rates decrease with age, however, and it was felt that the ASHRAE values would likely overestimate the actual metabolic rate of the seniors in KEP. Metabolic rate is also typically different for males and females. Therefore medical papers were consulted in order to determine the metabolic rate of elderly males and females. Based on the findings published in 5 medical journals the average rate for senior males and females was found to be 1.13 Met (or 65.8 W/m^2) [3.4-3.8]. A Canadian study of over 650 people found the average surface area of an adult to be 1.88 m^2 [3.10] and the metabolic CO_2 emission rate for humans was found to be 4×10^{-5} L/(s·W) [3.11]. These values result in an average daily CO_2 emission rate of 536 mg/min per tenant. Based on measured peak CO_2 emissions, estimated peak occupancy, and measured minimum CO_2 emissions, the average daily building occupancy for the measurement period was calculated to be approximately 122. Using these average values the total building infiltration was found for each hour and is presented in Figure 3.8.

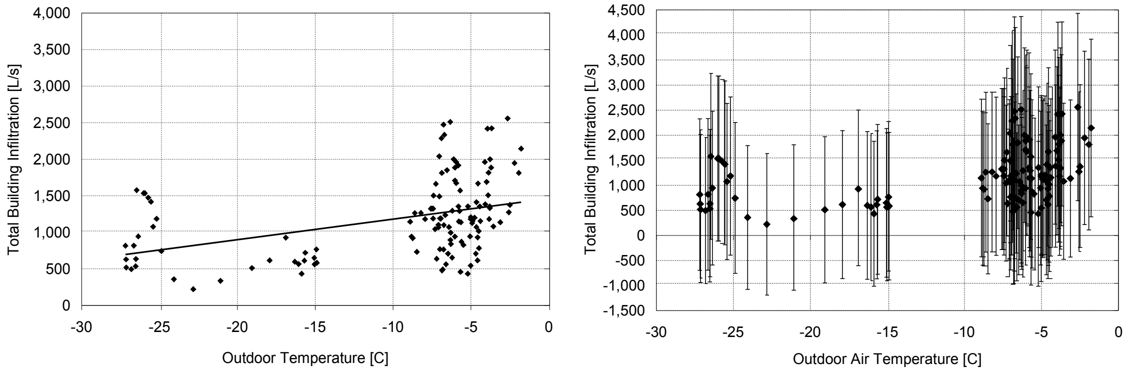

Figure 3.8: Infiltration as a function of outdoor air temperature, with linear trend-line and without error bars (left) and with error bars (right)

The average infiltration rate of the data points in Figure 3.8 is 1,190 L/s and the average uncertainty of this average rate is ± 1,632 L/s (Appendix A2.2). There is significant scatter in the data and the precision uncertainty is ± 1,073 L/s. The bias uncertainty is ± 1,230 L/s and the largest component of this uncertainty is the uncertainty in the CO_2 emission rate of the tenants. It is interesting to note the trend is for infiltration to decrease as outdoor air temperature decreases. In theory, when the outdoor temperature decreases, infiltration should increase. This assumes, however, that the size of the penetrations in the building envelope are constant. For KEP it was believed that the occupants closed more windows as the outdoor temperature decreased, resulting in a lower infiltration rate.

A thorough study of tenant window opening behaviour was not made but on warmer (above -15ºC) winter days it was observed that over 25 windows would be fully open. On colder days (below -15ºC), however, it was observed that typically less than 5 windows would be fully open (with many still partially open). In addition to window opening behaviour, the installation/removal of window mounted air conditioners (WMAC) is also likely to impact infiltration rates. In the summer of 2005, 26 WMAC units were installed in suite windows and in the following winter this number was reduced to 13. It is not known exactly at what point tenants would decide to remove their window mounted units but it is likely that decreasing outdoor temperature would be a factor in their decision.

The default in the computer modeling program EE4 is a constant infiltration rate for all times, regardless of wind speed or outdoor temperature. It is possible, through editing of the DOE text file created by EE4, to account for outdoor temperature and wind velocity when determining infiltration in the building model by using the crack method to define infiltration. This should be a better method of defining infiltration than using a constant average infiltration rate. Use of this method was investigated but Figure 3.8 indicates that occupant control of the windows may counterbalance the effect of decreasing outdoor air temperature. With occupant control nearly unpredictable, it was felt that it was best to follow the CBIP modeling guidelines and use a single average infiltration rate for the year based on the measured results. This method certainly has drawbacks associated with it but it was felt that the complexity of defining infiltration for a building that is dynamically impacted by both the environment and its occupants was beyond the scope of this work.

The EE4 program requires the user to enter infiltration rate based on exterior wall area. When the average measured infiltration rate into the building (1,190 L/s) is divided by the total exterior wall area of the building the infiltration rate becomes equal to 0.294 L/(s·m^2) and the uncertainty in this rate becomes ± 0.40 L/(s·m^2). Infiltration can only be entered into the computer model using 2 decimal places, however, and it was therefore entered as 0.29 L/(s·m^2). It was found that if the infiltration rate entered into the computer model was increased or decreased by 0.01 L/(s·m^2) the total natural gas consumption estimated by the 2005 computer model would respectively increase or decrease by approximately 0.6%.

3.4.3 MODEL AND MEASUREMENT MATCHING – INFILTRATION

The infiltration rate of 0.29 L/(s·m^2) ± 0.40 L/(s·m^2) was used in the 2005 computer model and it was expected that the rate of infiltration would decrease from 2003 to 2005 because of the air tightening retrofits undertaken in the building by SRC in 2003. Therefore the 2003 computer model was created by defining all other variables in the model and iteratively increasing infiltration rate from 0.29 L/(s·m^2) until the predicted natural gas consumption of the 2003 model matched the measured consumption in 2003.

Figure 3.9 shows the measured natural gas consumption in 2003 and the consumption of the 2003 computer model with infiltration equal to 0.29 L/(s·m^2). Linear trend lines have been fitted to both sets of data and model points are weekly averages.

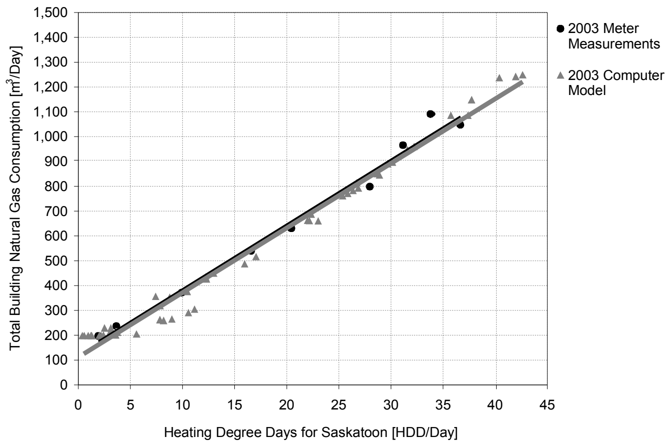

Figure 3.9: First infiltration iteration of 2003 computer model (0.29 L/s·m^2)

Table 3.2 shows the results from each iteration of infiltration rate. In order to match the consumption predicted by the computer model to the measured data, annual natural gas consumption was determined using the annual effective natural gas consumption equation previously presented in Section 2.2 (Equation 2.1). Annual consumption was matched in this way because the meter measurements in 2003 were taken on a monthly basis and the consumption during the days in which the computer model is run using the 2003 weather data was not known. The slope and y-intercept of the measured natural gas data in Figure 3.9 is 26.075 m^3/HDD and 125.24 m^3/Day (R^2 = 0.984). To determine infiltration in the 2003 model infiltration rate was increased using steps of 0.01 L/(s·m^2) because this is the lowest allowable increment in the EE4 model.

Table 3.2: Infiltration iterations when matching model to measured data (2003)

Infiltration [L/(s m²)]	Slope [m³/HDD]	Y-Intercept [m³/Day]	Modeled Annual Consumption [m³/Year]	Modeled Annual Consumption [kWh/Year]	Difference from Measured Data [%]	Trendline R^2
0.29	25.662	123.80	197,876	2,047,956	-1.50%	0.993
0.31	25.996	123.38	199,710	2,066,938	-0.60%	0.993
0.32	26.158	123.20	200,608	2,076,234	-0.10%	0.993
0.33	26.324	122.97	201,512	2,085,587	0.30%	0.993

Table 3.2 shows that the best match to the measured annual natural gas consumption in 2003 was 0.32 L/(s·m²). The 2005 infiltration rate of 0.29 L/(s·m²) corresponds to 1,176 L/s and the 2003 infiltration rate of 0.32 L/(s·m²) corresponds to 1,297 L/s. Thus, in the computer model, there was a 9.4% decrease in infiltration from the year 2003 to the year 2005. This decrease resulted in a savings of approximately 2.4% in annual natural gas consumption.

3.4.4 VALIDITY OF INFILTRATION VALUES USED

This section discusses whether the infiltration values entered into each computer model are reasonable by referencing measurements and literature. As noted previously, the EE4 program uses a default value of 0.25 L/(s·m²) for all buildings, 14% lower than the value of 0.29 L/(s·m²) in the 2005 model and 22% lower than the value of 0.32 L/(s·m²) in the 2003 model. The MNECB states that 0.25 L/(s·m²) is the recommended value for infiltration in a new building. This value is not given at a stated pressure, making it difficult to compare it to values found in literature because typically air leakage is given at pressures such as 50 or 75 Pa.

During the 2003 BEM audit SRC performed a blower door test on a 4th floor suite in KEP. The equivalent leakage area (ELA) measured in this suite and comparative values of other buildings in Saskatchewan (from SRC BEM audit data of over 20 buildings) can be seen Table 3.3.

Table 3.3: Equivalent leakage area measured by SRC in 2003

KEP [cm²]	Best [cm²]	Average [cm²]	Worst [cm²]
167	107	195	341

Table 3.3 shows that in 2003 the suite measured in KEP had an ELA that was 36% higher than the best measured by SRC and 14% lower than the Saskatchewan average measured by SRC. Suite blower door tests inside apartments can be misleading because it is unknown how much leakage occurs across the interior walls between suites. Studies of other Canadian apartment buildings have found, however, that leakage between suites was less than 5% [3.12].

A Canadian study of infiltration in high-rise apartment buildings published coefficients for an infiltration correlation based on measurements taken in a 22 story apartment in Ottawa [3.12]. The correlation breaks apartment suites into three types, as labeled in Figure 3.10.

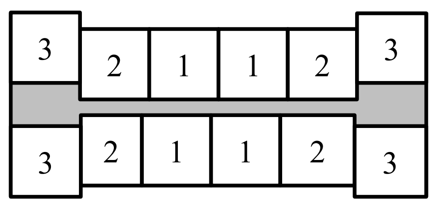

Figure 3.10: Typical floor and 3 suite types in Ottawa study

The grey area between the suites in Figure 3.10 is the hallway. The typical floor plan for KEP is very similar to the floor plan in Figure 3.10.

The study calculated infiltration using the power law equation for cracks:

$$Q = C_C (\Delta P)^n \qquad (3.6)$$

where Q is the fluid flow rate (L/s), C is a flow coefficient (L/(s·Pa^n)), and ΔP (Pa) is the pressure across the exterior wall ($P_{out} - P_{in}$). The values for C and n are different for each of the three types of suites seen in Figure 3.10.

In the winter of 2005, at a time when the outdoor temperature was -12ºC and the average wind speed was 7 km/hr [3.13], pressure measurements were taken across doors and windows in the central corridors on 5 floors in KEP in order to determine the indoor-outdoor ΔP profile. Figure 3.11 shows the measured values and a linear trend-line ($R^2 = 0.89$) fitted to the 5 data points.

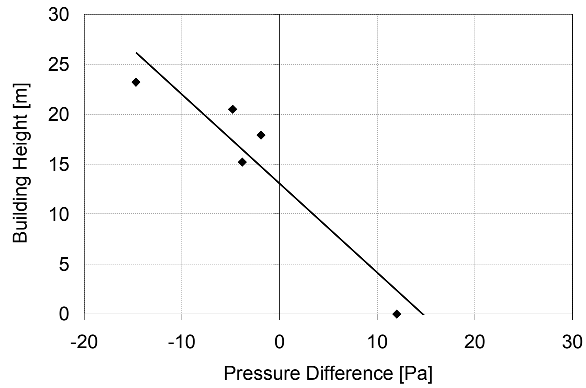

Figure 3.11: Measured ΔP ($P_{out} - P_{in}$) on December 19, 2005

Using the coefficients from the infiltration study and the pressure differences found from the linear trend-line in Figure 3.11, the infiltration rate for each floor in KEP was calculated to be 986 L/s. This is 17% less than the average measured infiltration rate of 1,190 L/s and well within the scattering of infiltration data previously shown in Figure 3.8. This is not a comprehensive study of the pressure profile in KEP and it is questionable how much infiltration rates of two different buildings can be compared. It does show, however, that the measured infiltration rates previously shown in Figure 3.8 are of the same magnitude as what would be predicted from a correlation determined from detailed measurements in a similar Canadian high-rise apartment.

Perhaps the best validation for infiltration, however, is the fact that boiler efficiency is so reasonable. The section on boilers in the next chapter will discuss how boiler thermal efficiency was found by matching natural gas consumption of the 2005 computer model to the measured natural gas consumption in 2005. This required entering the measured average infiltration rate of 0.29 L/(s·m^2) into the 2005 model. By using a model matching approach to determine the thermal efficiency of the boilers, a different value for infiltration would have resulted in a different value for the boiler thermal efficiency. If the infiltration rate in the 2005 computer model had been assumed to be the EE4 default value of 0.25 L/(s·m^2) the boiler thermal efficiency would have been reduced from 75% to 73% (see Figure 4.3). A thermal efficiency of 73% is reasonable and therefore using the EE4 default value for infiltration would have probably been satisfactory.

However, if infiltration had not been measured the computer model would not have been completed by assuming the default infiltration rate was correct. Instead, the boiler efficiency would have been assumed based on values in literature and infiltration would then have become the variable found by iteratively matching natural gas consumption. If the infiltration rate had not been known the annual fuel utilization efficiency (defined in the next chapter) of the boilers in the 2005 model would have been assumed to be 68%. The actual annual fuel utilization efficiency that was arrived at in the 2005 model was 67.8%. Therefore the infiltration rate determined from this method would have been greater than the measured average by less than 0.01 $L/(s \cdot m^2)$.

CHAPTER 4
BOILERS, CHILLER, WATER HEATERS, AND PUMPS

This chapter gives an overview of the boilers, chiller, water heaters, and pumps in KEP and describes measurements that were taken to define these systems in the computer models.

4.1 BOILERS

The building has 20 atmospherically drafted cast iron hot water boilers which are located in the 11^{th} floor mechanical room and can be seen in Figure 4.1.

Figure 4.1: Boilers in 11^{th} floor mechanical room

Each boiler has a standing pilot light and the boiler system shuts down when the outdoor temperature exceeds 18ºC. Boiler hot water outlet temperature is controlled by an outdoor air reset but must remain within maximum and minimum setpoints. Each boiler has an output capacity of 70.3 kW (240,000 BTU/hr) and the total output capacity of the boiler system is 1.41 MW (4,800,000 BTU/hr). The boilers are cycled continuously using a digital control system.

Each boiler has a chimney that connects to a central stack that serves a bank of 5 boilers. Thus there are 4 large chimneys penetrating the roof as a result of the boilers. Hot return water travels through the boilers using a "first-in, last-out" piping system for each bank of 5 boilers. This piping system results in the hot return water passing through the first boiler in a bank of five and exiting from the last boiler in the bank. Thus all 20 boilers are continuously heated by the return water and subsequently continuously vent warm air up their exhaust stacks. Heating in the suites is provided by baseboard convection heaters supplied with hot water from the central boilers. Hot water from the boilers is also supplied to small wall and roof mounted unit heaters in the stairwells, mechanical rooms, 11^{th} floor mechanical room, and crawlspace.

4.1.1 MODEL AND MEASUREMENT MATCHING - BOILER EFFICIENCY

This section discusses how the thermal efficiency of the boilers was determined by matching the natural gas consumption of the 2005 model to the measured consumption in 2005. Thermal efficiency of the boilers was determined by defining all other variables in the 2005 computer model and then iteratively reducing the thermal efficiency of the boilers from 100% until the consumption predicted by the computer model best matched the consumption data for 2005. The measured infiltration rate of 0.29 L/(s·m^2) was one of the important variables used to define the 2005 model. Figure 4.2 shows the measured natural gas consumption in 2005 and the consumption estimated by the 2005 computer model when the boiler thermal efficiency is set to 100% (model points are weekly averages).

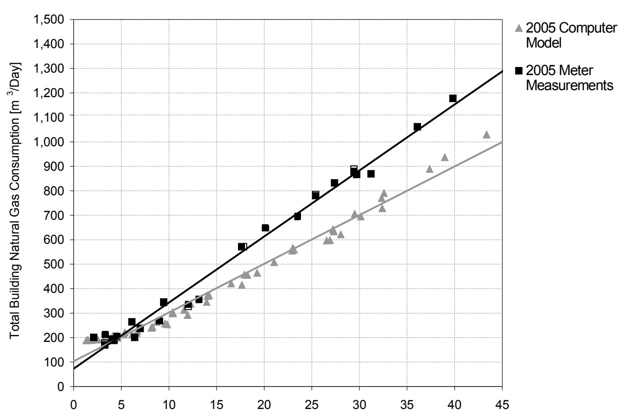

Figure 4.2: Metered consumption vs. 2005 computer model (boiler efficiency = 100%)

Table 4.1 shows results from each successive iteration in boiler thermal efficiency. It includes the percent difference between the total annual consumption measured in 2005 and the 2005 computer model results. The R^2 of each computer model linear trend-line was 0.984 and a thermal efficiency of 75.0% was the best fit to the measured data.

Table 4.1: Boiler thermal efficiency iterations, matching model to meter readings (2005)

Boiler Thermal Efficiency [0-1]	Slope [m^3/HDD]	Y-Intercept [m^3/Day]	Annual Consumption [m^3/Year]	Annual Consumption [kWh/Year]	Difference from Measured Data [%]
1.000	20.058	104.8	157,579	1,630,894	-15.9%
0.760	26.392	79.4	185,996	1,925,005	-0.8%
0.750	26.743	77.9	187,571	1,941,301	0.1%
0.740	27.107	76.5	189,206	1,958,220	0.9%

Figure 4.3 shows the boiler thermal efficiency values that would have been found if different infiltration rates had been used. Recall that if the default infiltration rate of 0.25 L/(s·m^2) had been used in the 2005 model the resulting boiler thermal efficiency would be approximately 73%.

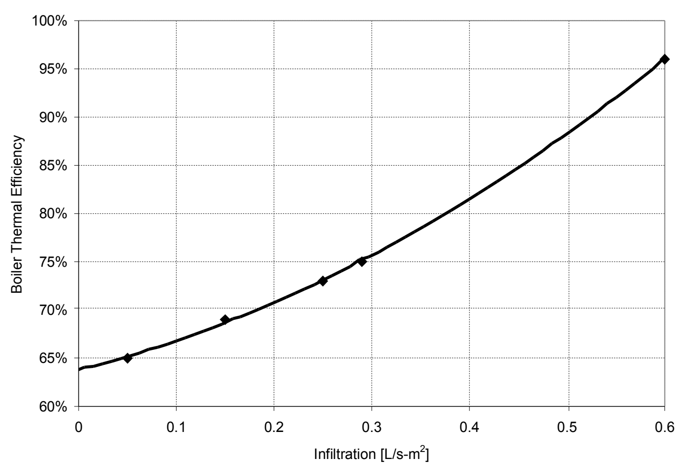

Figure 4.3: Boiler thermal efficiency for different infiltration rates (2005 model)

4.1.2 VALIDITY OF BOILER EFFICIENCY IN MODEL

This section investigates if the boiler thermal efficiency found by matching the model to measured consumption is reasonable. Thermal efficiency is the efficiency of the boiler system when it is operating at its full-load and it is the maximum possible efficiency of a boiler system. According to the nameplate rating of the boilers this should be 80%. In the 2003 BEM audit, SRC measured the exhaust gas temperature rise and carbon dioxide concentration of 10 boilers in KEP and calculated the combustion efficiency for each. The average measured combustion efficiency at that time was 78.0%. There are 20 boilers in KEP and together they form a system with an efficiency that will be different than the average combustion efficiency of the individual boilers due to continuous heat losses through the boiler stacks and jackets. Therefore, the thermal efficiency of the boiler system will be lower than the measured combustion efficiency, indicating that 75% is a reasonable value.

When the computer model calculates fuel consumption, the thermal efficiency of the boilers is adjusted by a quadratic part-load correlation. The amount of time a boiler needs to meet low operating loads greatly impacts the seasonal efficiency of the system because boilers are most efficient when operating at full load. The thermal efficiency correlation that determines boiler fuel consumption in the EE4 program is defined in Section A.3 of the 1999 NRC document, *Performance Compliance for Buildings* [4.1]. Figure 4.4 was generated using this correlation and the assumption that the design efficiency was equal to the measured average combustion efficiency (78.0%). It shows how boiler efficiency steadily decreases as load percentage decreases.

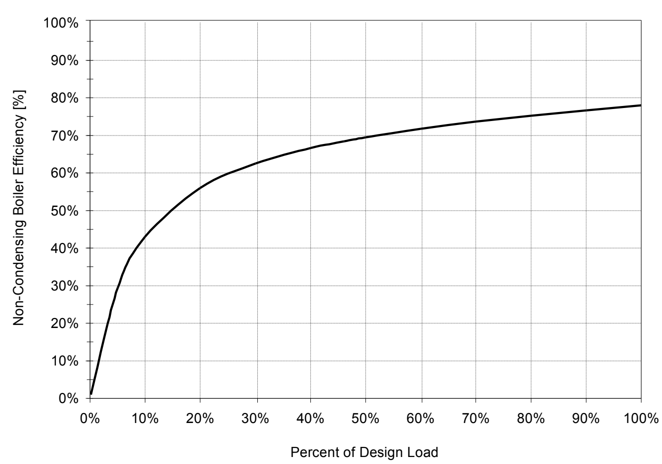

Figure 4.4: NRC relationship between boiler efficiency and boiler load percentage (for non-condensing boilers)

Figure 4.5 shows how part-load ratio and boiler efficiency varies throughout the year in the 2005 computer model when 75% is used as the thermal efficiency of the boilers. The minimum and maximum boiler efficiencies in Figure 4.5 are 57.8% and 72.5% respectively. The average of the efficiency values in Figure 4.5 is 65.5%.

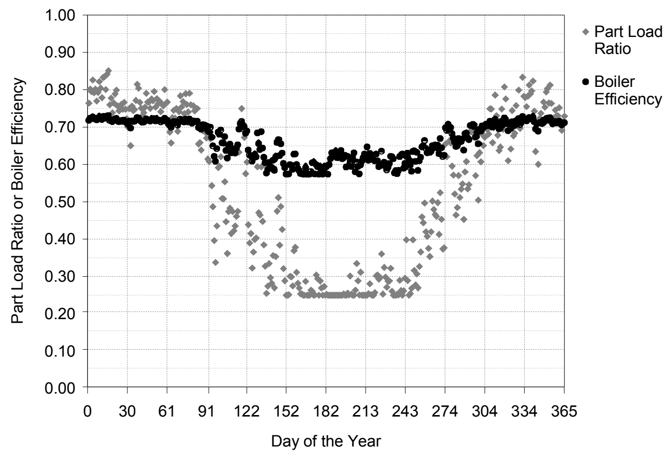

Figure 4.5: Weekly average boiler efficiency and part-load ratio (2005 computer model)

The annual fuel utilization efficiency (AFUE) of a heating system is equal to the total heat delivered over the year divided by the fuel consumed in order to generate that heat. The AFUE rating of older, low-efficiency, atmospherically drafted heating systems with continuous pilot lights and a heavy heat exchanger is expected to be 68%–72% [4.2]. When the sum of the heating loads for each hour in the computer model of the building are divided by the sum of the boiler fuel consumption calculated for each hour the resulting AFUE value is 70.8%. When the consumption of the 20 continuously running pilot lights are included, however, the AFUE of the boilers falls to 67.8%.

It is not known how the previously stated range of 68%-72% accounts for losses in efficiency over the lifetime of the boilers. An AFUE value of 67.8% may therefore be marginally higher than what was expected for a boiler system that has been in operation for over 20 years. The higher efficiency may be due to the digital controls used to manage the boiler system. Overall it was felt that both the thermal efficiency and AFUE of the boilers were reasonable and only long term detailed measurements of the boilers in operation would result in greater confidence in the values used.

4.2 CHILLER

Central cooling is provided by a reciprocating 28 ton (98 kW) rooftop water chiller. The unit is air cooled and designed for a liquid flow rate of 4.24 L/s. During the cooling season the chiller conditions the ventilation air provided to the hallways to a temperature of 18ºC-20ºC. The cooling provided to the building is apparently insufficient, however, as in 2005 there were 26 window mounted air conditioning (WMAC) units operating in the suites and in the summer of 2006 there were 39. Tenants with air conditioners in their windows pay a fixed amount during the summer months for their use.

4.3 DOMESTIC HOT WATER HEATERS

Domestic hot water (DHW) is provided by 3 atmospherically drafted hot water tanks in the 11th floor mechanical room. Each has a rated input capacity of 146 kW (500,000 BTU/hr), a storage capacity of 260 L, and a recovery rate of 1,590 L/hr (420 US gal/hr). Figure 4.5 shows the DHW tanks after they were insulated by SRC in 2003.

Figure 4.5: Insulated DHW tanks

Each DHW tank in KEP is natural gas fired and has a standing pilot light. The 3 chimneys exiting the DHW heaters connect together and exhaust from a single stack in the roof. With no stack dampers in place, the draft from any single water heater may also draw heat from the other tanks.

The computer models of the building require the user to input the maximum DHW use, on a per occupant basis, for each room. In the model the load for each hour is then determined by multiplying this maximum DHW use by hourly load percentages defined in the zone DHW schedule. Thus for each hour of the day, the actual DHW use in each room is a specific fraction of the maximum. This maximum value was determined from meter measurements of actual natural gas consumption in KEP during the years 2003 and 2005 to be 170 m^3/Day for the 2005 model and 189 m^3/Day for the 2003 model (Appendix A1.4). The average peak DHW water use entered into the computer models was 864 W/Occ. KEP is expected to be a "low" user of DHW in comparison to an average apartment building because the tenants are seniors [4.3]. One average given by CMHC for the total annual measured water use in Canadian apartment buildings is 182 m^3/suite [4.4]. In 2003, the tenants in KEP used an average of 175 m^3/suite. This indicates that if the proportion of DHW use in both average values is approximately the same, KEP may be considered a low user of DHW. Appendix A1.4 also includes a calculation of the expected peak DHW load for a low-water use building based on values found in the 1999 ASHRAE HVAC Applications Handbook [4.3]. Peak DHW from this source was found to be approximately 863 W/Occ. Average peak domestic hot water consumptions in the model is therefore similar to the ASHRAE recommended value for this type of building.

4.4 PUMPS

KEP has 12 pumps and their rated powers, speeds, and flow-rates can be seen in Table 4.2.

Table 4.2: Listing of pumps in KEP including rated power, speeds, and flow-rates

Pump	Rated Power [kW]	Rated Head [kPa]	Rated RPM	Rated Flow [L/s]	Control
Outdoor Air Coil	1.12	89.7	1750	5.4	Continuous Operation
Reclaim	1.12	134.5	1750	3.2	Continuous Operation
Chilled Coil	1.12	119.6	1750	4.4	Continuous Operation
Boiler Circulation 1	1.49	89.7	1750	8.8	Continuous Operation
Boiler Circulation 2	1.49	89.7	1750	8.8	Manually Turned Off
Glycol Fill	0.25	74.7	3450	0.9	Automatic
Booster Pump 1	2.24	328.8	3500	1.9	Automatic - Pressure Based
Booster Pump 2	3.73	328.8	3500	4.7	Manually Turned Off
Booster Pump 3	5.60	328.8	3500	6.0	Manually Turned Off
DHW Circulation	0.09	-	3250	-	Automatic - Temperature Relay
Sump Pump 1	0.30	-	-	-	Float in Sump Pit
Sump Pump 2	0.30	-	-	-	Float in Sump Pit
Sump Pump 3	0.30	-	-	-	Float in Sump Pit

There are two boiler circulation pumps that supply hot water to the finned-tube baseboard convection heaters throughout the building. Only one boiler circulation pump operates at any given time, however, as they are manually alternated at the beginning of each heating season. Booster pumps are used to raise the pressure of water from the municipality. In high-rise buildings they are typically necessary in order to deliver the municipal water to the top floors of the building. The building manager stated that the booster pumps in KEP, however, rarely operate as the water pressure in that area of the city is sufficient. Thus the two large booster pumps are off and the remaining pump automatically engages when needed. The DHW circulation pump is controlled by a thermostat set to 55ºC.

The four variables that can be entered into the computer model to define the heating and cooling circulation pumps are: effective head, design temperature drop, pump efficiency, and motor efficiency. The design temperature drop, pump efficiency, and motor efficiency were determined from manufacturers' specifications and literature. The effective head is the pressure during actual operation and rather than entering the manufactures rated values into the computer models, the annual power consumption of each pump was estimated from measurements taken while the pumps were in operation. The effective head was then iteratively varied in the computer model until the pump motor electrical consumption calculated by the model equaled the annual energy consumption found from the pump motor measurements.

To approximate the electrical power consumption of the motors driving each pump the following equation was used:

$$Energy\,Consumed = Rated\ Power \cdot Load\ Percent \cdot Time \qquad (4.1)$$

The load percent of each pump motor was estimated by measuring the operating speed of each pump motor using a Monarch Nova-Strobe DB digital stroboscope with a resolution of ±0.1 RPM and recording the motors rated power. After pump motor speed was measured, the load percentage was approximated using the equation [4.5, 4.6]:

$$Load\ Percent = \frac{1800 - Measured\ Speed}{1800 - Rated\ Speed} \qquad (4.2)$$

(for 4-pole motors) which may have an uncertainty as high as ± 20% [4.6].

Table 4.3 shows the measured operating speeds of the 4 circulation pumps in August and October 2006. Measurements were taken during two different operating seasons as it was thought that pump power may vary seasonally.

Table 4.3: Measured speed and calculated percent load for each pump motor

		Aug-06		Oct-06		Average	
Pump	Rated RPM	Measured RPM	Pump Load [%]	Measured RPM	Pump Load [%]	Measured RPM	Pump Load [%]
Boiler Circulation	1745	1764.0	65%	1764.4	65%	1764.2	65%
Chilled Coil	1745	1754.5	83%	1755.7	81%	1755.1	82%
Reclaim	1745	1740.8	108%	1746.1	98%	1743.5	103%
Outdoor Air Coil	1745	1755.3	81%	1758.9	75%	1757.1	78%

The flow resistance of the heating coil, reclaim coil, and chilled water coil should all remain relatively constant throughout the year but in the case of the boiler circulation pumps it was thought that there may be variations in the flow resistance when tenants adjust their thermostats. The difference in measured values between August and October, however, is negligible. There may still be seasonal variations that occur but it was assumed that the measured values sufficiently represented the average annual speed of the pumps.

Table 4.4 shows the calculated annual average energy consumption of each continuously operating pump. Annual electrical consumption of the pumps in the computer model was matched to the values in Table 4.4 by iteratively adjusting pump effective head. The remaining pumps listed in Table 4.2 were entered into the computer models as receptacle loads and will be discussed in Chapter 6.

Table 4.4: Average annual pump motor electrical consumption

Pump	Rated Power [kW]	Load [%]	Hours / Year	Annual Energy [kWh]	kWh/Day
Boiler Circulation	1.49	0.65	8,760	8,502	23.3
Chilled Coil	1.12	0.82	8,760	7,995	21.9
Reclaim	1.12	1.03	8,760	10,087	75.3
Heating Coil	1.12	0.78	8,760	7,639	20.9

CHAPTER 5
MECHANICAL VENTILATION AND HEAT RECOVERY

This chapter describes the building's mechanical ventilation and heat recovery systems and the field measurements undertaken to define them in the computer models.

5.1 MECHANICAL VENTILATION SYSTEMS SUMMARY

Mechanical ventilation is provided in the building by 4 air handling units (AHU). Table 5.1 summarizes the rated specifications for each of these units.

Table 5.1: Building AHU ratings summary

AHU	Flow Rate [L/s]	Static Pressure [Pa]	Fan Power [kW]	Motor Power [kW]
Central supply AHU	4388	747	5.8	7.5
Central exhaust AHU	4388	498	3.9	5.6
Main floor recirculation AHU	1199	249	0.5	0.6
Second floor AHU	1982	374	1.3	1.5
Crawlspace AHU	-	225	-	1.3

Mechanical ventilation of the above ground floors is provided by a TRANE Climate Changer packaged AHU located in the 11th floor mechanical room and labeled as the central supply AHU in Table 5.1. It delivers 100% outdoor air to the hallways and this air enters the suites by flowing under and around the suite doors. This AHU is pneumatically controlled and it conditions the outdoor ventilation air to constant temperatures of approximately 23ºC during the heating season and 18ºC during the cooling season. Humidification is installed but it has been shut off for many years.

A second TRANE Climate Changer AHU, labeled the central exhaust AHU in Table 5.1, continuously draws exhaust air from exhaust ducts connected to the bathrooms in the building. The central exhaust AHU is also located in the 11th floor mechanical room, directly adjacent to the supply AHU. It can be seen in Figure 5.1.

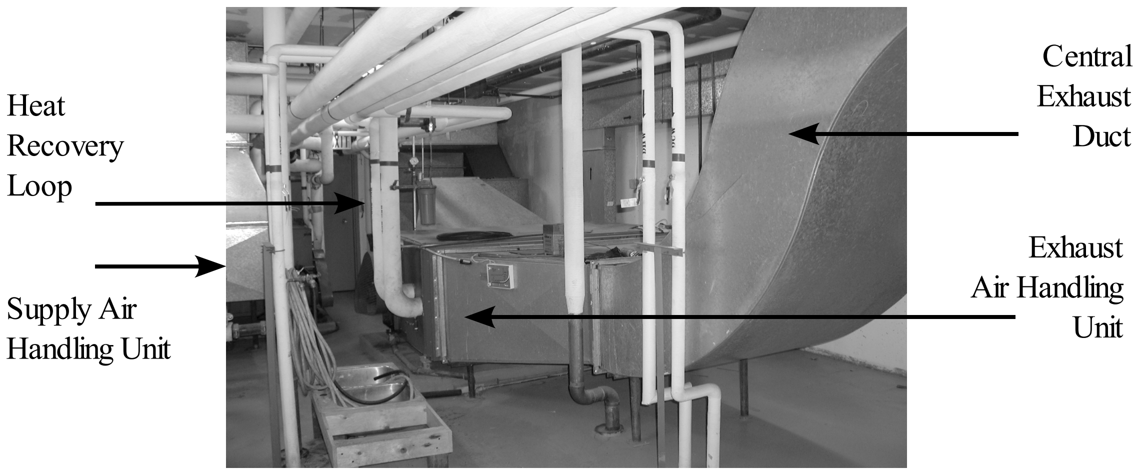

Figure 5.1: Central exhaust air handling unit

Heat is recovered from the central exhaust air using a run-around glycol system which can also be partially seen in Figure 5.1. In addition to this large central exhaust AHU a small fan in the second floor storage room exhausts air from the building's laundry rooms at a rate of 57 L/s.

The building also has two ceiling mounted TRANE Climate Changer units that recirculate air in the main and second floor recreation areas. These units are supplied with hot water from the boilers and cold water from the rooftop chiller. They continuously condition and recirculate the air in the main and second floor recreation rooms.

A heating and ventilation system for the unfinished areas of the crawlspace was not included in the original design of the building. One year after construction, however, a system was installed due to moisture problems. Outdoor air is provided to the crawlspace and heated with hot water from the central boilers. The air is first conditioned by a Flair 300600 compact air-to-air heat recovery unit. This is labeled as the crawlspace AHU in Table 5.1. Venmar was contacted for information on the performance of this model and they stated that it was no longer in production and had been replaced by their 12LC unit. The rated effectiveness of the 12LC unit is 60% and it was assumed that the effectiveness of the AHU in KEP would be the same.

5.2 MECHANICAL VENTILATION SYSTEMS MEASUREMENTS

This section presents 3 different types of measurements that were taken in the building in order to better define the mechanical ventilation systems in the computer models of KEP. The three types of measurements were supply and exhaust air flow rates, fan motor speed, and system static pressure. Measuring these values allowed for the mechanical efficiency of the fans to be calculated for each system. Mechanical fan efficiency is one of the variables needed by the computer model in order for it to calculate the electrical consumption of the building's AHUs. All of the AHUs use forward-curved centrifugal fans.

In October 2003, SRC measured the central supply and exhaust flow rates to be 3,190 L/s and 3,120 L/s respectively. In June 2006, the supply and exhaust flow rates were re-measured as part of this work and were found to be 3,307 L/s and 3,270 L/s respectively. An increase in the flow rates was expected as both the central supply and exhaust ducts had been cleaned since the October 2003 measurement. Three sets of velocity measurements were taken in 2006 using a TSI VelociCalc Plus model 8384-E-GB hot-wire air velocity probe with an accuracy of ± 3% of the reading or ± 0.015 m/s (whichever is greater) and a resolution of 0.01 m/s. Average duct velocity was found by averaging the individual point velocities following a log-Tchebycheff rule grid (ISO Standard 3966) [5.1]. The uncertainty in the measured flow rates is ± 10% (Appendix A2.1).

Table 5.2 shows the measured rotational speeds of the four above ground AHUs in KEP. The central fan motor speeds can be seen to be approximately constant throughout the year.

Table 5.2: Measured rotational speeds of building fan motors

	Aug 2006 [RPM]	Oct 2006 [RPM]	Jan 2007 [RPM]	Average [RPM]
Central Supply Motor	1741.1	1743.4	1737.2	1740.6
Central Exhaust Motor	1764.2	1765.0	1765.9	1765.0
Main Floor Motor	-	-	1738.2	1738.2
Second Floor Motor	-	-	1735.9	1735.9

Using the measured motor speeds and the motor relationship previously described in the pump section of Chapter 4 the ventilation fan motor powers seen in Table 5.3 were calculated.

Table 5.3: Fan motor power

	Average [RPM]	Rated [RPM]	Load [%]	Rated Power [kW]	Power [kW]
Central Supply Motor	1740.6	1720	74.3%	7.46	5.54
Central Exhaust Motor	1765.0	1740	58.3%	5.59	3.26
Main Floor Motor	1738.2	1720	77.2%	0.56	0.43
Second Floor Motor	1735.9	1720	80.1%	1.49	1.19

Static pressures were measured in each system using an Energy Conservatory DG-500 digital pressure gauge with a resolution of ±0.1 Pa. A 10 s average was used for all measurements. Figure 5.2 shows the horizontal locations of the pressure measurements taken in the central supply air system. Pressure measurements were taken along the most accessible face of the duct or AHU (often they ran together along the ceiling or ground).

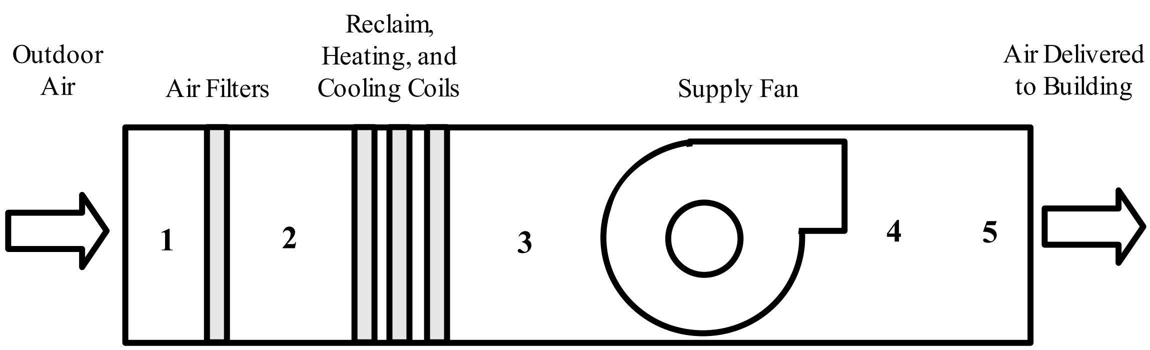

Figure 5.2: Supply air pressure measurement locations

Measurements in the central supply system were taken on December 17, 2006, January 3, 2007, and January 9, 2007. On December 17 and January 3 measurements were only taken along the centerline of the duct or AHU. On January 9 the number of measurements per location was increased to 5, as shown in Figure 5.3.

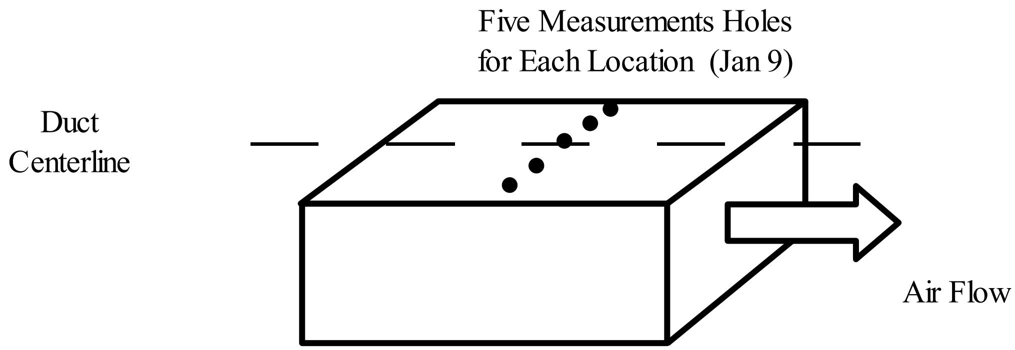

Figure 5.3: Measurement holes for each location in Figures 5.2 and 5.4

Table 5.4 shows the pressures measured inside the central supply air system. The pressures on Dec 17 and January 3 are averages from 5 measurements per location. The pressures on January 9th are averages of 25 measurements per location. Therefore the average pressures in the final column of the table are weighted averages.

Table 5.4: Central supply air system measurements

Location		Dec 06 Average Pressure [Pa]	Jan 3, 07 Average Pressure [Pa]	Jan 9, 07 Average Pressure [Pa]	Average Pressure [Pa]	2·StDev [Pa]
1	Inside mechanical room, prior to air filters	-98.4	-93.9	-	-96.1	32.5
2	Post air filters, pre heating, cooling, and reclaim coils	-97.3	-93.3	-96.3	-95.8	32.5
3	Post coils, pre fan	-721.8	-716.0	-712.7	-715.4	9.2
4	Post Fan	137.6	134.9	153.4	145.8	16.4
5	Prior to exiting mechanical room and entering building	67.6	67.6	79.3	74.1	11.8

The measured pressure drop across the filters in Table 5.4 is approximately zero because the filters are removed during the winter months. The average measured pressure drop across the reclaim, heating, and cooling coils was 620 Pa (2.5 in H_20). The total average measured pressure rise across the fan was 861 Pa (3.5 in H_20). This table also shows that 74 Pa (0.3 in H_20) was required to deliver air down the central shaft, and into the hallways.

Figure 5.4 shows the locations of the pressure measurements taken in the central exhaust air system.

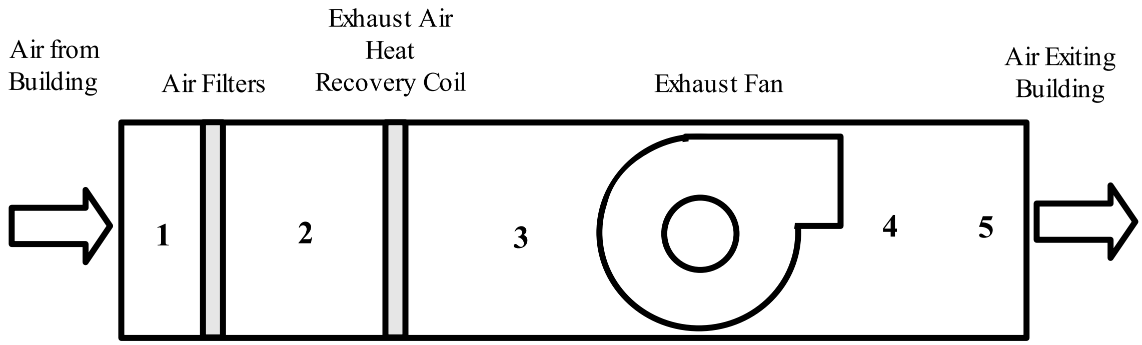

Figure 5.4: Exhaust air pressure measurement locations

Measurements for this system were taken in an identical manner as the central supply system. Table 5.5 shows pressures measured for each day and the overall weighted average for each location.

Table 5.5: Central exhaust air system measurements

Location		Dec 06 Average Pressure [Pa]	Jan 3, 07 Average Pressure [Pa]	Jan 9, 07 Average Pressure [Pa]	Average Pressure [Pa]	2·StDev [Pa]
1	Pre air filter	-245.7	-233.0	-232.2	-235.4	16.3
2	Post air filter, pre reclaim coil	-284.0	-282.3	-296.3	-290.5	13.1
3	Post reclaim coil, pre fan	-465.4	-484.3	-491.2	-483.9	43.8
4	Post fan	15.3	19.8	15.5	16.4	11.6
5	Prior to exiting the building	0.2	1.0	-	0.6	1.2

The average measured pressure drop across the exhaust AHU filters was 51 Pa (0.2 in H_20). The average measured pressure drop across the reclaim coil was 194 Pa (0.8 in H_20). This is approximately one-third the pressure drop across the 3 supply air coils. The total average measured pressure rise across the fan was 500 Pa (2 in H_20). Table 5.5 also shows that the average measured pressure associated with the ductwork prior to the filters was 235 Pa (0.9 in H_20). The total pressure drop in the ducts, diffusers, return grills, and restrictions in the building space is 310 Pa (1.2 in H_20).

The next two systems measured were the main and second floor air recirculation systems. Figure 5.5 shows the locations of the pressure measurements taken in these two systems. Only three probe holes were drilled for each location because the AHUs and ducts were smaller than the central systems. It was also desirable to keep the number of holes drilled into the AHUs to a minimum. It should be noted that it was not possible to measure the pressure prior to the air filters in the main floor system.

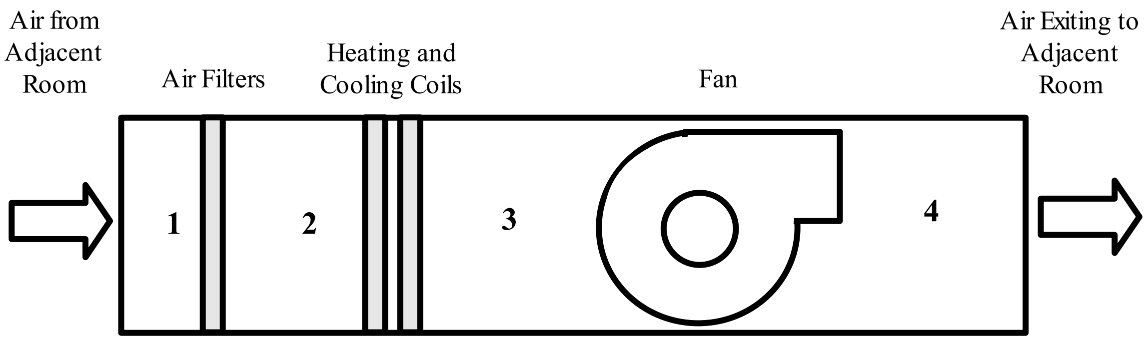

Figure 5.5: Measurement locations in main and second floor recirculation systems

Tables 5.6 and 6.7 shows the pressures measured inside the main and second floor recirculation systems.

Table 5.6: Main floor recirculation system

Location		Jan 3, 07 Average Pressure [Pa]	Jan 9, 07 Average Pressure [Pa]	Average Pressure [Pa]	2·StDev [Pa]
1	Pre air filters	-	-	-	-
2	Post air filter, pre heating and cooling coils	-57.1	-59.2	-58.6	0.2
3	Post coils, pre fan	-127.4	-132.1	-130.7	2.1
4	Post fan, prior to entering the recreation area	48.0	58.8	55.7	14.7

Table 5.7: Second floor recirculation system

Location		Jan 3, 07 Average Pressure [Pa]	Jan 9, 07 Average Pressure [Pa]	Average Pressure [Pa]	2·StDev [Pa]
1	Pre air filters	-54.9	-	-54.9	0.4
2	Post air filter, pre heating and cooling coils	-68.2	-71.1	-70.3	1.1
3	Post coils, pre fan	-363.5	-375.9	-372.4	4.0
4	Post fan, prior to entering the recreation area	37.7	58.8	52.8	39.5

The airflow rate of the crawlspace system was measured to be 350 L/s by SRC during their BEM audit. At this flow rate the rated pressure drop across the heat recovery system is 225 Pa (3.5 in H_20) per air stream. The actual pressure drop across the unit could not be measured in Jan 2007 because the heat recovery cores had been temporarily removed.

With measured air flow rate, fan motor power, and static pressure in each system, fan efficiency is calculated using the following formula:

$$Fan\ Efficiency = \frac{(Flow\ Rate)(Static\ Pressure)}{(Motor\ Electrical\ Power)(Motor\ Efficiency)} \qquad (5.1)$$

Table 5.8 shows the efficiencies that were calculated for the forward-curved fans based on measured values and assumed efficiencies for the motors [5.2].

Table 5.8: Fan efficiency

AHU	Motor Efficiency [%]	Flow Rate [m^3/s]	Static Pressure [kPa]	Fan Efficiency [%]	Combined Efficiency [%]
Central Supply AHU	84.0	3.307	0.888	63%	53%
Central Exhaust AHU	83.0	3.270	0.500	60%	50%
Main Floor AHU	71.0	1.133	0.186	69%	49%
Second Floor AHU	76.0	1.176	0.425	55%	42%

5.3 HEAT RECOVERY

The building uses a run-around glycol loop to recover heat from the exhaust air and transfer it to the incoming supply air. This section outlines how the effectiveness of this system was calculated from field measurements of air temperatures and flow rates and how discrepancies in the heat recovery control methods used in the actual building and the computer model of the building were resolved. In KEP, a three way valve controls the glycol flow in order to protect the exhaust coil from developing frost. The EE4 program uses a single effectiveness value and does not have frosting controls. Specifying how effectiveness in the KEP system varies with outdoor air temperature and glycol loop temperature therefore needed to be simplified in order to incorporate heat recovery control into the computer model.

5.3.1 HEAT RECOVERY MEASUREMENTS

Figure 5.6 shows the 4 temperature measurement locations that are typically used to determine the effectiveness of a heat recovery system. It also shows the three-way mixing valve that controls the flow of glycol in the loop and the 1.12 kW (1.5 HP) pump that continuously circulates the glycol.

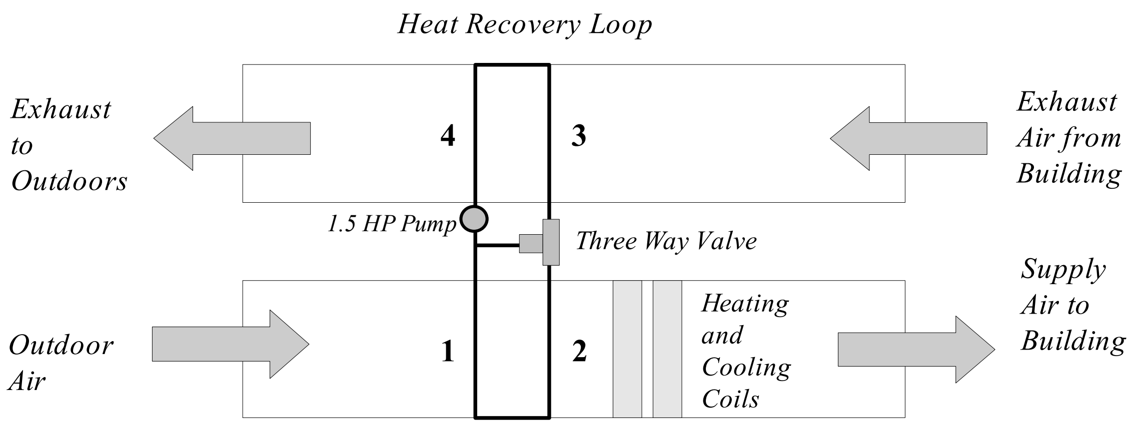

Figure 5.6: Thermocouple grid locations

Locations 1 and 2 are the supply air prior to and after heat recovery respectively, location 3 is the exhaust air prior to heat recovery, and location 4 is the exhaust air after heat recovery. When taking field measurements to determine heat recovery effectiveness it is best to measure the temperature at all 4 locations. In this case, however, it was not practical to accurately measure the temperature at location 2 because placing a grid of thermocouples in this location would have required shutting down the supply air ventilation equipment in order to open it and work safely. This would have required the cooperation and a large amount of time from the building manager and was not pursued.

Effectiveness of the system was therefore defined as:

$$\epsilon = \frac{m_E Cp_E (T_3 - T_4)}{m_{MIN} Cp_{MIN} (T_3 - T_1)} \tag{5.2}$$

where ϵ is the heat recovery effectiveness (dimensionless), m_E is the mass flow rate of the exhaust fluid (kg/s) (at the time the measurements were taken the hot fluid was always the exhaust air), m_{MIN} is the minimum mass flow rate of either the hot or cold fluid (kg/s), and Cp is the specific heat of the respective fluid. As section 5.2 previously discussed, the central supply and exhaust flow rates were previously measured to be

3,307 L/s and 3,270 L/s respectively. Thus m_H and m_{MIN} were both equal to the mass flow rate of the exhaust air. The air temperatures were measured using a grid of five thermocouples connected in parallel which gives the average temperature. A schematic of the measurement grid used in each location can be seen in Figure 5.7.

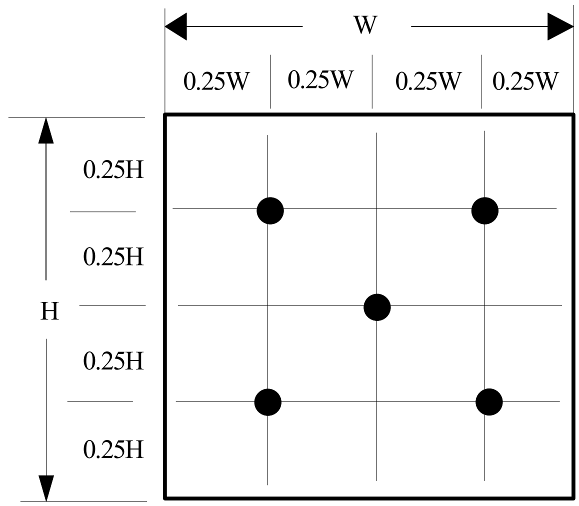

Figure 5.7: Thermocouple grid for each measurement location

Figure 5.8 shows the air temperatures that were measured and the calculated effectiveness of the heat recovery system for every 5 minute interval over the 8 day monitoring period. As stated in the introduction to this section, the flow of glycol is controlled in order to reduce the system's effectiveness and avoid frosting on the exhaust air recovery coil and therefore the effectiveness can be seen to decrease at times.

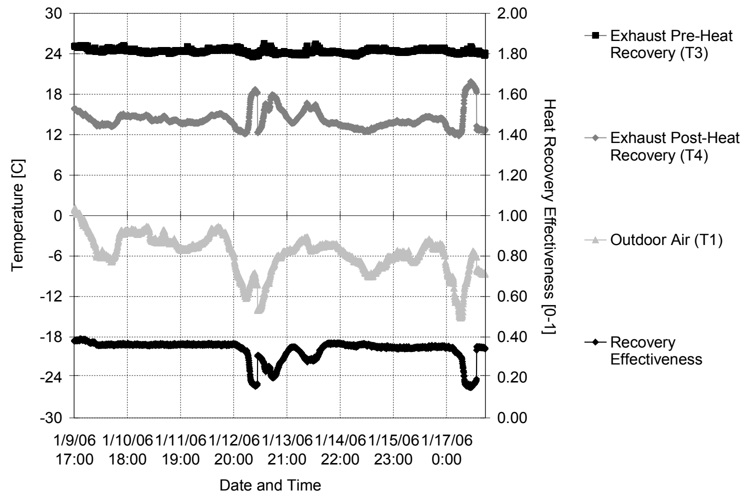

Figure 5.8: Measured airflow temperatures and calculated heat recovery effectiveness values in January 2006

The maximum and minimum heat recovery effectiveness values over the monitoring period were 0.36 and 0.16 respectively. The uncertainty in heat recovery effectiveness is ± 0.06 (Appendix A2.3). The uncertainty of ± 0.06 assumes that the uncertainty in the exhaust air flow rate is ± 10%. If it was increased to ± 20% then the uncertainty in the heat recovery effectiveness would increase to ± 0.10.

5.3.2 HEAT RECOVERY CONTROL METHODS: MODEL VS. ACTUAL

The heat recovery system in KEP is a run-around glycol loop that is controlled using a three-way mixing valve that controls the amount of fluid entering the supply air coil. Temperature sensors monitor both the glycol temperature and the post heat recovery exhaust air temperature. Based on these two temperatures the mixing valve adjusts the glycol flow on the supply air side to ensure the exhaust air does not condense and result in frost build up on the exhaust heat recovery coil. Figure 5.8 shows that the exhaust air temperature after the heat exchanger (T_4) does not drop below 12ºC and when it does approach this temperature the effectiveness of the system drops rapidly. This indicates that a post heat recovery exhaust temperature of approximately 12ºC is the control temperature for the mixing valve. Supporting this is the fact that the pneumatic control setting for the heat recovery system was observed to be set to approximately 10ºC.

The blueprints for the building specify that the control temperature should be set to 2ºC and a temperature of 2ºC may even be conservative. If the relative humidity in the building was 25%, frosting should not occur until the post heat recovery exhaust air temperature reaches approximately -4ºC. It is evident that there is a large amount of waste heat not being captured by the run-around system due to the heat recovery control settings. The exhaust air temperature quickly rises in Figure 5.8 after it falls to approximately 12ºC because the effectiveness has been reduced and less heat is being removed from the exhaust air before it leaves the building.

The average exhaust air temperature prior to the heat recovery coil (location 3) was measured to be 24.4ºC. Assuming this is a typical exhaust air temperature during the winter, an effectiveness of 0.36 and a post heat recovery exhaust control temperature of 12ºC corresponds to an outdoor air temperature of -10.2ºC. Thus the current system is controlled such that at an outdoor air temperature of approximately -10ºC the three way mixing valve will begin to reduce the system effectiveness. Figure 5.8 supports this as the effectiveness can be seen to begin to drop at outdoor air temperatures of approximately -10ºC, -13ºC, and -15ºC.

The computer model of the building controls the heat recovery system based on a relay monitoring the return air and outside air temperature. Two of the commands that turn on the heat recovery system in the model are:

1. If the return air temperature is more than 5.6ºC above outdoor dry-bulb temperature,
2. If the outside air temperature is less than the supply air set point temperature.

Therefore, if the return air temperature is 24ºC and the supply air temperature is set to 22ºC, the heat recovery system in the model will be active for all outdoor air temperatures below 22ºC. This presented a modeling problem because during the coldest weather of the year the computer model would continue to run the heat recovery system at its maximum effectiveness; whereas the system in KEP would actually be operating at a reduced effectiveness. This would result in the computer model under predicting the energy required to heat the outdoor air entering the building during the winter. This problem was addressed by running the computer model of the building twice using different constant effectiveness values. The energy consumption calculated for the building was then filtered at every hour, based on outdoor air temperature. Constant heat recovery effectiveness values of 0.36 and 0.16 were used for temperatures above -15ºC and equal to or below -15ºC respectively. A temperature of -15ºC was chosen for the filtering temperature because effectiveness varies gradually in Figure 5.8. A setting of -10ºC or -13ºC was thought to drop the effectiveness too soon, resulting in lower system performance. The effectiveness also did not reach the minimum value of 0.16 in Figure 5.8 until the measured outdoor air temperature was approximately -15ºC.

The model could have been run with several progressively increasing constant effectiveness values in order to simulate a gradual adjustment in the heat recovery effectiveness and there are three reasons why only one additional model was run. First, the effectiveness values are low and the temperature region in which the effectiveness varies between 0.16 and 0.36 is small (-10ºC to -15ºC). Second, below measured outdoor temperatures of -10ºC the effectiveness drops relatively quickly to a minimum of 0.16. Lastly, each additional model requires a significant amount of time to create and process and it was necessary to keep this time to a minimum.

It should be noted that if the heat recovery effectiveness of the system had not been measured to be 36% the effectiveness would likely have been assumed to be 60%. Figure 5.9 shows the impact on total natural gas consumption as the maximum effectiveness of the heat recovery system is varied. The figure presents "maximum effectiveness" because each point uses two effectiveness values in order to approximate the impact frosting controls at low outdoor air temperatures. Each maximum effectiveness value is the effectiveness used above outdoor air temperatures of -15ºC and for each point the effectiveness value used below -15ºC is equal to the maximum minus 0.20.

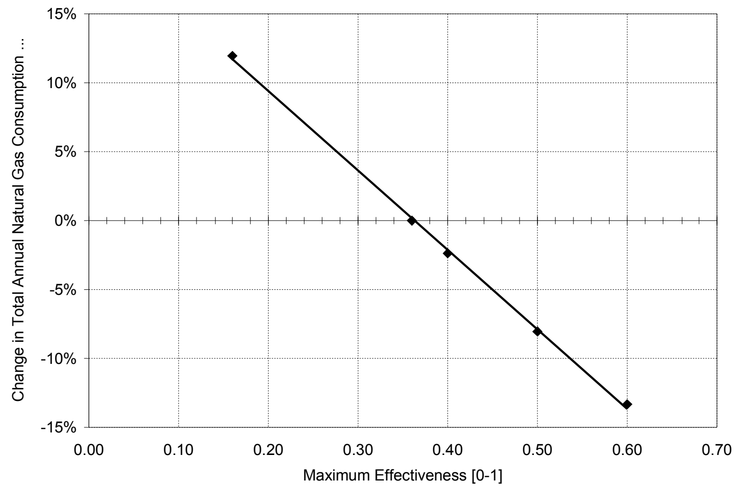

Figure 5.9: Impact of maximum heat recovery effectiveness on total natural gas consumption

If the effectiveness of the heat recovery system in KEP had been assumed to be 60%, the annual fuel utilization efficiency (AFUE) of the boiler system would have been found to be 52% (by iteratively matching the 2005 model to measured natural gas consumption in 2005). An annual efficiency of this amount is much lower than what would be expected.

CHAPTER 6
ELECTRICAL LOADS

This chapter details the allocation of the electrical loads in the computer models. Throughout this thesis, electrical consumption labeled as "building" refers only to electrical consumption that is measured by the "building" electrical meter. In KEP, all the electrical loads internal to the suites are measured using a single separate "suite" electrical meter. As there are only two electrical meters for the entire building, tenant electrical utility charges are based on the average building electrical consumption rather than individual suite consumption.

6.1 LIGHTS

There were 3 different areas in the building that have significantly different lighting schedules: suites, building areas that operate 24 hours/day (hallways, stairwells, and elevators), and building areas that operate only part of the day (lounges, laundry rooms, mechanical rooms, salon, and the crawlspace). The building also has exterior lighting, but exterior loads cannot be included in the EE4 model. Exterior lighting was therefore accounted for outside of the model. When defining the computer model, the number and type of fixtures in each suite was determined from the original building blueprints and the 2003 BEM audit by SRC. It was assumed that suite lighting in the building had not changed from 2003 to 2005.

Table 6.1 provides a list of the type and number of fixtures installed in each single suite. Double bedroom suites have an additional fixture in the second bedroom that contains two 60 W incandescent bulbs.

Table 6.1: Suite lighting summary for a single bedroom suite, including estimates of hourly use from the 2003 BEM audit report by SRC

Room	Fixture Type	Fixture Wattage [W]	Number of Fixtures	Annual Hours [hr/Yr]	Hrs / Day	Annual Energy Use [kWh/Yr]
Bedroom	Two 60 W incandescent bulbs	120	1	1,500	4.1	180.0
Storage Room	One 60 W incandescent bulb	60	1	30	0.1	1.8
Bathroom	Two 60 W incandescent bulbs	120	1	1,500	4.1	180.0
	Infrared Heat Lamp	250	1	30	0.1	7.5
Living Room	Two 60 W incandescent bulbs	120	1	3,000	8.2	360.0
Hall	Two 60 W incandescent bulbs	120	1	500	1.4	60.0
Kitchen	2 ft, T12, single lamp fluorescent fixture	30	1	3,000	8.2	90.0
	4 ft, T12, single lamp fluorescent fixture	47	3	3,000	8.2	423.0
					Total	1,302.3

EE4 only allows one lighting schedule per room and therefore an equal number of florescent fixtures and a representative number of 60 W incandescent bulbs were entered into the computer models to account for the lights listed in Table 6.1. In order to determine the number of incandescent bulbs that would result in an equivalent amount of annual energy use as the amount shown in Table 6.1 a lighting schedule was created specifically for an apartment building housing seniors. It can be seen in Figure 6.1.

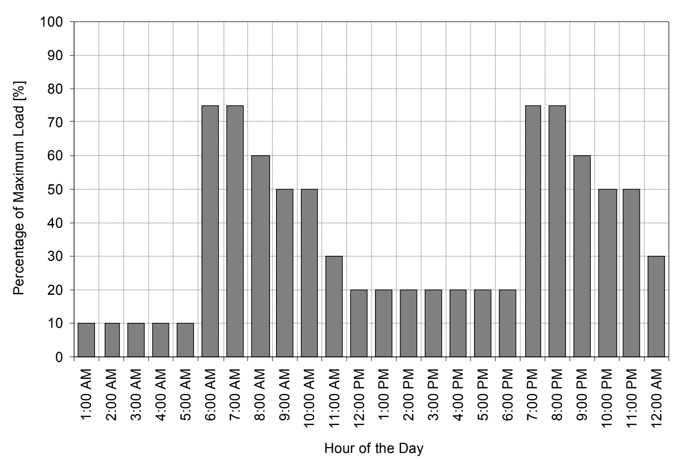

Figure 6.1: Lighting schedule for zones containing suites

The lighting schedule that was created was guided by the EE4 default schedules for multi-family residential and hotel guest rooms but modified based upon assumed behaviour of seniors. It was assumed that typically only one room in each suite would be occupied during most hours based on the assumption that seniors would be relatively conservative in their lighting use and the fact that there is typically only one tenant in each suite. The exception to this assumption was the early morning and evening meal preparation hours when it was thought to be likely that two rooms would have lights on.

Table 6.1 showed that SRC estimated the annual electrical lighting use for a single suite to be 1,300 kWh/Year. Table 6.2 lists the representative number of 60 W bulbs that were entered into each suite in the computer models.

Table 6.2: Lights entered into single suites in computer model

Room	Fixture Type	Fixture Wattage [W]	Number of Fixtures	Annual Hours [hr/Year]	Hours / Day	Annual Energy Use [kWh / Year]
Bedroom, l	60 W incandescent	60	4	3176	8.7	762.1
Kitchen	2 ft, T12, single lamp fluorescent fixture	30	1	3176	8.7	95.3
Kitchen	4 ft, T12, single lamp fluorescent fixture	47	3	3176	8.7	447.7
					Total	1305.1

Annual suite lighting consumption in Table 6.2 is 1,305 kWh/Year per suite, less than 1.0% higher than the SRC estimate in their 2003 BEM audit. Double suites were given one additional 60 W bulb. The total electrical consumption of the suite lights in the computer models was approximately 154,000 kWh/Year.

Defining the interior building lights did not require the creation of a lighting schedule based on assumed occupant behaviour as the majority of the building common area and hallway lights are on 24 hours per day. Exceptions are the two lounges, the mechanical rooms, the laundry rooms, the salon, and the crawlspace which were modeled using the most appropriate schedule in the EE4 library. A new schedule was created for the salon, however, as it is only open on Fridays from 9am-5pm. Light numbers and fixture types entered into the model for these rooms matched both the building blueprints and the SRC audit. The computer model calculated the total annual consumption of the interior building lights to be approximately 225,000 kWh/Year.

The exterior building lights in KEP are controlled by a photoelectric sensor and do not consume energy during daylight hours. Data on the number of daylight hours per day was found for Saskatoon in 2002 and used to determine the number of hours in 2002 that the exterior lights would have been on. SRC's 2003 BEM audit report states that the total power of the exterior lights is 1.77 kW. Using this and the daylight hours data, the total monthly consumption of the exterior lights in 2002 was determined and can be seen in Figure 6.2.

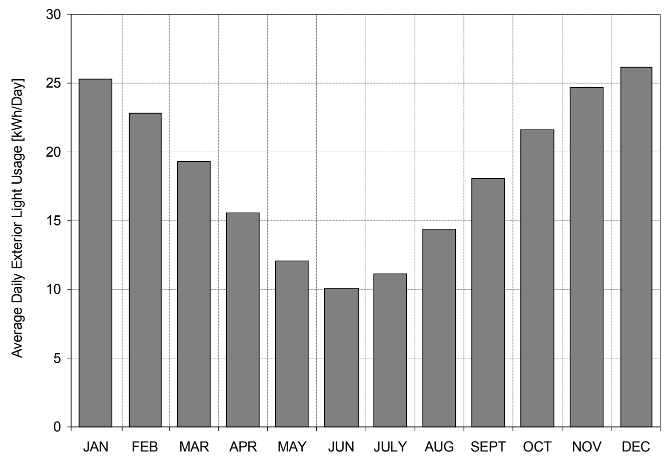

Figure 6.2: Average daily exterior lighting consumption for each month in 2002

6.2 RECEPTACLE LOADS IN SUITES

This section determines the receptacle loads (or plug loads) for each suite based on monthly meter measurements of suite electrical consumption. Suite lighting has already been defined in the previous section and the average daily receptacle load was determined by subtracting the consumption of the lights from the total measured suite consumption.

6.2.1 METERED SUITE ELECTRICAL CONSUMPTION

Figure 6.3 shows measured suite electrical consumption in KEP dating back to January 2002.

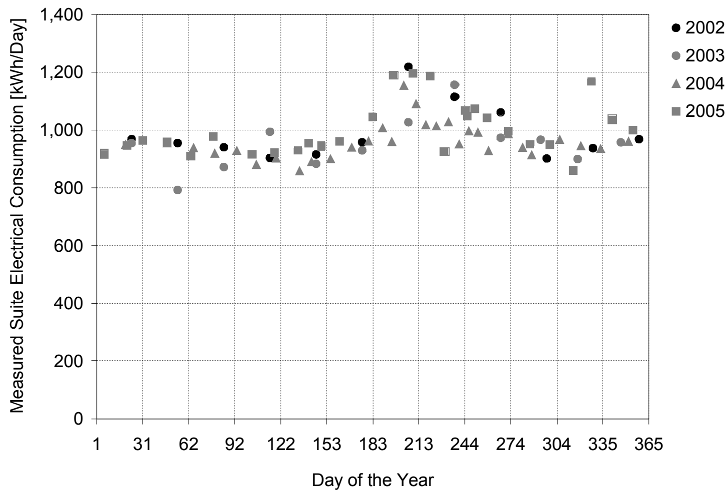

Figure 6.3: Historic measured suite electrical consumption

A consistent pattern in annual suite electrical consumption is apparent. Consumption can be seen to relatively constant but there is a large increase during the summer months of June, July, August, and September (days 152-274 in Figure 6.3). It was assumed that the increases in electrical consumption during the summer was due to tenants using window mounted air conditioning (WMAC) units in their suites. The electrical consumption of these units is discussed in the following section.

In 2003 and 2005, the average measured suite electrical consumption for all months except July, August, and September was 916 kWh/Day and 957 kWh/Day respectively. These were assumed to be the constant annual base-load for the suites during those years. The estimated suite lighting consumption was 423 kWh/Day, and therefore to achieve base loads of 916 kWh/Day and 957 kWh/Day in the suites, receptacle loads of 493 kWh/Day (1,548 kWh/Year per suite) in 2003 and 534 kWh/Day (1,680 kWh/Year per suite) in 2005 were included in the computer model. The receptacle loads were 7.7% higher in 2005 than in 2003.

The average suite receptacle load entered into the 2003 and 2005 computer models was therefore approximately 1,600 kWh/Year per suite. Table 6.3 shows a list of receptacle loads that are likely to be present in every suite. The total consumption of the loads in Table 6.3 is 1,365 kWh/Year per suite.

Table 6.3: Standard receptacle loads in a suite [6.1]

Equipment	Expected Household Energy Use [kWh/Yr]
Fridge	517
Stove	300
Colour TV	137
DVD or VCR	60
Microwave Oven	209
Coffee Maker	116
Cordless Telephone	26
Total	1,365

Table 6.4 shows additional loads that may also be in the suites. Most of the values in Table 6.3 and Table 6.4 are for households and because the majority of the suites in KEP are single occupant, consumption of appliances in KEP should be less than values for households.

Table 6.4: Other potential receptacle loads in a suite [6.1]

Equipment	Expected Household Energy Use [kWh/Yr]
Two additional 60 W bulbs	88
Small Portable Stereo	20
Compact Chest Freezer	279
Desktop Computer	262
Printer Without Fax/Copier	45
Total	694

There are many other potential receptacle loads that were not included in the previous two tables, but any addition loads are likely to be small compared to those that have been accounted for. In a 1987-2001 study of household electrical use, the US Energy Information Administration found that no single appliance dominated household electrical use [6.1]. Refrigerators consumed the most electricity, followed by lighting, clothes dryers, freezers, and color TV's. This was based on the total average electrical use for all households studied and indicates that these are the appliances most commonly found in the households [6.1]. Each of these electrical loads has been accounted for, with the exception of the clothes dryers which are located in laundry rooms and are therefore building receptacle loads.

Figure 6.4 shows a comparison of measured suite consumption in 2005 and the consumption calculated by the 2005 computer model. Measured and modeled results for the year 2003 are similar.

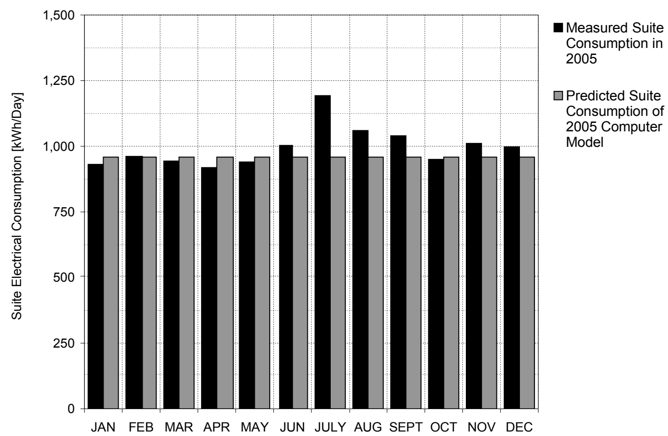

Figure 6.4: KEP measured suite consumption vs computer model (2005)

During the 8 non-summer months, the average electrical consumption of the computer models match the average measured suite consumption of the non-summer months within ± 0.5%. Summer was defined as June – September. The 2005 computer model consumption in Figure 6.4 includes the previously stated receptacle loads but not WMAC units and small fans that were assumed to be used for cooling during the summer. These loads are discussed in the next section.

6.2.2 WINDOW MOUNTED AIR CONDITIONING UNITS

Figure 6.4 showed that suite electrical consumption peaked in the month of July. It was assumed that this additional summer consumption was due to tenants operating WMAC units and fans in order to condition their suites during the summer. In July of 2005, twenty-six tenants used WMAC units in their suites and the hourly electrical consumption of 3 of these units was monitored over a period of 15 days. The average daily use by the three tenants monitored was 6.7 kWh/day, 4.2 kWh/day, and 1.9 kWh/day.

KEP is a seniors' building and some tenants experience difficulty in performing daily tasks. The three tenants whose units were monitored were chosen because they were identified as being the most reliable tenants in terms of being able to remember to manually record their energy use each day. This potentially implies that they might also be the most likely to monitor and control their energy use. The third tenant, whose consumption was 1.9 kWh/Day, achieved these savings because she diligently turned her unit off at night and when she left her suite during the day. The tenant with the second lowest energy use also stated that the majority of the time she ran only the fan in the unit in order to conserve electricity. Thus, the two tenants with the lowest measured consumption were identified as conscientious energy users.

The tenant with the highest electrical use did not regularly turn her unit off at night or when she left her suite during the day. Tenants have no economic incentive to conserve electricity (they pay a fixed amount per month to use their WMAC units) and two additional tenants that were spoken to indicated that they almost never shut their units off during the summer. In addition to economic considerations, it is also likely that tenants do not attempt to conserve energy by shutting off the units as the average building exhaust air temperature was once measured on a July afternoon to be 28.6ºC when the outdoor air temperature was 33ºC (Appendix A1.3).

If the additional summer load in July of 234 kWh/day is divided by 26 units the load per unit is 9.0 kWh/Day per unit. This is approximately 25% greater than the maximum measured tenant usage. In addition to the behavioral aspects previously mentioned, the output capacity of each unit is also not equal. The average capacity of the 3 units measured was 1.6 kW. The average capacity of 12 units found in a storage room during the winter of 2006-2007 was 1.9 kW, 16% higher than the average of the 3 studied. The size of the 12 units ranged from 1.5 kW to 2.9 kW. Thus the three units selected for the study were also in the lower range of air conditioning units expected to be in the suites.

If the monthly consumption in 2005 is used to determine the annual consumption per unit, and the number of units is assumed to be 26, the annual electrical consumption per unit can be found to be 544 kWh. The Energy Information Administration in the United States states that the average annual electrical consumption of a household WMAC in the United States is 580 kWh [6.1]. Along with the previously presented information, this indicates that allocating approximately 544 kWh/Year for each unit is reasonable.

Figure 6.5 shows the suite electrical consumption of the base computer model and the average monthly suite electrical consumption measured during the years 2002-2005.

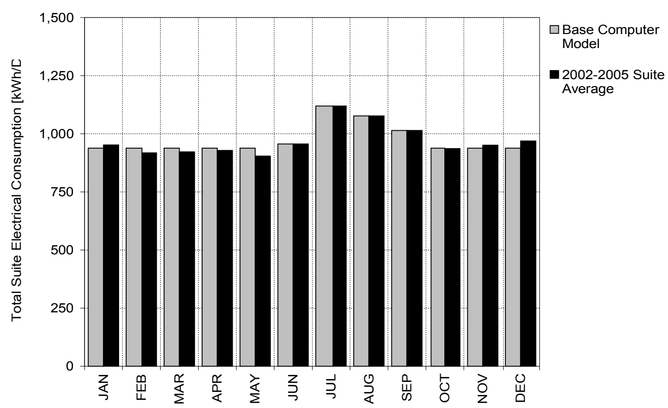

Figure 6.5: Suite electrical consumption – Base model and 2002-2005 monthly averages

Figure 6.5 shows that the allocation of suite electricity in the base model acceptably matches average measured suite electrical consumption. The total suite electrical consumption in the base model was approximately 355,000 kWh/Year, of which 12,650 kWh/Year was allocated for WMAC units.

6.3 BUILDING ELECTRICAL CONSUMPTION

This section details how the building electrical consumption in the computer models was determined and distributed. Based on values entered by the user the computer models calculate the energy consumption of several building electrical loads such as ventilation fans, heating and cooling circulation pumps, and air conditioning. Loads such as the washing machines, additional pumps, exterior consumption, and elevators, however, need to be included as general building receptacle loads. Exterior loads such as the heat tape system and block heaters also need to be accounted for.

6.3.1 METERED BUILDING ELECTRICAL CONSUMPTION

Figure 6.6 shows the chronological electrical consumption recorded from the building meter starting in the year 2002. The data points are connected in order to more clearly show the consumption pattern. Meter readings in 2004-2006 were taken twice as frequently as in 2002-2003, resulting in less scatter and a more refined profile.

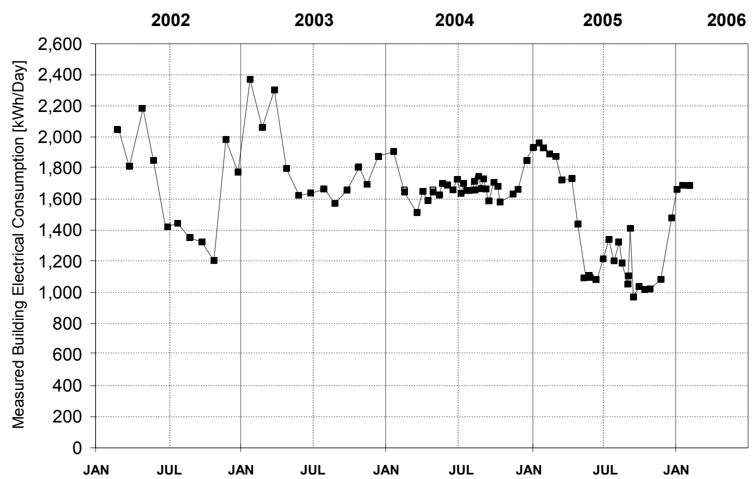

Figure 6.6: Chronological building electrical consumption

The pattern of building electrical load in each year is not as consistent as the suite loads were in Figure 6.3. One trend that stands out in the data is the large increases in electrical consumption during each winter. The North patio sidewalk heat tape system and the car block heaters are the two most likely reasons for the large increases in winter consumption each year. They are discussed in more detail in the next two sections of this chapter. Also of interest in Figure 6.6 is the fact that the summer consumption in 2002 and 2005 is approximately 500 kWh/Day less than the summer consumption in 2003 and 2004. After consulting with the building maintenance supervisors it was concluded that the most likely reason for the high summer consumption in 2003 and 2004 was that the sidewalk heat tape below the North brick patio had not been manually shut off at the end of the winter.

The year 2005 also appears to have a lower base electrical load than the year 2002 and this is most likely due to the lighting retrofit that occurred in December 2002. Based on the number of fixtures, the original bulb wattage, and the number of hours the bulbs were on each year (8760), it was estimated that the savings from replacing the incandescent bulbs in the hallways with compact fluorescent lamps (CFL) in December 2002 was 163 kWh/day. Figure 6.7 compares average building electrical consumption for the years 2002 and 2005 when the estimated savings of 163 kWh/Day is subtracted from the 2002 data.

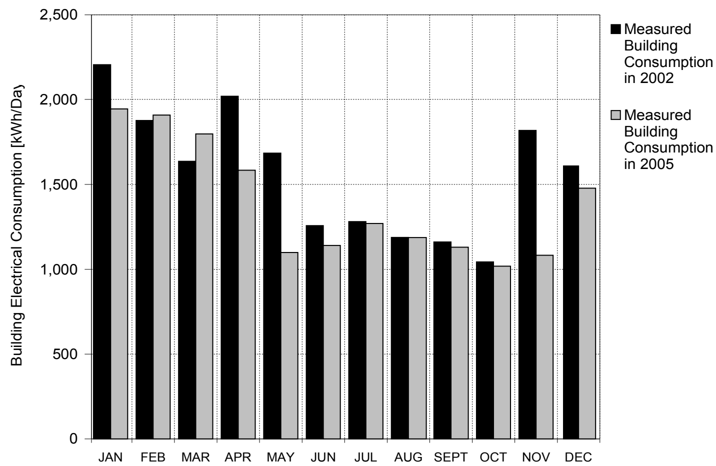

Figure 6.7: Total measured building electrical consumption, 2002 vs 2005, with estimated savings from 2002 lighting retrofit subtracted from 2002 measurements

When the lighting retrofit is accounted for, the consumption in 2002 and 2005 is very similar but in May and November of 2002 the building's electrical consumption is significantly higher than it is in 2005. Again, this difference is most likely due to the sidewalk heat tape system.

6.3.2 BLOCK HEATERS

The parking lot in KEP has 32 stalls and typically all stalls will be rented. Each stall has access to electrical outlets that are continuously supplied with power. Several literature sources were consulted for estimates of typical block heater energy use and they ranged from 100-240 kWh/Month. Most estimates were intended for homeowners and typically block heaters were listed as having a power draw of 500 W [6.2-6.4]. In March 2005 at approximately 11 am it was observed that 21 of the 22 remaining cars parked in the lot were using their block heaters. The average measured power requirement for these 21 block heaters was 474 W. In addition to 21 of the 22 remaining cars being plugged in on this day, of the 10 cars missing from the lot 8 had extension chords plugged into the outlets beside their cars. This suggests that over 85% of the tenants regularly used their block heaters in the year 2005. Of the 21 vehicles plugged in that day, 5 were covered with several inches of snow, indicating that they had not been moved recently. In mid-afternoon on December 11, 2006, 9 cars were observed to have their block heaters plugged in when it was approximately -10ºC. At noon on January 3, 2007, 11 cars were observed to have their block heaters plugged in when it was approximately +1ºC. Observations suggest that several vehicle owners leave their block heater plugged in continuously when the vehicle is not in use, regardless of outdoor temperature. As tenants are not charged for their electrical consumption and KEP is a seniors building where tenants have limited mobility, this may often occur.

The number of tenants using block heaters and the number of hours the heaters are in use will vary greatly depending on many factors. If on average 29 block heaters were used for 16 hrs/day during the winter months and each had a power draw of 475 W, the average electrical consumption for all of the block heaters would be 220 kWh/Day. Alternatively this would be 231 kWh/Month for each block heater. This is in the upper range of the literature values found and it corresponds well to the expected behaviour of the tenants in KEP. This amount was therefore used in the computer models.

6.3.3 NORTH SIDEWALK HEAT TAPE SYSTEM

Figure 6.8 shows the brick patio in front of the North entrance to the building during the winter of 2005-2006.

Figure 6.8: Brick patio for North entrance

The building uses an electrical heat tape system to melt snow that falls on this patio during the winter months. A section of the heat tape system which had begun to malfunction during the winter of 2005-2006 can be seen in Figure 6.8 to still be covered with snow while the remainder of the patio is clear. The system was originally installed in 1993 but there are plans to replace it. Based on the size of the patio, the heat tape company contracted to do the replacement recommended that the capacity of the new system be 45 kW.

Voltage and current measurements were taken on the existing system in an attempt to determine its capacity but this proved to be unsuccessful. Drawings of the system could not be found, one section of the system was experiencing an unknown malfunction, and the system was observed to have been incorrectly wired when installed (possibly the reason for the malfunction). For these three reasons a circuit diagram could not be drawn and the installed capacity could not be determined based on measurements. A manufacturer's catalog was found, however, and based on the sizes given in the catalog and the size of the patio, the system is either 30 kW or 42 kW. Given that the replacement system is recommended to be 45 kW, it is likely that the installed system is 42 kW. Compared to approximately 60 kW being required to power every light in the building, this is a very large load.

The heat tape system is designed to keep the patio at a constant temperature using a thermostat that monitors a thermistor buried below the patio. In addition to this automatic control, the building manager also typically turns the heat tape system off manually once winter is over. He stated, however, that he may not do this for several months after the last snowfall as he relies on the automatic control system to turn the heat tape off when the outdoor temperature is high. Typically a heat tape system such as this is set to maintain a temperature slightly above 0ºC, but in the winter of 2005-2006 the thermostat setting was observed to be 28ºC.

Figure 6.9 (left) is a picture of a steel pillar and doors exiting onto the North brick patio. It is provided as a reference for the infrared photograph of the North brick patio (right) taken in the winter of 2005-2006. White denotes hot regions and dark denotes colder regions. Where the heat tape is functioning the brick patio is bright white. North exit doors can be seen in the top right corner of each picture.

Figure 6.9: Regular (left) and infrared (right) photographs of the North brick patio

In the upper left corner of Figure 6.9 the colour of the patio darkens due to the malfunctioning section. When the photograph is viewed in colour, it shows that the bright white region of the patio has a temperature of 25.8ºC. The dark black region of the brick patio was measured to be -15.7ºC. It is not known whether the thermostat setting has been changed in recent years but the building manager, his supervisors, and the company servicing the malfunctioning system all stated that they have never adjusted it.

Table 6.5 shows the average electrical consumption that was calculated for the North patio electrical snow melt system.

Table 6.5: Average consumption of the electric snow melt system

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
kWh/Day	793	613	442	704	236	0	0	0	0	0	169	261
Hours/Day	19	15	11	17	6	0	0	0	0	0	4	6

Figure 6.10 shows the difference between the modeled and measured electrical consumption for the year 2005. The winter difference was assumed to be due to the additional winter consumption by the sidewalk heat tape system and the block heaters. The values in Table 6.5 were determined by averaging the difference between the measured and modeled electrical consumption in the winter months of the years 2003 and 2005 and subtracting 220 kWh/Day to account for the block heaters.

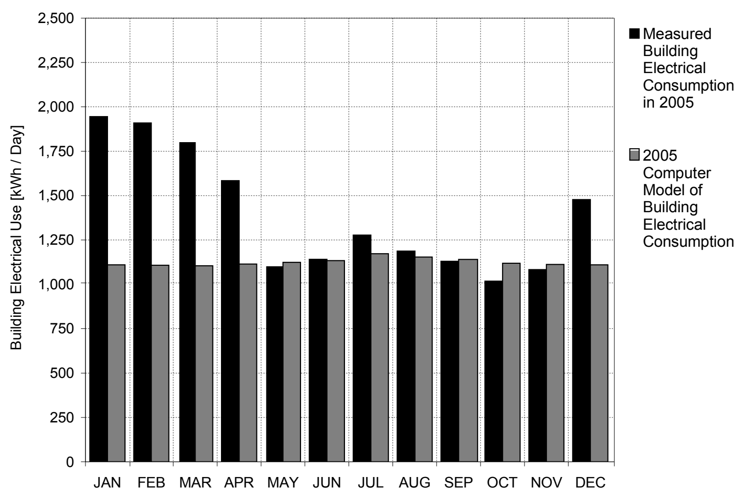

Figure 6.10: Modeled and measured building electrical consumption (2005)

Table 6.5 also includes the number of hours per day that the heat tape system would need to operate in order to consume the stated amount of power (assuming a power draw of 42 kW). Without reliable measurements, it is difficult to estimate the monthly consumption of the heat tape system, but Table 6.5 does suggest that the power consumption attributed to the heat tape system is reasonable because the number of hours per day does not exceed 24. Based on the discussion in this section and previous sections it was felt that it was reasonable to attribute the building's additional winter consumption to the block heaters and North patio ice melt system. This electric heat tape system is also the most likely reason why KEP had a higher than average electrical consumption when it was previously compared to other Saskatchewan apartment buildings audited by SRC (Section 2.3, Figure 2.7).

6.3.4 BUILDING RECEPTACLE LOAD

The two base years for the computer model are 2003 and 2005. However, as it was believed that during the year 2003 the sidewalk heat tape system was consuming an unknown amount of electricity during the summer months, measured building electrical consumption from this year was not usable as a reference for the 2003 computer model. Instead, the building electrical load was based on data from the year 2002, with the estimated savings from the lighting retrofit accounted for. Values of 316 kWh/Day and 314 kWh/Day were used as the average daily building receptacle loads in the 2005 and 2003 models respectively. They were found by matching the model consumption to the measured building consumption after loads for the heat tape system, block heaters, laundry rooms and elevators were accounted for. Together, the 2 elevators were assumed to use 6,000 kWh/Year. The 8 washing machines were assumed to use 9,280 kWh/Year (80 kWh/Suite per year) in electricity and the 8 clothes dryers were assumed to use 55,100 kWh/Year (475 kWh/Suite per year) in electricity. The laundry and elevator consumptions were determined from literature and detailed calculations can be found in Appendix A1.5.

A load of 1,000 kWh/Year was also allocated to the recreation/lounge area on the second floor to account for the periodic use of the computer, fridge, stove, electric organ, lamps, coke machine, and other electrical appliances found in the lounge areas. A receptacle load of 500 kWh/Year was allocated to the building manager's office for security cameras, black and white surveillance televisions, computer, and other equipment. Approximately 10,090 kWh/Year was allocated to the 11th floor mechanical room for the glycol run-around pump (Chapter 4, Table 4.4). The remaining receptacle load, approximately 25,000 kWh/Year, was allocated based on floor area to the building's 11th floor mechanical room and crawlspace mechanical room. All remaining potential sources of electrical consumption were assumed to be accounted for by this load, including the smaller pumps mentioned in Chapter 4 and the 0.75 kW air compressor that powers the pneumatic HVAC controls.

One potential reason for the remaining 25,000 kWh/Year in the mechanical room is that the estimated load for the elevators is too low. The elevator electrical consumption that was used is equal to the CBIP modeling recommended values. When it was compared to other literature sources (provided in Appendix A1.5) it was found to be reasonable but possibly too low. A more confident value for the elevator electrical consumption could not be determined from the literature and measurements in the building would have been necessary to better define this load.

Figure 6.11 compares the building electrical consumption of the base computer model to the average measured consumption in 2002 and 2005 (the 2002 data was modified to take the lighting retrofit into account).

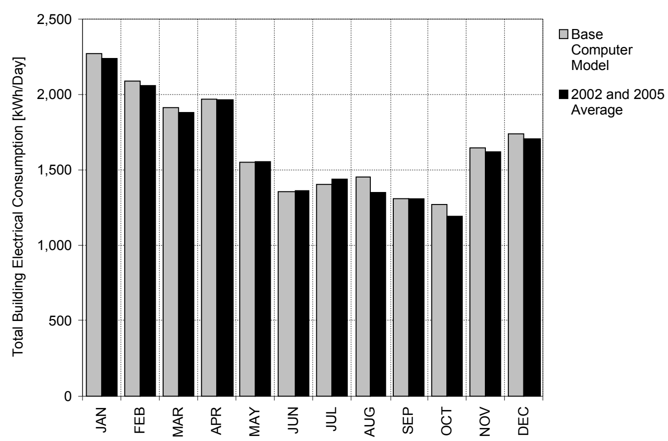

Figure 6.11: Building electrical consumption, base model vs. measured average consumption of the years 2002 and 2005

The total building electrical consumption in the base model is approximately 610,000 kWh/Year. This includes loads of approximately 97,000 kWh/Year and 33,220 kWh/Year for the sidewalk heat tape system and block heaters respectively.

CHAPTER 7
RETROFIT STRATEGY TO ACHIEVE FACTOR 10

This chapter presents a retrofit strategy to achieve a factor 10 reduction in the grid purchased energy (GPE) of King Edward Place (KEP). It begins by presenting the energy consumption, utility costs, and greenhouse gas emissions of the base computer model of the existing building. It is the "base" model of the building because it represents the building prior to energy saving retrofits that have occurred since 2002 and it is also the model with which the proposed retrofits will be simulated. The total annual energy consumption of this pre-retrofit base model is approximately 360 kWh/m^2. When energy consumption in this chapter, and throughout this thesis, is given on a per unit area basis it is referring to the total above ground floor area (8,351 m^2).

After presenting the base building, the estimated cost and calculated energy savings for each retrofit are listed and explained. Three tables summarizing 28 general retrofits are presented first and they are organized in order of increasing payback periods. The remainder of the retrofits are presented as systems or interconnected groups. The two systems with the longest simple payback periods are presented last.

Cost estimates for the retrofits were intended to be conservative but likely still underestimate the actual cost of certain retrofits because there is a high potential for unforeseen costs. Most estimates are based on quotes from suppliers or RSMeans 2002 Building Construction Data [7.1]. RSMeans cost estimates were scaled using a location factor for Saskatoon and include materials, labour, overhead, and profit. To account for potential increases in prices from 2002 to present and unforeseen additional costs these RSMeans estimates were increased by 20%. Estimates are also typically rounded up when presented in the tables.

The focus of this chapter is presenting the energy savings resulting from the recommended retrofit strategy. Appendix 3 provides more information of why certain retrofits were chosen over other alternatives and also more details on how some of the energy savings were calculated. It also provides several of the assumptions made when calculating the cost estimates. Appendix 4 provides a summary of all sources and assumptions for each cost estimate presented in this chapter.

7.1 BASE MODEL SUMMARY

The "base" computer model of the building is intended to be a model of the building's consumption during an average year, prior to the energy saving retrofits performed between 2002 and 2007. It was created from the values used in the 2003 and 2005 computer models of the building. As the previous chapters have discussed, these two computer models of the building were created from measurements in the building, literature, and assumptions based on observations.

Table 7.1 provides a list of key variables used in the 2003, 2005, and base models of the building.

Table 7.1: Summary of variables used in each computer model of the building

Variable	2005 Model	2003 Model	Base Model
Boiler Thermal Efficiency	75.0%	75.0%	75.0%
Infiltration (based on exterior wall area)	0.29 L/s/m^2	0.32 L/s/m^2	0.32 L/s/m^2
DHW Tank Thermal Efficiency	72.3%	71.9%	71.9%
DHW Load for Suites (based on suite occupancy)	825 W/Occ	930 W/Occ	878 W/Occ
DHW Load for Laundry Rooms (based on laundry room occupancy)	16,766 W/Occ	18,900 W/Occ	17,833 W/Occ
Receptacle Load for Suites (based on suite floor area)	8.38 W/m^2	7.70 W/m^2	8.04 W/m^2
Receptacle Load for Boiler Rooms (based on mechanical room floor area)	11.68 W/m^2	14.2 W/m^2	13.1 W/m^2
Central Supply Air Flow Rate	3307 L/s	3190 L/s	3307 L/s
Central Exhaust Air Flow Rate	3270 L/s	3120 L/s	3270 L/s
Building Hallway Lights	Compact Fluorescent	Compact Fluorescent	60 W Incandescent
Weather File	Saskatoon 2005	Saskatoon 2003	Saskatoon 2003

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For all models, boiler thermal efficiency was assumed to be the same in each year. In the base model, infiltration and DHW tank efficiency were each set to their pre-retrofit values. The DHW load for the suites and laundry rooms, and the receptacle load for the suites and boiler rooms in the base model are the average of the 2003 and 2005 model values because these are occupant dependent loads that vary from year to year. The supply and exhaust air flow rates in the base model are equal to the measured rates in 2005 because these rates represent a cleaner duct system and are more indicative of the building operating as intended. It also shows the building owners the current potential savings that would result from changing this rate in the building. The hallway lights in the building were changed to their original, pre-retrofit bulbs (60 W incandescent). The 2003 weather file was chosen as it represented an average year for Saskatoon based on the annual heating degree days and average annual solar radiation during recent years (2002-2005).

Figure 7.1 shows the average weekly natural gas consumption calculated by the base computer model of the building as a function of heating degree days per day. The slope and Y-intercept of the linear trend-line fitted to the data are 26.21 m^3/HDD and 118.10 m^3/Day respectively. The total annual natural gas consumption is approximately 2,040,000 kWh (244 kWh/m^2).

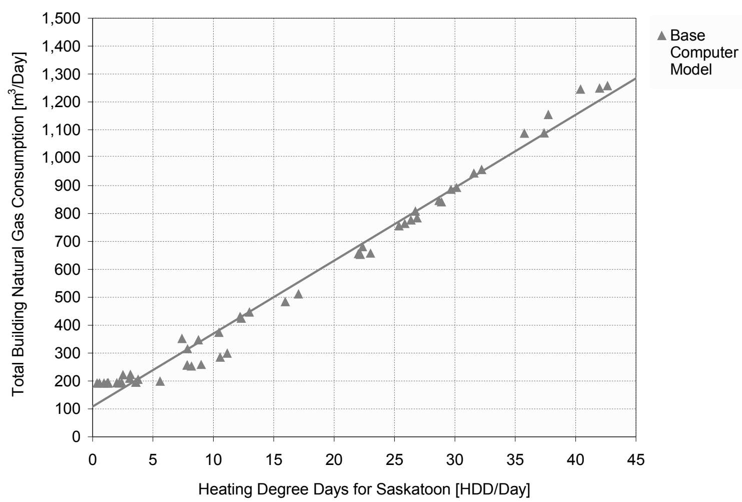

Figure 7.1: Total natural gas consumption – Base model

Table 7.2 lists the heating loads in the base computer model of the building during the hour with the highest heating load. The total peak space heating load prior to beginning to retrofit the building is approximately 249 kW.

Table 7.2: Base peak heating loads for the whole building and per unit floor area

	Base Model	
Building Peak Load Component	**[kW]**	**[W/m²]**
Wall Conduction	101.4	12.1
Roof Conduction	17.7	2.1
Windows and Frame Conduction	87.1	10.4
Window Glass Solar Heat Gain	-5.4	-0.6
Door Conduction	0.8	0.1
Underground Surface Conduction	5.6	0.7
Occupants to Space	-7.9	-0.9
Lights to Space	-15.8	-1.9
Equipment to Space	-15.4	-1.8
Infiltration	81.2	9.7
Total	249.4	29.9

Figure 7.2 shows a complete breakdown of the energy allocated in the base model of KEP. The total annual electrical consumption is approximately 965,000 kWh/Year (116 kWh/m^2), giving a total building energy consumption of approximately 360 kWh/m^2. The three loads that consume the greatest amount of energy in the building are natural gas for space and outdoor air ventilation heating (45.3%), natural gas for DHW (22.6%), and electricity for building lights (7.7%).

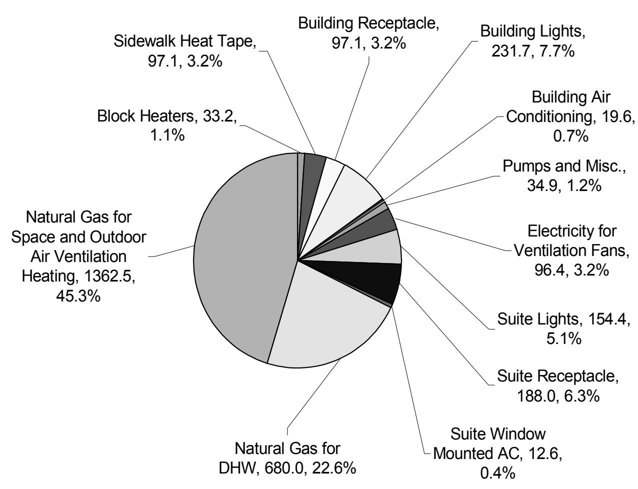

Figure 7.2: Energy consumption in KEP base model (values are in MWh/Year)

Figure 7.2 shows that the amount of energy targeted to be reduced by the factor 10 retrofits is 360 kWh/m^2. In Chapter 2, Figure 2.10 (the building retrofit and research time-line) showed that 2002 is a pre-retrofit year and would be expected to have a similar energy consumption as the base model. Also in Chapter 2, Figure 2.7 (the comparison of KEP to other Saskatchewan buildings audited by SRC) showed that the annual GPE consumption of KEP during this year was approximately 370 kWh/m^2. The base model consumes less energy than the measured consumption in 2003 because it was defined as being operated during a "typical" year (of the 4 years studied, 2002-2005).

The first reason for the difference is that the rear brick patio that is electrically heated to remove snow and ice remained on for several spring and summer months during the year 2002 (resulting in an additional consumption of approximately 40,000 kWh/Year) and in the base model of the building the heat tape system was only assumed to be on during the winter months. The second reason for the lower base model consumption is that the number of annual heating degree days in 2002 were 3.2% higher than the average number of annual heating degree days of the years being studied (the total natural gas consumption for space and outdoor ventilation air heating in 2002 was approximately 1,430,000 kWh) and the weather file used in the base model was approximately an average year (in terms of both HDD per year and solar radiation, Figure 2.1). The third, smaller reason, is that the suite receptacle consumption in 2002 was 1.7% higher (6,000 kWh/Year) than the average suite receptacle consumption during the years that were studied.

Figure 7.3 shows a breakdown of the utility costs in the base model. It was generated using utility rates of \$0.11/kWh for electricity and \$0.03/kWh for natural gas. These were the actual utility charges for the building in 2003 (including taxes). The three most costly services in the building are space and outdoor ventilation air heating (\$40,874, 22.3%), interior building lights (\$25,490, 13.9%), and suite receptacle loads (\$20,684, 11.3%). The total annual utility cost for the base building is approximately \$167,500 (\$1,340/Year per occupant).

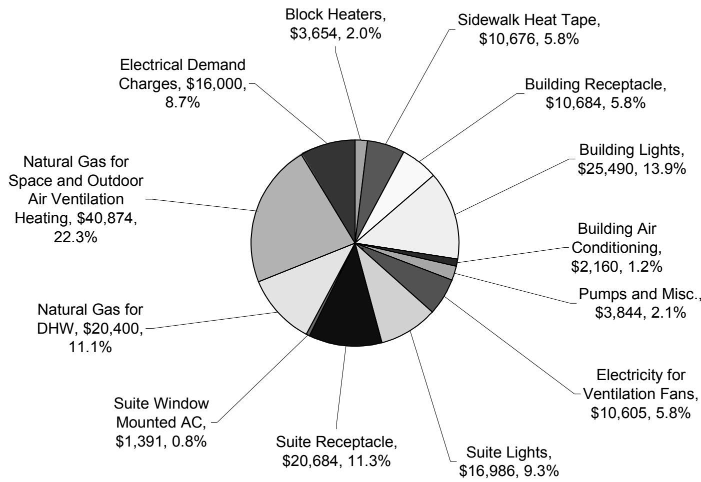

Figure 7.3: Base building utility cost

The average greenhouse gas emissions from electrical use in Saskatchewan, measured in equivalent kg of carbon dioxide and calculated by SaskPower, is 266.7 kg eCO_2/GJ [7.2]. Space and domestic hot water heating in the building comes from natural gas and SaskEnergy has calculated the equivalent kg of carbon dioxide from burning natural gas to be 51.9 kg eCO_2/GJ [7.2], 5.1 times less than electricity because electricity in Saskatchewan is predominantly generated by coal-fired power plants. The units "equivalent" kg of CO_2 account for the fact that each type of greenhouse gas will have a different global warming potential. Methane is rated to have a global warming potential of 21 and CO_2 is rated as 1. Therefore 1 kg of methane emissions equals 21 kg eCO_2. Based on the stated emission values, the total equivalent tonnes of CO_2 produced by the base building is approximately 1,300 Tonnes/Year (10.4 Tonnes/Year per occupant) and the breakdown is shown in Figure 7.4.

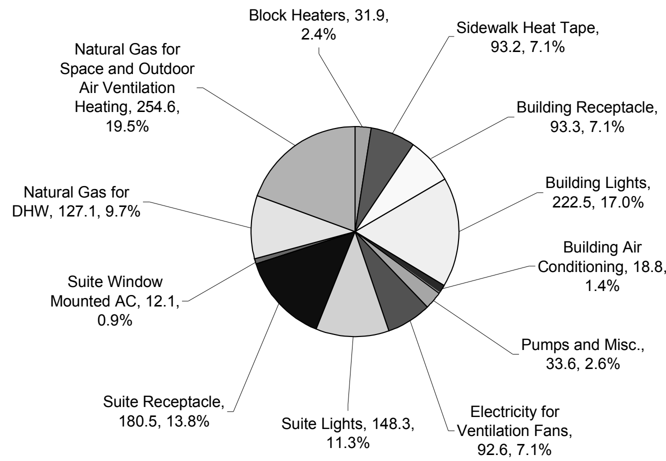

Figure 7.4: Base building greenhouse gas emissions (values are in eTonnes CO_2)

7.2 GENERAL RETROFITS IN ORDER OF INCREASING PAYBACK PERIOD

This section presents the first set of retrofits proposed for the building. Table 7.3 lists 12 general retrofits that each have simple payback periods of less than 2 years (a minimum return on investment of 50% per year). The retrofits are listed in order of increasing simple payback period. The retrofits in Table 7.3 produce a cumulative GPE savings of 17.3%. Their estimated cost is $13,220, resulting in a simple payback period of 0.3 years.

Table 7.3: Cost and savings of general retrofits with simple payback periods less than 2 years

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
1	Discontinue use of North sidewalk heat tape system	97,053	0	$10,676	$100	0.0	3.23%	3.2%
2	Set building thermostat to 22ºC (in both suites and common areas)	0	82,096	$2,463	$100	0.0	2.73%	6.0%
3	Set stairwell, storage, and mechanical room temperatures to 18ºC	0	18,738	$562	$100	0.2	0.62%	6.6%
4	Set crawlspace thermostat to 10ºC	0	34,637	$1,039	$200	0.2	1.15%	7.7%
5	Replace all incandescent bulbs with 13 W compact fluorescent or LED bulbs (in both suites and common areas)	177,194	-104,954	$16,343	$4,000	0.2	2.40%	10.1%
6	Reduce ventilation rates to ASHRAE standard 62-2001 minimum levels (2,622 L/s) on above ground floors and reduce recirculation rate in recreation areas	28,870	135,411	$7,238	$2,500	0.3	5.47%	15.6%
7	Remove unnecessary incandescent and fluorescent fixtures	20,218	-10,395	$1,912	$500	0.3	0.33%	15.9%
8	Install power factor correction	0	0	$3,413	$1,500	0.4	0.00%	15.9%
9	Reduce supply air temperature from 23ºC to 22ºC	0	983	$29	$20	0.7	0.03%	16.0%
10	Reduce crawlspace ventilation rates by 65%	2,127	9,132	$508	$500	1.0	0.37%	16.3%
11	Install variable frequency drives on heating and cooling recirculation pumps	20,578	-7,355	$2,043	$3,700	1.8	0.44%	16.8%
Total		**346,040**	**158,293**	**$46,226**	**$13,220**	**0.3**	**16.78%**	**16.8%**

The first column in Table 7.3 denotes the retrofit number. Below each table in this chapter more details for each retrofit are provided and referenced using the notation R#. Column 3 is electrical savings, column 4 is natural gas fuel savings, column 5 is annual utility bill savings, column 6 is the estimated cost of the retrofit, and column 7 is the simple payback period of the retrofit. This payback period is the total capital cost divided by the annual utility savings and does not include the time value of money, rising energy costs, equipment maintenance, lost opportunity costs, and other factors that are typically present in a detailed economic analysis. For more information on detailed economic analysis the reader is referred to the ASHRAE Applications Handbook [7.3]. Column 8 is the savings in grid purchased energy (GPE) resulting from the retrofit, and column 9 is the cumulative GPE savings for this and all previous retrofits.

The electrical and natural gas savings for each retrofit in this chapter were determined by summing their respective hourly energy consumptions (calculated by the computer model). Decisions regarding which retrofits to include were partially based on simulations of various different individual retrofits (Appendix 3). This chapter, however, presents energy savings resulting from a series of sequential retrofits aimed at reducing GPE by a factor of 10. Therefore, the energy savings from retrofit R3, for example, will be the energy savings that result when retrofits R3, R2, and R1 are all completed compared to the energy savings that result when retrofits R2 and R1 are completed. In this way, the coupling of the various retrofits are included. All of the retrofits presented in this chapter are calculated in this way. Thus, reducing the building temperature in retrofits R2-4 will reduce the energy savings obtained from retrofits presented later in this chapter, such as adding insulation to the envelope (retrofits R47-51) or replacing the boilers with more efficient models (retrofit R56).

R1 The first retrofit that is proposed is to disconnect the electric heat tape below the North patio. Rather than using electricity to heat the brick patio, snow can be removed from the rear patio manually. It may be necessary to apply de-icing compounds to ensure a safe walking surface for all tenants. Disconnecting the heat tape system for one year will produce enough annual savings ($10,676) to finance the capital cost of 10 of the 12 retrofits listed in Table 7.3.

R2 The average building thermostat temperature is currently 24.5ºC and in this retrofit it is reduced to 22ºC.

R3 The stairwells, mechanical rooms, and storage rooms are rarely occupied. Their temperatures are reduced to 18ºC in this retrofit.

R4 The crawlspace is currently heated to a temperature of 19ºC and in this retrofit it is reduced to 10ºC. This temperature will ensure that the water lines in the crawlspace do not freeze.

R5 In retrofit 5 all of the incandescent bulbs in the suites and throughout the building are replaced with compact fluorescent lamps (CFL) and light emitting diodes (LED). CFLs are placed in all fixtures that used 60-120W bulbs and LEDs are placed in the building's exit signs [7.4]. It should be noted that this retrofit results in an increase in natural gas consumption (a negative savings in Table 7.3) because a large portion of the energy delivered to the lights heats the building. Therefore, decreases in energy consumption of the lights increases natural gas consumption.

R6 In this retrofit outdoor air flow rates delivered to the hallway are reduced to minimum levels in ASHRAE Standard 62-2001. Each suite receives 22 L/s. The amount of air being recirculated in the main and second floor recreation areas is also reduced. Appendix A3.1 describes in greater detail the determination of the final building flow-rates.

R7 This retrofit addresses the fact that many areas in the building are over-lit. Based on recommended lighting levels by Saskatchewan Occupational Health and Safety [7.5] and observations made in the building by both the author and SRC during their building energy management (BEM) audit in 2003, several light fixtures are removed [7.6]. As with retrofit 5, retrofit 8 results in an increase in natural gas consumption.

R8 Power factor correction is recommended for the building. In larger buildings, power factor correction is needed because of the presence of induction motors and magnetic lamp ballasts. Capacitors are added to the building's electrical system in order to reduce the inductive component of the current and the consequential supply losses. This retrofit does not save energy but does result in utility cost savings through reduced peak electrical demand charges [7.6].

R9 The current average supply air temperature during the heating season is approximately 23ºC and in this retrofit it is reduced to 22ºC.

R10 This retrofit addresses the fact that the current crawlspace ventilation rate exceeds the minimum requirements recommended for a crawlspace in the CBIP modeling guidelines [7.7]. In this retrofit the crawlspace mechanical ventilation rates are reduced to minimum levels. Mechanical crawlspace ventilation is not eliminated because of the need to maintain an above zero temperature in the crawlspace and concerns about moisture build-up in the space.

R11 In this retrofit the motors for the heating and cooling recirculation pumps in the model are modified to have variable frequency drives. These pumps motors currently operate continuously and one reason for the significant energy savings is the reduction in pump run times during periods when heating or cooling is not necessary [7.8].

Table 7.4 lists the second set of general retrofits recommended for the building. These retrofits have simple payback periods between 2-10 years and bring the cumulative GPE savings up to 22.0%.

Table 7.4: Cost and savings of general retrofits with simple payback periods between 2-10 years

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
12	Reduce pressure drop in the ducting by cleaning and sealing central supply shaft (25% savings) and cleaning and sealing the exhaust ducts (25% savings)	4,554	-1,995	$441	$1,000	2.3	0.09%	16.9%
13	Replace fluorescent fixtures with more efficient ballasts and bulbs and retrofit double bulb fluorescent fixtures to use a single bulb with a silver reflector	74,667	-57,776	$6,480	$15,000	2.3	0.56%	17.4%
14	Install setback thermostats in building common areas and set evening setback temperature to 18ºC	0	8,539	$256	$650	2.5	0.28%	17.7%
15	Replace washing machines and clothes dryers with higher efficiency front loaded models	39,062	62,062	$6,159	$16,000	2.6	3.36%	21.1%
16	Reduce stairwell and hallway lighting to 20% from 12pm-7am and install occupancy controls	10,068	-7,936	$869	$3,000	3.5	0.07%	21.1%
17	Install day lighting controls in recreation and foyer areas	4,629	-4,111	$386	$2,000	5.2	0.02%	21.2%
18	Install block heater control system	24,915	0	$2,741	$8,000	5.8	0.83%	22.0%
	Monitor block heater consumption and charging renters based on their consumption (additional 10% savings)				$8,000			
Total		**157,895**	**-1,217**	**$17,332**	**$53,650**	**3.1**	**5.21%**	**22.0%**

R12 This retrofit assumes savings in duct pressure drop will occur as a result of duct cleaning and sealing. Part of these savings occur from the central supply air shaft traveling down through the building being air sealed. This retrofit requires a person traveling down the central supply shaft using a rope and harness.

The central supply and exhaust ducts in the 11th floor mechanical room are also air sealed in retrofit 12. In an air balancing report written in March 1998, Centre West Air of Saskatoon stated that their balancing tests revealed “a considerable amount of leakage in the system” [7.9]. The report also states that at that time, in order to compensate for the significant air leakage, the central fan motors were adjusted to operate at their maximum amperage. It was apparent from this report and visual inspection of the ductwork inside the 11th floor mechanical room that there is significant potential for air sealing measures.

The 2003 building audit by SRC also found numerous holes in the building's ductwork, particularly where the central supply shaft connects to the hallway wall. All of the supply and exhaust grills in the building are removed in this retrofit in order for them to be cleaned and to seal holes in the ducting. Cleaning the exhaust grills in tenants suites also accounts for a large part of the savings that are assumed to be achieved. In the 2003 BEM audit report the exhaust flow in 10 bathrooms were measured. Of the 10, all were below the desired rates, all were in need of cleaning, and one grill was measured to have zero flow.

R13 In this retrofit all of the T12 fluorescent fixtures with magnetic ballasts are replaced with T8 fixtures with electronic ballasts. Electronic ballasts increase the frequency of the electricity entering the fluorescent bulbs to between 25,000 and 40,000 Hz (as opposed to 60 Hz from a magnetic ballast). This improves the efficiency of the fixture [7.10]. If the T12 fixture was a double lamp fixture it is replaced by a single T8 lamp and a silver reflector. Appendix A3.1 discusses in greater detail payback periods for different fluorescent lighting retrofit options and shows that the use of silver reflectors has a greater rate of return than continuing to use two bulbs.

R14 Setback thermostats are installed in the building common areas (laundry rooms, main and second floor recreation areas, garbage room, and the main foyer) in this retrofit. Temperature control settings in the thermostats are set to 22ºC from 7am-12am and 18ºC from 12am-7am.

R15 In this retrofit the current 8 washing machines and 8 electric dryers (which are estimated to be over 20 years old) are replaced with the most efficient front loading models in the EnergyStar directory. Newer EnergyStar front loading washing machines have been found to result in a 62% reduction in domestic hot water use and a 40% savings in electrical use [7.11, 7.12]. In addition to having a greater efficiency, the front loading machines also remove a greater amount of water during their spin cycle. This has been found to reduce the electrical consumption of clothes dryers by 40% [7.13]. New dryers are also inherently 25% more efficient than older models and thus a total savings of 65% was applied to the dryer loads in the building [7.14]. To help ensure that the expected savings were achieved, the current washing machines and clothes dryers are also replaced with coin operated models. This should result in more conservative use of the machines by the tenants.

R16 In this retrofit the lighting schedule for the hallways and stairwells is dimmed to 20% during periods when tenants were assumed to be asleep (12am-7am). For safety the hallway and stairwell lights are not shut off entirely. Six occupancy sensors are installed on each floor (one in the stairwell and three per hallway) to ensure that if tenants do exit their apartment in the evening the hallways and stairwells will be fully lit.

R17 Daylighting controls are added in this retrofit for lights in the main and second floor recreation areas and the main floor foyer. These areas are very well lit during the day because of their many windows.

R18 In the final retrofit in Table 7.4, a block heater control system is installed to control the electrical output of the parking lot receptacles. Figure 7.5 shows the proposed new controller. The manufacturers of this product call it an Intelligent Parking Lot Controller (IPLC).

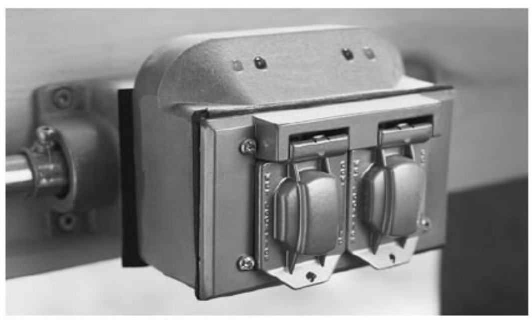

Figure 7.5: Intelligent Parking Lot Controller [7.15]

Engine block heaters are typically simple resistance heaters that consume energy as long as the vehicle is plugged in. Optimum heating of the engine, however, does not require the heater to be continuously engaged. The proposed controller won Natural Resources Canada's (NRCan) 2000 Energy Efficiency award in the category of Energy Management Technology. It controls the amount of energy sent to a block heater by measuring engine temperature, outdoor temperature, wind chill, the amount of current drawn, the time of day the heater is in use, and the length of time the heater has been plugged in. NRCan states that on average these controllers reduce block heater electrical consumption by 65% in comparison to conventional uncontrolled block heaters [7.15].

Chapter 6 discussed how the block heaters in KEP likely consume more electricity than those in a typical residence. Due to the believed over consumption of the block heaters this retrofit assumes that the combination of installing the IPLC and electrical metering will result in a total savings of 75% as tenants currently are not directly charged for the electrical usage of their block heaters.

Table 7.5 lists the third grouping of general retrofits recommended for the building. These retrofits have simple payback periods greater than 10 years. They provide only 0.78% savings in GPE, but cost approximately $252,000. While total energy savings resulting from the 10 retrofits listed in Table 7.5 are small, one of their benefits is that they result in less electrical energy consumption and greater natural gas consumption. This will reduce greenhouse gas emissions and decrease the required size of the photovoltaic system (the highest cost retrofit) that is proposed at the end of this chapter.

Table 7.5: Cost and savings for general retrofits with simple payback periods greater than 10 years

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
19	Install occupancy lighting controls in crawlspace, mechanical rooms, laundry rooms, public washrooms, and storage rooms	2,764	-1,622	$255	$3,000	11.7	0.04%	22.0%
20	Reduce the pressure drop in the ceiling mounted lounge/recreation area AHU's by cleaning coils and ducts, maintenance, and duct sealing (main floor ΔP reduced by 25% & second floor ΔP reduced by 25%)	316	-229	$28	$400	14.3	0.00%	22.0%
21	Increase heat recovery effectiveness of the crawlspace HRV to 85%	0	5,033	$151	$3,000	19.9	0.17%	22.2%
22	Reduce suite receptacle consumption by 20% (not including refrigerator consumption)	35,093	-30,272	$2,952	$103,240	23.5	0.16%	22.4%
	Reduce suite lighting consumption by 15%	8,942	-7,686	$753			0.04%	22.4%
	Reduce window mounted air conditioner consumption by 50%	6,324	0	$696			0.21%	22.6%
23	Replace suite refigerators	25,077	-22,238	$2,091	$58,000	27.7	0.09%	22.7%
24	Replace heating and cooling recirculation pump motors with higher efficiency models	715	0	$79	$2,500	31.8	0.02%	22.7%
25	Replace crawlspace ventilation motors with higher efficiency motors.	293	-56	$31	$1,000	32.7	0.01%	22.7%
26	Replace crawlspace fans with higher efficiency models	270	-179	$24	$2,000	82.2	0.00%	22.7%
27	Replace heating and cooling circulation pumps with	547	-398	$48	$4,000	82.9	0.00%	22.2%
28	Reduce unspecified building receptacle consumption by 10% and install digital controls	2500.00	-1785.71	221.43	$75,000	338.7	0.02%	22.8%
Total		**82,841**	**-59,433**	**$7,330**	**$252,140**	**34.4**	**0.78%**	**22.8%**

R19 In the first retrofit in Table 7.5, occupancy lighting controls are installed in the crawlspace, mechanical rooms, laundry rooms, and storage rooms.

R20 The main and second floor systems in KEP each have two coils in each recirculation system and in retrofit 20 they are cleaned. Based on an article in the ASHRAE Journal [7.16] a 30% reduction in pressure drop is assumed to result from cleaning the coils, cleaning the ducts, and sealing holes in the ductwork of the main and second floor lounge air recirculation systems. The Journal article showed that approximately 14% savings in pressure drop per heating and cooling coil was measured as a result of cleaning (in a New York City office building). Prior to beginning measurements it had been approximately one year since the building's last coil cleaning. The study also states that coil cleaning increases indoor air quality as there is less potential for mold and bacteria to build up inside the coils.

R21 In this retrofit the heat recovery system in the crawlspace is replaced with an 85% effective unit [7.17].

R22 In the base computer model of the building there is approximately 25,000 kWh/Year in general receptacle loads that were not specifically defined. This retrofit assumes that a 10% reduction in this load is achieved through greater attention to energy use by the building managers, replacing the bulbs in the soft drink vending machine with more efficient fluorescent bulbs [7.18], and replacing the pneumatic controls in the mechanical room with digital controls. The air compressor in the mechanical room cycles frequently and electrical savings will result from its removal. The savings from removing the compressor do not justify the additional $75,000 cost assumed for the digital controls but the digital controls are recommended as a required retrofit in order to ensure that the building operates properly. Installing proper control systems and commissioning the building will be necessary in order for it to operate efficiently.

Another potential way to achieve the 10% savings in general building receptacle load is to replace the elevator drive systems with a higher efficiency variable-voltage, variable-frequency, system. The cost of such as retrofit, however, would be very large because of the need to bring the elevators up to the most recent code requirements.

R23 Retrofit 23 combines three sources of energy savings that result from the installation of wireless electricity monitoring devices. These devices are installed in each suite in order to meter tenant electrical consumption and charge them accordingly. Based on literature that quoted 10-26% savings in total energy consumption as a result of monitoring [7.19-7.22], savings of 20% in suite receptacle load, 15% in suite lighting load, and 50% in window mounted air conditioner load are assumed to result from monitoring. Wireless monitoring devices are recommended because they were assumed to be easier to install.

The savings of 20% in suite receptacle load assumes that tenants will replace some of their current appliances with more efficient models. The act of monitoring tenants energy usage should result in greater incentive for them to upgrade their older appliances. The only appliance that was specifically recommended to be replaced was the refrigerator (retrofit 24) because it is an appliance that is owned by the building owner. There is significant potential for greater savings, however, through the purchase of other new appliances. Greater savings than the 10-26% quoted in the literature [7.19-7.22] are assumed for the window mounted air conditioners for two reasons. First, later in this chapter the central air conditioning unit is retrofit and the average building temperature is reduced as a result. Second, measurements presented in Chapter 6 showed that tenants who are conservative in their use of their window mounted units can achieve considerable energy savings.

R24 In this retrofit the suite refrigerators are replaced with equally sized higher efficiency EnergyStar models [7.23]. Savings were determined by measuring the consumption of the current refrigerators. Refrigerators are the only appliance specifically retrofit because they are provided with the suite. Stoves are also provided with the suite but their annual energy use was not known and newer electric stoves are not measurably more efficient than older units.

Retrofits R23 and R24 reduce the suite receptacle power in the computer model to 5.4 W/m^2 (based on suite floor area). The default value recommended in the CBIP modeling guidelines for apartments is 5.0 W/m^2 [7.7]. The reduced load entered into the computer model therefore still exceeds recommended values found in literature.

R25 In this retrofit the motors driving the heating and cooling recirculation pumps are replaced with higher efficiency (86%) motors [7.24, 7.25].

R26 In this retrofit the supply and exhaust motors in the crawlspace ventilation system are replaced with high efficiency (85.5%) motors [7.24, 7.25].

R27 The supply and exhaust fans in the crawlspace ventilation system are replaced with higher efficiency (70%) fans in this retrofit [7.26].

R28 In the last retrofit from Table 7.5 the pumps in the computer model are replaced with higher efficiency (70%) models [7.27, 7.28].

7.3 REPLACEMENT OF SUPPLY AIR HANDLING UNIT

This retrofit details the savings and cost associated with replacing the central supply air handling unit (AHU) in the 11th floor mechanical room and switching the positions of the supply and exhaust AHUs. Table 7.6 outlines the associated costs and savings that result from this retrofit.

Table 7.6: Cost and savings for retrofitting the central air handling units

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
29	Remove existing central supply AHU	0	0	$0	$2,000		0.00%	22.8%
30	Install low face velocity supply AHU	10,561	-8,836	$897	$10,000	11.2	0.06%	22.8%
31	Place new supply AHU on opposite side of the mechanical room and install new air intake for this unit (70% savings in mechanical room ducting ΔP).	5,296	-4,930	$435	$5,000	11.5	0.01%	22.8%
32	Install premium efficiency motors	4,841	-466	$519	$2,800	5.4	0.15%	23.0%
33	Increase fan efficiency to 80%	9,005	-6,855	$785	$4,200	5.4	0.07%	23.1%
34	Place central supply motor inside airstream	-91	1,692	$41	$200	4.9	0.05%	23.1%
35	Additional installation expenses				$10,000		0.00%	23.1%
Total		**29,612**	**-19,395**	**$2,675**	**$34,200**	**12.8**	**0.34%**	**23.1%**

R29 This retrofit is the cost associated with removing the existing supply AHU.

R30 The replacement supply AHU is a low face velocity model (1.52 m/s face velocity as opposed to a traditional face velocity of 2.54 m/s). Selecting a system with a lower face velocity reduces the pressure drop across an AHU. By selecting a well-designed, low face velocity unit, the pressure drop in the supply AHU is reduced in this retrofit from 435 Pa to 250 Pa [7.29, 7.30].

R31 When the new AHU is installed it is placed on the opposite side of the mechanical room in order to reduce the pressure drop in the ducting. Figure 7.6 shows the placement of the central supply and exhaust AHUs and how the current method of ducting the supply AHU uses six 90º corners. The total pressure drop from locations A to B and C to D in Figure 7.6 was measured to be approximately 170 Pa at a flow rate of approximately 3,300 L/s.

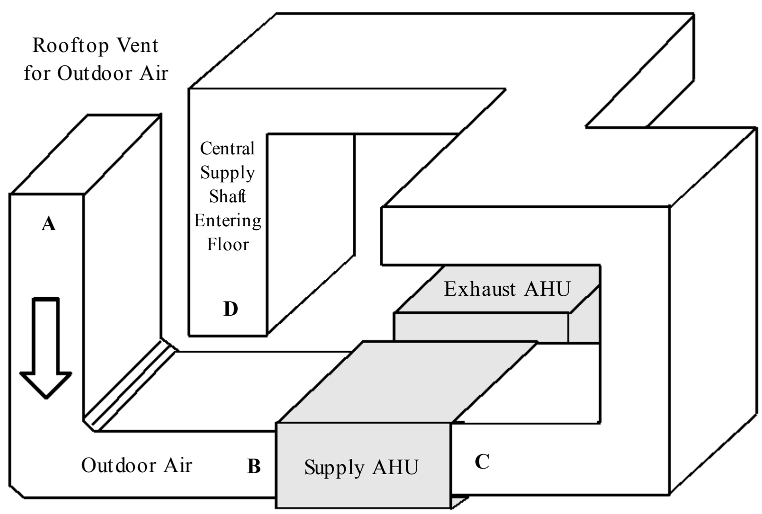

Figure 7.6: Current method of ducting supply air from air handler to central shaft

A 70% savings in pressure drop is assumed in this retrofit because the number of corners is reduced from 6 square 90º corners to 2 rounded corners and the total duct length is reduced by over 50%. The new duct configuration can be seen in Figure 7.7.

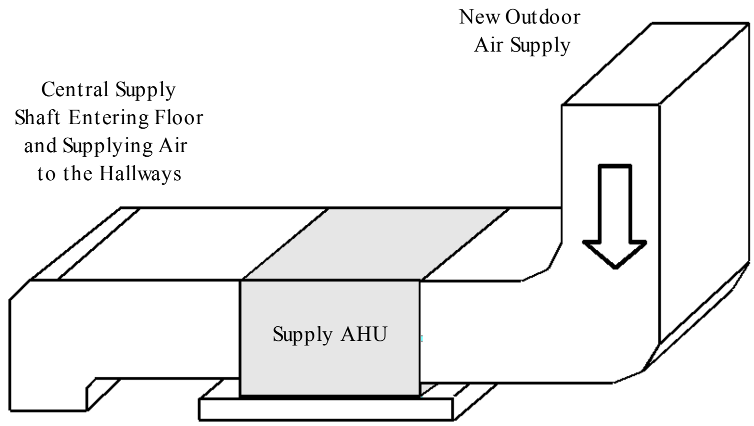

Figure 7.7: Ducting method for new supply AHU

R32 In this retrofit the efficiency of the fan motor in the new supply AHU is specified to be 85% and the fan motor in the exhaust AHU is replaced with a higher efficiency (84%) model [7.24, 7. 25].

R33 The fan in the supply AHU is specified as being higher efficiency (80%) airfoil fans in this retrofit. The exhaust fan is also replaced with a higher efficiency model. Airfoil fans are the highest-efficiency centrifugal fans that are commercially available [7.26].

R34 In this retrofit the new supply AHU is also specified as having its motor in the air stream. This results in motor heat loss being transferred to the ventilation air and natural gas savings during the heating season. A smaller negative side effect is that electrical consumption increases in the cooling season because of the additional air conditioning load.

R35 An additional installation cost is added to to the other retrofits listed in Table 7.6 in order to account for additional expenses, including $1,000 for a half day crane rental [7.31] to remove the existing AHU and install the new AHU.

A final recommended change to the supply and exhaust AHUs is for cogged V-belts to be used to drive the fans as opposed to conventional V-belts. A comparison of the two types of belts can be seen in Figure 7.8.

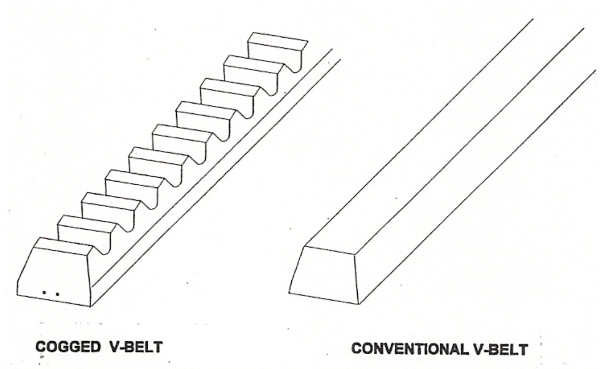

Figure 7.8: Belt comparison [7.32]

Cogged V-belts have lower flexing losses and are generally 1-3% more efficient than conventional belts. Typically the replacement of conventional belts with cogged V-belts have payback periods less than 1 year [7.32]. Savings associated with switching belt type was not calculated and this retrofit is recommended as a best practice.

7.4 VENTILATION AIR ENERGY RECOVERY

In this section the existing heat recovery system, which had a maximum effectiveness of approximately 36%, is replaced with two energy recovery wheels each having effectiveness values of 81% (alternatively a single 90% effective system could be used). The combination of two 81% effective wheels results in a system with a total effectiveness of 90%. The cost of the 90% effective heat recovery unit is assumed to be $12/(L/s), twice the typical cost of a standard heat recovery unit [7.33]. Table 7.7 outlines the cost ($40,000 with an 2.8 year simple payback) and savings (14.5% in total GPE) associated with this retrofit. The cumulative savings in GPE increase to 37.6% as a result of the retrofits in Table 7.7.

Table 7.7: Cost and savings for replacing the existing glycol run-around system with two energy wheels

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
36	Removing run-around glycol heat recovery system (includes disconnecting the glycol circulation pump)	10,079	-5,040	$958	$2,500	2.6	0.17%	23.3%
37	Install two energy recovery wheels with effectiveness values of 81%. Total system effectiveness is 90%	0	421,138	$12,634	$32,000	2.5	14.01%	37.3%
38	Install two 200 W motors that will operate the two energy recovery wheels for approximately 8,100 hours per year	-2,430	1,680	-$217	$0	0.0	-0.02%	37.3%
39	Cooling contribution of HR	9,145	0	$1,006	$0	0.0	0.30%	37.6%
40	Capital savings from downsizing replacement air conditioning unit				-$4,725		0.00%	37.6%
41	Installation of equipment				$10,000		0.00%	37.6%
Total		**16,794**	**417,778**	**$14,381**	**$39,775**	**2.8**	**14.46%**	**37.6%**

R36 Installing a new energy recovery system requires the current glycol run around heat recovery system to be removed. In this retrofit electrical savings result from no longer needing a 1.1 kW pump continuously circulating glycol.

R37 In this retrofit two energy recovery wheels with a combined effectiveness of 90% are installed. Energy recovery was modeled using TRNSYS and more details of this analysis can be found in Appendix A3.3. Frosting was accounted for by reducing the effectiveness of the system for outdoor air temperatures below -16ºC. From -16ºC to -40ºC the effectiveness was varied linearly from 0.90 to 0.55. These settings resulted in a reduction in recovered energy of approximately 20,000 kWh/Year but are necessary to avoid frost build up on the wheel.

R38 The energy recovery system requires two wheel motors to be operating during the heating and cooling seasons. The motors are assumed to be 200 W [7.30] in this retrofit and they are assumed to operate at an average load of 75%. From the weather file, the number of hours the energy recovery system would be in operation was found to be approximately 8,100 hours per year.

R39 This retrofit shows the electrical savings that are predicted to result from the cooling provided by the energy recovery system during the summer (when the outdoor air temperature is greater than the exhaust air temperature). These savings were calculated using a TRNSYS model.

R40 Because the energy recovery system provides cooling in the summer the replacement air conditioning unit that is proposed later in this chapter is able to be downsized by 27 kW.

R41 An additional installation cost is added in this retrofit to account for additional expenses including $1,000 for a half day crane rental [7.31] to install and remove equipment into and from the 11^{th} floor mechanical room.

7.5 DOMESTIC HOT WATER CONSUMPTION AND HEATING

The three atmospherically drafted hot water heaters currently in the building (total output 440 kW) were replaced in this retrofit with a single 150 kW higher efficiency (85%) model. Domestic hot water (DHW) consumption is also reduced from the installation of low flow shower heads, aerating faucets, and water monitoring devices in each suite. Table 7.8 lists these retrofits and their associated savings and costs.

Table 7.8: Cost and savings from retrofits that impact domestic hot water consumption and production

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
42	Reduce suite DHW load by installing low-flow shower-heads	0	77,715	$2,331	$8,000	3.4	2.59%	40.2%
	Reduce suite DHW load by installing aerating faucets		62,253	$1,868	$8,000	4.3	2.07%	42.2%
	Install water monitoring devices in suites to reduce tenant DHW consumption by an additional 10%		32,985	$990	$103,356	104.4	1.10%	43.3%
43	Remove one existing DHW tank	0	0	$0	$1,000	0.0	0.00%	43.3%
44	Purchase and install one 150 kW, 85% efficient, DHW tank	0	110,716	$3,321	$14,000	4.2	3.68%	47.0%
Total		**0**	**283,669**	**$8,510**	**$134,356**	**15.8**	**9.44%**	**47.0%**

R42 The first retrofit in Table 7.8 is the installation of low flow shower heads, aerating faucets, and wireless water monitoring devices in every suite [7.34-7.36]. Two wireless water monitoring devices are installed per suite, one for domestic water and the other for DHW (the savings from reducing domestic water consumption were not included in the analysis). An additional benefit to the installation of the recommended wireless water monitoring devices (from Wellspring Wireless) is that they are also equipped with a “continuous low flow” alarm. Significant amounts of water are wasted on a continual basis due to water leakage (particularly in toilets and faucets) and this alarm helps building owners become aware of, and detect, water losses in their building [7.22].

After reducing the DHW load in the suites through retrofit R42, the peak hourly DHW load in the suites of the computer model is reduced to 560 W/Occupant. The default value recommended in the CBIP modeling guidelines for apartments is 500 W/Occupant [7.7]. The proposed retrofit consumption therefore still exceeds recommended values found in literature.

R43 In this retrofit one of the existing DHW heaters is removed, all of the tanks are disconnected, and the chimney penetration in the 11th floor mechanical room is sealed. The other DHW heaters can be removed if they have salvage value.

R44 The last retrofit in Table 7.8 is replacing the 3 existing DHW heaters in the computer model replaced with a single higher efficiency (85%) DHW heater. Savings from installing the new DHW heater are mostly due to decreasing standing losses and increasing the part load efficiency of the DHW system. The replacement tank is sized to meet the peak DHW load and an additional safety factor is not included because the next retrofit being proposed is solar water heating for DHW.

7.6 SOLAR WATER HEATING FOR DOMESTIC HOT WATER

Natural gas consumption for heating DHW is reduced in this retrofit by installing a solar water heating (SWH) system. Table 7.9 shows the savings and expected cost of this retrofit. The remaining DHW fuel consumption after retrofits 42-44 is approximately 338 MWh/Year and the proposed SWH system is sized to meet 99% of this load.

Table 7.9: Cost and savings from installing a solar DHW system

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
45	Install a solar DHW system sized to provide 99% of the DHW load	-2,140	337,966	$9,904	$294,800	29.8	11.17%	58.2%
46	Add 51 mm of polyurethane insulation to the exterior surface of the South exterior wall	0	18,834	$565	$15,000	26.5	0.63%	58.8%
	Total	**-2,140**	**356,800**	**$10,469**	**$309,800**	**29.6**	**11.80%**	**58.8%**

R45 In this retrofit the solar panels for SWH of DHW are mounted vertically on the South wall of the building. The building's South face can be seen in Figure 7.9 and, excluding windows, it has a South facing area of over 1,000 m^2. Parts of the wall are shaded at times, however, and were not considered optimal for mounting solar panels. The area of the wall where there is the least concern for shading is approximately 840 m^2 and 400 m^2 of this is used to mount the solar panels for heating DHW.

Figure 7.9: South face of KEP in 2003 (Photograph credit, SRC)

The proposed SWH system was modeled using RETScreen. Figure 7.10 shows the design schematic that the RETScreen model is based upon. The working fluid in the solar collector is specified to be a water/glycol mixture and the system uses a heat exchanger to transfer collected heat to a storage tank. The effectiveness of this exchanger was assumed to be 65%.

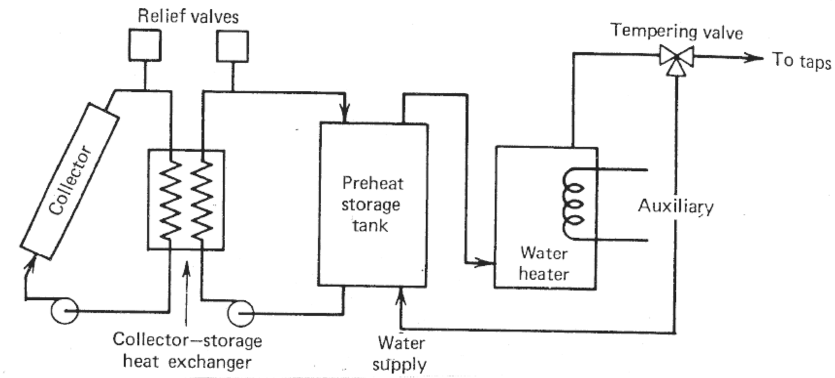

Figure 7.10: Solar DHW Schematic [7.37]

Solarco SC 22 panels were selected for the system because they had the best performance characteristics in the RETScreen product database. Their performance characteristics were (Fr τ α) = 0.79 and (Fr UL) = 3.25 (W/m^2K) where Fr is the collector heat removal factor, τ is the solar transmittance of the glazing, α is the collector plate absorbance, and UL is the collector loss coefficient. The total pumping power was assumed to be 3 W/m^2, the piping and solar tank losses were assumed to be 1%, and the losses due to snow and/or dirt were assumed to be 3%.

From the computer model of the building the DHW use in the building was known to be 80.8 L/Day per occupant (10,100 L/Day in total). Using this load and a reference collector size of 400 m^2 Figure 7.11 was generated. It shows the energy output of the SWH system as the ratio of tank storage capacity to collector area is increased.

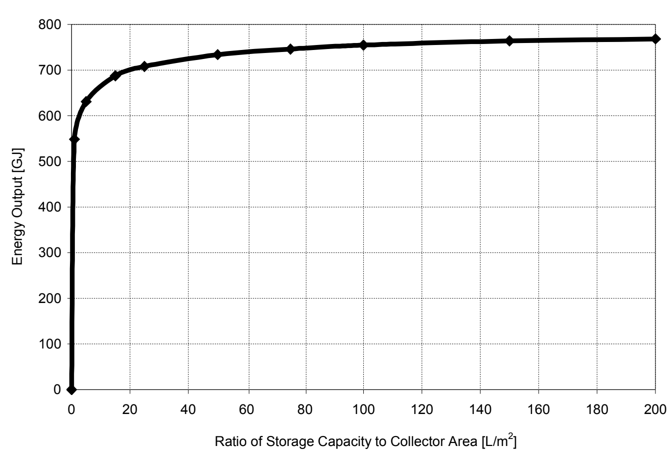

Figure 7.11: Energy production as ratio of tank capacity to collector area is increased

Based on the results in Figure 7.11 the storage capacity ratio is specified in this retrofit to be 100 L/m^2 (based on collector area). Often it is not possible to install tanks of this size but KEP has a very large unused crawlspace. Figure 7.12 shows the foundation in KEP and a dotted rectangle marks the proposed storage tank location. The volume of the space within the rectangle is approximately 100 m^3. Placing the storage tank in the crawlspace avoids structural and space concerns that might result from placing the tanks above ground. It is also a location where all of the building's water pipes can be easily accessed.

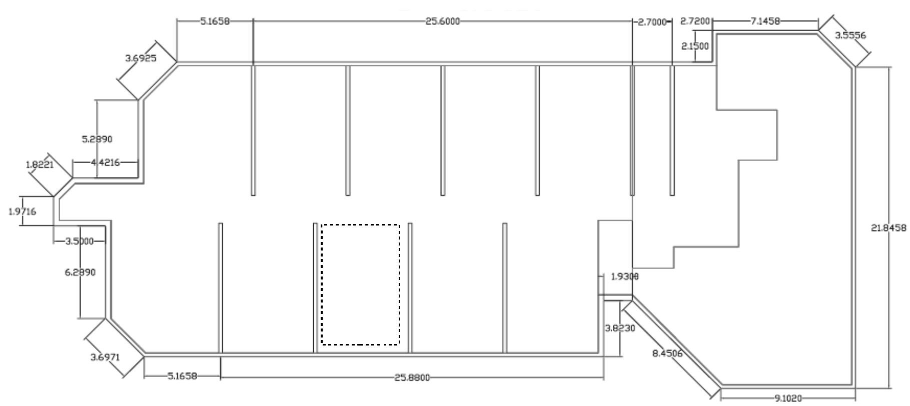

Figure 7.12: Crawlspace with potential storage tank location marked (dimensions in m)

Figure 7.13 shows the fraction of the total DHW load that the solar system would provide as collector area is increased, using the selected storage capacity to collector area ratio of 100 L/m^2.

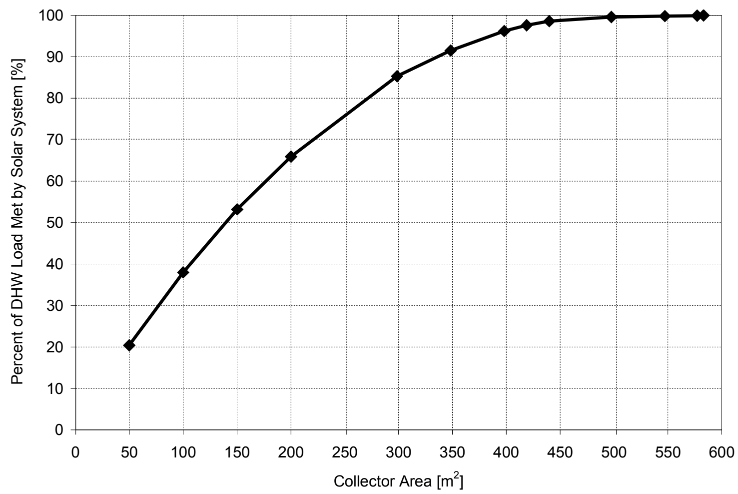

Figure 7.13: Fraction of DHW load as collector area increases

In Figure 7.13 the percentage of the DHW load met by the collectors begins to decrease most noticeably after 400 m^2. A collector size of 440 m^2 was selected as this was the required amount to meet 99% of the total DHW load (meeting 100% of the load would have limited the available South wall area needed for the second solar water heating system proposed later in this chapter).

From RSMeans data, the cost of the system was initially estimated to be approximately \$500/m^2 (based on collector area). A case study published by Natural Resources Canada states that the final installed cost of a 228 m^2 retrofit installation of a similar solar DHW system in Nova Scotia was \$670/m^2 [7.38]. This cost includes actual design, installation, material, and building modification costs, while the initial estimate of \$500/m^2 likely underestimates these costs. To account for additional expenses, the assumed price of the collectors and installation was increased to \$670/m^2.

The Nova Scotia installation also received a rebate from the Government of Canada for 50% of the total cost. If a rebate of the same amount was awarded to this project the final cost and payback period would be reduced to approximately \$150,000 and 15 years. Government rebates are not included in the cost estimate because many of the past programs have expired and it is not known at this time what the details are of programs that will be available in the future.

R46 In combination with retrofit 45, behind each solar panel, 51 mm of rigid polyurethane insulation (2.6 m^2K/W, R 14.8) is added to the exterior wall. A significant benefit of adding insulation to the exterior surface of the building is the reduction in thermal bridging through the concrete floors. Greater energy savings could have been obtained by adding more insulation to the exterior wall but the thickness of the insulation was limited to 51 mm for structural, aesthetic, and moisture reasons. Moisture would be the greatest concern with adding insulation to the exterior wall and the estimated cost for this retrofit includes the need to ensure a high quality, moisture conscious, installation of the panels and insulation. The next section discusses building envelope retrofits in greater detail.

7.7 BUILDING ENVELOPE

This section details retrofits proposed for the building envelope. To reduce building heat loss, polyurethane insulation (0.0513 $m^2K/(W \cdot mm)$, R 7.4/inch) with a painted gypsum board finish is added to the majority of the inside surfaces of the building's exterior walls, except for on the South facade where the solar collectors are located (as discussed in Section 7.6). When investigating the most cost effective methods to add insulation to the exterior walls it was found that the cost of adding insulation to the exterior surface of the exterior walls was approximately 3 times more than the cost to add insulation to the inside surface, mainly due to the cost of maintaining an exterior brick finish. Appendix A3.2 provides more information on cost estimation comparisons for different ways to add insulation to the building. A drawback to adding insulation to the inside surface of the exterior walls is that thermal bridging through the concrete floors will still occur.

Table 7.10 shows the savings and expected costs for retrofitting the building envelope. It also shows the area of each retrofit. The total, non-window, exterior wall area of KEP is approximately 3,446 m^2. All of the walls in the building that could not be feasibly retrofit and locations, such as the elevator shafts, remain at their original insulation levels. This retrofit results in a 18.5% GPE savings, but is very expensive ($745,000) and has a very long payback period (44.6 years).

Table 7.10: Cost and savings for envelope retrofits

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]	Area [m^2]
47	Insulate crawlspace walls with R10 insulation	0	12,445	$373	$5,000	13.4	0.41%	59.2%	265
48	Above Baseboard Heaters	0	99,898	$2,997	$65,000	21.7	3.32%	62.5%	1,754
49	Above Baseboards - South Solar	0	17,063	$512	$31,000	60.6	0.57%	63.1%	836
50	Stairwells, Storage, and Mechanical Rooms	0	36,114	$1,083	$27,000	24.9	1.20%	64.3%	650
51	Sloped Metal Roofs	0	33,968	$1,019	$42,000	41.2	1.13%	65.4%	619
52	Replace South windows with triple pane, low-e windows (ThermoTech ER 15) and North windows with quadruple pane, low-e, insulated windows (ThermoTech ER 6)	0	211,712	$6,351	$486,400	76.6	7.04%	72.5%	608
53	Replace doors with steel polyurethane filled well insulated doors	0	2,714	$81	$5,500	67.5	0.09%	72.6%	
54	Air seal leakage paths and compartmentalize floors in building (10% savings in infiltration)	0	25,677	$770	$6,000	7.8	0.85%	73.4%	
55	Reduce infiltration by an additional 40% (50% in total)	0	117,202	$3,516	$77,420	22.0	3.90%	77.3%	
Total		**0**	**556,794**	**$16,704**	**$745,320**	**44.6**	**18.53%**	**77.3%**	

Figure 7.14 shows the simulated energy savings as polyurethane insulation is progressively added to five of the envelope surfaces in KEP. Labels in Table 7.10 and Figure 7.14 such as "Above Baseboards" are explained in the following sections and are consistent with the labels used in Table 7.10.

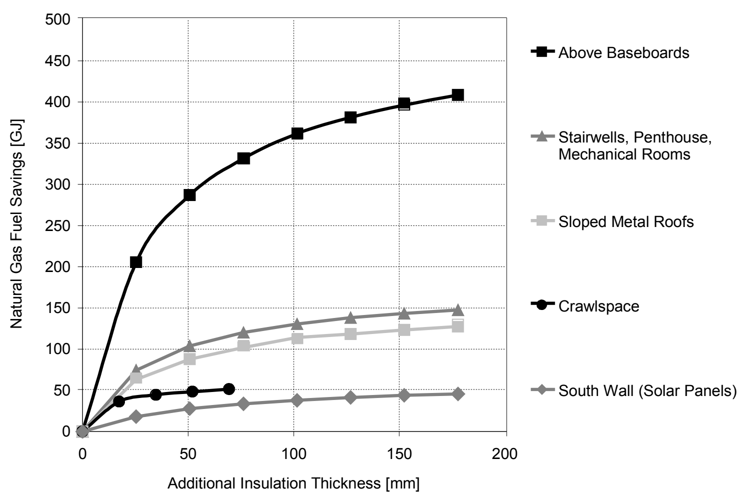

Figure 7.14: Annual energy savings from the addition of insulation

R47 In the first retrofit of this section the interior surface of the crawlspace walls are insulated with 35 mm of rigid polyurethane (1.76 m^{2}K/W, R 10.0). Figure 7.14 showed that marginal gains are achieved beyond this thickness.

R48, Above Baseboard Heaters: An obstacle when adding insulation to the interior surfaces of the building's exterior walls are the baseboard convection heaters. Figure 7.15 shows two of these units inside a vacant suite.

Figure 7.15: Suite bedroom with wall mounted convection heaters

In this retrofit all of the walls that are not South facing and had baseboard heaters are insulated with 102 mm of polyurethane insulation (5.3 m^2K/W, R 30.1) and had their enclosures moved 51 mm away from the wall. Insulation is added to the wall above the baseboard heaters and finished with painted 12.7 mm thick gypsum board.

Figure 7.16 shows the dimensions of the heater enclosures with a cross section of the square fin elements attached to the hot water pipes and the proposed method of retrofitting the walls and the enclosures. The width of the top of the enclosure is 64 mm and in order to maintain an aesthetically pleasing appearance the enclosures are moved 51 mm away from the wall. For safety, fire rated gypsum is placed between the insulation and the top of the enclosure.

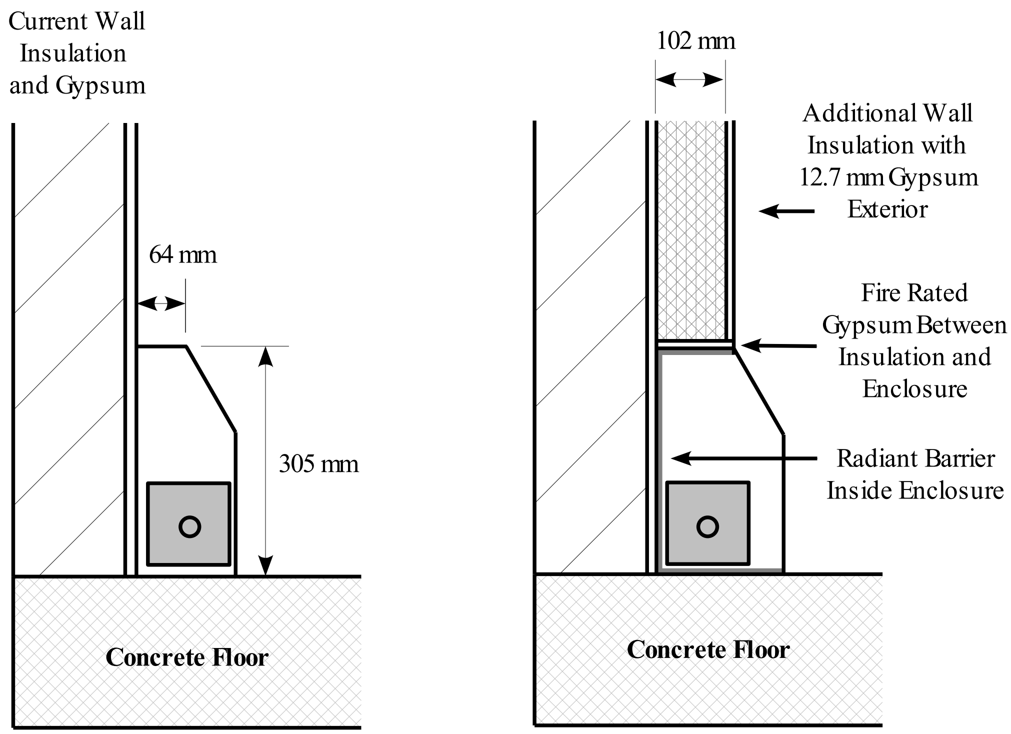

Figure 7.16: Typical wall heater (left) and proposed interior wall retrofit (right)

From an energy perspective, it would be better to move the heaters away from the wall and place insulation behind them. The layout of the hot water piping for these heaters, however, makes moving them difficult. The system would need to be drained and a great deal of labour would be required to add in small sections of piping and cut out sections of the walls between suites. This would be a very costly retrofit and highly intrusive for the tenants.

When adding insulation to the wall above the baseboard heaters the enclosures for each heater are removed in order to air-seal the wall-floor joint and install a radiant barrier between the fin elements and the wall. The radiant barrier is installed along the floor, wall, and underside of the top of the baseboard enclosure, resulting in greater reflectance of heat into the space.

While Figure 7.14 previously showed that greater energy savings would be achieved beyond 102 mm of insulation, the thickness of the added insulation is limited to 102 mm because of concern about reducing the floor area in the suites. It was also assumed that the enclosure covers should not be moved too far away from the wall. The total effective wall thermal resistance of these walls in the computer model after this retrofit is 5.3 m^2K/W (R 30.1).

R49, Above Baseboards – South Solar: All of the walls on the South face of the building that already have SWH panels and 51 mm of polyurethane insulation (2.6 m^2K/W, R 14.8) on their exterior surface are further insulated in this retrofit by adding 51 mm of polyurethane insulation to the inside surface of the wall. The insulation is also finished with 12.7 mm of painted gypsum. The total wall thermal resistance of these walls after this retrofit is 6 m^2K/W (R 34.1).

The enclosures are also removed during this retrofit in order to air-seal the wall-floor joint and install the radiant barriers between the fin elements and the wall. Because the added insulation is only 51 mm, however, the enclosures are re-mounted to the wall in their original location.

R50, Stairwells, Storage, and Mechanical Rooms: All walls in these three areas are further insulated with 102 mm of polyurethane insulation and finished with 12.7 mm of painted gypsum in this retrofit. These walls do not have baseboard heaters and therefore the added insulation covers the wall from the top of the concrete floor to the ceiling above. The total effective wall thermal resistance of these walls after this retrofit is 5.5 m^2K/W (R 31.2).

R51, Sloped Metal Roofs: In this retrofit the sloped metal roofs above the suites on the main and tenth floor are further insulated with 102 mm of polyurethane insulation and finished with 12.7 mm of painted gypsum. The total effective roof thermal resistance after this retrofit is 7.1 m^2K/W (R 40.3) for the roofs with 150 mm of batt insulation and 8.5 m^2K/W (R 48.3) for the roofs with 300 mm of batt insulation.

R52 A variety of combinations of quadruple glazed, triple glazed, and two triple glazed replacement windows for different walls were modeled in an attempt to find a high performance and affordable window retrofit recommendation. The chosen retrofit is to replace the existing windows with windows from ThermoTech, a Canadian window manufacturer that claims to make the world's most energy efficient windows and doors. All double hung windows in the computer model are replaced with casement windows rated to have an energy rating (ER) value of 6, a U-value of 1.11 W/m^2K, and a SHGC of 0.38. All fixed windows are replaced with windows rated to have an ER value of 15, a U-value of 0.97 W/m^2K, and a SHGC of 0.51 [7.39]. The SHGCs are reduced from their rated values when entered into the computer model because of the presence of interior shading, as was similarly done in Section 3.3.

R53 Eleven doors on the main floor and the three South balcony doors are replaced in this retrofit with well insulated, polyurethane filled, steel doors having U-values of 0.88 W/m^2K [7.40].

R54 This retrofit recommends the same air sealing and floor compartmentalization retrofits that were actually performed by SRC in 2004. This includes weatherstripping stairwell doors, garbage chutes, sealing floor penetrations, and weatherstripping the main floor entrance doors. A reduction in infiltration of 10% is approximately equal to the savings determined for this retrofit in Chapter 3. The cost of this retrofit is equal to the actual cost incurred when SRC undertook this project.

R55 An additional 40% savings in infiltration is assumed to result from the replacement of the windows and doors, mandating that tenants remove their air conditioning units during the winter, sealing between the wall and floors during the wall insulation retrofit, and installing energy monitoring devices in the hot water pipes for the convection heaters in each suite.

Canadian air tightening consultants CanAm have found that windows present the largest potential for energy savings when compared to other air tightening measures [7.41]. The existing windows in the building are double hung vertical sliders and the proposed replacement windows are casement models which can be designed to be much more air tight [7.42].

Wireless energy monitoring devices are installed in each suite in this retrofit in order to monitor the energy consumption of the convection baseboard heaters. It is assumed that the frequency of tenants leaving their windows open during the winter would be reduced by installing these monitoring devices.

In the two winters that the building was studied, the number of window mounted air conditioners that were not removed during the winter was 13 and 26. These units are likely not well sealed in their window openings and present significant potential for air leakage. Their removal in the winter should reduce infiltration during the heating season.

In a study published by SRC the average savings in infiltration that were obtained from home retrofits by 5 contractors of 86 Canadian homes was 37%. The maximum reduction in infiltration in the study was 71% (an average savings for 6 homes retrofit by SRC) and these retrofits did not include the replacement of windows. This study shows that through retrofitting, Canadian homes can reduce infiltration by more than 50%.

Although infiltration reductions of greater than 50% are obtainable for a home, a reduction of 50% was assumed to be obtainable in KEP because it is a high rise building with many vertical leakage paths. Floor penetrations such as the elevator shafts make limiting the stack effect in KEP difficult. A report by the National Institute of Standards and Technology contains a literature review of infiltration reductions resulting from envelope retrofits [7.43]. The report lists retrofits that have achieved infiltration reductions of 35% (average of two Canadian high-rise buildings), 43% (20-story Canadian office building), 63% (average of two U.K. office buildings), and 75% (computer simulations of a U.K. industrial building). CanAm, a Canadian company that states that they are building envelope specialists, reports savings of 37% in infiltration in a 17 story Canadian high rise office building due to air sealing measures less extensive than those proposed for KEP [7.44]. They also estimated a savings of 40% from air-sealing measures in a Canadian high-rise condominium [7.45]. The savings of 37%-40% that CanAm quotes are for retrofits where the windows are weatherstripped. A retrofit where the windows are replaced with high quality windows that are specifically designed to be air tight should achieve even greater savings. Despite the challenges associated with reducing infiltration in a tall building, when window replacement, wall sealing, tenant energy monitoring, door replacement, and air conditioner removal are all combined a savings of 50% should be obtainable.

The estimated cost assigned to the 40% reduction in infiltration retrofit accounts for the cost to purchase the convection heating energy meters ($57,420) plus $20,000 of additional expenses assumed to be necessary to ensure high quality air sealing during the wall retrofits and window installation.

The installation of overhangs on the South side of the building in order to reduce the air conditioning load in the building was also investigated as a potential envelope retrofit but they were found to have minimal impact on average building temperature during the summer months. This may indicate a deficiency in the computer model and other users of EE4 have expressed to SRC their dissatisfaction with the model's ability to simulate the effects of overhangs [7.46]. In the actual building, overhangs may have worthwhile cooling savings.

7.8 HOT WATER BOILERS

Table 7.11 lists the heating loads in the building during the hour with the highest heating load for both the base model and the model after all of the previously presented retrofits have been implemented. It shows that the remaining peak space heating load after all of the previous retrofits is 104 kW. This is 18% more than the output capacity of one of the current boilers (presently there are 20 boilers in the building).

Table 7.11: Base and retrofit peak heating loads for the whole building and per unit floor area

	Base Model		Retrofit Model	
Building Peak Load Component	**[kW]**	**[W/m^2]**	**[kW]**	**[W/m^2]**
Wall Conduction	101.4	12.1	44.5	5.3
Roof Conduction	17.7	2.1	6.7	0.8
Windows and Frame Conduction	87.1	10.4	32.3	3.9
Window Glass Solar Heat Gain	-5.4	-0.6	-1.1	-0.1
Door Conduction	0.8	0.1	0.6	0.1
Underground Surface Conduction	5.6	0.7	2.7	0.3
Occupants to Space	-7.9	-0.9	-7.9	-0.9
Lights to Space	-15.8	-1.9	-4.8	-0.6
Equipment to Space	-15.4	-1.8	-11.5	-1.4
Infiltration	81.2	9.7	42.7	5.1
Total	249.4	29.9	104.3	12.5

Table 7.12 presents the costs and savings associated with disconnecting the current 20 boilers and installing two new condensing models.

Table 7.12: Cost and savings for boiler replacement retrofit

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
56	Purchase and install 2 condensing boilers	0	136,533	$4,096	$27,000	6.6	4.54%	81.9%
Total		**0**	**136,533**	**$4,096**	**$27,000**	**6.6**	**4.54%**	**81.9%**

R56 In this retrofit all of the current boilers in the building are disconnected, two are removed, and four chimney roof penetrations are sealed. Two Viessmann Vitodens 200, 67 kW, digitally controlled multi-stage condensing boilers with annual fuel utilization efficiencies of 95.2% are installed as the replacement heating plant [7.47].

The measured supply and return water temperatures in February 2005 were 78ºC and 71ºC respectively. In order to achieve an efficiency of 95% for the proposed condensing boilers, the return water temperature of the boilers will need to be reduced to at least 40ºC [7.48]. This will result in a lower water temperature in the convection heaters but these heaters will still be able to heat the space because the heating loads have been reduced significantly. The radiant barriers proposed in the envelope section of this chapter will also assist in delivering heat to the space. A high supply water temperature is also assumed to not be desirable in the retrofit building because the room heating loads are low and a high water temperature may result in cyclic overheating of the suites. In order to achieve the desired efficiency and reduce the potential for space overheating both the boiler outlet temperature and pumping rate of the hot water will need to be reduced and adjusted until optimum performance of the building is achieved.

7.9 SPACE TEMPERATURE AND AIR CONDITIONING LOAD

In this retrofit the current 98 kW rooftop chiller (COP 3.1) is replaced in the computer model with an 85 kW higher efficiency unit (COP 4.2). Table 7.13 shows a summary of the savings and costs associated with this retrofit. The total grid purchased energy savings after this retrofit is completed is approximately 82%.

Table 7.13: Cost and savings for rooftop chiller replacement

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
57	Replace current air conditioner with a new 85 kW unit that has a COP 4.2	11,284	0	$1,241	$10,000	8.1	0.38%	82.3%
Total		**11,284**	**0**	**$1,241**	**$10,000**	**8.1**	**0.38%**	**82.3%**

R57 Figure 7.18 shows a comparison of the average building temperature calculated by the base computer model prior to any retrofits and the new building temperature after the previously listed retrofits have been installed and the supply air temperature has been reduced from 18ºC to 12ºC during months that require cooling.

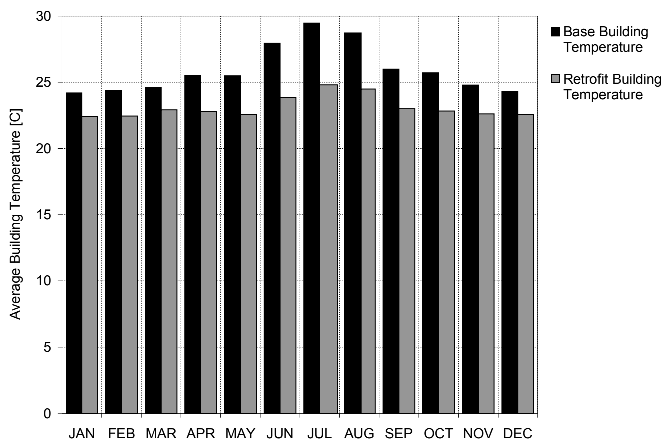

Figure 7.18: Comparison of pre and post retrofit average building temperature

Figure 7.18 shows that thermal comfort of the tenants should be significantly improved if retrofit 57 is performed in the building. In the computer model of the pre-retrofit base building, the average building temperature in July was above 28ºC. This is outside the ASHRAE comfort zone [7.49]. Peak monthly average building temperature in the retrofit building is calculated to be approximately 24ºC and the peak hourly average building temperature is 26ºC.

The temperatures in Figure 7.18 do not account for the impact of window mounted air conditioning (WMAC) units. When reductions in suite electrical consumption was presented in Table 7.5 of this chapter the use of WMAC units was only reduced by 50%. Therefore in the retrofit model, tenants still have the ability to additionally cool their suites.

The peak hourly cooling load for the building is approximately 112 kW (32 tons). This is 14 kW more than the capacity of the existing rooftop chiller. The average cooling contribution of the energy recovery system during the summer is 9 kW and the peak cooling output of the energy recovery wheels is 36 kW. This allowed for the replacement chiller to be sized lower than the peak cooling load.

The cost to purchase the new chiller is estimated to be approximately $10,000. It should be noted that the existing chiller uses R22 as its refrigerant which means that it must be replaced before 2020 due to restrictions on the use of R22 refrigerant [7.50].

7.10 SOLAR WATER HEATING OF VENTILATION AIR

The second last retrofit that is proposed is the installation of solar water heating (SWH) panels on the remaining 400 m^2 of non-shaded exterior South wall area. These panels are used to heat outdoor ventilation air in order to both temper the air and provide space heating. Table 7.14 shows the cost and savings associated with this retrofit. The cost, panel type, orientation, storage ratio, heat losses, and pumping power for this system are the same as the DHW system presented in section 7.6.

Table 7.14: Cost and savings for heating ventilation air using solar water panels

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
58	Install a solar water heating system for heating the outdoor ventilation air	-1,840	76,484	$2,092	$268,000	128.1	2.48%	84.7%
59	Add 51 mm of polyurethane insulation to the exterior surface of the South exterior wall	0	16,546	$496	$3,500	7.1	0.55%	85.3%
Total		**-1,840**	**93,030**	**$2,589**	**$271,500**	**104.9**	**3.03%**	**85.3%**

R58 In this retrofit a SWH system collects solar energy and stores it in a water storage tank located in the crawlspace of the building. This tank is then used for heating the outdoor ventilation air after it has exited from the energy recovery system.

Figure 7.19 shows the remaining baseboard and outdoor air coil loads in the building when outdoor ventilation air heated to 22ºC is delivered to the hallways.

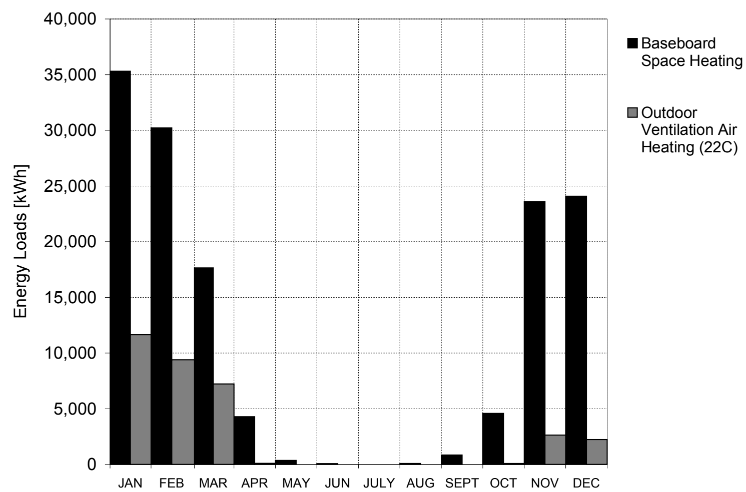

Figure 7.19: Remaining monthly baseboard and outdoor air heating loads

The baseboard heating loads in Figure 7.19 can be reduced by delivering air to the hallways at temperatures above 22ºC. The reduction in baseboard heating load that results from air being delivered to the space at higher temperatures will depend on the temperature of the rooms in the building. Table 7.15 shows the average building temperature calculated by the computer model when the ventilation air temperature is 22ºC during the heating season and the average monthly delivery temperature that would be necessary in order to reduce the baseboard heating loads in Figure 7.19 to zero.

Table 7.15: Average building temperature when ventilation air is supplied at 22ºC and required outdoor air ventilation temperature to meet 100% of the baseboard loads

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC
Average Building Temperature [C]	22.4	22.5	22.9	22.8	22.5	23.9	24.8	24.5	23.0	22.8	22.6	22.6
Required Delivery Temperature to Meet Baseboard Heating Loads [C]	39.1	37.5	31.2	24.6	22.0	22.0	22.0	22.0	22.0	24.3	34.1	34.4

Ventilation air cannot be delivered to the hallways at the temperatures listed in Table 7.15 because overheating of the hallways would occur during large portions of the year. The temperature difference between the suites and the hallway should be kept to a minimum. Also, the maximum hourly temperature was 56.6ºC, an unacceptable temperature for ventilation air in the hallways. The maximum load that the solar system could provide for space heating was therefore determined by specifying a maximum allowable ventilation temperature of 25ºC [7.50]. The total load for heating the ventilation air between 22ºC-25ºC (depending on the baseboard heating load during each hour) was approximately 73,000 kWh/Year.

Solar energy collection was modeled using the RETScreen SWH model. This model is designed to calculate load fractions for DHW systems. When defining a DHW load in the RETScreen model three of the necessary variables are tank temperature, tank supply water temperature, and water flow rate. A 400 m^2 system is used because this is the remaining South wall area that is not already being utilized for solar heating of DHW. The effectiveness of the water-air heat exchanger was assumed to be 65% and by specifying a desired tank temperature of 30ºC the flow rate of water was found for each month and solar loads were entered into the program. A desired tank temperature of 30ºC was chosen because the tank temperature needed to be greater than 25ºC but too high a temperature would result in greater heat loss from the solar collectors.

Table 7.16 shows the monthly average temperature of the air before entering the heating coil, the total solar load for each month of the year, and the monthly collected solar energy. The system is able to meet 98.0% of the desired solar load.

Table 7.16: Monthly average temperature of air entering heating coil, solar air heating loads, collected solar energy, and solar load fraction

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC
Outdoor air post energy recovery [C]	16.8	17.7	18.8	22.0	22.0	22.0	22.0	22.0	22.0	22.0	20.8	21.0
Solar load [kWh]	18,362	15,887	12,470	2,549	356	67	4	6	803	3,003	9,115	8,726
Collected solar energy [kWh]	17,047	15,887	12,470	2,549	356	67	4	6	803	3,003	9,115	8,726
Load fraction	93%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 7.14 previously showed that the payback period of this SWH system is 105 years and Table 7.9 previously showed that the payback period of the SWH system for heating DHW is approximately 30 years. There are two main reasons why the payback period for the solar outdoor ventilation air heating system is much greater than the solar DHW system. First, the ventilation air only needs to be heated for less than half of the year. Second, the return water temperature entering the storage tank for the outdoor ventilation air SWH system is much higher than the temperature of the water from the

city (the water entering the DHW storage tank). Higher water and tank temperatures result in greater collector heat losses.

Table 7.16 shows that there are several months in the summer where the solar loads are small and the SWH system will have large amounts of excess production. If a system of this size is installed, after a year of monitoring to evaluate the actual excess energy production, it may be possible to provide heat to adjacent buildings. One potential location to supply hot water to is the large swimming pool in the YWCA building next door to KEP. The size of the pool in the YWCA was estimated to be approximately 170 m^3. Using the RETScreen software for pool heating, it is estimated that approximately 40,000 kWh/Year of energy could be provided to the pool.

R59 Similar to R46, in Section 7.6, 51 mm of rigid polyurethane insulation is added to the exterior wall behind each solar panel.

Unglazed transpired collectors (UTC), often called a SolarWall [7.51] were also investigated as a retrofit option for heating outdoor ventilation air. A UTC is a perforated unglazed metal solar panel that can be used to heat air before it enters a building. The panels are typically installed on the exterior wall of a building in order to pre-heat ventilation air. A Canadian manufacturer of UTCs quoted a purchase cost of \$250/m^2 for UTC panels. This is approximately the same as the purchase cost given by RSMeans for a solar water heating panel [7.1].

There are two main reasons why UTCs are not a recommended retrofit. First, the collectors would pre-heat air prior to the energy recovery system; whereas in the proposed design, additional heat is most beneficial after the air-to-air energy exchanger. While there is the potential for energy savings from heating the air before it enters the air-to-air energy exchanger, particularly for preheating the outdoor air during frosting conditions, these savings are marginal. Second, a UTC delivers almost all of its energy potential during daylight hours, while the SWH system used to heat the ventilation air has the ability to collect energy during the day and heat the outdoor ventilation air during the evening.

The optimal use of UTCs in the final design was not investigated fully but previous modeling showed that when energy recovery was possible in a building it was not economical to install UTCs (especially for an energy recovery system with an effectiveness of 90%). It was thought that the limited South wall area was therefore best utilized by solar water heating panels. When energy recovery is not possible and large amounts of ventilation air are necessary, such as a garage or hanger with large overhead doors that regularly open, UTCs have very attractive economic and energy saving benefits [7.52].

7.11 PHOTOVOLTAIC PANELS

After all of the previous retrofits have been undertaken the final required energy savings in order to reach the goal of factor 10 is approximately 142,000 kWh/Year. To produce this amount of energy a 546 m^2, 88 kW, photovoltaic (PV) system that transfers electricity production directly into the municipal grid is used. The installation of the PV panels is the most costly of the proposed retrofits and is therefore presented as the last retrofit necessary to meet the goal of factor 10. Table 7.17 shows a summary of the costs and savings associated with this system.

Table 7.17: Cost and savings from installing a photovoltaic system

#	Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Annual Savings [$]	Capital Cost [$]	Simple Payback [Years]	GPE Savings [%]	Cum. GPE Savings [%]
60	Install a 88 kW of photovoltaic system	142,000	0	$15,620	$1,232,000	78.9	4.72%	90.0%
Total		**142,000**	**0**	**$15,620**	**$1,232,000**	**78.9**	**4.72%**	**90.0%**

R60 Figure 7.21 shows a cross section of the roof in KEP and the locations where the PV panels, shown in solid grey, are proposed to be installed on the building.

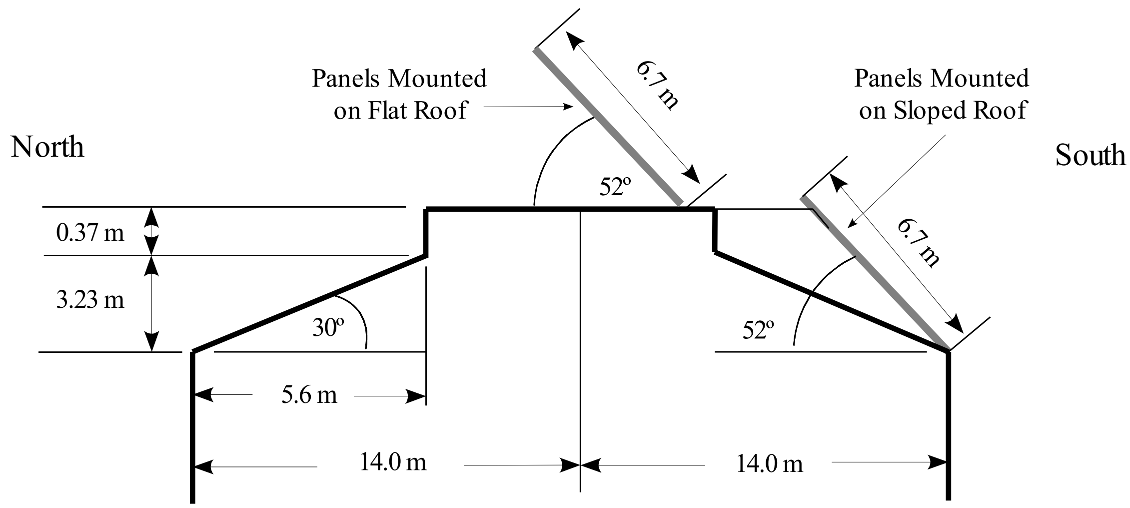

Figure 7.20: Cross section of West building face and PV panel orientation

Solar energy production was calculated using RETScreen and the PV panels that were selected were mono-Si, from the manufacturer Canadian Solar, model # CS5A-195M. Their nominal module efficiency is 17.3%, their normal operating cell temperature is 45ºC, and their temperature coefficient is 0.40%/ºC. They were selected because they have the greatest efficiency in the RETScreen product database. Miscellaneous PV array losses was assumed to be 5.0%, the average inverter efficiency was assumed to be 90%, and the power conditioning losses was assumed to be 1%. A mounting angle of 52º was chosen because optimum PV collection angle is approximately the latitude of the location.

7.12 RETROFIT MODEL SUMMARY

The goal of simulating a factor 10 reduction in grid purchased energy has been achieved and this section summarizes the final energy consumption of the retrofit building. Figure 7.22 compares the natural gas consumption of the base computer model of the building and the retrofit model of the building. The annual natural gas consumption of the retrofit building model has been reduced from approximately 2,050,000 kWh (245 kWh/m^2) to 85,000 kWh (10.2 kWh/m^2).

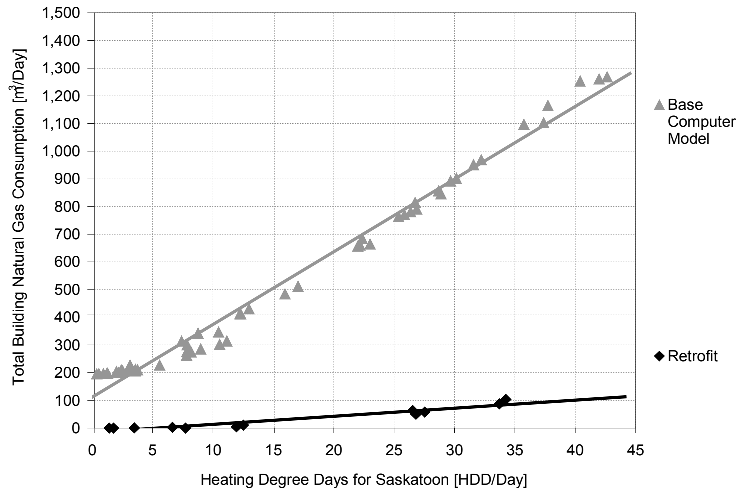

Figure 7.21: Natural gas consumption, base model and factor 10 retrofit model

Figure 7.22 shows a complete breakdown of the energy used in the retrofit model of KEP.

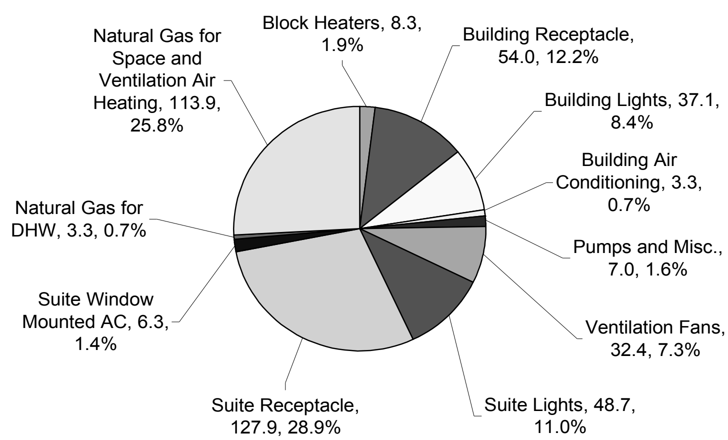

Figure 7.22: Energy consumption of retrofit model (values are in MWh/Year)

The base computer model of the building consumed approximately 964,000 kWh (116 kWh/m^2) of electricity per year. When the production of the photovoltaic panels is subtracted from the values in Figure 7.23, the building's total annual grid purchased electrical consumption is reduced to approximately 215,000 kWh/Year (25.8 kWh/m^2). Total energy consumption of the building is therefore 36 kWh/m^2. The three largest components of the remaining GPE are electricity for suite receptacle loads (28.9%), natural gas for space and outdoor ventilation air heating (25.8%), and building receptacle loads (12.2%).

Figure 7.23 shows a breakdown of the utility costs in the retrofit model.

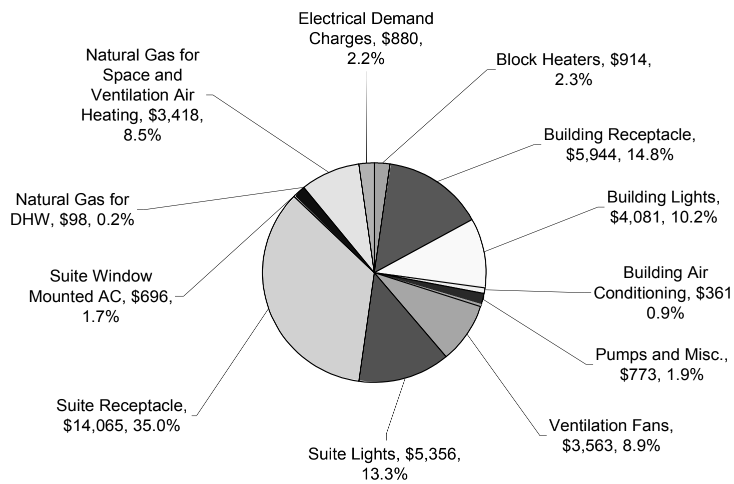

Figure 7.23: Retrofit building utility cost

The three most costly services in the building are suite receptacle ($14,065, 35.0%), building receptacle ($5,944, 14.8%), and suite lights ($5,356, 13.3%). When the savings from the electrical production of the PV panels are included the total annual utility cost for the building is approximately $30,500 ($244/Year per occupant). This is a factor 6 reduction in utility costs (83%).

Figure 7.24 shows a breakdown of the total equivalent tonnes of CO_2 produced by the building. When the reduction in emissions due to the PV panels is included the total emissions from the building is 200 Tonnes/Year, or 1.6 Tonnes/Year per occupant. This is a factor 6.6 reduction in greenhouse gas emissions (85%).

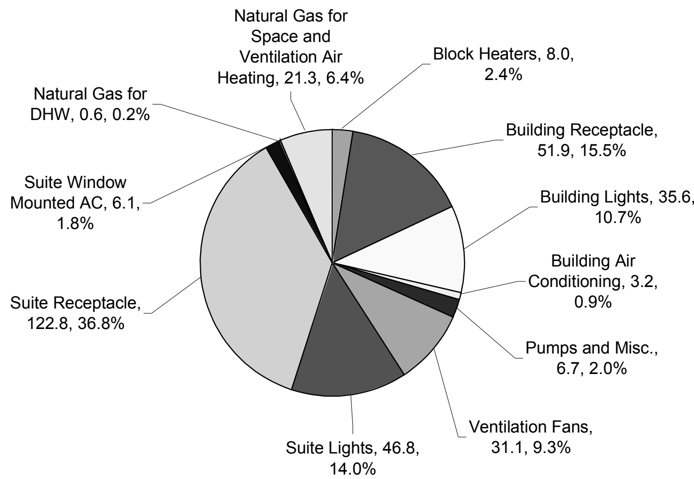

Figure 7.24: Retrofit building greenhouse gas emissions (values are in eTonnes CO_2)

Figure 7.25 is a plot of the percent reduction in GPE that each retrofit achieved and the simple payback period of that particular retrofit.

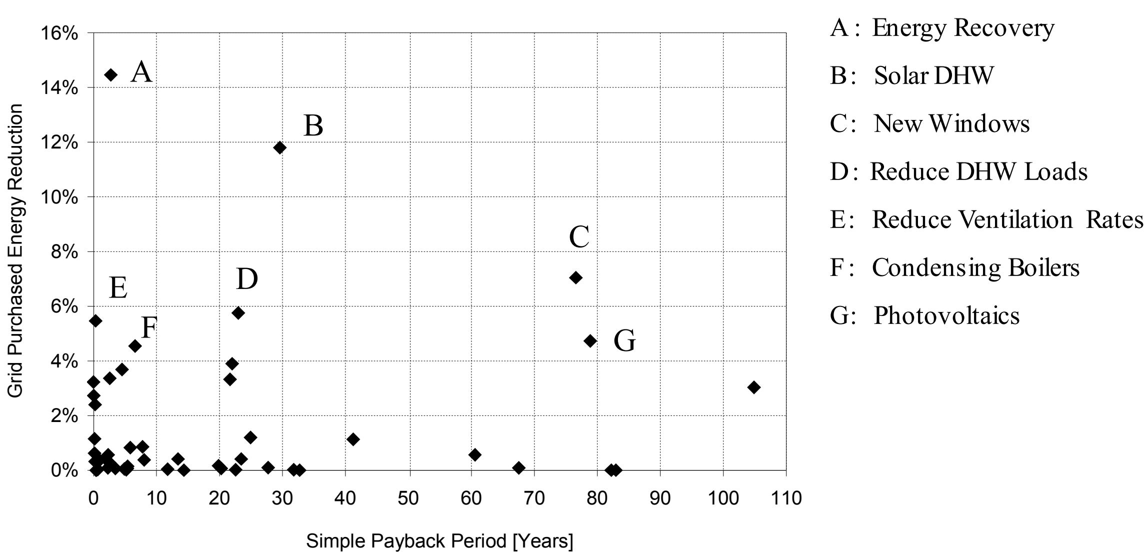

Figure 7.25: Reduction in GPE vs. simple payback period for each retrofit

Three main conclusions can be drawn from the scatter of data in Figure 7.25. First, there are only 7 retrofits that individually achieve more than a 4% reduction in total GPE. Achieving a factor 10 reduction in GPE required integrating many small retrofits. There are over 30 retrofits that reduced GPE by less than 2%. While individually these retrofits save small amounts of energy, when they are combined their total savings is 11%. Second, the 7 retrofits that achieved energy savings greater than 4% were critical to achieving factor 10. The total reduction in GPE from these 7 retrofits was approximately 54%. The seven retrofits with the largest GPE savings were the energy recovery system (14.5%), SWH for DHW (11.8%), new windows (7.0%), the reduction in DHW load from new shower heads and faucets and tenant energy monitoring (5.8%), reducing the ventilation rates to minimum requirements (5.5%), installing the PV system (4.7%), and installing two condensing boilers (4.5%). The third conclusion is that the majority (30 out of 49) of the retrofits have simple payback periods that are less than 20 years. Since the payback periods for these energy saving measures are greater in an existing building than in a new building this indicates that large energy savings should be economically feasible when proposed for the design of new buildings.

Figure 7.26 plots the cumulative savings in GPE as allowable payback period increases. It shows the total energy savings that are achievable as the simple payback period cut-off point for allowing a retrofit to be undertaken is increased. The payback periods used in Figure 7.26 are for each individual retrofit.

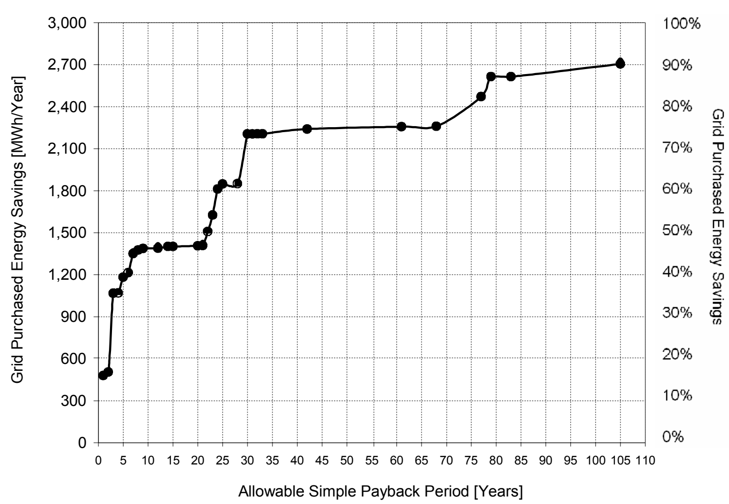

Figure 7.26: Cumulative GPE savings as the allowable payback period of each individual retrofit increases

Figure 7.27 shows total grid purchased energy savings as the total simple payback period is increased. The data in Figure 7.27 was generated by sorting all of the retrofits based on increasing simple payback period and then calculating the cumulative energy savings and total simple payback period (cumulative capital cost divided by cumulative utilities savings) as retrofits with progressively increasing simple payback periods are combined. Figure 7.27 shows that if all of the proposed retrofits were implemented in the building, the total payback period would be approximately 21 years. It also shows that a goal of factor 4 (75%) corresponds to a total simple payback period of approximately 10 years.

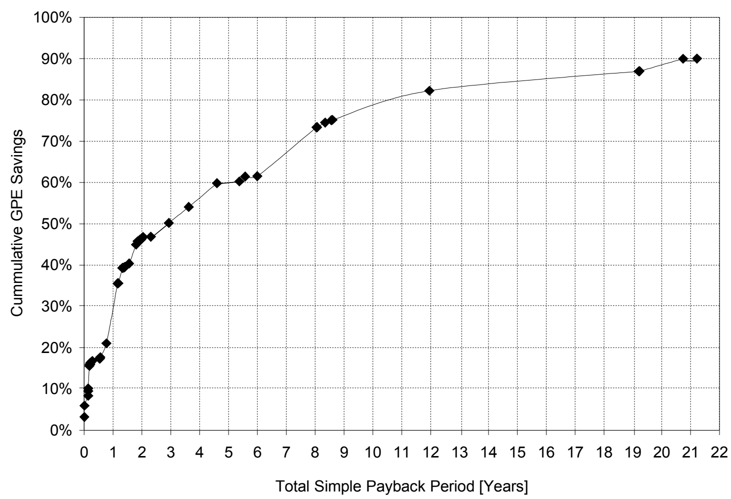

Figure 7.27: Cumulative GPE savings and total payback period as individual retrofits are combined in order of increasing simple payback period

It should be noted that there are limitations to breaking down the retrofits based on their individual payback periods as has been done in Figures 7.25-7.27 because the cost and savings from a retrofit such as replacing the boilers with condensing models is dependent on the previous retrofits that have been undertaken. These figures do give an indication, however, of the path to factor 10 and the savings that could be achieved before retrofits with long simple payback periods are needed to achieved further energy savings.

Table 7.18 lists the payback periods and GPE savings for each of the retrofits plotted in Figure 7.25 and 7.26. The first column denotes the ranking of each retrofit and the second column denotes the retrofit number. Ranking of the retrofits is based on total percent GPE reduction divided by simple payback period. This system of ranking values retrofits with high energy savings and short payback periods. As was just mentioned, this method of ranking the retrofits has limitations because the cost and savings associated with certain retrofits are dependent on previous retrofits. In these tables some of the smaller retrofits that are more appropriately accounted for as a single system were grouped as a single retrofit.

Table 7.18: Building retrofit ranking

Rank	R#	Building Retrofit	Simple Payback [Years]	GPE Savings [%]	GPE / PB
1	1	Discontinue use of North sidewalk heat tape system	0.0	3.23%	344.734
2	2	Set building thermostat to 22ºC (in both suites and common areas)	0.0	2.73%	67.273
3	6	Reduce ventilation rates to ASHRAE standard 62-2001 minimum levels (2,622 L/s) on above	0.3	5.47%	15.825
4	5	Replace all incandescent bulbs with 13 W compact fluorescent or LED bulbs (in both suites	0.2	2.40%	9.820
5	4	Set crawlspace thermostat to 10ºC	0.2	1.15%	5.987
6	36-41	Removing run-around glycol heat recovery system (includes disconnecting the glycol Install two energy recovery wheels with effectiveness values of 81%. Total system Install two 200 W motors that will operate the two energy recovery wheels for approximately Cooling contribution of HR Capital savings from downsizing replacement air conditioning unit Installation of equipment	2.8	14.46%	5.219
7	3	Set stairwell, storage, and mechanical room temperatures to 18ºC	0.2	0.62%	3.505
8	15	Replace washing machines and clothes dryers with higher efficiency front loaded models	2.6	3.36%	1.295
9	7	Remove unnecessary incandescent and fluorescent fixtures	0.3	0.33%	1.250
10	43, 44	Remove one existing DHW tank Purchase and install one 150 kW, 85% efficient, DHW tank	4.5	3.68%	0.816
11	56	Purchase and install 2 condensing boilers	6.6	4.54%	0.689
12	45,46	Install a solar DHW system sized to provide 99% of the DHW load Add 51 mm of polyurethane insulation to the exterior surface of the South exterior wall	29.6	11.80%	0.399
13	10	Reduce crawlspace ventilation rates by 65%	1.0	0.37%	0.381
14	11	Install variable frequency drives on heating and cooling recirculation pumps	1.8	0.44%	0.243
15	13	Replace fluorescent fixtures with more efficient ballasts and bulbs and retrofit double bulb	2.3	0.56%	0.243
16	55	Reduce infiltration by an additional 40% (50% in total)	22.0	3.90%	0.177
17	48	Above Baseboard Heaters	21.7	3.32%	0.153
18	18	Install block heater control system monitor block heater consumption and charging renters	5.8	0.83%	0.142
19	14	Install setback thermostats in building common areas and set evening setback temperature to	2.5	0.28%	0.112
20	54	Air seal leakage paths and compartmentalize floors in building (10% savings in infiltration)	7.8	0.85%	0.110
21	52	Replace South windows with triple pane, low-e windows (ThermoTech ER 15) and North	76.6	7.04%	0.092
22	60	Install a 88 kW of photovoltaic system	78.9	4.72%	0.060
23	9	Reduce supply air temperature from 23ºC to 22ºC	0.7	0.03%	0.048
24	50	Stairwells, Storage, and Mechanical Rooms	24.9	1.20%	0.048
25	57	Replace current air conditioner with a new 85 kW unit that has a COP 4.2	8.1	0.38%	0.047
26	12	Reduce pressure drop in the ducting by cleaning and sealing central supply shaft (25%	2.3	0.09%	0.038
27	47	Insulate crawlspace walls with R10 insulation	13.4	0.41%	0.031
28	58, 59	Install a solar water heating system for heating the outdoor ventilation air Add 51 mm of polyurethane insulation to the exterior surface of the South exterior wall	104.9	3.03%	0.029
29	32	Install premium efficiency motors	5.4	0.15%	0.027
30	51	Sloped Metal Roofs	41.2	1.13%	0.027
31	42	Reduce suite DHW load by installing low flow showerheads Reduce suite DHW load by installing aerating faucets Install water monitoring devices in suites to reduce tenant DHW consumption by an additional	23.0	5.75%	0.250
32	16	Reduce stairwell and hallway lighting to 20% from 12pm-7am and install occupancy controls	3.5	0.07%	0.021
33	23	Reduce suite receptacle consumption by 20% (not including refrigerator consumption) Reduce suite lighting consumption by 15% Reduce window mounted air conditioner consumption by 50%	23.5	0.41%	0.018
34	33	Increase fan efficiency to 80%	5.4	0.07%	0.013
35	34	Place central supply motor inside airstream	4.9	0.05%	0.011
36	49	Above Baseboards - South Solar	60.6	0.57%	0.009
37	21	Increase heat recovery effectiveness of the crawlspace HRV to 85%	19.9	0.17%	0.008
38	17	Install day lighting controls in recreation and foyer areas	5.2	0.02%	0.003
39	19	Install occupancy lighting controls in crawlspace, mechanical rooms, laundry rooms, public	11.7	0.04%	0.003
40	29-31, 35	Remove existing central supply AHU Install low face velocity supply AHU Place new supply AHU on opposite side of the mechanical room and install new air intake for	20.3	0.07%	0.003
41	24	Replace suite refigerators	27.7	0.09%	0.003
42	22	Reduce unspecified building receptacle consumption by 10%	22.6	0.02%	0.001
43	53	Replace doors with steel polyurethane filled well insulated doors	67.5	0.09%	0.001
44	25	Replace heating and cooling recirculation pump motors with higher efficiency models	31.8	0.02%	0.001
45	20	Reduce the pressure drop in the ceiling mounted lounge/recreation area AHU's by cleaning	14.3	0.00%	0.000
46	27	Replace crawlspace fans with higher efficiency models	82.2	0.00%	0.000
47	28	Replace heating and cooling circulation pumps with higher efficiency (70%) models	82.9	0.00%	0.000
48	8	Install power factor correction	0.4	0.00%	0.000
49	26	Replace crawlspace ventilation motors with higher efficiency motors.	32.7	0.01%	0.000

The retrofit with the longest payback period was the use of SWH to heat the ventilation air (R 58/R 59, payback period of 105 years) and the retrofit with the greatest capital cost was the installation of PV panels (R60, $1,232,000). Prior to these two retrofits, total GPE had been reduced by 82.3% as a result of reducing natural gas and electrical consumption by 89.7% and 66.5% respectively. Together, these two high cost retrofits reduce the total GPE consumption of the base building by approximately 233,000 kWh/Year.

The size of the proposed PV system could have been reduced if more aggressive measures to reduce electrical consumption were undertaken. Table 7.19 lists 93% of the remaining electrical consumption and the energy savings that would be achieved if these loads were eliminated.

Table 7.19: Impact of eliminating 93% of the remaining electrical loads

Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Total Savings [kWh / Year]
Reducing suite repectacle consumption by 100%	127,865	-65,784	62,081
Reducing suite lighting consumption by 100%	48,692	-28,909	19,783
Reducing building lighting by 100%	37,102	-16,759	20,343
No longer allowing the use of block heaters	8,305	0	8,305
No longer allowing the use of window mounted air conditioning units in suites	6,324	0	6,324
Eliminating 40,000 kWh of general receptacle loads (pumps, elevators, security cameras, appliances and computer in recreation room, etc.)	40,000	-20,579	19,421
No longer providing outdoor ventilation air	32,390	31,000	63,390
Total Savings			199,647

The proposed PV system reduces the electrical consumption in KEP by 142,000 kWh/Year and it does so in a way that does not increase space heating loads. Table 7.19 shows that it would be difficult to achieve significant energy savings by targeting electrical consumption. While the size of the PV system could possibly be reduced, one would still likely be necessary.

The PV panels would not be necessary if 100% of the natural gas consumption in the building and an additional 20,000 kWh of electrical consumption was eliminated. Table 7.20 shows the energy savings that would result from extreme retrofits to the building in an effort to achieve these savings. The options in Tables 7.19 and 7.20 are not appropriate retrofits to be proposed and renewable energy was therefore required to achieve the goal of factor 10.

Table 7.20: Unfeasible retrofits to the building envelope and ventilation systems

Building Retrofit	Elec. Savings [kWh / Year]	NG Savings [kWh / Year]	Total Savings [kWh / Year]
Reduce infiltration by 100%	0	91,163	91,163
Increase insulation levels of all exterior surfaces to 17.61 m^2K/W (R 100)	0	42,348	42,348
Remove all windows (window area is replaced with walls having insulation levels of 17.61 m2K/W (R 100)	0	16,406	16,406
No longer providing ventilation air	32,390	31,000	63,390
Total Savings			213,307

The solar water heating system for heating the outdoor ventilation air was the other high cost renewable energy retrofit that was proposed. This system had the longest payback period and the reduction in GPE it achieves could also have be met by more PV panels. Additional PV panels would need to be mounted vertically on the South facade, however, as there is a limited amount of room on the roof of the building. A vertically mounted PV system sized to achieve the same GPE reduction as the proposed SWH system would cost $755,000 and it would have a simple payback period of approximately 95 years. The payback period of the SHW system was 105 years, but the capital cost was only $270,000. The significantly higher capital cost of the PV system makes it the least desirable retrofit option.

While more savings could have been achieved in the building in order to reduce the size of the renewable energy systems (including the SWH system for DHW), a final advantage renewable energy technologies have over other potential retrofits is that they are supported by government subsidy programs. On March 21, 2007, the Government of Saskatchewan announced a $900,000 program designed to help Saskatchewan residents produce their own energy from sources such as solar or wind. They also announced their support for allowing residents to provide power back to the provincial electricity grid. At the time of writing this document the complete details of the program had not yet been released but it is clear that in the future there will be programs available that support the use of renewable energy.

CHAPTER 8
CONCLUSIONS

8.1 CONCLUSIONS

The objective of researching and presenting a method to achieve a factor 10 reduction in annual grid purchased energy in a high rise apartment building has been achieved. The total modeled energy consumption of the proposed retrofit building is approximately 36 kWh/m^2. Retrofitting the building to reduce GPE by 90% resulted in a factor 6 reduction in utility costs (83%) and a factor 6.6 reduction (85%) in greenhouse gas emissions. The estimated cost for all of the proposed retrofits was approximately $3,123,000 and their simple payback period is approximately 21 years. This does not take into account interest rates and escalating utility rates.

The utilization of solar energy collection and energy recovery technologies were critical to achieving the targeted reductions as factor 10 could not be realistically obtained only through energy conservation. Factor 10, however, was not achieved only by a small number of large retrofits. Many small retrofits needed to be integrated in order to achieve this goal. The 10 highest energy saving retrofits with simple payback periods less than 5 years were energy recovery in the outdoor ventilation air (14.5% GPE savings, 2.8 year simple payback), reducing the outdoor air ventilation rate to the minimum requirement (5.5%, 0.4 years), replacing the three large atmospherically drafted DHW tanks with a single higher efficiency tank (3.7%, 4.5 years), replacing the clothes dryers and washing machines with new higher efficiency models (3.4%, 2.6 years), discontinuing the use of the electric heater below the North brick patio (3.2%, 0 years), reducing the average building temperature from 24.4ºC to 22ºC (2.7%, 0 years), reducing suite DHW use by installing low-flow shower-heads (2.6%, 3.4 years), replacing all of the incandescent bulbs in the building with compact fluorescent lamps (2.4%, 0.3 years), reducing suite DHW use by installing aerating faucets (2.1%, 4.3 years) and retrofitting all of the building's fluorescent fixtures to have more efficient ballasts and bulbs and silver reflectors (0.6%, 2.3 years). Together, these retrofits reduced the grid purchased energy of the base building by over 40%. These retrofits, along with many of the other smaller retrofits that have short simple payback periods, show that buildings similar to the base model of KEP should be able to achieve a minimum of 30% savings in GPE. New buildings in particular should be able to achieve this goal. The more modest target of 30% is given because the replacement DHW tank is likely undersized for a building that would not have solar water heating, the DHW savings from the aerating faucets and low-flow shower-heads are based on the assumption of conservative DHW use by the tenants, and because most buildings will not have an electric sidewalk heating system. Installing a 90% effective energy recovery system may also be a challenge in some cases, but the savings for this system were achieved in spite of there already being a 36% effective heat recovery system in place.

Several retrofits that were presented required making assumptions regarding tenant behaviour. In order to operate the building efficiently and achieve the assumed savings, tenants will need to be educated about the ways in which they can conserve energy in the building. The building manager may also benefit from additional education and information on how to efficiently operate the building and detect energy related problems.

Cost estimates were provided for each retrofit and most retrofits have reasonable simple payback periods (30 of the 49 retrofits listed in Table 7.18 have payback periods less than 20 years). It appears that it would be economically justifiable to undertake many of the proposed retrofits. Some cost estimates may be too low, however, as unexpected additional costs associated with retrofitting a building can be numerous. The cost estimates were intended to assist in the evaluation of potential retrofits and ultimately the building owners will need to perform their own cost estimates that take into account factors such as government grants, savings from bulk purchasing, labour rates, preferred suppliers, and building codes.

Two significant factors that would likely dictate the feasibility of undertaking an actual factor 10 retrofit of the building are rising energy prices and government programs. At the time of writing this document both the Provincial Government of Saskatchewan and the Federal Government of Canada were in the process of unveiling new programs designed to support energy conservation and the use of renewable energy technologies. When these programs are implemented, and if cost of energy continues to rise, some of the longer payback retrofits (particularly solar water heating for domestic hot water) may also become attractive options for the building owner to pursue.

In addition to the financial considerations associated with performing a factor 10 retrofit, the reduction in greenhouse gas emissions has many positive benefits. While reducing emissions does not currently appear on the balance sheets of most building owners, there is an increasing realization throughout Canada that the greenhouse gas reduction targets advocated by members of the global community need to be taken seriously. As time progresses, methods of working towards factor 10 in industrialized countries may become increasingly researched and advocated. If this is the case then the results of this research project will certainly be relevant and worthy of further study.

8.2 FUTURE WORK

As work on this document progressed some of the findings were presented to the people responsible for the maintenance and improvement of KEP. Following the completion of this thesis, meetings will be arranged with these people again in order to present the results and answer any questions they may have. Future work on this project will depend on the interest and ability of the building owner to implement proposed retrofits.

If the proposed retrofits were to proceed, one area of the results that should be further investigated is the computer modeling of the solar water heating systems. The RETScreen tools are intended to be pre-feasibility modeling tools and an hourly simulation would add greater confidence to the recommendations. The predicted annual energy production of the DHW system modeled in RETScreen should be very similar to the actual production of a real system because of the size of the system and known reliability of the f-Chart correlations. There is less confidence in the monthly results for the modeling of the ventilation air heating system, however.

Two research areas that would be of interest in order to enhance the area of building science would be to further investigate the method used to measure infiltration and to create a methodology for doing field measurements of the seasonal efficiency of boiler systems. Boiler replacement decisions by building owners may be based on assumed efficiency values that are higher than the actual annual fuel utilization efficiency of their boiler system, resulting in underestimating the potential savings from undertaking boiler systems retrofits. An additional reason for greater investigation into boiler seasonal efficiency is that boiler efficiency and infiltration were the two most challenging variables to define in the computer models and boiler efficiency would be the easiest to study and publish conclusions that would be applicable to a greater number of buildings.

REFERENCES

1.1 Natural Resources Canada, 2001, Canada's Third National Report on Climate Change, Government of Canada, http://www.climatechange.gc.ca/english/publications/3nr/3NRChap2-Eng.pdf

1.2 Canadian Mortgage and Housing Corporation, 2004, Canadian Housing Observer 2004 - The State of Canadian Housing, Government of Canada, http://www.cmhc-schl.gc.ca/en/cahoob/anov2004/index.cfm

1.3 Mel Hurtig, 2000, Pay the Rent or Feed the Kids: The Tragedy and Disgrace of Poverty in Canada, McClelland & Stewart

1.4 K. Winder, 2003, Factor 10 Energy Reduction Retrofit Investigation for Canadian Residences, Thesis Project, Department of Energy Technology, Kungl Tekniska Hogskolan (Royal Institute of Technology), Stockholm, Sweden

1.5 Saskatchewan Research Council, 2007, The Factor 9 Home, www.factor9.ca

1.6 EHDD Architecture, 2006, Chicago Factor 10 Home, http://ehdd.com/

1.7 Schmidt-Bleek and Coworkers, 1993, The Unfolding of the Factor 10- and MIPS-Story (in English) at the Wuppertal Institute, Special Issue of the Fresenius Environmental Bulletin, http://www.factor10-institute.org/pdf/mipsfuture.pdf

1.8 Wuppertal Institute, Devision U - Sustainable Enterprise Program, Döppersberg 19, D-42103 Wuppertal, Germany, www.wupperinst.org.

1.9 Population Reference Bureau, 2006, Human Population: Fundamentals of Growth, Population Growth and Distribution, http://www.prb.org/Content/NavigationMenu/PRB/Educators/Resources_Guides/Human_Population/Population_Growth/Population_Growth.htm, Population Reference Bureau

1.10 Environmental Protection Agency, Online Glossary, Queensland Government, Australia, http://www.epa.qld.gov.au/environmental_management/sustainability/industry/sustainability_roadmap/glossary/

1.11 Redefining Progress, 2005, Footprint of Nations Report, http://www.ecologicalfootprint.org/pressrelease.html

1.12 Alex Kirby, 2002, Human Use Exhausts Earth, BBC News http://news.bbc.co.uk/1/hi/sci/tech/2062729.stm

1.13 Dr. W. Rees, The Built Environment and the Ecosphere: A Global Perspective, 1998, Volume 1: Conference Proceedings, Green Building Challenge 98, Natural Resources Canada, Government of Canada, pp 3-14

1.14 H. Agerley, Global Consumption Growth Calculator, Sonderborg, Denmark, http://home1.stofanet.dk/agerley/index.html#calc

1.15 Personal communications, Dr. R. Dumont, 2006, Saskatchewan Research Council

1.16 Intergovernmental Panel on Climate Change, United Nations Environment Programme & The World Meteorological Organization, http://www.ipcc.ch/

1.17 E. Rosenthal and A. Revkin, Feb 2, 2007, Panel Issues Bleak Report on Climate Change, New York Times, http://www.nytimes.com/2007/02/02/science/earth/02cnd-climate.html?pagewanted=1&ei=5088&en=1cafd041af902dd5&ex=1328072400&partner=rssnyt&emc=rss

1.18 D. Anderson P.C., M.P., Minister of the Environment, 2001, Speaking Notes, National Press Club, Government of Canada, Ottawa, http://www.ec.gc.ca/minister/speeches/2001/010511_s_e.htm

1.19 L. Hunter Lovins, A. Lovins, and E. Ulrich von Weizsäcker, 1998, Factor Four: Doubling Wealth - Halving Resource Use: A Report to the Club of Rome, Earthscan Publications Ltd.

1.20 The Sustainability Advantage, 2002, Dr. B. Willard, New Society Publishers, http://www.sustainabilityadvantage.com/

1.21 Guardian Capital Advisors LP, 2004, Financial Definitions, http://www.gcaweb.com/definitions.htm

1.22 B. J. Brinkworth, 2001, Solar DHW System Performance Correlation Revisited, Solar Energy, Vol. 71, No. 6, pp. 377–387

1.23 P.T. Tsilingiris, 1996, Solar Water Heating Design - A New Simplified Dynamic Approach, Solar Energy, Vol. 57, No. 1, pp. 19-28

1.24 RETScreen International, Government of Canada, http://www.retscreen.net/

2.1 Forrester Scott Bowers Walls Architects and Engineer, 1984, King Edward Place

Blueprints

2.2 Saskatchewan Research Council, January 2006, Building Energy Management Audit Measurements Summary

2.3 Canadian Mortgage and Housing Corporation, 2001, Analysis of the Annual Energy and Water Consumption of Apartment Buildings in the CMHC HISTAR Database, Research Highlights, Technical Series 01-142, Government of Canada

3.1 Forrester Scott Bowers Walls Architects and Engineer, 1984, King Edward Place Blueprints

3.2 ASHRAE, 1997, ASHRAE Fundamentals Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia

3.3 Enermodal Engineering Limited, August 2002, Daylighting Guide for Canadian Commercial Buildings, Report prepared by on behalf of Public Works and Government Services Canada,
http://www.enermodal.com/Canadian/pdf/DaylightingGuideforCanadianBuildingsFinal6.pdf

3.4 Z. Gerontol Geriatr, P. Platte, J. Hellhammer, J. Zimmer, Pirke, 2004, Basal Metabolic Rate and Energy Expenditure in the Elderly,., Universitat Wurzburg, Biologische und Klinische Psychologie, Marcusstr., Wurzburg, Germany, 9-11,Oct, 37(5), pg 387-92,
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=15503077&dopt=Abstract

3.5 RD. Starling, MJ. Toth, WH. Carpenter, DE Matthews, ET Poehlman, 1998, Division of Clinical Pharmacology and Metabolic Research, Department of Medicine, University of Vermont, Burlington, Vermont, USA, Journal of Applied Physiology, pg 1063-9.
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=9729584&query_hl=7&itool=pubmed_docsum

3.6 MI. Goran, ET. Poehlman , 1992, Department of Medicine, College of Medicine, University of Vermont, Burlington, Metabolism, Jul, 41(7), pg 744-53,
http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=1619993&query_hl=7&itool=pubmed_docsum

3.7 EM. Rothenberg, IG. Bosaeus, KR Westerterp, BC Steen, 2000, Resting energy expenditure, activity energy expenditure and total energy expenditure at age 91-96 years,. Clinical Nutrition, Goteborg University, Goteborg, Sweden, British Journal of Nutrition, Sept, 84(3), pg 319-24, http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=10967610&query_hl=7&itool=pubmed_docsum

3.8 MI. Goran, ET. Poehlman, 1992, Endurance Training Does Not Enhance Total Energy Expenditure in Healthy Elderly Persons, Department of Medicine, College of Medicine, University of Vermont, Burlington, American Journal of Physiology, Nov, 263(5 Pt 1), http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=1443128&query_hl=7&itool=pubmed_DocSum

3.9 P. Tikuisis, P. Meunier, CE. Jubenville, 2001, Human body surface area: measurement and prediction using three dimensional body scans, Defence and Civil Institute of Environmental Medicine, Human Protection and Performance, Toronto, Ontario, European Journal of Applied Physiology, Aug, 85(3-4), pg 264-71, http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=pubmed&cmd=Retrieve&dopt=AbstractPlus&list_uids=11560080&query_hl=30&itool=pubmed_docsum

3.10 International Energy Agency, August 1983, Annex IX, Minimum Ventilation Rates, Literature Review to Special Research Fields and Proposal of R&D Projects, Final Report, Stephanus Druck GmbH, D-7772 Uhld.-Muhlhofen, Fed. Rep. Of Germany, pg 12

3.11 P. Karava, A. Athienitis & T. Stathopoulos, 2006, Modeling of Indoor-Outdoor Air-Exchange in a Multi-Unit Residential Building, Research in Building Physics and Building Engineering

3.12 Environment Canada Weather Office, 2007, National Climate Data and Information Archive, Government of Canada, http://www.climate.weatheroffice.ec.gc.ca/Welcome_e.html

4.1 National Research Council of Canada, May 1999, Performance Conpliance for Buildings, Specifications for Calculation Purposes for Demonstrating Compliance to the Model National Energy Code for Buildings Using Whole Building Performance, Government of Canada, http://irc.nrc-cnrc.gc.ca/pubs/fulltext/nrcc46028.pdf

4.2 United States Department of Energy, 2005, A Consumers Guide to Energy Efficiency and Renewable Energy, Furnaces and Boilers, United States Government, http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12530

4.3 ASHRAE, 1999, ASHRAE HVAC Applications Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia, pg 48.12, Table 8

4.4 D. Hill (Canadian Mortgage and Housing Corporation) & A. Pride (Minto Developments Inc.), 2005, City of Cornwall Social Housing Division, Top 10 Energy and Water Saving Tips in Multi-Unit Residential Buildings, Powerpoint presentation
4.5 Personal communications with Dr. R. Dumont of the Saskatchewan Research Council

4.6 U.S. Department of Energy, Determining Electric Motor Load and Efficiency, http://www1.eere.energy.gov/industry/bestpractices/pdfs/10097517.pdf

5.1 ASHRAE, 1981, ASHRAE Fundamentals Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia, pg 14.17

5.2 T. Johansson, B. Bodlund, and R.H. Williams, 1989, Electricity, Efficient End-Use and New Generation Technologies, and Their Planning Implications, Lund University Press, page 20, Figure 2

6.1 Energy Information Administration, 2001, End-Use Consumption of Electricity, United States Government, http://www.eia.doe.gov/emeu/recs/recs2001/enduse2001/enduse2001.html

6.2 Red River College, Energy Saving Tips, http://www.rrc.mb.ca/index.php?pid=888#4

6.3 Helsinki Energy, 2006, Consumption Figures of Electrical Appliances, http://www.helsinginenergia.fi/en/sahko/consumption_figures.html

6.4 Hydro-Quebec, Appliance Consumption Chart, http://www.hydroquebec.com/residential/energywise/calcul_consom.html

7.1 RSMeans, 2002, Building Construction Cost Data, 60th Annual Edition, RSMeans Company Inc., Kingston, MA

7.2 Personal communications, 2006, T. MacDermott, Saskatchewan Research Council

7.3 ASHRAE, 1999, ASHRAE Applications Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia, pg 35.1-35.12

7.4 Dr. R. Dumont, 1997, Exit Sign Energy Efficiency Upgrade, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

7.5 Dr. R. Dumont, 1997, De-Lamping for Energy Savings, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

7.6 L. Snodgrass, Dr. R. Dumont, October 2003, Saskatchewan Research Council, Building Energy Management (BEM) Program Audit Report of King Edward Place
7.7 Natural Resources Canada, April 2006, Modelling Guide for EE4-CBIP Version 1.6, Government of Canada, www.sbc.nrcan.gc.ca/documentation/EE4/manual_cbip_may2006.pdf

7.8 Natural Resources Canada, 2002, Use of Variable Frequency Drives for Fan and Pump Control, Energy Innovators Initiative, Technical Fact Sheet, Government of Canada, http://oee.nrcan.gc.ca/Publications/infosource/Pub/ici/eii/M92-242-2002-11E.pdf

7.9 Centre West Air, 1988, Air Balancing Report, Mechanical Operation and Maintenance Manual, Kinsmen Park Apartments

7.10 Dr. R. Dumont, 1997, Improved Efficiency Fluorescent Lamps and Ballast, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

7.11 Canadian Mortgage and Housing Corporation, 2003, Multi-Residential High Efficiency Clothes Washer Pilot Project, Research Highlights, Technical Series 02-137

7.12 Natural Resources Canada, 2005, Office of Energy Efficiency, Historic Energy Consumption Values: Clothes Dryers, Government of Canada, http://oee.nrcan.gc.ca/equipment/english/page11.cfm

7.13 Green Peace Canada, Twelve Clever Ways to Save Lots of Electricity and Money, http://www.greenpeace.org/canada/en/campaigns/climate-and-energy/solutions/energy-efficiency/12-steps

7.14 Natural Resources Canada, 2006, Office of Energy Efficiency, EnerGuide Appliance Directory 2006, Appliance Energy-saving Tips and Distributors by Brand Name, Clothes Dryers, Government of Canada, http://oee.nrcan.gc.ca/publications/infosource/pub/appliances/2006/page11.cfm?attr=0

7.15 Natural Resources Canada, 2005, Intelligent Controller Heats Vehicle Engines for Less, Government of Canada http://oee.nrcan.gc.ca/publications/infosource/pub/ici/caddet/english/r433.cfm?attr=20

7.16 R. D. Montgomery, P.E., and R. Baker, Nov 2006, Study Verifies Coil Cleaning Saves Energy, ASHRAE Journal, Nov 2006, pg 34

7.17 UltimateAir RecoupAerator, 2007, http://www.ultimateair.com/

7.18 Dr. R. Dumont, 1997, Reducing Energy Consumption of Drink Coolers, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

7.19 The Energy Detective, 2007, http://www.theenergydetective.com/
7.20 Solplan Review, July 2005, Pay as You Go Electricity, The Independent Journal of Energy Conservation, Building Science, and Construction Practice, The Drawing-Room Graphics Service, pg 13

7.21 D. Parker and D. Hoak (Florida Solar Energy Center) and A. Meier and R. Brown (Lawrence Berkeley National Laboratory), 2006, How Much Energy Are We Using? Potential of Residential Energy Demand Feedback Devices, Florida Solar Energy Center, University of Central Florida, Florida USA, http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1665-06.pdf

7.22 Wellspring Wireless, 2007, Promotional Advertisement, http://www.impactmovie.com/wellspring/

7.23 Natural Resources Canada, 2005, EnerGuide for Equipment, EnerGuide Appliance Directory 2005, Government of Canada, http://oee.nrcan.gc.ca/energuide/index.cfm

7.24 Natural Resources Canada, 2004, Premium Efficiency Motors, Technical Fact Sheet, http://oee.nrcan.gc.ca/Publications/infosource/Pub/ici/eii/pdf/M144-21-2003E.pdf

7.25 National Electrical Manufacturers Association (NEMA), 2002, Premium Motors, Product Scope and Nominal Efficiency Levels, http://www.nema.org/stds/complimentary-docs/upload/MG1premium.pdf

7.26 BC Hydro, 2004, Power Smart Tips & Practices: Fans, http://www.bchydro.com/business/investigate/investigate804.html

7.27 Personal communications, HVAC Sales, Feb 7, 2007, Regina Saskatchewan

7.28 European Commission, 2003, European Guide to Pump Efficiency for Single Stage Centrifugal Pumps, http://energyefficiency.jrc.cec.eu.int/motorchallenge/pdf/EU_pumpguide_final.pdf

7.29 J. Weale, P.E., and P. Rumsey, P.E., 2005, Laboratories for the 21st Centrury: Best Practices, Low-Pressure-Drop HVAC Design for Laboratories, U.S. Environmental Protection Agency, U.S Department of Energy, http://www.labs21century.gov/pdf/bp_lowpressure_508.pdf

7.30 R. Besant, P.Eng, Fellow ASHRAE, and C. Simonson, Ph.D, P.Eng, Associate Member, ASHRAE, Air-to-Air Exchangers, ASHRAE Journal, April 2003

7.31 Personal communications, Eagle Crane, March 2007, Saskatoon, Saskatchewan, 306-664-0088

7.32 Dr. R. Dumont, 1997, Energy Efficient Electric Motors and Drive Systems, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

7.33 Professor C. Simonson, 2006, ME 491 Class Notes, College of Mechanical Engineering, University of Saskatchewan

7.34 BC Hydro, 2004, Power Smart Tips & Products: Low Flow Shower Heads, http://www.bchydro.com/powersmart/elibrary/elibrary699.html

7.35 D. Hill (Canadian Mortgage and Housing Corporation) & A. Pride (Minto Developments Inc.), 2005, City of Cornwall Social Housing Division, Top 10 Energy and Water Saving Tips in Multi-Unit Residential Buildings, Powerpoint Presentation

7.36 Environment Canada, 2006, Water Saving Devices, Government of Canada, http://www.ec.gc.ca/water/en/info/pubs/brochure/e_iwdww2.htm

7.37 J. Duffie and W. Beckman, 1980, Solar Engineering of Thermal Processes, Wiley-Interscience, John Wiley & Sons, New York

7.38 Natural Resources Canada, 2002, Water Heating System for Apartment Building – Quinpool Towers, Halifax, Nova Scotia, ISBN 0-662-32128-6, Government of Canada, http://www.canren.gc.ca/app/filerepository/EC8A53B6FB3945518B9C9BD6B5664CEB.pdf

7.39 Thermotech Windows, 2007, Product Specifications, http://www.thermotechfiberglass.com/products.htm

7.40 Natural Resources Canada, 2006, Hot2000 Modeling Library, Thermal Resistance of Polyurethane Insulated Doors, Government of Canada, http://oee.nrcan.gc.ca/residential/personal/new-homes/r-2000/standard/hot2000.cfm?attr=4

7.41 T. Woods, 2003, Does Your Building Suck?, CanAm Building Envelope Specialists Inc., http://www.canambuildingenvelope.com/files/pdfs/330-1058.pdf

7.42 S. Thwaites, 2006, Stephen's Column: Double Hung Inherently Flawed, Thermotech Windows, http://www.thermotechfiberglass.com/Column3.htm

7.43 S. J. Emmerich, T. McDowell, W. Anis, 2005, Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use, National Institute of Standards and Technology, Technology Administration, U.S Department of

Commerce, http://www.canambuildingenvelope.com/files/pdfs/NISTIR7238.pdf

7.44 CanAm, Smoke Safety, Energy Efficiency, Comfort: How to Improve All Three by Controlling Air Leakage in High-Rise Buildings, CanAm Building Envelope Specialists Inc., http://www.canambuildingenvelope.com/files/pdfs/330-1173.pdf

7.45 T. Woods, 2004, Building Envelope News, CanAm Building Envelope Specialists Inc., http://www.canambuildingenvelope.com/files/pdfs/330-1168-Electronic-Sup2-v6.pdf

7.46 Integrated Designs, 2007, Report submitted to the Saskatchewan Research Council regarding EE4 modeling they had been contracted to perform

7.47 Viessmann Canada, 2007, Viessmann Manufacturing Company Inc., http://www.viessmann.ca/web/canada/ca_publish.nsf/Content/Vitodens200_ca_english

7.48 ASHRAE, 2000, ASHRAE HVAC Systems and Equipment Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia, pg 27.4, Figure 5

7.49 ASHRAE, 1997, ASHRAE Fundamentals Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia, pg 8.12, Figure 4

7.50 Personal communications with Dr. R. Dumont, Saskatchewan Research Council, March 2007

7.51 SolarWall, 2006, Conserval Engineering Inc., http://solarwall.com/home/

7.52 SolarWall, 1996, Canadian Bombardier Case Study, Conserval Engineering Inc., http://solarwall.com/home/CaseHistory.aspx

APPENDIX 1: ADDITIONAL EE4 INFORMATION

Appendix 1 provides additional information on how the EE4 computer models of the 2003, 2005, and base building were created. References appear at the end of each appendix.

A1.1 CREATION OF WEATHER FILES

The first variables required in the weather file are latitude, longitude, and monthly average ground temperatures. The monthly average ground temperatures for the new Saskatoon weather files were assumed to be equal to the values found in the North Battleford weather file provided with the EE4 program. In addition to these variables the weather files also requires 14 columns of hourly data. These columns, and their respective units, are:

1. Outdoor air wet bulb temperature [F]
2. Outdoor air dry bulb temperature [F]
3. Atmospheric pressure [in Hg]
4. Cloud amount [0-10]
5. Snow No/Yes [0,1]
6. Rain No/Yes [0,1]
7. Wind direction (measured in intervals of 24 degrees from North) [0-15]
8. Humidity ratio [lb H_20 / lb Air]
9. Outdoor air density [lb / ft^3]
10. Outdoor air enthalpy [BTU / lb]
11. Total solar horizontal radiation [BTU / hr ft^2]
12. Direct normal solar radiation [BTU / hr ft^2]
13. Cloud type [0-2]
14. Wind speed [knots]

Hourly data was available from Environment Canada's website for variables 2, 3, 7, and 14. Variables 4, 5, 6, and 13 were also determined from the Environment Canada data but some judgment was needed as weather conditions were presented qualitatively in the data. For each hour, the weather file provided 32 verbal descriptions of the weather conditions based upon Environment Canada's *Manual of Surface Weather Observations*. These verbal descriptions needed to be converted into quantitative values in the new weather files.

Variables 5 and 6 are simple No/Yes toggles that were set to either 0 or 1 depending on the presence of the word “Rain” or “Snow” in the weather description. Variable 4 defines the amount of cloudiness from 0-10 and Environment Canada states that for their data “Clear” corresponds to a cloudiness level of 0, “Mainly Clear” corresponds to a level of 1-4, “Mostly Cloudy” corresponds to a level of 5-9, and “Cloudy” denotes a level of 10. The cloudiness levels that corresponded to the remaining 28 weather descriptions were then defined based on these guidelines. Variable 13 assigns a value of 0-2 depending on the opaqueness of the cloud cover. A value of 0 denotes cirrus clouds (the most transparent cloud type), 1 denotes stratus clouds (the most opaque cloud type), and 2 denotes any cloud type that falls between. A value of 2 is the default for most weather conditions. Table A1.1 shows the values assumed for variables 4, 5, 6, and 13 for each of the 32 different weather descriptions.

Table A1.1: Values assumed for weather codes

	Rain [0-1]	Snow [0-1]	Cloud Type [0-2]	Cloud Amount [0-10]
Blowing Dust	0	0	2	8
Blowing Snow	0	1	2	9
Clear	0	0	0	0
Cloudy	0	0	2	10
Drizzle	1	0	2	7
Dust	0	0	2	7
Fog	0	0	2	10
Freezing Drizzle	1	0	2	7
Freezing Fog	0	0	2	7
Freezing Rain	1	0	2	7
Haze	0	0	1	7
Heavy Rain	1	0	1	9
Heavy Rain Showers	1	0	1	9
Heavy Snow	0	1	1	9
Heavy Thunderstorms	1	0	1	9
Ice Crystals	0	0	2	5
Ice Pellets	0	1	2	5
Ice Pellets Showers	0	1	2	5
Mainly Clear	0	0	0	3
Moderate Rain	1	0	2	7
Moderate Rain Showers	1	0	2	7
Moderate Snow	0	1	2	7
Moderate Snow Showers	0	1	2	7
Mostly Cloudy	0	0	1	7
Rain	1	0	2	8
Rain Showers	1	0	2	8
Smoke	0	0	2	8
Snow	0	1	2	8
Snow Grains	0	1	2	8
Snow Pellets	0	1	2	8
Snow Showers	0	1	2	9
Thunderstorms	1	0	1	10

Variables 1, 8, 9, and 10 were not directly available from the Environment Canada data and needed to be calculated. The hourly simulation tool TRNSYS was used with dry bulb temperature and dew point temperature as the inputs. Its built in psychometric calculator then outputted values for each of these 4 variables. The program PsyCalc98 from Linric Company was used to verify the TRNSYS calculations by manually checking several points from different time periods of each year.

The final variables that were defined were 11 and 12 (hourly solar radiation). SRC measures total horizontal hourly solar radiation and therefore variable 11 was directly determined from their measurements. The computer program TRNSYS was needed again, however, to determine variable 12 as SRC measures only diffuse horizontal and total horizontal radiation. TRNSYS contains built in radiation processors and a TYPE 16i was used to convert the measured total horizontal and diffuse radiation to direct normal solar radiation.

A1.2 WINDOWS

The ASHRAE Handbook of Fundamentals (1997) [1] was used to define the U-values of the windows. The handbook shows how the total overall U-value of a window can be estimated if the separate heat transfer contributions of the center glass, edge glass, and frame are known.

The overall U-Value for each window was calculated and a summary of the results for each window can be seen in Table A1.2.

Table A1.2: Properties of the five window types in KEP

Window Code	Location	Type	Window Width [m]	Window Height [m]	Total Window Area [m^2]	Edge of Glass Area [m^2]	Center of Glass Area [m^2]	Frame Width [m]	Frame Area [m^2]	Af [m^2]	U_F [W/m^{2}K]	U [W/m^{2}K]
A	Suite	Fixed	0.865	1.607	1.390	1.09	0.304	0.041	0.209	1.599	2.90	3.182
B	Suite	Operable	0.660	1.607	1.061	0.78	0.278	0.071	0.342	1.403	3.29	3.220
C	Suite	Fixed	0.540	1.200	0.648	0.44	0.209	0.041	0.149	0.797	2.90	3.110
D	Suite	Operable	0.660	1.200	0.792	0.57	0.225	0.071	0.284	1.076	3.29	3.212
E	Recreation Area	Fixed	1.750	1.500	2.625	2.22	0.406	0.041	0.273	2.898	2.90	3.231

The solar heat gain coefficient (SHGC) is a dimensionless value that represents the solar heat gain properties of an entire fenestration product. It is equal to the fraction of incident irradiance that enters through the glazing and becomes heat gain. It is needed to determine the solar radiant heat gain through a window's glazing system.

The total window SHGC at normal incidence, for an uncoated, double glazed window, with a glass thickness of 6.4 mm, and a non-aluminum frame, is 0.52 for operable windows and 0.61 for fixed windows [1]. These SHGC values are for unshaded windows, however, and all of the windows in KEP have interior shading of some kind. The most type of interior shading was observed to be light coloured curtains. Draperies and other methods of interior shading have been found to have significant effects on heating and cooling loads in buildings and it was decided that they could not be ignored when defining SHGCs in the model [1].

The shading coefficient of a window is a multiplier that adjust the solar gain values of clear glass to a value for glass that is tinted. It is defined as the ratio of the SHGC of a glazing system to that of a single, clear, pane of glass; or:

$$SC = \frac{SHGC(\Theta)_{test}}{SHGC(\Theta)_{ref}} \tag{A1.1}$$

where θ indicates the requirement for the two coefficients to be of the same angle of incidence and incident solar spectrum. The ratio remains constant, however, as the solar spectrum and angle of incidence varies for clear, double glazed, windows [1]. The shading coefficient method has limitations and is not recommended by ASHRAE for complicated glazing systems. The glazing system in question, however, is relatively simple, being only two clear glazings and a single curtain. Therefore it was assumed that the shading coefficient method would suffice.

ASHRAE Fundamentals provides a table of estimated shading coefficients for different methods of interior shading. Values taken from the table are assumed to be valid for windows located on any side of the building. The table requires choosing the fabric classification based on colour and weave. Pictures taken in 2006 reveal that of approximately 300 windows in KEP, only 6 suites had non-white curtains. Three suites had dark curtains and the remainder were covered with aluminum foil. Curtains were therefore assumed to be light in colour. For the weave of the fabrics used in the curtains, it was assumed, based on observations made in 2006, that half were of a semi-open weave and half were of a closed weave.

The reference SHGC for a single, clear glazing, at normal incidence, using the standard ASTM solar spectrum, is 0.87. Dividing the SHGC of the windows in KEP by 0.87, their SC were found to be 0.60 for the operable window and 0.70 for the fixed window. Locating a fixed window with two clear glazings and a 13 mm airspace in the ASHRAE table of shading coefficiencts, the SC for the semi-open and closed weaves were found to be 0.48 and 0.42 respectively [1]. Their average, 0.45, is 36% less than the SC for the fixed window without curtains. It was therefore assumed that the SHGCs for windows with curtains were 36% less than the ASHRAE values for unshaded windows. The exception will be the main and second floor sun room windows as it is known that they have curtains with an open weave. Using the table again, the reduction in SHGC for these windows was found to be 20%.

It is unlikely, however, that all of the tenants will choose to completely block out the sunlight with their blinds during the day. Photographs taken after noon in the summer of 2005 show that approximately 81% of the windows on the North side of the building had their blinds closed during the day. On the South face of the building approximately 84% of the windows were observed to be closed. Photographs taken after noon in the winter of 2006 show that approximately 85% of the windows on the North side of the building had their blinds closed during the day. On the South face of the building approximately 86% were observed to be closed. It was therefore assumed that at any time during the year 85% of the windows will have their curtains closed and 15% will not. Adjusting for this, the SHGC's for the windows in KEP were found to be 0.33 (37% less) for the operable suite windows, 0.39 (36% less) for the fixed suite windows, and 0.49 (20% less) for the fixed sun room windows.

A1.3 BUILDING TEMPERATURE

The energy loads for a building cannot be defined without knowledge of the indoor temperature. The purpose of this section is to show that the building temperatures calculated by the computer model for each month are reasonable and match the actual temperature of the building.

When creating a temperature schedule in the computer model it is possible to specify the desired temperature for each hour of every day. The building manager stated, however, that the thermostats in the building are not adjusted and it was therefore assumed that the target temperatures for the schedules would be constant throughout three different seasons: winter, change over, and summer. These three seasons were created based on the three control settings that define the performance of the mechanical systems in the building. The first control setting is the warm weather shutdown for the boilers, which occurs once the outdoor temperature is greater than 18ºC. The second is the activation of the air conditioning unit, which occurs when the ambient temperature is greater than 15ºC. The third is occupant control over suite thermostats. Studying the weather trends for Saskatoon revealed that based on these control temperatures the most reasonable seasons would be October 1 – April 30 for winter, September 1-30 and May 1-31 for the change over periods, and June 1 – August 31 for summer.

In the winter of 2005-2006, it was observed that the hallway thermostats on each floor were set to slightly above 24ºC. The exception was the second floor which was set to 26ºC. The lounge thermostats on the first and second floors were also set between 24ºC and 25ºC. The building manager stated that he did not adjust the thermostats during the year and in the summer of 2005 the thermostats were checked again. All were set to the same temperatures as they were in the winter. Each suite also has a thermostat that allows tenants to control the temperature of their rooms. The actual average thermostat setting that tenants choose is not known, although three tenants that were interviewed stated that their room thermostats were always set to zero as they found their rooms to be too hot even in the winter. This is likely due to the "purge" cycle that occurs in their baseboard radiators.

In order to reduce maintenance of the radiators, their control valves fully open every twenty minutes, "purging" the pipes with a sudden flow of hot water. This protects the pipes from freezing. Also, after over 20 years of use, some of the valves may now be stuck in the open position or unable to close fully. Thus, regardless of the thermostat setting by the occupant, their radiators will be continuously supplied with hot water from the boilers. This greatly reduces the occupants ability to control the temperature of their suites. The likelihood of suites overheating is further increased by the fact that the minimum temperature of the water exiting the boilers is set to 65.6ºC, several degrees higher than necessary. It is true that the majority of the tenants likely do enjoy a temperature greater than 22ºC, but several tenants that were interviewed expressed that the building was too hot throughout the year.

Measurements of the central exhaust air temperature should give a good indication of the average temperature of the above ground floors. Figure A1.1 shows the measured temperature of the central exhaust air during a 10 day measurement period in January 2006. These temperatures were measured while determining the heat recovery effectiveness and more detail on their measurement can be found in Chapter 5, Section 2. The average measured central exhaust air temperature of the data in Figure A1.1 is 24.4ºC.

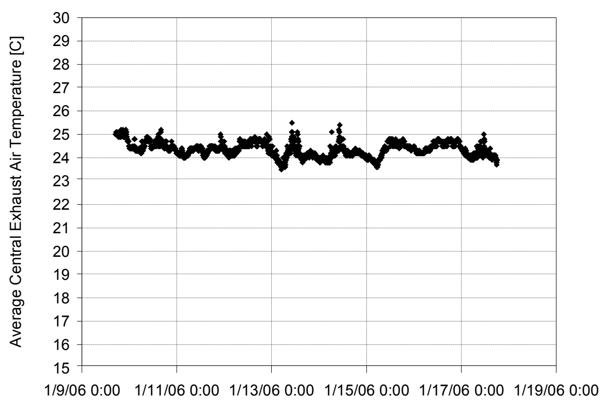

Figure A1.1: Measurement of central exhaust air temperature

The temperatures that were used in the computer model for each area of the building, along with the seasons for each of those temperatures, can be seen in Table A1.3.

Table A1.3: Design and scheduled temperature settings

		Schedule Temperature					
	Design Temperature [C]	Winter Heating [C]	Change Over Heating [C]	Summer Heating [C]	Winter Cooling [C]	Change Over Cooling [C]	Summer Cooling [C]
Suites	24.4	24	22	18	24	22	18
Hallways & Stairwells	24.4	24	22	18	24	24	24
Lounge & Sunroom	24.4	24	22	18	24	24	24
Penthouse / Mechanical	24.4	24	22	18	35	35	35
Crawlspace	19.6	19	19	18	35	35	35

The suites, hallways, lounges, and penthouse were all assumed to have the same heating schedule. Schedules for cooling were different for each of the spaces. The suites in the building have a tendency to overheat in the summer and it was assumed that tenants would likely set their thermostats below 22ºC, and in most cases right down to zero. In the summer, the boilers shut down when the outdoor temperature is above 18ºC and during this season they will rarely be operating. Therefore the summer heating and cooling schedule temperatures were set to 18ºC, knowing that the air conditioning unit in the model would not have the capacity to reduce the temperature of the rooms to 18ºC. In the changeover seasons the boilers will not be operating continuously and some of the tenants will also have likely begun to turn down their thermostats. It was felt that during this period a medium temperature of 22ºC would be used for the suites. The main and second floor lounges have their own thermostats, which can only be adjusted by the building manager, and therefore their scheduled cooling temperature was set to 24ºC for both summer and winter. The 11th floor penthouse and the crawlspace do not have cooling coils and therefore their cooling schedule temperature were set to 35ºC.

Figure A1.2 shows the average building temperature calculated by the computer model when the ventilation air temperature was 18ºC during the heating season. In this figure the average suite temperature in the month of July is 29.5ºC.

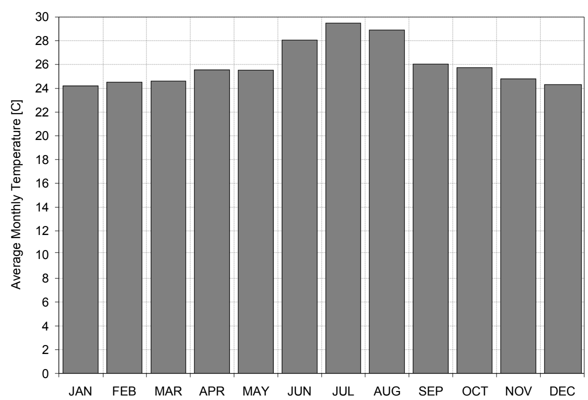

Figure A1.2: Monthly average temperature of the suites, hallway, penthouse, and stairwells when the minimum ventilation air temperature was set to 17.5ºC

To confirm if the building could reach temperatures as high as those in Figure A1.2, air temperature measurements were taken on July 26, 2006, at 3pm. The outdoor air temperature at this time was approximately 33°C. An Omega HH309 data logger thermometer with 4 thermocouples was used to measure the exhaust air temperature at the same location as the exhaust temperature measurements described in Chapter 5, Section 2. Placing the 4 thermocouples across a cross section of the duct, for a period of 5 minutes, using a sampling time of 10 s, the average temperature of the central exhaust air leaving KEP was found to be 28.6°C. Using the Omega meter in several other locations throughout the building, the average temperature of the stairwells and the boiler room penthouse was measured to be 29.3°C and 30.9°C respectively.

It is apparent that the building overheats significantly during the summer and some room temperatures can rise to be above 30ºC in July. An average monthly temperature of 29.5ºC is likely still too high, however, for the average July monthly building temperature. There was believed to be two main reasons for the higher than expected average building temperatures.

The first is that the cooling effect of the window mounted air conditioning units in suites are not being taken into account by the computer model. When the building was visited in July, 2006, 39 tenants (31%) had air conditioning units mounted in their windows. One tenant, on the 8th floor of the south side of the building, agreed to allow temperature measurements to be taken in his suite. This tenant stated that he operated a 1.8 kW (6,000 Btu/hr) air conditioning unit 24 hours/day, everyday, during the summer. He also had opaque white plastic curtains covering his windows and two large fans circulating the air in his apartment. With all of these measures being taken to reduce the temperature of his suite, it was still measured to be 24.7°C in his bedroom and the temperature of the air exhausting from his bathroom was measured to be 26.5°C.

Considering that window mounted air conditioning units may contribute as much as 70 kW additional cooling and the rooftop unit servicing the building is only 98 kW, it is likely that they would be able to reduce the average building temperature and cause the computer model to overestimate the July building temperature.

The second reason for the high temperatures calculated by the computer mode is that cooling from the heat recovery system is not taken into account. The building has a run-around glycol loop that operates year round. The computer model, however, shuts off its heat recovery system above outdoor temperatures of 22ºC. Using the transient hourly simulator discussed in Appendix 3, Section 3, it was estimated that 2,500 kWh/Year of cooling from the heat recovery unit in the actual building is not taken into account by the computer model.

Figure A1.3 shows the average temperatures, calculated by the computer model, of the main and second floor lounge areas.

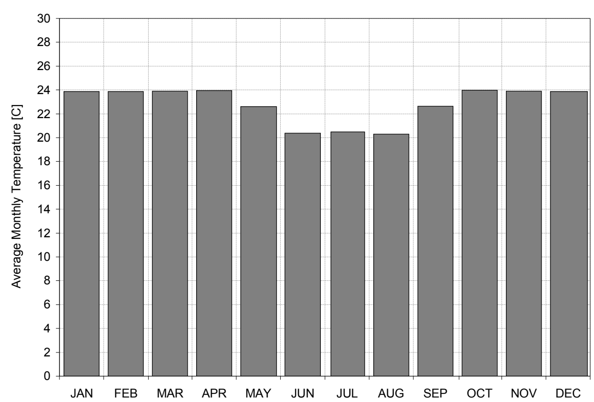

Figure A1.3: Monthly average main and second floor lounge temperatures

The majority of the lounge temperatures match well to air temperature measurements taken in the building but the summer (June, July, August) temperatures are approximately 2ºC lower than observed. This is most likely due to the computer model treating the space as isolated from the rest of the building. In reality the warmer building air and lounge air will mix and raise the average lounge air temperature.

Figure A1.4 shows the average crawlspace temperature calculated by the computer mode.

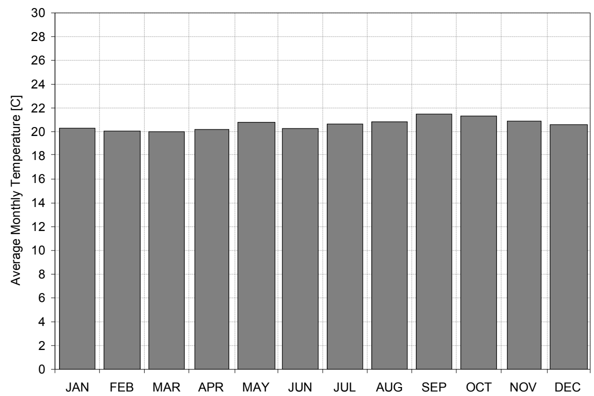

Figure A1.4: Monthly average crawlspace temperatures

The crawlspace heating system was installed after the building was built and no blueprints are available that describe its design or control. With the help of experienced staff from SRC and the SHA attempts were made to determine the exact method in which the system controlled and monitored crawlspace temperature but the system's components were not labeled and controls such as a thermostat could not be found. It was decided therefore to rely on measurements of the actual crawlspace temperature. Taking two measurements approximately 30 minutes apart from each other, on October 17th, 2005, the crawlspace exhaust air temperature was measured to be 19.9ºC and 19.8ºC. On Nov 9, 2005, in approximately the center of the West crawlspace area, the crawlspace temperature was measured to be 19.2ºC. The air in the crawlspace is very well mixed and the rate of air change in the space is 0.85 air changes per hour. The crawlspace design and schedule temperature was therefore set to be the average of these three measurements, 19.6ºC. Figure A1.4 shows that the computer model results acceptably matched the actual measured crawlspace temperature.

A1.4 DOMESTIC HOT WATER LOAD

This section discusses how measured natural gas consumption and literature were used to determine the domestic hot water (DHW) loads in the 2003 and 2005 computer models.

Figure A1.5 shows a theoretical plot of natural gas consumption for a building. The horizontal portion of the plot corresponds to natural gas consumption when there is little or no need to heat the building.

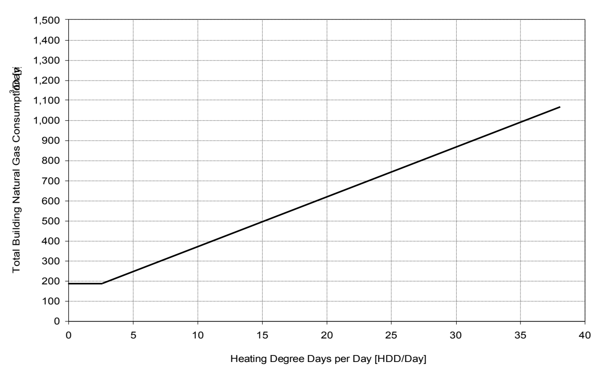

Figure A1.5: Theoretical shape of natural gas consumption graph

The boilers and domestic hot water heaters are the only systems in the building that consume natural gas and the boilers in KEP shut down above an outdoor air temperature of 18ºC. Therefore, at 0 heating degree days per day, the boilers can only be consuming the gas required for their pilot lights. Gas consumption at this point then must be due to pilot lights and the heating of domestic hot water. If the Y-Intercept of the horizontal section of the plot is known, and the consumption of the pilot lights is estimated, the average daily energy required for heating DHW can be therefore be determined.

Figure A1.6 shows the actual natural gas consumption in KEP for the year 2005. Added to the data points in the figure is a linear trend-line which has a Y-intercept of 73.5 m^3/day.

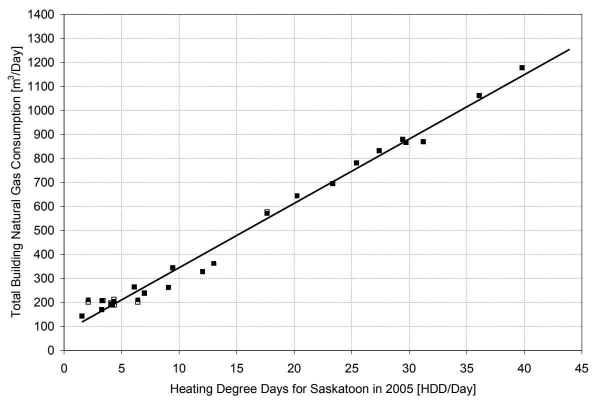

Figure A1.6: Metered natural gas consumption of KEP for the year 2005

It was felt that using the Y intercept of a linear fit to the data would underestimate the actual natural gas consumption for DHW as the initial part of the natural gas consumption, during low heating degree days, is theoretically horizontal. The actual Y-intercept of the data will therefore be much higher than the intercept of a linear trend-line. Also, the data points used to create Figure A1.6 are bi-monthly meter readings and in order to clearly see the low HDD/Day horizontal section in the data, more frequent meter readings would be preferred. Despite the limitations in the readings, a grouping of data points whose average appears to be horizontal does occur for heating degree days less than 5. It was decided to use the average of these first 5 points to determine the horizontal Y intercept for low HDD/Day data. For the 2005 data this average was found to be 194.0 m^3/day.

Figure A1.7 shows the measured meter consumption for the years 2002 and 2003.

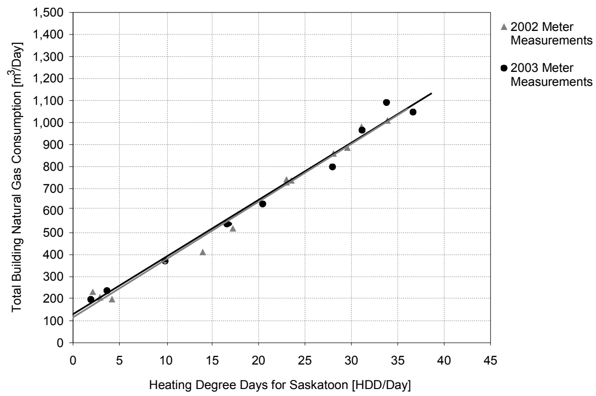

Figure A1.7: Comparison of measured natural gas consumption for the years 2002 and 2003

In 2003 meter measurements were taken on a monthly basis and this having only 2 points where the HDD/Day were below 5. This was felt to be insufficient to base the computer model upon and instead the 2002 and 2003 data was combined. Linear trend-lines have been applied to the data points and the two years have very similar consumption profiles. This supports the assumption that it would be acceptable to use both the 2002 and 2003 data to determine the average daily natural gas consumption for the year 2003.

Figure A1.8 shows low HDD/Day natural gas consumption for 2002 and 2003. The addition of the 2002 data gives 3 more points to base the average daily consumption upon. The average of the 5 points seen in Figure A1.8 is 213.4 m^3/Day. This is 8.9% higher than the value found for the year 2005.

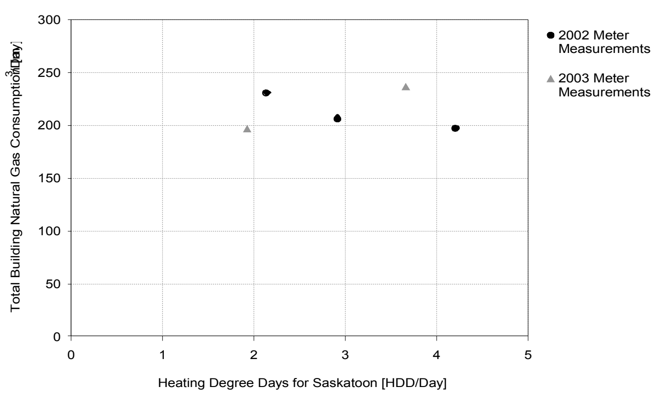

Figure A1.8: Natural gas consumption in 2002 and 2003 for low HDD/Day data

Figure A1.9 is a comparison of the measured natural gas consumption in 2003 and 2005. Linear trend lines have been applied to the data and they shows a consistent increase in the 2003 consumption, supporting the assumption that in 2003 the daily average natural consumption was greater than in 2005.

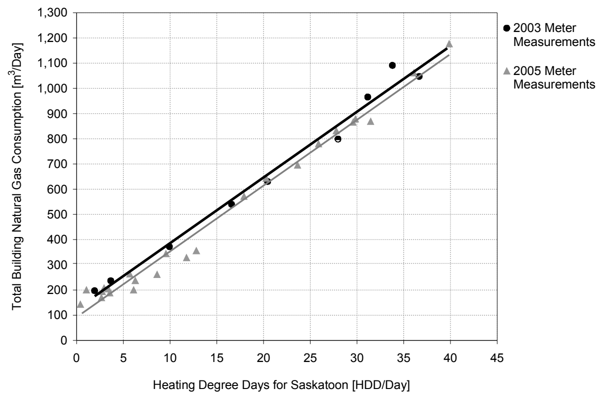

Figure A1.9: Comparison of the measured consumption in 2003 and 2005

On average, pilot lights consume approximately 0.29 kW (1000 Btu/hr) [3] and there are 23 pilot lights in KEP (20 for boilers and 3 for DHW tanks). Pilot lights therefore consume approximately 15.6 m^3/day. The remaining DHW consumption needed to be matched in the model was then 178.4 m^3/Day for the year 2005 and 197.8 m^3/Day for 2003. To convert these values for fuel consumption to a load that could be used by the program the average seasonal efficiency of the DHW heaters needed to be estimated.

Section A.1 of the 1999 document, *Performance Compliance for Buildings,* from the Natural Research Council of Canada [4], states that when modeling buildings according to Canada's Model National Energy Code for Buildings the following equations for fuel part-load consumption of service water heaters must be used for non-condensing hot water heaters:

$$Fuel_{part-load} = Fuel_{design}\, x\, FHeatPLC(Q_{part-load}, Q_{rated}) \qquad \text{(A1.2)}$$

$$FHeatPLC = (a + b\,x\,\frac{Q_{part-load}}{Q_{rated}} + c\,x(\frac{Q_{part-load}}{Q_{rated}})^2) \qquad \text{(A1.3)}$$

where FHeatPLC is the Fuel Heating Part Load Efficiency Curve, $Fuel_{part\text{-}load}$ is the fuel consumption at part load conditions (Btu/hr), $Fuel_{design}$ is the fuel consumption at design conditions (Btu/hr), $Q_{part\text{-}load}$ is the boiler capacity at part load conditions (Btu/hr), Q_{rated} is the boiler capacity at design conditions (Btu/hr), a is a constant (0.021826), b is a constant (0.977630), and c is a Constant (0.000543).

Equations A1.2 and A1.3 adjust the DHW heater's fuel consumption by varying its efficiency. This efficiency relationship can be plotted if the capacity and thermal efficiency of the DHW heaters are known. The combustion efficiency of each heater was measured during the 2003 building audit by SRC. The measured efficiencies were 75.7%, 75.4%, and 72.7%, and their average is 74.6%. Using this average efficiency and equations A1.2 and A1.3, Figure A1.10 was generated. It shows how the efficiency of a non-condensing DHW heater decreases as load percentage decreases.

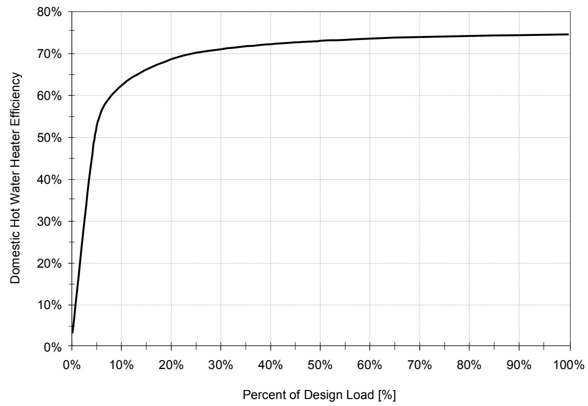

Figure A1.10: NRC relationship between DHW heater efficiency and load percentage

The load on the DHW tanks will in practice rarely or never be exactly equal to the full load capacity of the DHW heaters and therefore each DHW heater will always be operating at an efficiency lower than its thermal, or combustion, efficiency. Note, however, that the slope of the curve seen in Figure A1.10 is very low for part loads greater than 30%. This indicates that the efficiency of the DHW heaters should remain relatively constant regardless of their load ratio.

Under the low water use category, the 1999 ASHRAE Applications Handbook gives 4 L/Person as a guideline for the peak 15 minute water use in an apartment building [5]. This is equal to a peak use of 0.0044 L/s/Occ. The peak 15 minute water use for a medium water use building is given as 7.5 L/Person, or 0.0083 L/s/Occ. If the peak flow rate was assumed to be 0.0044 L/s/Person, the hot water tank temperature is 58ºC [6], and the average annual water temperature in Saskatoon is 11ºC [3], then the estimated peak heat requirement for DHW is 862.5 W/Occ.

CMHC research has found that the average total water usage (includes both hot and cold) for Canadian apartment buildings is 202 m^3/apartment/year [8]. This average includes buildings occupied by seniors, single occupants, and families. Seniors apartment buildings are typically low users of water [7] and the CMHC study found that the average water use of the 13 seniors buildings monitored was 149 m^3/Suite, 44% less than apartment buildings occupied by families. In the year 2003 KEP used 20,346 m^3, or 162.8 m^3/apartment/year, 9.3% greater than the CMHC average for seniors buildings. One possible reason why KEP may be a greater than average user of water, as compared to other seniors buildings, is that the clothes washers located on the second and main floor of the building are not coin operated. Based on the fact that KEP appears to have a similar water consumption as a low water use building, its DHW consumption should be similar to the low water use ASHRAE estimate.

Each DHW heater has a capacity of 146.4 kW and together the three tanks have a total output capacity of 439.3 kW (1,500,000 Btu/hr). If the low water use value of 862.5 W/Occ is multiplied by the 125 occupants in KEP the estimated peak power requirement for DHW is 107.8 kW. Thus, the DHW tank output capacity is potentially 4 times larger than required and the maximum part load percentage of the system would be 25%. Figure A1.10 estimates that this would result in a maximum thermal efficiency of 70%. This could be too low of an estimate for the thermal efficiency of the DHW tanks, however, as the curve is designed for a single tank, not three operating together. Greater efficiency should occur when multiple tanks are used. However, the system is large enough that the opposite may occur. Three large atmospherically drafted DHW tanks that continuously vent heat to the outdoors and also continuously loosing heat to their surroundings through their tank walls will have significant standing losses. The problem of defining the thermal efficiency of the tanks is further complicated as insulation was added to the outside of the tanks by SRC during a retrofit in 2003. The thermal efficiency of the two years (2003 and 2005) should therefore not be equal.

Based on the measured combustion efficiency it is known that the thermal efficiency for both 2005 and 2003 must be equal to or lower than 74.6%. Based on the estimated amount of oversizing, Figure A1.10 predicts a thermal efficiency of 70%. The thermal efficiency in the 2005 model should be greater than in the 2003 model due to the insulation of the tanks. It was decided to use 72.3%, the average of the chart estimate and the measured thermal efficiency, for the 2005 model. The measured consumption in 2003 is 8.4% higher than 2005 and it is not likely that this can all be attributed to increasing the efficiency of the DHW tank. SRC estimated in the 2003 building audit report that insulating the tanks would save 1.25 m^3/Day in natural gas consumption, which is only 0.6% of the consumption in 2003. If 72.3% is assumed to be the post insulation efficiency and 1.25 m^3/Day is assumed to be the savings from insulating the tanks, the DHW tank efficiency prior to adding the insulation would be 71.9%. This was used for the 2003 computer model.

To determine the DHW load for each hour, the program requires the user to enter the maximum hourly load for each room in the model. Each room has a schedule which multiplies this maximum value by an hourly percent load fraction that is defined by a DHW schedule. It was assumed that the DHW schedule for KEP was equivalent to EE4's default DHW schedule for an apartment building. The 24 hour average percent load of this schedule is 31.5%. The DHW load must be entered into EE4 on a per occupant basis and scaled based on the operating schedule. There are 125 occupants in KEP and recalling that the consumption needed to be matched by EE4 was 178.4 m^3/day for the year 2005, the average daily consumption per occupant is 14.8 kWh/(Day·Occ).

Entering 72.3% as the thermal efficiency of the DHW heaters in the 2005 model and using 862.5 W/Occ as an initial guess for the peak DHW demand, EE4 calculated the average DHW heater efficiency to be 64.4%. Multiplying the average daily consumption by the average efficiency resulted in an average daily load of 9.51 kWh/Day/Occ. All DHW loads were applied to the suites and laundry rooms. The laundry room load was determined by assuming that 18% of the total DHW load was due to laundry use [8,9]. The consumption needed to be matched by EE4 in the 2003 model was 197.8 m^3/day. Assuming a seasonal efficiency of 64.0% the average daily load per occupant was estimated to be 10.5 kWh/Day/Occ. This estimated DHW load for 2003 is 9.4% greater than the 2005 load.

Using an average daily load of 9.51 kWh/Day/Occ, the maximum hourly loads for the 2005 computer model were found to be 1,017 W/Occ for the suites and 20,674 W/Occ for the laundry rooms. Note that the laundry room consumption is quite high because the laundry rooms are modeled as having less than 2 occupants. The same DHW schedule was used in the 2003 model and assuming the average daily load was 10.5 kWh/Day/Occ, the maximum hourly loads for the 2003 computer model were found to be 1,074 W/Occ for the suites and 21,833 W/Occ for the laundry rooms. The use of these values in the computer simulations, however, resulted in the natural gas consumption of the computer model being greater than the measured natural gas consumption.

The values used for domestic hot water consumption were iteratively reduced until the computer model and measured consumption matched within less than ±0.5%. The final natural gas consumption arrived at for DHW in the 2005 model was 169.9 m^3/Day, a 4.8% reduction from the 5 point average. The corresponding loads for this model were 825 W/Occ for the suites and 16,766 W/Occ for the laundry rooms. The final natural gas consumption arrived at for DHW in the 2003 model was 189.3 m^3/Day, a 4.3% reduction from the 5 point average. The corresponding loads for this model were 930 W/Occ for the suites and 18,900 W/Occ for the laundry rooms.

A1.5 BUILDING RECEPTACLE LOADS

This section outlines how the measured building electrical consumption and literature were used to determine the building receptacle loads (or plug loads) in the 2003 and 2005 computer models. Figure A1.12 shows the measured building electrical consumption and the consumption initially estimated by the computed model for the year 2005. The estimated consumption of the exterior lights is included but the receptacle load is not.

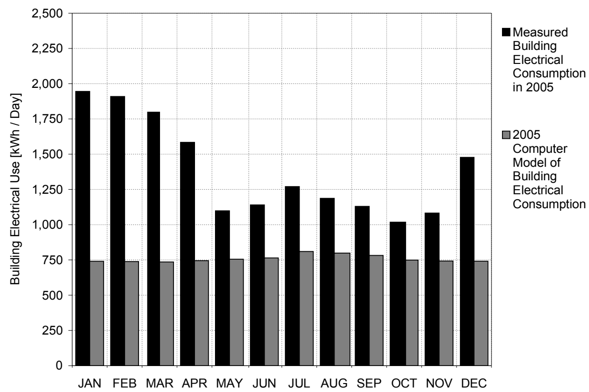

Figure A1.12 Electrical consumption (2005), receptacle load not included in model

The months of January-April and November-December in the 2005 data were believed to include consumption of the sidewalk heat tape and block heaters. The model was therefore matched to the data based on the months in which it was believed that these two loads were not present. The average building electrical consumption for these months, May-October, was 1,141 kWh/Day in 2005. With exterior lights taken into account, the 2005 EE4 model estimated the building electrical consumption to be 825 kWh/Day. The difference between the computer model estimate and the measured average was 316 kWh/Day and this was used as the average daily building receptacle load in the 2005 computer model of the building.

Figure A1.13 shows the building electrical consumption for the year 2002 and the electrical consumption estimated by the computer model of the year 2003. Exterior lights are included in the model, the estimated lighting savings of 163.1 kWh/day have been removed, and the receptacle load in the computer model is zero.

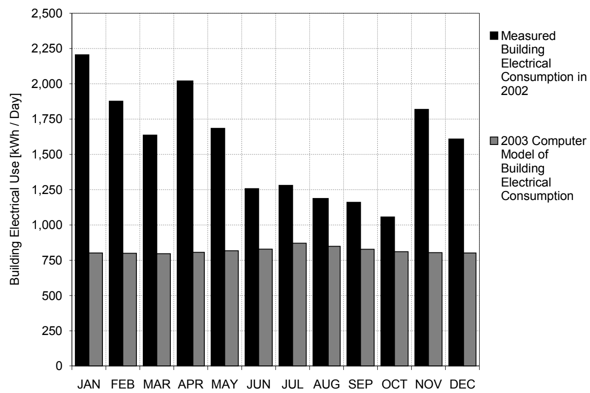

Figure A1.13: Measured (2002 minus lighting retrofit savings) and model consumption (2003)

The months of January-May and November-December in the 2002 data are believed to include consumption by the heat tape and block heaters. The average measured building electrical consumption for the months of June-October is 1,186 kWh/Day. With exterior lights taken into account and the building receptacle load set to zero, the 2005 EE4 model estimated the building electrical consumption to be 872 kWh/Day. The difference between the computer model estimate and the measured average in 2002 was 316 kWh/Day (1% lower than the 2005 value) and this was used as the average daily building receptacle load for 2003 computer model of the building. Once the average daily receptacle loads of 316 kWh/Day and 314 kWh/Day were determined they were allocated to the laundry rooms, elevator rooms, and mechanical rooms.

Based on measurements in Dr. R. Dumont's house it was assumed that the electrical consumption of the washing machines was 80 kWh/Year per occupant [3]. This amount is equal to the amount consumed in his household (3 occupants) and it would be expected that the consumption on a per tenant basis would be less in KEP. The washing machines in KEP are much older than the machine in Dr. Dumont's house, however, and also the Dumont household is likely to be conservative in their energy use. Therefore it was assumed that the less conservative tenants in KEP, using older washing machines, would consume the same amount as the Dumont residence.

Typically a new residential clothes dryer will use approximately 920 kWh/Year [10]. In a 1999 report the Canadian Residential Energy End-use Data and Analysis Centre estimated that in an apartment clothes dryer consumption would be 315 kWh/Suite [11]. The clothes dryers in KEP are very old models and models of their age should consume approximately 1,103 kWh/Year in a household [10]. It was measured in a Toronto study of 6 different apartment buildings with coin operated laundry rooms that the two seniors buildings in the study used approximately 60% less laundry cycles per suite than the remaining mixed/family apartment buildings [12]. This would equal 441 kWh/Year per suite. The laundry machines in KEP are not coin operated, however, and this should have an affect on consumption. It was therefore decided to assume 475 kWh/Year per suite for clothes dryers because they are older models and not coin operated. This is a total clothes dryer electrical consumption of 55,100 kWh/Year.

A second significant contributer to the building's receptacle load are the two elevators. The CBIP modeling guide states that 3,000 kWh/yr should be used for each elevator less than 15 stories and the guideline is based on research done by Enermodal Engineering [13]. Their calculation uses 200,000 door openings per year.

In 1986 Shroeder [14] developed a general formula for calculating the energy consumption of typical elevator systems. The formula developed by Schoeder was:

$$E = \frac{R * ST * TP}{3600} \quad \text{(A1.8)}$$

where R is the motor power (kW), ST is the estimated number of stops per day, and TP is the average trip time (s). Schoeder also provided a table of average trip times for different elevator systems [15].

In KEP the elevator system is gearless generator-motor and the trip time values from Schoeder for this system are 4-6 s. For greater accuracy, when there are two elevators in a building, the lower trip time is used to calculate the energy of the larger motor and the higher trip time is used for the smaller motor. The motors in KEP are 15 kW and 19 kW. Using the recommended value from the CBIP of 6,000 kWh/Year, this results in a total of 356 starts per day, or 2.85 starts per day for each tenant. This was felt to be a reasonable value for the occupants of KEP. Therefore it was decided to use the CBIP recommended value of 6,000 kWh/Year for the 2 elevators in the building.

A source from CMHC, however, quotes 6% of the total building energy use is for elevators [9]. This would be approximately 180,000 kWh/Year in the case of KEP. It is possible that the estimate of the elevator electrical consumption is too low, but 180,000 kWh/Year is much too high of an electrical consumption for just the elevators.

Appendix 1 References

1. ASHRAE, 1997, ASHRAE Fundamentals Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia
2. W.C. Brown and K. Ruberg, 1988, National Research Council, Window Performance Factors, Government of Canada, http://irc.nrc-cnrc.gc.ca/pubs/bsi/88-2_e.html
3. Dr. R. Dumont, 2006, Saskatchewan Research Council, Personal communications
4. National Research Council of Canada, May 1999, Performance Compliance for Buildings, Specifications for Calculation Purposes for Demonstrating Compliance to the Model National Energy Code for Buildings Using Whole Building Performance, Government of Canada, http://irc.nrc-cnrc.gc.ca/pubs/fulltext/nrcc46028.pdf
5. ASHRAE, 1999, ASHRAE HVAC Applications Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia, Pg 48.12, Table 8
6. L. Snodgrass, Dr. R. Dumont, October 2003, Building Energy Management (BEM) Program Audit Report of King Edward Place, Saskatchewan Research Council
7. Canadian Mortgage and Housing Corporation, CMHC Research Highlights, Technical Series 01-142, Analysis of the Annual Energy and Water Consumption of Apartment Buildings in the CMHC Highstar Database, Government of Canada
8. Canadian Mortgage and Housing Corporation, Feb 2003, CMHC Research Highlights, Technical Series 02-137, Multi-Residential High Efficiency Washer Pilot Project,

Government of Canada

9. D. Hill (Canadian Mortgage and Housing Corporation) & A. Pride (Minto Developments Inc.), 2005, City of Cornwall Social Housing Division, Top 10 Energy and Water Saving Tips in Multi-Unit Residential Buildings, Powerpoint presentation

10. Natural Resources Canada, 2006, Appliance Energy-saving Tips and Distributors by Brand Name: Clothes Washers, EnerGuide Appliance Directory, Government of Canada http://oee.nrcan.gc.ca/publications/infosource/pub/appliances/2006/page10.cfm?attr=0

11. M. Aydinalp, A.S. Fung, & V. Ismet Ugursal, 1999, Survey of Unit Energy Consumption (UEC) Estimates for Space Heating, DHW Heating, and Appliances Energy Usage, Canadian Residential Energy End-use Data and Analysis Centre (CREEDAC), http://creedac.mechanicalengineering.dal.ca/reports/pdfs/report.pdf

12. City of Toronto Works and Emergency Services and the Toronto Community Housing Corporation, 1999, City of Toronto Multi-Unit Residential Clothes Washer Replacement Pilot Project, http://www.toronto.ca/watereff/washer/pdf/multi-unit_clothes_washer_pilot.pdf

13. H. M. Sachs, 2005, Opportunities for Elevator Energy Efficiency Improvements, American Council for an Energy-Efficient Economy, http://www.aceee.org/buildings/coml_equp/elevators.pdf

14. J. Schroeder, 1986, “The energy consumption of elevators”, Elevator Technology

15. Dr. L. R. Al-Sharif, 1995, Lift Power Consumption, Published in Elevation Magazine, and reprinted in Elevator World (May)

APPENDIX 2: UNCERTAINTY ANALYSIS

This appendix discusses the uncertainty in the measured results and the ability of the RETScreen model to estimate solar water heating energy production.

A2.1 CENTRAL SUPPLY AND EXHAUST FLOW

The air flow rates in the central supply and exhaust ducts were measured in June 2006. Velocity measurements were taken using a TSI VelociCalc Plus model 8384-E-GB hot-wire air velocity probe with an accuracy of 3% of the reading or 0.015 m/s (whichever is greater) and a resolution of 0.01 m/s. Average duct velocity was found using a straight average of individual point velocities following a log-Tchebycheff rule grid (ISO Standard 3966) [1]. The internal cross-sectional areas of the supply and exhaust ducts were 0.590 m^2 (0.590 m x 1.000 m) and 0.652 m^2 (0.595 m x 1.095 m) respectively. The hydraulic diameters of the supply and exhaust ducts were 0.742 m and 0.771 m respectively.

ASHRAE 1997 recommends a minimum of 25 measurement locations for rectangular ducts of this size [1]. The measurements were taken at 25 different grid locations in each duct. At each location the 3 measured velocities were averaged and therefore 75 measurements were taken per duct. All measurements were sampled using a 10s average, which also effectively increases the number of measurements taken per location. ASHRAE 1997 also states that, if possible, measurement points should be located at least 7.5 diameters downstream and 3 diameters upstream from flow disturbances such as corners. For both the supply and exhaust ducts, however, meeting this criteria was not possible. This is, in part, the reason for increasing the number of measurements to 75.

Supply air velocity measurements were taken in the longest available straight section of supply air ductwork. This was also the location in which the 2003 SRC audit measurements were taken. It was 1.95 m (2.7 diameters) downstream from the nearest upstream disturbance (a large 90 bend). The ducting that follows the measurement location passes though the penthouse floor and into the interior walls of the floors below, resulting in the nearest downstream disturbance being over 3 diameters upstream.

The building exhaust air returns from the suites through several small ducts that gradually connect together on each side (North and South) of the penthouse. The last connection of the smaller exhaust ducts is a large Y duct in the center of the penthouse that combines the exhaust air from each half of the building. After this Y connection there is a 3.3 m straight section of ducting that enters an S duct leading directly into the exhaust fan. This straight section was the most suitable location to measure the exhaust air velocity and measurements were taken 2.2 m (2.9 diameters) downstream from the nearest upstream disturbance (the Y connection) and 1.1 m (1.4 diameters) upstream from the nearest downstream disturbance (the S duct). This was also the location where SRC took their measurements in 2003.

In October 2003 SRC measured the supply and exhaust flow rates to be 3,190 L/s and 3,120 L/s respectively. In June 2006 the supply and exhaust flow rates were measured by the author to be 3,307 L/s and 3,270 L/s respectively. An increase in the flow rates was expected as both the central supply and exhaust ducts had been cleaned since the October 2003 measurement.

Confirming the assumption that the supply and exhaust flow rates are constant were measurements of the rotational speed of the supply and exhaust fans and motors. Table A2.1

shows pulley speeds measured in August 2006, October 2006, and January 2007. A Monarch Nova-Strobe DB digital stroboscope with a resolution of ±0.1 RPM was used. There is almost no difference in the measured rotational speeds of the fans and motors for the central supply and exhaust systems.

Table A2.1: Measured rotational speed of the central supply and exhaust fan pulleys

	Aug 2006 [RPM]	Oct 2006 [RPM]	Jan 2007 [RPM]	Average [RPM]
Central Supply Fan	1530.4	1532.1	1525.5	1529.3
Central Exhaust Fan	1624.9	1625.6	1625.6	1625.4

Figures A2.1 and A2.2 show the velocities measured by the author in June 2006. Repeated measurements are not expected to agree exactly. Random, or precision, errors will be observed in any repeated measurement because of the many uncertainty sources that are present. The standard deviation (StDev) is a measure of the distribution of precision error and for a normal uncertainty distribution two times the standard deviation (2·StDev) will include approximately 95% of the total scatter of measurements (based on the number of measurements taken) [2].

	81 mm	317 mm	550 mm	783 mm	1019 mm
574 mm	5.50	6.55	7.18	7.63	7.05
441 mm	5.90	6.60	7.90	8.18	7.05
310 mm	5.95	5.83	5.78	6.98	7.40
179 mm	4.94	3.72	4.72	6.00	7.03
46 mm	2.56	1.81	3.67	5.03	3.92

Figure A2.1: Supply velocity measurements (m/s) and duct grid point locations

	81 mm	317 mm	550 mm	783 mm	1019 mm
556 mm	7.28	5.98	4.51	3.43	1.90
427 mm	7.80	6.53	5.12	3.66	2.80
300 mm	7.37	6.80	3.96	4.40	4.80
173 mm	7.07	6.10	6.63	2.90	6.08
44 mm	6.60	2.57	5.73	6.35	5.98

Figure A2.2: Exhaust velocity measurements (m/s) and duct grid point locations

A large value for 2·StDev indicates significant scatter in the measurements. The average measured velocity in the supply and exhaust ducts was found to be 5.60 m/s and 5.02 m/s respectively. For the supply and exhaust air velocity measurements, 2·StDev was found to be 3.2 m/s (± 55%) and 3.6 m/s (± 67%) respectively. This is misleading, however, as an estimate of the total uncertainty in the measurements as it is expected that the velocity measured near the walls of the duct will be different than the velocity measured in the center of the duct.

The precision index, S, is an estimate of the standard deviation and is used to determine the precision uncertainty in a series of measurements. It is defined as [2]:

$$S = \left[\sum_{k=1}^{N} (X_K - \bar{X}) \right]^{\frac{1}{2}} \qquad \text{(A2.1)}$$

where $\bar{X}$ is the average of N measured values of X_K. Precision uncertainty is reduced by increasing the number of measurements and when several measurements are averaged precision index becomes defined as:

$$S_X = \frac{S}{\sqrt{N}} \qquad \text{(A2.2)}$$

For the average supply and exhaust duct velocities S_X was found to be 0.21 m/s and 0.19 m/s.

Bias uncertainty is a constant systematic uncertainty that is present in any test. The manufacturers state that the accuracy of the hot-wire probe used is ±3% of the reading or 0.015 m/s (whichever is greater). This will be assumed to be the bias uncertainty. The total root sum squared uncertainty, U_{RSS}, for a 95% coverage of an average of N measurements, is equal to:

$$U_{RSS} = \left[B^2 + (tS_X)^2 \right]^{\frac{1}{2}} \qquad \text{(A2.3)}$$

where t is a function of the number of degrees of freedom and can be taken from statistics tables. As over 30 measurements were taken t is 2.0 [2]. The total uncertainty, U_{RSS}, for the average supply and exhaust duct velocities is therefore ± 0.45 m/s (± 8.0%) and ± 0.41 m/s (± 8.1%) respectively.

The typical uncertainty in hot-wire velocity measurements of average duct velocity has been estimated to be approximately 1-20% for a low velocities (0.05 to 5 m/s). The average measured duct velocities were slightly higher than 5 m/s, however, and uncertainty in high velocity measurements (up to 300 m/s) is estimated to be 1-10% [4]. The potential for uncertainty decreases as velocity increases, and as the measured velocities were greater than 5 m/s, it is not likely that the uncertainty is as high as 20%. The total uncertainty, U_{RSS}, was found to be 8%, but this does not include the potential for uncertainty as a result of the measurements being taken at locations that are near flow disturbances. It was therefore assumed that the uncertainty in the average duct velocity measurements was ±10%.

A2.2 INFILTRATION

This section presents an uncertainty analysis of the measured infiltration rate of 0.29 L/(s·m^2) for the building during the winter of 2005. Chapter 3, Section 4, discusses how carbon dioxide concentrations (CO_2) were measured in the central supply and exhaust ducts of the building in order to calculate the flow of infiltration into the building. The CO_2 was used as a tracer gas by assuming a generation rate from the occupants.

The steady-state indoor pollutant concentration of a building can be determined from the mass balance:

$$(Q_S + Q_I) C_o + S = (Q_{Exh} + Q_{Exf}) C_i \qquad \text{(A2.4)}$$

where C_i is the steady-state indoor concentration (mg/m^3), C_O is the steady-state outdoor concentration (mg/m^3), S is the total pollutant source strength (mg/s), Q_S is the mechanical supply air rate (m^3/s), Q_I is the infiltration rate (m^3/s), Q_{Exh} is the mechanical exhaust air rate (m^3/s), and Q_{Exf} is the exfiltration rate (m^3/s). If it is assumed that changes in density are negligible then for mass to be conserved ($Q_S + Q_I$) must equal ($Q_{Exh} + Q_{exf}$) and the rate at which air enters or leaves the space, Q_t, will be:

$$Q_t = (Q_S + Q_I) = (Q_{Exh} + Q_{Exf}) \tag{A2.5}$$

The rate at which air enters or leaves the building, Q_t, can then be defined by:

$$Q_t = \frac{n\,R}{\Delta C} \tag{A2.6}$$

where:

ΔC = C_{EX} - C_S (mg/m^3)
C_{EX} = Concentration of CO_2 in the exhaust air (mg/m^3)
C_S = Concentration of CO_2 in the supply air (mg/m^3)
n = Number of tenants (persons)
R = CO_2 emission rate of tenants (mg/s/person)

Using the letter U to denoted the uncertainty in each variable, the equation for the uncertainty in Q_t is:

$$\begin{aligned} UQ_t &= \sqrt{\left(\frac{\partial Q_t}{\partial n} Un\right)^2 + \left(\frac{\partial Q_t}{\partial R} UR\right)^2 + \left(\frac{\partial Q_t}{\partial \Delta C} U\Delta C\right)^2} \\ &= \sqrt{\left(\frac{R}{\Delta C} Un\right)^2 + \left(\frac{n}{\Delta C} UR\right)^2 + \left(\frac{n\,R}{\Delta C^2} U\Delta C\right)^2} \end{aligned} \tag{A2.7}$$

The CO_2 emission rate of tenants is defined as:

$$R = r\,M\,A_{DU}\,\rho_{CO2} \tag{A2.8}$$

and its uncertainty, UR, is:

$$UR = \sqrt{(M\,A_{DU}\,\rho\,Ur)^2 + (r\,A_{DU}\,\rho\,UM)^2 + (r\,M\,\rho\,UA_{DU})^2 + (r\,M\,A_{DU}\,U\rho)^2} \tag{A2.9}$$

where r is the metabolic CO_2 emission rate of tenants (L/(s·W)), M is the average tenant metabolic rate (W/m^2), A_{DU} is the average human surface area (m^2), and ρ_{CO2} is the density of carbon dioxide, CO_2, at room temperature (kg/m^3).

Knowing that the CO_2 metabolic emission rate of a person is 4 x 10^{-5} L/(s·W), the average surface area of a human is 1.88 m^2, the average tenant metabolic rate is 1.13 Met (65.8 W/m^2), and the density of CO_2 is 1.805 kg/m^3, the CO_2 emission rate of each tenant can be found to be 536 mg/min. From medical journals the metabolic rate and human surface area were determined and the average uncertainty in M was given in the journals as ±15% and the average uncertainty in A_{DU} was given as ±10%. If it is assumed that the average uncertainty in r is ±15% and the uncertainty in ρ_{CO2} is ±2%, then the uncertainty in R, UR, is 126 mg/min, or ±24%.

The uncertainty in the concentration difference, ΔC is defined as:

$$U\Delta C=\sqrt{UC_{Ex}{}^2+UC_S{}^2} \quad \text{(A2.10)}$$

The VAISALA meter specifies its accuracy to be 20 ppm + 2% of the reading. The YES Falcon meter specifies its accuracy to be 5% of the reading. The average hourly supply and exhaust concentrations were measured to be 677 mg/m^3 and 922 mg/m^3 respectively. The average uncertainty in C_{Ex} and C_S was then calculated to be 10 mg/m^3 and 24 mg/m^3 (1.4% and 2.6%) respectively. Assuming a 10% uncertainty in average occupancy the average uncertainty in Q_t is 1,113 L/s, or 25%.

The equation for determining infiltration is:

$$I=Q_t-Q_S \quad \text{(A2.11)}$$

and the uncertainty in infiltration is:

$$UI=\sqrt{UQ_t{}^2+UQ_S{}^2} \quad \text{(A2.12)}$$

The uncertainty in infiltration rate per square meter of exterior wall area, I_A, is therefore:

$$UI_A=\sqrt{\left(\frac{UI}{A}\right)^2+\left(\frac{I\,UA}{A^2}\right)^2} \quad \text{(A2.13)}$$

However, the uncertainty in the wall area divided by the wall area squared is a negligible term and therefore the uncertainty in infiltration per square meter of exterior wall area becomes:

$$UI_A=\frac{UI}{A} \quad \text{(A2.14)}$$

Previously in this appendix the uncertainty analysis for the hot wire probe measurements of the supply and exhaust air flow rates was found to be approximately 10%. The uncertainty in infiltration was then calculated for each measurement point. The average bias error in the total infiltration rate equaled ± 1,230 L/s (± 103%). Twice the standard deviation in the measured infiltration rates is 1,073 L/s. Thus the total uncertainty in the average infiltration rate is ± 1,632 L/s. Figure A2.3 shows the measured infiltration rates (per unit area) with the calculated uncertainty plotted as error bars for each measurement point. Twice the standard error of the estimate in the measured values in Figure A2.3 is 0.24 $L/(s\cdot m^2)$.

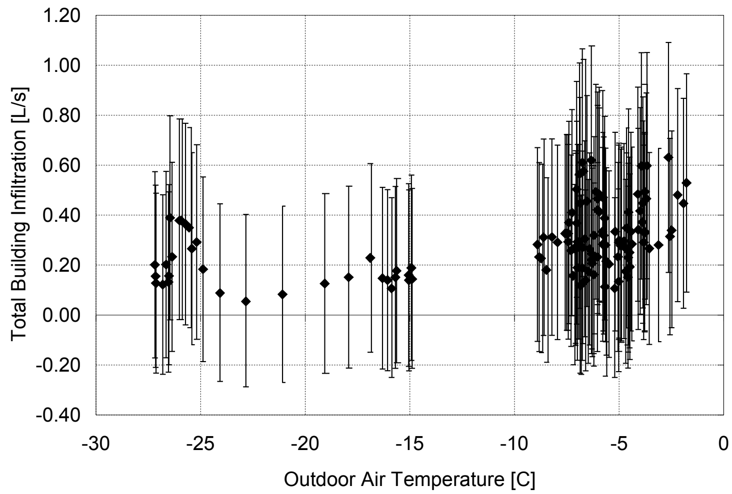

Figure A2.3: Uncertainty in measured infiltration rate

A2.3 HEAT RECOVERY EFFECTIVENESS

This section discusses the uncertainty in the calculation of the heat recovery effectiveness of the run-around glycol system. Using the average of seven temperature measurements for each location the local temperature for each grid point was found. These temperatures and their locations can be seen in Figure A2.3.

Outdoor Air Exhaust Air (Post HR) Return Air (Pre-HR)

Figure A2.4: Temperatures at Each Grid Location

For uniform air flow, temperature, and humidity conditions the bias (B) and precision (P) uncertainty of thermocouples is ± 0.2ºC and ± 0.1ºC respectively [**4**]. However, air flow in a building will have spatial variations in temperature and velocity that result in an increased bias uncertainty. The bias uncertainty for each flow stream (B_{TD}) was calculated as twice the standard deviation of each set of measurements.

The total bias uncertainty will be equal to:

$$B_T = (B_{TD}{}^2 + B_{UT}{}^2)^{\frac{1}{2}} \tag{A2.14}$$

where B_{UT} is the bias found for uniform temperature air flow. The total root-sum-squared uncertainty, U_{RSS}, is then equal to:

$$U_{RSS}=(B_T{}^2+P^2)^{\frac{1}{2}} \quad (A2.15)$$

Table A2.2 summarizes these results and shows that the outdoor air temperature measurement is the most uncertain.

Table A2.2: Summary of Temperature Grid Measurements

	Max [C]	Min [C]	Average [C]	P [C]	B_{UT} [C]	B_{TD} [C]	B_T [C]	U_{RSS} [C]
Outdoor Air	-5.1	-6.1	-5.8	0.1	0.2	0.89	0.91	0.92
Exhaust Air (Post HR)	14	13.8	13.9	0.1	0.2	0.18	0.27	0.29
Return Air (Pre-HR)	24.4	23.9	24.1	0.1	0.2	0.20	0.28	0.30

Effectiveness

Recall that the effectiveness was equal to:

$$\varepsilon=\frac{m_H(T_{HI}-T_{HO})}{m_{MIN}(T_{HI}-T_{CI})} \quad (A2.16)$$

which can also be defined as:

$$\varepsilon=\frac{m_H \Delta T_1}{m_{MIN}\Delta T_2} \quad (A2.17)$$

The uncertainty, U, in the effectiveness is then equal to: (A2.18)

$$U\varepsilon=\sqrt{\left(\frac{\Delta T_1}{m_{MIN}\Delta T_2}Um_H\right)^2+\left(\frac{m_H}{m_{MIN}\Delta T_2}U\Delta T_1\right)^2+\left(\frac{m_H\Delta T_1}{m_{MIN}{}^2\Delta T_2}Um_{MIN}\right)^2+\left(\frac{m_H\Delta T_1}{m_{MIN}\Delta T_2{}^2}U\Delta T_2\right)^2}$$

where:

$$\Delta T_1=T_{HI}-T_{HO} \quad (A2.19)$$

$$\Delta T_2=T_{HI}-T_{CI} \quad (A2.20)$$

$$U\Delta T_1=\sqrt{UT_{HI}{}^2+UT_{HO}{}^2} \quad (A2.21)$$

$$U\Delta T_{21}=\sqrt{UT_{HI}{}^2+UT_{CI}{}^2} \quad (A2.22)$$

Previously in this appendix it was stated that the uncertainty in the supply and exhaust air flow rates was 10%. Using this value the average bias uncertainty in the calculated effectiveness values was found to be ± 0.051. For data when the heat recovery system was not being controlled, twice the standard deviation in the recovery effectiveness is 0.03. Thus the total uncertainty in the maximum effectiveness (0.36) is ± 0.057. Figure A2.5 shows the uncertainty that was calculated for each data point.

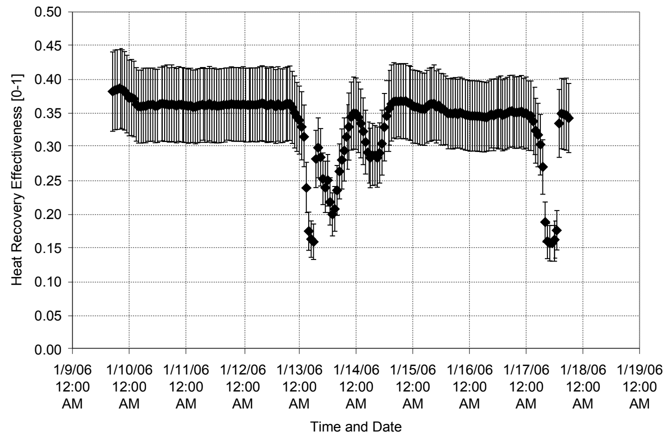

Figure A2.5: Measured effectiveness with uncertainty uncertainty bars added

If the uncertainty in the supply and exhaust flow rate was increased to 20% the average uncertainty in the heat exchanger effectiveness would increase to ± 0.10.

Appendix 2 References:

1. ASHRAE, 1997, ASHRAE Fundamentals Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia
2. ANSI/ASME Standard PTC 19.1-1985, Measurement uncertainty, pg 23, The American Society of Mechanical Engineers, New York.
3. ASHRAE, 1987, ASHRAE Fundamentals Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia
4. A. B. Johnson, R.W.Besant, and C.J Simonson, 1998, Uncertainty analysis in the testing of air-to-air heat/energy exchangers installed in buildings, ASHRAE Trans., 104(1B), 1639-1650.

APPENDIX 3: RETROFIT INVESTIGATIONS

This appendix provides additional information on the retrofits that were investigated for KEP. The purpose of this appendix is to present the electrical, natural gas, and monetary savings that would result from potential retrofits. By doing so, each retrofit can be differentiated and ranked, providing reasons for the choice of certain retrofits to be included in the final design.

A3.1 ELECTRICAL RETROFITS

This section of the appendix discusses proposed retrofits to systems in KEP that consume electricity. Savings from each retrofit are shown at the end of each section and these savings are for that retrofit alone. For example, it is expected that a retrofit such as installing compact fluorescent light bulbs will lower the cooling load and thus result in air conditioning savings. Such a retrofit should also increase the heating load and result in greater natural gas consumption by the boilers. However, these consequential impacts are not presented in this section. Only the electrical savings directly resulting from each specific retrofit are presented. Complimentary energy savings is presented in Chapter 7. Utility savings presented in this section do not include savings from reducing electrical demand charges.

Tenant Energy Monitoring

Throughout this section reference will be made to savings of 10-25% as a result of energy monitoring. This refers to the practice of monitoring the energy use of each tenant and requiring them to pay for the energy they consume rather than an average payment based on the utilities for the whole building. It also includes giving direct feedback to the tenants that informs them of the amount of energy, and corresponding utility cost, they are responsible for. The Energy Detective is one of many different types of electrical monitoring devices that is commercially available. Their website states that studies have shown the savings associated with real-time monitoring of personal electrical usage range from 10-20% [1]. Customers in Woodstock Ontario have been paying using a pay-as-you go system since 1989 and monitoring studies have shown that 15-20% savings were achieved as compared to homes using traditional billing methods [2]. A paper published on the Florida Solar Energy Center website also states that existing studies support a 10-15% savings due to instantaneous feedback on household electrical demand [3]. Another technology that could be used is wireless transducers. The American company Wellspring Wireless provides wireless transducers and acquisition systems specifically designed for energy monitoring of tenants in rental buildings. Wellspring Wireless states that their products can accurate measure all forms of energy and water consumption in a building and on average a 26% savings has been experienced by users of their products [4].

A quote to monitor water, heat, and electricity in KEP was obtained from Wellspring Wireless. They estimated an installed cost of approximately $254,000, or $2,190/Suite. In the retrofit building the total savings attributed to occupant energy monitoring is approximately $185/Year per suite. The simple payback period of this retrofit is therefore approximately 12 years. This does not include the additional savings from reducing water consumption and estimates of tenant energy savings due to monitoring were typically conservative.

Elevators

The elevators in the base building were assumed to consume 6,000 kWh/Year (0.2% of the building's total annual energy consumption). The two elevators in the building are powered by 19 kW and 15 kW generators that are connected to 18.6 kW and 14.9 kW motors. The larger motor-generator pair travels from the basement to the tenth floor while the smaller pair operates only the main to tenth floor. There are more efficient methods of driving the elevators than the current method of converting the output of AC generators to DC motors that drive the elevator cables. A representative from ThyssenKrupp Elevators was contacted regarding replacement of the motors and generators with a higher efficiency variable-voltage, variable-frequency, system. They estimated that a 30% savings in electrical use could be achieved by the replacement.

Performance of this retrofit could reduce the building's electrical consumption by 1,800 kWh/Yr, 0.2% of the total electrical consumption and 0.1% of the building's total energy consumption. The expected reduction in annual utility costs that would result from such a retrofit is $198. An exact cost estimate for performing this retrofit in KEP could not be obtained but the representative from ThyssenKrupp stated that it was almost never cost effective to retrofit elevators unless they have failed. This was not only due to the cost of replacing the equipment but also due to the cost associated with bringing a 20 year old elevator system up to the most recent code requirements.

Increasing the Efficiency of Pumps and Pump Motors

There are four pumps in KEP that operate continuously and were estimated to consume 34,223 kWh/Year (1.1% of the building's annual energy consumption). They are each in-line mounted, centrifugal pumps and their efficiency values were found from manufacturer's pump curves. Literature consulted stated that current best practice is to avoid using pumps that have an efficiency of 55% or less [5]. This amount, 55%, is also the efficiency used as the industry standard for estimating the performance of a pump when the actual efficiency is unknown [6]. The literature consulted also stated that pumps could be purchased with efficiencies as high as 80% [7]. Using a guide listing the efficiency values for premium quality European centrifugal pumps [7] and choosing the maximum practical efficiency from this guide (based on rated flow rate), Table A3.1 was created.

Table A3.1: Pump information

Pump	Rated Flow Rate [m^3/hour]	Base Efficiency [%]	Premium Efficiency [%]
Boiler Circulation Pump	31.8	65.0	81.0
Chiller Pump	15.9	59.0	77.0
Reclaim Pump	11.4	50.0	74.0
Heating Coil Pump	19.3	54.0	78.0

In practice, however, pumps with efficiencies as high as the values listed in Table A3.1 could not be found locally. Two Saskatchewan based companies were contacted to obtain price estimates on higher efficiency pumps and neither were able to source pumps that would be significantly more efficient than those currently installed. One company provided a price estimate for replacing the pumps. The cost, as well as the rated efficiency, of each pump can be seen in Table A3.2. If high efficiency pumps are commercially available, they would likely have a significant cost premium.

Table A3.2: Replacement pumps [8]

Pump	Efficiency [%]	Replacement Cost [CAN $]
Boiler Circulation Pump	68.0	1,195
Chiller Pump	53.0	995
Reclaim Pump	46.0	995
Heating Coil Pump	64.0	1,135

Each pump is also driven by a motor that could be replaced with a higher efficiency model. Table A3.3 shows the efficiencies for the current motors and the resulting efficiency if a NEMA premium motor was installed [8, 9].

Table A3.3: Motor information

Motor	Rated Power [kW]	Base Efficiency [%]	Premium Efficiency [%]
Boiler Circulation Pump	1.49	76.0	87.0
Chiller Pump	1.12	71.0	86.0
Reclaim Pump	1.12	71.0	86.0
Heating Coil Pump	1.12	71.0	86.0

The cost, as well as the rated efficiency, of each replacement motor can be seen in Table A3.4. NEMA premium motors typically cost 10-15% more than other energy efficient motors [10].

Table A3.4: Replacement motors [11]

Motor	Efficiency [%]	Replacement Cost [CAN $]
Boiler Circulation Pump	87.0	$550
Chiller Pump	86.0	$500
Reclaim Pump	86.0	$500
Heating Coil Pump	86.0	$500

Table A3.5 shows the resulting combined efficiency when the current pumps and motors are replaced with premium models.

Table A3.5: Combined efficiency

	Base Combined Efficiency [%]	Replace Motors, Not Pumps [%]	Replace Both Motors and Pumps [%]
Boiler Circulation Pump	49.4	56.6	70.5
Chiller Pump	41.9	50.7	66.2
Reclaim Pump	35.5	43.0	63.6
Heating Coil Pump	38.3	46.4	67.1

Another option to reduce the energy consumption of the circulation pumps is the use of variable frequency drives (VFD). VFD convert AC power to a DC signal and re-transmit the power signal to the motor at varying frequencies and voltages [12]. VFD systems save energy by reducing motor speeds when full flow is not required. Typically HVAC systems are designed to meet peak cooling or heating loads. These peak loads, however, only occur during a small portion of the year and the remainder of the time the HVAC systems will be operating at a reduced capacity [13]. When running throughout the year, these motors will typically turn at a constant speed while the pumps or fans that they drive may be operating at less than maximum design speed. A VFD accommodates this speed reduction by varying the shaft speed of the motor. With fans and pumps, power consumed is proportional to the cube root of shaft speed. If shaft speed is reduced by 10%, flow is reduced by 10%, but power consumption is reduced by 27%. If speed is reduced by 20%, power is reduced by 49% [14]. Slowing a pump or fan in this manner reduces energy consumption much more effectively than allowing the motor to run at constant speed and then restricting or bypassing the flow with a valve or damper [13].

Installed costs of these systems can be as low as $250/kW [12] but are typically about $940/kW for motors that are around the size of 0.75 kW [13]. The total power of the four existing pumps in KEP is 4.85 kW. The cost to replace the drive systems for these pumps would therefore be approximately $3,395. When VFD is selected as an option in the computer model the electrical savings are 20,578 kWh/Year.

Table A3.6 provides 9 potential retrofit options for the pumping systems. It assumes the "premium" European pumps with the previously stated efficiencies would cost 200% more than the prices listed in Table A3.4.

Table A3.6: Pump retrofit options

Option	Retrofit	Savings [kWh/Yr]	Total Electrical Savings [%]	Total Energy Savings [%]	Savings [$Year]	Payback Period [Yrs]
1	Replace pumps with high efficiency models	1,149	0.1%	0.0%	$126	52.6
2	Replace motors with high efficiency models	1,502	0.2%	0.1%	$165	12.4
3	Replace both pumps and motors	2,420	0.3%	0.1%	$266	32.7
4	Reduce operating hours with no equipment replacement	9,618	1.0%	0.3%	$1,058	0.0
5	Replace motors (not pumps) and reduce operating hours	10,333	1.1%	0.3%	$1,137	1.8
6	Replace motors & pumps and reduce operating hours	10,165	1.1%	0.3%	$1,118	7.8
7	Install variable frequency drives	20,578	2.1%	0.7%	$2,264	1.5
8	Replace motors (not pumps) and install VFD	21,293	2.2%	0.7%	$2,342	2.3
9	Replace motors & pumps and install VFD	21,840	2.3%	0.7%	$2,402	5.0

Table A3.6 shows that substantial savings result from installing variable frequency drives. This is mostly because in addition to there being many hours when the pumps are not operating at full capacity, there are also many hours when the pumps do not need to run at all. The boilers in KEP shut down above an outdoor temperature of 18ºC and the chiller shuts down below an outdoor temperature of 15ºC. Thus the pumps do not need to run when the systems they serve are not operational. In the weather-file used for the computer model, there are 7159 hours below 18ºC and 2202 hours above 15ºC. Therefore the number of hours the heating and cooling pumps need to be engaged could be reduced by approximately 18% and 75%.

General Building Savings

The building controls operate pneumatically and are powered by a 1 HP compressor. Air leaks in pneumatic systems can be a major source of energy loss in a building [15] as leaks in a pneumatic system can result in frequent cycling of the compressors.

In the 2003 building audit by SRC, the Coke machine in the main floor lounge was estimated to use 1250 kWh/Year. The energy consumption of this cooler could be reduced by removing the light bulbs inside the machine and by placing it on a timer. The machine does not need to operate during the hours when people are sleeping and the canned beverages will not spoil if their refrigeration is cycled on and off. If savings of 25% could be achieved using a timer, the resulting savings would be approximately 312 kWh/Year. This would reduce the utility costs by $31.25. If a $30 timer was bought, this retrofit would have a payback period of approximately 1 year.

Reduction of Ventilation Air Rates

The base building continuously delivers 3,307 L/s of outdoor air to the hallways for ventilation (equal to the measured rates in 2005). An additional 277 L/s of outdoor air is also delivered to the crawlspace on a continuous basis. This is an air change rate of 0.60 air changes per hour in the unfinished and unoccupied crawlspace area. The electricity required to deliver all of the outdoor air supplied to the building was predicted by the base computer mode to be 122,778 kWh/Year (4.1% of the building's total annual energy consumption). Table A3.7 shows the outdoor airflow rates used in the base computer model and the amounts proposed for the retrofit building. In the retrofit, the total outdoor air delivered to the building could be reduced to as low as 2,657 L/s. This is a 21.0% reduction in outdoor air delivered to the above ground floors and a 25.9% reduction in total outdoor air delivered to the building. The rates shown in Table A3.7 were determined based on ASHRAE Standard 62-2001 [16], as the following will describe.

Table A3.7: Current and minimum outdoor airflow rates for the base and proposed building

Floor	Outdoor Air Supplied (Base) [L/s]	Outdoor Air Supplied (Retrofit) [L/s]
Crawlspace	353	35
Main	323	248
2	323	248
3	323	257
4	323	257
5	323	257
6	323	257
7	323	257
8	323	257
9	323	257
10	323	257
Penthouse	76	75
Total	**3,660**	**2,657**

The minimum outdoor air rate for a space defined as a mechanical room is 0.25 L/(s·m^2).

Using this minimum rate, 35 L/s was allocated to the crawlspace for the mechanical and storage rooms that make up the finished portion of the crawlspace. In this section it is assumed that air is not directly delivered to the unoccupied, unfinished, crawlspace areas. This follows the original design of the building, prior to the additional ventilation added to the crawlspace in order to deal with the moisture problems. It was felt that the unoccupied areas of the crawlspace should not be heated and ventilated and the moisture problem should be dealt with through remediation that stops the water from entering the crawlspace (CS), rather than through ventilation and conditioning. Ventilation also does not appear to be working as it is clear from visits to the building that there is still a significant amount of moisture present in the crawlspace. It should be noted, however, that in the main body of this thesis ventilation in the crawlspace is not completely eliminated.

In KEP the penthouse is not actually ventilated. In the computer model, however, ventilation needed to be added to this space as the program would not run without the space meeting its minimum outdoor air requirements. Therefore, while Table A3.7 states that 75 L/s is delivered to the penthouse, in the actual building the 75 L/s would be divided equally amongst the hallways and distributed throughout the building. With this adjustment, the outdoor air rates per suite and per occupant that would be delivered in the actual building can be seen in Table A3.8. A rate of 22 L/s/Suite is consistent with ASHRAE Standard 62-2001. Each room would also be naturally ventilated to some degree by infiltration.

Table A3.8: Actual outdoor air provided per suite and per occupant

Floor	Outdoor Air [L/s]	Number of Suites per Floor	Outdoor Air Per Suite [L/s]	Typical Floor Population	Outdoor Air per Occupant [L/s]
CS	35	-	-	-	-
Main	255	10	22.0	11	23.2
2	255	10	22.0	10	25.5
3	264	12	22.0	13	20.3
4	264	12	22.0	13	20.3
5	264	12	22.0	13	20.3
6	264	12	22.0	13	20.3
7	264	12	22.0	13	20.3
8	264	12	22.0	13	20.3
9	264	12	22.0	13	20.3
10	264	12	22.0	13	20.3

In the previous table the main floor and second floor are supplied with a greater amount of outdoor air per occupant due to the presence of intermittently occupied recreation rooms. These two floors are provided with 22 L/s/Suite plus an additional 35 L/s for their recreation areas. Table A3.9 provides information on the size and observed occupancy of these recreation areas. It shows that the only space which is regularly occupied by a large number of people is the recreation area on the second floor. The recreation rooms described in Table A3.9 are open to each other and significant mixing of air between these spaces is expected.

Table A3.9: Room areas and typical operation

Floor	Room	Floor Area [m^2]	Typical Use	Operating Hours
Main	Sun Room	37.9	Waiting for visitors to arrive (family picking up tenants), and playing pool.	Rarely Occupied
Main	Salon	11.4	Hair salon / Barber shop	10am - 5pm, Fri
Main	Kitchen	7.1	Not used, all appliances are unplugged and all cupboards are locked.	Unused
Main	Storage	11.6	Caretaker's storage, effectively not occupied.	Rarely Occupied
Main	Recreation Area	37.9	Walking area for kitchen and sun room, effectively a corridor and therefore not occupied.	Rarely Occupied
Main	Office	6.5	Caretaker's office containing security camera and files. Often not occupied as caretaker typically works from his suite.	Rarely Occupied
2nd	Kitchen	13.0	Occasionally used for special events (2-3 times per year)	Rarely Occupied
2nd	Recreation Area	45.6	Occupied in the evening for special events such as bingo nights. Events are held regularly but not every day.	6pm-8pm, Mon-Fri
2nd	Recreation Area	66.2	Computer, tables for making puzzles, and library are located here. This is the most occupied recreation area.	9am-6pm, Daily

The additional 35 L/s for each lounge area was first determined by assuming the spaces could be defined as corridors. The minimum outdoor air rate for a space defined as a corridor is 0.25 L/s/m^2. Using this rate, the main floor recreation areas would require 28.1 L/s and the second floor recreation areas would require 31.2 L/s. The estimated typical intermittent daytime occupancy of the second floor recreation areas, however, is approximately 5 people. This is greater than the expected occupancy of a corridor. If each of these people required 8 L/s, a minimum outdoor air flow rate of 40 L/s would be necessary. This suggests that the ventilation rates should be greater than corridor requirements. It is also possible for the occupancy to exceed 5 people during the day. Occupancy will be intermittent, however, and according to ASHRAE Standard 62-2001 [16]:

> When contaminants are associated only with occupants or their activities, do not present a short-term health hazard, and are dissipated during unoccupied periods to provide air equivalent to acceptable outdoor air, the supply of outdoor air may lag occupancy.

This standard provides a chart for determining the maximum permissible ventilation lag time of an intermittently occupied space. Using the chart, knowing that the total volume of the rooms in question is 457 m^3, and assuming that typical intermittent occupancy is 5 people, a requirement of 8 L/s/Person gives a maximum permissible ventilation lag time greater than 10 hours. Thus, even with small increases in occupancy during the day, assuming the space is a corridor should be reasonable.

There are times, however, when these recreation rooms may be occupied by a large number of people engaged in an activity such as doing exercises or playing bingo. It is possible for one large activity to take place during the day and for another activity during the evening. Based upon the available seating area in the space and knowledge of the tenants occupancy patterns, the estimated peak potential occupancy for a typical large gathering is 20 people. Using the chart within the ASHRAE standard again, the maximum permissible ventilation lag time for an occupancy of this size is approximately 1 hour. A larger activity typically engaged in by the tenants would likely be greater than 1 hour in length and therefore it was felt that more ventilation than a corridor should be recommended for this space. In the actual building, however, no outdoor air is actually directly delivered to this space. Instead, an unknown amount of outdoor air transfers from the corridors and main entranceway. Some of this air is provided by the central air handling system and some will enter as infiltration, most notably through the entranceway doors which are directly adjacent to the space.

Natural ventilation will assist in ventilating the recreation areas, the permissible ventilation lag time is nearly enough to ventilate the space during a large gathering, and large gatherings of people rarely occur. It was decided to therefore increase the outdoor air rate to 35 L/s, moderately above the corridor rates, and rely on the mixing of the air between the two recreation areas to ensure adequate ventilation. Recirculation of the air inside the recreation areas will also assist in mixing the air on the main floor (where the rooms are effectively unoccupied) with the air on the second floor (where large gatherings may occur). Table A3.10 shows the proposed ventilation rates for the retrofit building. It also shows the ASHRAE recommended outdoor air requirements if each space was assumed to be a corridor. The recirculation rate was set to be equal to the rate of outdoor air.

Table A3.10: Reduced ventilation rates for recreation areas

		Base Rates		ASHRAE	Retrofit Rates	
Zone	**Area [m^2]**	**Outdoor Air [L/s]**	**Outdoor + Recirculated Air [L/s]**	**OA Required (Corridor) [L/s]**	**Outdoor Air [L/s]**	**Outdoor + Recirculated Air [L/s]**
M2/S - Sun Room	37.9	8.5	274	9.5	11.8	24
M/SE - Salon	11.4	2.5	112	2.9	3.5	7
M/SE - Storage/Kitchen	63.1	15.7	680	15.8	19.6	39
Main Floor Total	**112.4**	**26.7**	**1,066**	**28**	**35.0**	**70**
2/NE - Kitchen/Rec	124.8	16.0	424	31.2	22.9	46
2/SE - Rec Room	66.2	18.1	479	16.6	12.1	24
Second Floor Total	**191.0**	**34.1**	**903**	**48**	**35.0**	**70**

Recall that the minimum airflow rate was a 25.9% reduction in the amount of outdoor air delivered to the building. Table A3.11 provides a list of potential amounts to reduce the outdoor air rate, along with predicted energy savings and payback periods. The cost of reducing the outdoor air flow rate for the above ground floors was assumed to be $700 for air balancing services (based on invoices found for previous air balancing services) and $300 for additional services. The labour cost to reduce the amount of air being recirculated in the main and second floor lounge areas was assumed to be $500. The labour cost to stop the crawlspace system from providing outdoor air and recirculating air inside the crawlspace was assumed to be $500. Note that the annual savings of approximately $5,000 could be used to finance the remediation measures needed to keep moisture out of the crawlspace.

Table A3.11: Electrical savings from incremental reductions in ventilation rate

Retrofit	Electrical Savings [kWh/Yr]	Electrical Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Payback Period [Years]
Limiting CS ventilation to occupied/finished areas	3,921	0.4%	0.1%	$431	1.3
Reducing recirculation rate in main and second floor lounge areas	19,315	2.0%	0.7%	$2,125	0.3
3076 L/s - 7% reduction in above ground outdoor air flow	6,713	0.7%	0.2%	$738	1.5
2844 L/s - 14% reduction reduction in above ground outdoor air flow	13,839	1.4%	0.5%	$1,522	0.7
2622 L/s - 21% reduction in above ground outdoor air flow	20,504	2.1%	0.7%	$2,255	0.5
2622 L/s (21% reduction in above ground outdoor air flow), no ventilation in CS, and reduction in recirculation rate of lounge areas	43,746	2.5%	0.8%	$4,812	0.5

Ventilation Pressure Drop

A report published by Rumsey Engineering, in collaboration with Lawrence Berkeley National Laboratory, The U.S. Department of Energy, and the U.S. Environmental Protection Agency, states that reductions in pressure drop provide the most opportunities for significantly improving the efficiency of a laboratory ventilation system [17]. Reviewing their definition of a "laboratory" ventilation system showed that it is almost identical to the system used in KEP. The report also states that fan motor sizes can be reduced by 25-50% as a result of lowering the pressure drop in just the air handler alone. This section discusses savings in fan electrical consumption when the pressure drop in the ventilation systems are reduced. Pressure reductions are presented first, followed by the resulting energy and cost savings. Pressure data presented in this section are explained in greater detain in in Chapter 5, Section 2.

The total measured pressure drop across the supply fan was 888 Pa. The measured pressure drop from the supply air system to the central duct that supplies the corridors with ventilation air was 72.5 Pa. The measured pressure required to supply the corridors with ventilation air was 76 Pa. Also, there is a 96.1 Pa pressure drop before the air enters the system. Therefore, in total the pressure drop associated with the ducting accounts for approximately 244.6 Pa (27.5%) of the 888 Pa pressure rise across the fan. The remainder, 643 Pa, was associated with the air handling unit.

In an air balancing report written in March 1998, Centre West Air of Saskatoon stated that their balancing tests revealed "a considerable amount of leakage in the system." The report also states that at that time, in order to compensate for the significant air leakage, the central fan motors were adjusted to operate at their maximum amperage. It is apparent from this report and visual inspection of the ductwork inside the penthouse mechanical room that there is significant potential for air sealing measures.

One potential source of air sealing is the central supply air shaft that delivers air to the hallways. Sealing this shaft may require having an individual travel down the central supply shaft using a rope and harness. The 2003 building audit also found holes in the ductwork where it connected with the interior hallway wall. All holes and cracks in the supply air system could be sealed using duct caulking and duct tape. Pressure drop savings of 10%, 15%, and 20% would correspond to 7.6 Pa, 11.4 Pa, and 15.2 Pa, respectively.

The pressure losses associated with supply air ducts inside the 11th floor mechanical room were measured to be approximately 169 Pa, 19% of the total fan pressure drop. One potential reason for this large pressure drop is the use of six 90º corners in the ductwork from the outdoors to the building (Figure 7.6 in the main body of this thesis).

One possible way to reduce the pressure drop in the system would be to use curved elbows and to angle a single duct across the roof of the penthouse. Alternatively, the supply air system could be moved to the opposite side of the penthouse. Either of these methods should significantly reduce the duct pressure losses in the system. Moving the supply air handling unit to the other side of the penthouse would require a complete retrofit of the piping connections. It would also require creating a new opening in the roof and sealing the old opening. It is difficult to estimate the pressure drop savings that would result from changing the ductwork, but if it is assumed that a 25% savings would result from configuration #1, and a 50% savings from #2, the respective duct pressure loss savings would be 42.3 Pa and 84.5 Pa.

In a study published in the ASHRAE Journal, cleaning of conditioning coils was found to produce significant energy savings. Coil cleaning also increases indoor air quality as there is less potential for mold and bacteria to build up inside the coils. Cleaning of heating and cooling coils in the building studied resulted in a reduction in an average measured pressure drop of approximately 14% across a conditioning coil. It also increased the coil thermal efficiency with respect to its ability to transfer energy to the passing air. At the time of the study it had been approximately one year since the coil's last cleaning [18]. If 14% savings could be achieved by cleaning the coils regularly, in KEP this would result in an average savings of approximately 28.9 Pa per coil.

The report by Rumsey Engineering also discusses how traditional air handlers are designed based on a face velocity of 500 feet per minute (2.54 m/s) at the coil face. Based on the designed air flow rates and coil size, KEP also appears to have been designed for this same rule-of-thumb face velocity. The report continues by stating that this is an outdated guideline based on optimizing cost for an office building, and today it is not optimal for systems that operate 8760 hours per year. Selecting a system with a lower face velocity reduces the pressure drop across an air handling unit. This reduces the power required to move the air by the square of the velocity reduction. One possible concern with reducing face velocity is having room to fit the coils into the mechanical room. In KEP this is not a concern, however, as there is ample room for increasing the size of the coils.

The report states that a better air handler face velocity is 300 feet per minute (1.52 m/s) and the pressure drop across an air handler should optimally be 250 Pa. This is consistent with other values found in literature [19]. The pressure drop across the air handler in KEP, without a reclaim coil assumed to have a pressure drop of 206.5 Pa, was measured to be 436.5 Pa. If a larger air handling unit, with a pressure drop of 250 Pa, was installed, pressure savings would be 186.5 Pa. This is a 43% reduction in the air handler pressure drop. Lastly, the stated optimum pressure drop of 250 Pa includes year-round installation of air filters. In KEP, however, the filters do not need to be installed during the winter months. This was assumed to result in an additional savings of 15 Pa.

The Rumsey Engineering report also includes values for energy recovery devices. It states that an energy wheel should have a pressure drop of 87 Pa per air-stream. The energy wheel recommended for the final design of KEP, however, will have a very high effectiveness and likely a greater pressure drop. Other literature sources assume a 200 Pa pressure drop per air stream for air-to-air exchangers [19]. Therefore it was decided to assume the pressure drop associated with an energy recovery wheel is 200 Pa per air stream. If the current supply air reclaim coil was replaced with a large energy recovery wheel, savings of approximately 16.5 Pa would occur.

Table A3.12 presents potential pressure savings from retrofitting the central supply air handling unit and ductwork. If 20% savings were achieved in the central supply air shaft, 50% savings were achieved using alternative penthouse ducting, the AHU was replaced by a low face velocity unit with the filters removed in the winter, and an energy recovery wheel was used instead of the reclaim coils, the final reduction in pressure would be 357.9 Pa (40.3%). The final pressure rise across the supply air fan would then be 530.1 Pa.

Table A3.12: Summary of supply air fan pressure savings

Retrofit	Reduction in Required Fan Pressure [Pa]	Reduction in Required Fan Pressure [%]
Cleaning and sealing the central supply air shaft (10% savings)	7.6	0.9%
Cleaning and sealing the central supply air shaft (15% savings)	11.4	1.3%
Cleaning and sealing the central supply air shaft (20% savings)	15.2	1.7%
Alternative ducting in penthouse (25% savings)	42.3	4.8%
Alternative ducting in penthouse (50% savings)	84.5	9.5%
Thoroughly cleaning all 3 coils	86.7	9.8%
Replacing AHU with a low face velocity unit and removing air filters in winter	201.5	22.7%
Replacement of reclaim coil with an energy recovery wheel	56.5	6.4%

Table A3.13 provides measured results for the central exhaust air system. It shows that the fan pressure needed by this air handling unit was measured to be approximately 500 Pa.

Table A3.13: Central exhaust system pressures

	ΔP [Pa]
Pressure prior to filters (drawing from building)	-235.4
Across filters	-55.1
Across reclaim coil	-193.5
Prior to exiting building	16.4

The pressure drop associated with the ductwork connecting the washrooms to the air handling unit is 235.4 Pa. In the 2003 building audit report, SRC stated that at that time, all suite bathroom exhaust grilles needed cleaning. In fact, one of the 5 suites measured had zero exhaust flow from their bathroom as their grill was plugged solid with dust and dirt. The specified flow for the exhaust grills in the bathrooms is 35 L/s and of the 9 measurements taken in 2003 (5 suite measurements, 4 public washroom measurements), the highest measured flow rate was 29.5 L/s. The average of all the washroom flows measured was 15.7 L/s, 55% lower than specified. Unlike the central supply air shaft, the central exhaust air ducts are too small for a person to fit into. They can be cleaned, however, along with every exhaust air grill in tenants suites. The exhaust air ductwork within the penthouse can also be sealed. The combination of these two actions should significantly reduce the exhaust air duct pressure drop. It was not felt that significant savings could be achieved by re-designing the exhaust air ductwork.

The pressure drop associated with the exhaust air handling unit is 248.6 Pa. Based on the previously discussed assumptions regarding installing a unit with a lower face velocity, this could potentially be reduced to 220 Pa.

Table A3.14 presents potential savings from retrofitting the central exhaust air handling unit and ductwork. If 20% savings were achieved in the central supply air shaft, the AHU was replaced by a low face velocity unit, and an energy recovery wheel was used instead of the reclaim coils, the final reduction in pressure would be 101.6 Pa (20.3%). The final pressure of the exhaust air fan would then be 398.4 Pa.

Table A3.14: Summary of exhaust air fan pressure savings

Retrofit	Reduction in Required Fan Pressure [Pa]	Reduction in Required Fan Pressure [%]
Cleaning and sealing the central exhaust air ductwork (10% savings)	23.5	4.7%
Cleaning and sealing the central exhaust air ductwork (20% savings)	47.1	5.3%
Cleaning and sealing the central exhaust air ductwork (30% savings)	70.6	8.0%
Throughly cleaning reclaim coil	27.1	3.1%
Replacement of reclaim coil with an energy recovery wheel	68.5	7.7%
Replacing AHU with a low face velocity unit (20% savings in filter pressure drop)	11.0	1.2%

Tables A3.15 and A3.16 show the measured pressure drops in the main and second floor recirculation systems. Total fan pressure drop in the main floor system is 186.4 Pa. Total fan pressure drop across the second floor system is 425.2 Pa.

Table A3.15: Main floor recirculation system pressures

	ΔP [Pa]
Across filters	-58.6
Across heating and cooling coils	-130.7
Pressure to deliver air to space	55.7

Table A3.16: Second floor recirculation system pressures

	ΔP [Pa]
Before air filters	-54.9
Across filters	-70.3
Across heating and cooling coils	-372.4
Pressure to deliver air to space	52.8

Extensive retrofits to these systems is likely not warranted. The most reasonable action to take is to extensively clean the coils. If a 14% savings due to coil cleaning was assumed for each heating and cooling coil, that would result in a 28% savings per system (each system has both a heating and cooling coil). This could also be combined with duct sealing where necessary. The resulting savings in pressure for the main floor system would be 36.6 Pa. The resulting savings in pressure for the second floor system would be 104.3 Pa. The final pressure for the two systems would be 149.8 Pa and 320.9 Pa for the main and second floor systems, respectively.

Table A3.17 presents a summary of potential electrical savings that could occur from retrofitting the air handling units and ductwork.

Table A3.17: Potential electrical savings from retrofitting air handling units and ducting

Retrofit	Pressure [Pa]	Total Electrical Savings [kWh/Yr]	Total Electrical Savings [%]	Total Building Energy Savings [%]
10% savings in central supply air handler	799	7,121	0.7%	0.2%
10% savings in central exhaust air handler	450	2,853	0.3%	0.1%
10% savings in main and second floor air handlers	168	1,988	0.2%	0.1%
10% savings in all air handling units	-	11,962	1.2%	0.4%
25% savings in central supply air handler	666	17801	1.8%	0.6%
25% savings in central exhaust air handler	375	7,138	0.7%	0.2%
25% savings in main and second floor air handlers	140	5,110	0.5%	0.2%
25% savings in all air handling units	-	30045	3.1%	1.0%
50% savings in central supply air handler	444	35393	3.7%	1.2%
50% savings in central exhaust air handler	250	14414	1.5%	0.5%
50% savings in main and second floor air handlers	93	10053	1.0%	0.3%
50% savings in all air handling units	-	59860	6.2%	2.0%

Replacement of Ventilation Fans and Motors

The base building continuously delivers 3,307 L/s of outdoor air to the hallways for ventilation. The electricity required to move this amount of air in the base computer model is 122,778 kWh/Year (4.1% of the building's total annual energy consumption). This section discusses the replacement of the current ventilation fans and motors with high efficiency models.

All of the ventilation fans in the building are forward curved centrifugal fans. Forward-curved impeller fans are typically compact but not efficient [20, 21]. Their impeller blades are also prone to filling with dirt over time. Air filters reduce dirt build-up, but fans that are not regularly inspected and cleaned can suffer losses in efficiency [20].

The highest-efficiency centrifugal fans that are commercially available use backward-curved impeller blades, often called airfoil blades. These fans can reach efficiencies as high as 80% [22]. Table A3.18 shows the efficiencies of the fans in the base computer model. As the table shows, typically smaller fans are less efficient than larger fans. Therefore it was assumed that the efficiency of the fans could be increased to 75% for the two smaller systems and 80% for the central system. The crawlspace system is not included in this table as it was assumed that the existing system could be disconnected and the crawlspace would be ventilated only by the central system.

Table A3.18: Base and retrofit fan efficiency

Fan	Rated Power [kW]	Base Efficiency [%]	Premium Efficiency [%]
Primary supply fan	5.80	43.3	80
Primary exhaust fan	3.90	58.4	80
Main floor recirculation fan	0.51	32.6	75
Second floor recirculation fan	1.30	39.0	75

The National Electrical Manufacturers Association (NEMA) in the United States provides minimum efficiency standards for “premium” motors, based upon their size. If the motors currently in the building were replaced by NEMA premium motors of the same size their efficiency's would increase by the amounts shown in Table A3.19 [23, 9]. Table 3.19 also shows the estimated cost of the premium motors [10].

Table A3.19: Fan motors

Motor	Rated Power [kW]	Base Efficiency [%]	Premium Efficiency [%]	Premium Efficiency [$]
Primary supply fan	7.46	84.0	91.7	$1,616
Primary exhaust fan	5.59	83.0	90.2	$1,100
Main floor recirculation fan	0.56	71.0	85.5	$450
Second floor recirculation fan	1.49	76.0	86.5	$550

The resulting combined efficiency of the replacement fans and motors can be seen in Table A3.20. The paper published by Rumsey Engineers [17] states that combined efficiencies up to approximately 72% are attainable.

Table A3.20: Combined efficiency

	Base Combined Efficiency [%]	Replace Motors [%]	Replace Fans [%]	Replace Both Motors and Fans [%]
Primary supply fan	36.4	39.7	67.2	73.4
Primary exhaust fan	48.5	52.7	66.4	72.2
Main floor recirculation fan	23.2	27.9	53.3	64.1
Second floor recirculation fan	29.6	33.7	57.0	64.9

Table A3.21 shows the savings along with payback periods for 3 potential retrofit options. Fan cost estimate is based on RSMeans data for an airfoil fan.

Table A3.21: Potential savings and payback periods from replacing fan motors and fans

Retrofit	Total Electrical Savings [kWh/Yr]	Total Electrical Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Payback Period [Yrs]
Replacement of fans	43,518	4.5%	1.5%	$4,787	0.9
Replacement of motors	11,818	1.2%	0.4%	$1,300	2.9
Replacement of fans and motors	55,336	5.7%	1.9%	$6,087	1.1

Scaling Back Ventilation During the Evening

Chapter 3, Section 3, provided measurements of CO_2 concentrations in the building. It showed that CO_2 concentrations would fall in the evening and this was assumed to be due to lower metabolic rates of the tenants as they slept. This presents an opportunity to save energy by lowering the ventilation rate during the evening. Table A3.22 shows the resulting electrical savings if the ventilation rate is reduced by specific percentages between the hours of 12pm and 6am. It assumes a $1,000 control system was installed.

Table A3.22: Savings from night reduction in ventilation rates

Retrofit	Electrical Savings [kWh/Yr]	Electrical Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Payback Period [Years]
Reduce night ventilation by 16.7%	5,253	0.5%	0.2%	$578	1.7
Reduce night ventilation by 33.3%	10,501	1.1%	0.4%	$1,155	0.9
Reduce night ventilation by 50.0%	15,743	1.6%	0.5%	$1,732	0.6

Reducing Suite Receptacle Load

From monitored electrical use the total electrical load per suite was found to be approximately 3,000 kWh/Year. After removing the estimated consumption of the lights, the receptacle load applied to each suites in the base model was 1,621 kWh/Year. This load could also include lamps and other lighting plugged into the wall. The total base suite receptacle load is 188,042 kWh/Year (6.4% of the building's total energy consumption).

The one load known to be present in all suites is a refrigerator. In August 2005 three refrigerator's in KEP were monitored by the author over a 1 month period in order to determine their average electrical consumption. It was found that on average each fridge (11 ft^3 total volume) would consume 517 kWh/Year. New EnerGuide fridges of slightly greater volume than the ones present in the building are available that consume 311 kWh/Year. Replacing the refrigerators would therefore result in a savings of 206 kWh/Year/Suite. Refrigerators are also an appliance whose energy consumption tenants have little control over.

A second appliance known to be present in all of the suites is an electric oven with four cook-top elements. The use of the ovens are not known, however, as seniors may prefer to use smaller cooking appliances such as microwaves and slow cookers. Two other appliances that typically consume a large amount of energy are the washing machine and drier. These two appliances are building loads rather than suite loads and dealt with in another section of this chapter. The remaining non-fridge suite electrical load is 1,104 kWh/Year.

In addition to replacing the refrigerators, each suite could also have an energy monitoring device installed. Charging tenants based on the electricity they consume has been shown to result in significant savings. A new fridge costs approximately $500 [24] and residential electrical monitoring devices typically cost approximately $150 [1]. An additional $100 per monitoring device was assumed for labour and wiring. Table 3.23 shows 8 potential retrofit options for reducing suite receptacle consumption.

Table A3.23: Suite receptacle retrofit options

Retrofit	Electrical Savings (per Suite) [kWh/Yr]	Total Electrical Savings [kWh/Yr]	Total Electrical Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Payback Period [Yrs]
10% savings in total suite electrical consumption through the use of a monitoring device	162	18,804	2.0%	0.6%	$2,068	14.0
15% savings in total suite electrical consumption through the use of a monitoring device	243	28,205	2.9%	1.0%	$3,103	9.3
20% savings in total suite electrical consumption through the use of a monitoring device	324	37,607	3.9%	1.3%	$4,137	7.0
Replacement of refrigerators	206	23,896	2.5%	0.8%	$2,629	22.1
Replacement of refrigerators & a 10% savings in the remaining suite electrical consumption through the use of a monitoring device	316	36,702	3.8%	1.2%	$4,037	21.5
Replacement of refrigerators & a 15% savings in the remaining suite electrical consumption through the use of a monitoring device	372	43,106	4.5%	1.5%	$4,742	18.3
Replacement of refrigerators & a 20% savings in the remaining suite electrical consumption through the use of a monitoring device	427	49,509	5.1%	1.7%	$5,446	16.0
Replacement of refrigerators & a 25% savings in the remaining suite electrical consumption through the use of a monitoring device	482	55,912	5.8%	1.9%	$6,150	14.1

Window Mounted Air Conditioners

Based on measurements in the building and monitored suite electrical data, the window mounted air conditioners were estimated to consume 12,647 kWh/Year (0.4% of the building's total energy consumption). Ideally these units would not be necessary in the suites and instead a high efficiency central unit, with the assistance of an energy recovery wheel, would provide all of the necessary cooling for the building. Removing these devices would reduce the building's electrical consumption by 12,647 kWh/Yr, 1.3% of the total electrical consumption and 0.4% of the building's total energy consumption. The resulting reduction in annual utilities would be $1,265. This would have an immediate payback period for the tenants. It may be difficult, however, to maintain an acceptable temperature in the suites without the use of window mounted units.

Incandescent Bulbs (60W, 100W, and 120 W)

The base building contains 422 incandescent bulbs, 409 of which were 60 W, and the remainder were 100 W and 120 W. Approximately 40% of the bulbs were metered by the building meter and the remainder were located in the tenants' suites. It was estimated in the base model that these lights consumed 212,012 kWh/Year, or 7.2% of the building's total annual energy consumption.

Each of these incandescent bulbs can be replaced by compact fluorescent lamps (CFL) that consume less energy but output approximately the same amount of light. The most common replacements for a 60 W incandescent bulb consume 14-19 W [25]. The 100 W and 120 W bulbs in KEP could also be replaced by 14-19 W CFL's as it is felt that the locations in which these bulbs are in use do not require high output bulbs.

In addition to replacing the incandescent bulbs with compact fluorescents, bulbs can be removed from fixtures in several areas that are felt to be over lit in the building. The main floor the recreation area is rarely used and when it is, it is typically only used in the daytime when there is an abundance of light entering the space from the windows. Yet this area contains 13 incandescent fixtures and 10 fluorescent T12 fixtures. The fluorescent lights provide adequate lighting for the room and the incandescent bulbs illuminate only a small area below the second floor balcony. This area is used only for walking into the games room and felt to be over-lit. Therefore 7 incandescent bulbs could be removed.

The second floor recreation area in the base building is lit with 16 incandescent bulbs and during the 2003 building audit SRC measured the lighting level to be over 600 lux. The minimum acceptable lighting level for the building was assumed to be 500 lux, based upon the recommendations of Saskatchewan Occupational Health and Safety [26]. They also stated that lighting can be reduced to 300 lux in laundry rooms and 150 lux in hallways and stairwells. This recreation area also has an over-lit section that is used essentially as a corridor or walkway. Therefore 8 of the 16 bulbs could be removed from this area.

There are also 28 exit signs in KEP and 22 fire alarm indicator lights which show the locations on each floor where a fire alarm can be pulled. Each exit sign contains two 15 W incandescent bulbs and each fire alarm indicator contains a single 8 W bulb. While these are small bulbs, they are lit 24 hrs/day and together consume approximately 8,900 kWh/Yr. The incandescent bulbs in these fixtures can be replaced with light emitting diodes (LED) that consume 2 W per bulb [27]. The bulbs could also just be removed from the fire alarm indicators as the fire code does not require them to be lit.

The cost of 1 CFL bulb is approximately $3 [28]. The 2003 building audit report by SRC estimated that the cost, including labour, to replace an exit sign was $60. If it is assumed that the cost, including labour, of replacing a fire alarm indicator was half this, the cost would be $30 per fixture. Table 3.24 shows the proposed retrofit options for reducing the electrical consumption of incandescent fixtures.

Table A3.24: Proposed retrofits of incandescent fixtures

Retrofit	Total Electrical Savings [kWh/Yr]	Total Electrical Savings [%]	Total Building Energy Savings [%]	Savings [$/Yr]	Payback Period [Yrs]
Replacement of all 60W, 100W, and 120W incandescent bulbs with CFL's	163,133	16.9%	5.5%	$17,945	0.1
Delamping overlit areas	1,924	0.2%	0.1%	$212	0.5
Replacing exit signs	6,377	0.7%	0.2%	$702	0.4
Replacing fire alarm indicators	1,156	0.1%	0.04%	$127	0.2
Removing fire alarm indicators	1,542	0.2%	0.1%	$170	0.2
Replacement of all incandescent bulbs with CFL or LED bulbs	173,274	18.0%	5.9%	$19,060	0.2

Fluorescent Fixtures

There are 412 fluorescent fixtures and 570 individual bulbs in the base computer model, 96 of which operate 24 hours/day. The fluorescent bulbs in the base model consume 132,237 kWh/Year (4.5% of the building's total energy consumption). In the 2003 BEM audit SRC measured the lighting levels in several rooms throughout the building and these values were used to help justify several of the retrofits proposed. The following describes each of the retrofits applied to the building and Table 3.26 at the end of this section provides a summary of the changes made.

The first retrofit presented is de-lamping over-lit areas. The main floor entranceway area was observed to be over lit in KEP. Measurements were not taken of the lighting levels in these areas but during a lighting retrofit the building manager removed over 50% of the original fixtures installed in the main floor entranceway and it was found that the lighting level in this area was still greater than necessary. Thus in the retrofit building 23 bulbs could be removed from the main entranceway (60% of the installed bulbs). The lighting level in the laundry rooms needs to only be 300 lux and SRC measured it to be 1035 lux during the 2003 building audit. Therefore the number of fixtures in the main floor laundry room could be reduced from 5 to 2 and the number of fixtures in the second floor laundry room could be reduced from 8 to 3. Table 3.24 shows the savings that would result from these retrofits.

Table 3.24: Savings from removing unnecessary fluorescent fixtures

Retrofit	Total Electrical Savings [kWh/Yr]	Total Electrical Savings [%]	Total Building Energy Savings [%]	Payback Period [Yrs]
Removing uncessary bulbs from overlit areas	8,897	0.9%	0.3%	0.0

Further de-lamping could be achieved in the building by retrofitting two-lamp fixtures to single lamp fixtures with a silver reflector. In this retrofit, a single bulb is placed in the middle of a fixture and a silver reflector is installed above it. The reflector directs light down towards the area in need of illumination, and the resulting loss of illumination from the retrofit is typically only 15-25% when a T12 lamp is replaced with T8 lamps [29]. A T-8 lamp produces an average of 28% more lumens per watt than a T-12 fixture. In the retrofit building all two lamp fixtures could be reduced to single lamp fixtures with a reflector [30]. Bulb lengths would remained the same when performing this retrofit. An exception to this is the stairwell fixtures which will be discussed at the end of this section.

A typical fixture in the building would be a 4 ft T12 bulb powered by a magnetic ballast. In addition to de-lamping several fluorescent fixtures, all T12 fixtures in the building could be replaced with T8 bulbs powered by an electric ballast. Electronic ballasts increase the frequency of the electricity entering the fluorescent bulbs to between 25,000 and 40,000 Hz, as opposed to 60 Hz from a magnetic ballast [29]. This improves the efficiency of the fixture. Therefore all 4 ft single lamp T-12 fixtures could be replaced with 3 ft single lamp T-8 fixtures and all 3 ft single lamp T-12 fixtures could be replaced with 2 ft single lamp T-8 fixtures.

The final potential retrofit of the fluorescent fixtures occurs in the stairwells. Each stairwell floor contains two, 2 lamp T12 fixtures, and thus there are over 48 bulbs continuously lighting stairwells that are rarely used by the tenants. The lighting levels in the stairwells are only required to be 150 lux and SRC measured the average stairwell lighting level to be 340 lux. The two fixtures located at each floor could therefore be reduced to two fixtures that each contain a single 3 ft T-8 bulb and a silver reflector.

Table 3.25 provides a summary of potential retrofits to the fixtures in KEP. The cells that are high-lit grey indicate that they are two alternative retrofits for the same fixture. Table 3.26 shows potential savings from the retrofits listed in Table 3.25. They include de-lamping that would occur from reducing the number of bulbs in a fixture from 2 to 1, but do not include the de-lamping savings listed in Table 3.24.

Table A3.25: Summary of potential retrofits applied to fluorescent light fixtures

Location	Original Fixture	Original Wattage [W]	Retrofit Fixture	Retrofit Wattage [W]	#	Retrofit Cost [$/Fixture]	Payback [Years]
Suites	T12, 4 ft, 1 Lamp	47	T8, 3 ft, 1 Lamp	23	200	$28.14	0.82
Suites	T12, 2 ft, 1 Lamp	30	T8, 2 ft, 1 Lamp	15	59	$27.39	0.53
Throughout building	T12, 4 ft, 2 Lamp	81	T8, 3 ft, 2 Lamps	46	58	$31.64	1.07
Throughout building	T12, 4 ft, 2 Lamp	81	T8, 4 ft, 1 Lamp, with silver reflector	28	58	$44.59	1.15
Throughout building	T12, 4 ft, 1 Lamp	47	T8, 3 ft, 1 Lamp	23	4	$28.14	0.82
Throughout building	T12, 3 ft, 1 Lamp	40	T8, 2 ft, 1 Lamp	15	6	$27.39	0.88
Throughout building	T12, 2 ft, 1 Lamp	30	T8, 2 ft, 1 Lamp	15	59	$27.39	0.53
Stairwells	T12, 4 ft, 2 Lamp	81	T8, 3 ft, 1 Lamp	23	46	$28.14	1.99
Stairwells	T12, 4 ft, 2 Lamp	81	T8, 2 ft, 1 Lamp, with silver reflector	15	46	$43.59	1.46

Table A3.26: Savings and payback periods for fluorescent fixture retrofits

Original Fixture	Retrofit Fixture	Total Electrical Savings [kWh/Yr]	Total Electrical Savings [%]	Total Building Energy Savings [%]
T12, 4 ft, 1 Lamp	T8, 3 ft, 1 Lamp	29,567	3.1%	1.0%
T12, 2 ft, 1 Lamp	T8, 2 ft, 1 Lamp	6,006	0.6%	0.2%
T12, 4 ft, 2 Lamp	T8, 3 ft, 2 Lamps	6,767	0.7%	0.2%
T12, 4 ft, 2 Lamp	T8, 4 ft, 1 Lamp, with silver reflector	10,236	1.1%	0.3%
T12, 3 ft, 1 Lamp	T8, 2 ft, 1 Lamp	981	0.1%	0.0%
T12, 4 ft, 2 Lamp (stairwells)	T8, 3 ft, 1 Lamp	22,003	2.3%	0.7%
T12, 4 ft, 2 Lamp (stairwells)	T8, 2 ft, 1 Lamp, with silver reflector	27,335	2.8%	0.9%
T8, 4 ft, 2 Lamp	T8, 4 ft, 1 Lamp, with silver reflector	5,543	0.6%	0.2%
-	All fixtures above - Without silver reflectors	65,324	6.5%	2.1%
-	All fixtures above - With silver reflectors	79,668	7.1%	2.3%

Payback period is presented in Table 3.26 in order to show the fixture comparison when they are running the same number of hours. Payback period was based on the bulbs operating 8760 hours per year. Cost estimates include the cost to purchase the bulbs, ballasts, reflectors, and shunts. A labour rate of $12/fixture was assumed.

If the de-lamping listed in Table 3.24 and all of the retrofits listed in Table 3.25, not including silver reflectors, was performed, the total savings would be 72,930 kWh/Yr, 7.6% of the electrical consumption and 2.5% of the building's total energy consumption. The annual utility cost reduction would be $7,293. If the de-lamping listed in Table 3.24 and all of the retrofits listed in Table 3.25, including silver reflectors, was preformed, the total savings would be 81,101 kWh/Yr, 8.4% of the electrical consumption and 2.7% of the building's total energy consumption. The annual utility fee reduction would be $8,110.

Interior Lighting Controls

In the base building, all of the hallway, entranceway, elevator, and stairwell lights remain continuously lit throughout the day and the year. In total, the 24 hr continuous lighting of these fixtures consumed 170,549 kWh/Year in the base building (5.8 % of the building's total annual energy consumption). These fixtures contain a mixture of fluorescent and incandescent bulbs. Significant savings in the retrofit could be achieved through the introduction of occupancy sensors and other lighting controls.

The computer model allows the user to choose from several lighting control methods for each fixture in the building. Two of the options available are occupancy sensors and daylight sensors. Many rooms in KEP are lit continuously or during hours when lighting is not necessary. For example, the main entranceway and the lounge areas are very well lit by their windows, yet their lights remain on during the day. One method of reducing the electrical consumption of these fixtures would be to install daylight and occupancy controls.

The potential also exists to reduce suite lighting loads through monitoring and charging tenants based upon their actual consumption. Suite lighting controls could also be achieved using a card system. These methods are typically used in hotels. Guests must insert a card when entering their suite and when they exit they must remove their card, which is their key to their room. Therefore lights are always turned off when the guest has left the room.

Table 3.27 lists potential retrofit options along with their savings and payback periods. The “Building occupancy sensors” retrofit uses occupancy controls in the following rooms: stairwells, laundry rooms, janitorial storage, garbage collection, building manager's office, second floor storage, public washrooms, penthouse/mechanical rooms, and crawlspace.

Table A3.27: Potential retrofits to lighting controls

Retrofit	Total Electrical Savings [kWh/Yr]	Total Electrical Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Payback Period [Yrs]
10% savings in suite lighting	15,443	1.6%	0.5%	$1,699	17.1
15% savings in suite lighting	23,164	2.4%	0.8%	$2,548	11.4
20% savings in suite lighting	30,885	3.2%	1.0%	$3,397	8.5
Hallway occupancy sensors	31,070	3.2%	1.0%	$3,418	0.3
Building occupancy sensors	14,742	1.5%	0.5%	$1,622	1.3
Daylight sensors in recreation areas and main foyer	5,548	0.6%	0.2%	$610	0.4

The suite electrical monitoring device was assumed to cost $150 plus $100 for labour and wiring. The “Daylight sensors in recreation areas and main foyer” option uses daylight sensors with multiple step dimming in the following rooms: main floor entranceway and foyer, main floor recreation area, and second floor recreation area. The total cost of a daylight photo sensor is approximately $15 [31, 32] and it was assumed that 6 would be needed and the labour associated with their installation would be $150. The total cost of an occupancy sensor is $80 [32] and it was assumed that 36 would be needed and the labour cost associated with their installation would be $360.

Exterior Lighting

The exterior light fixtures in KEP are already high efficiency and controlled by a photo-electric timer. No retrofits were recommended during the 2003 building audit by SRC and in the time since the audit no new lighting technologies have become available. Therefore no changes will be recommended for the exterior lights.

Power Factor Correction

Typically, if a customer exceeds a certain electrical demand from the power supplier, a demand charge will be applied. In Saskatchewan demand charges are applied above 50 kilovolt-amps. In any given month, if the peak electrical demand from a building exceeds this amount, the customer will pay a demand charge. In 2003, the demand charges for KEP were $10,243.

Power factor is the ratio between the actual load power (kW) and apparent load power (kVA). It is a measure of how effectively current is being converted into useful work. Real power is capable of doing work and apparent power determines, for a given load voltage, the amount of current that flows into the load [33]. Power factor correction is most commonly the addition of capacitors to electrical loads in order to reduce the electrical current drawn from the electrical power system [34]. In larger buildings, power factor correction is needed due to the presence of induction motors and magnetic lamp ballasts. The addition of capacitors in the system reduces the inductive component of the current, resulting in a reduction in supply losses [35].

In the 2003 building audit SRC estimated that the cost to install the power factor equipment would be $1,500 and the annual savings would be approximately $3,400. This is a payback period of approximately 0.4 years. This retrofit does not result in energy savings, but the financial savings are desirable and could be used to finance other retrofits.

A3.2 NATURAL GAS RETROFITS

The following is a discussion of proposed retrofits to systems in KEP that consume natural gas. In a similar manner as the previous chapter, savings from each retrofit are shown at the end of each section and the savings presented are for that retrofit alone. The majority of the cost estimates in this section were determined from RSMeans 2002 Building Construction Data [36]. Cost estimates were scaled using a location factor for Saskatoon and include materials, labour, overhead, and profit. To account for potential increases in prices from 2002 to present and unforeseen additional costs estimates in this section were also increased by 10%.

Addition of Insulation to the Exterior Walls

This section investigates the addition of polyurethane insulation to either the interior or exterior surface of the building's exterior walls. In order to increase the thermal resistance of the exterior walls insulation can be added to either the interior or exterior wall surfaces. The total non-window interior wall area is 3,185 m^2. A steady state thermal resistance circuit was used to analyze the addition of insulation to the interior surface of the exterior walls. When insulation is added to the interior surface, the concrete floor continues to be a direct thermal bridge to the outdoors.

Table A3.28 shows the resulting energy savings and associated costs for progressively adding 1 inch of polyurethane insulation to the entire interior surface of the building. It also includes the addition of 12.7 mm of gypsum. The polyurethane chosen has a thermal resistance of 0.0512 RSI/mm (R 7.4/Inch) [36]. Polyurethane was primarily chosen as it has a high R value per inch. This is important because the average suite size is already relatively small and it was desirable to maximize the tenants usable floor area. Polyurethane can also be applied as large uniform panels or sprayed on a wall. When installed properly, it can also act as an air barrier, reducing the potential for infiltration. Table 3.28 also shows the estimated cost and payback period associated with this retrofit. The cost of 25.4 mm (1 inch) of rigid polyurethane was assumed to be $9.89/m^2 ($0.92/ft^2) [36]. The cost of the interior finish was assumed to be $12.52/m^2 ($1.16/ft^2) [36] for taped, finished fire resistant gypsum, and $6.89/m^2 ($0.64/ft^2) [36] for a smooth, 2 coat, brushed paint finish.

Table A3.28: Savings and payback period when adding insulation to interior surface

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
1.38	134,549	6.6%	4.5%	$4,036	22.0
2.68	188,738	9.2%	6.4%	$5,662	21.4
3.98	219,179	10.7%	7.4%	$6,575	23.3
5.29	238,714	11.7%	8.1%	$7,161	25.9
6.59	251,908	12.3%	8.5%	$7,557	28.9

The payback periods shown in Table 3.28 do not account for the presence of the wall mounted baseboard heaters. An alternative to moving the baseboard heaters would be to insulate the wall above them and install a radiant barrier between the fin elements and the wall. This can be seen in Figure 7.16 in the main body.

Table 3.29 shows the estimated cost and payback period associated with this retrofit. It was calculated that approximately 750 m^2 of aluminum foil (with a reinforced scrim) would be needed and the cost would be $4.1/m^2 ($0.38/ft^2) [36]. For the 25.4 mm & 50.8 mm retrofits this cost was doubled to account for the additional labour needed to install the foil inside the enclosure. For the remaining insulation thicknesses the cost was tripled in order to account for mounting the enclosure further from the wall. Table 3.29 shows that the optimal additional thermal resistance, according to payback period, occurs when 51 mm (RSI 2.68) of insulation is added.

Table 3.29: Savings and payback period when adding insulation above baseboards

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
1.38	117,245	5.7%	4.0%	$3,517	24.1
2.68	164,236	8.0%	5.5%	$4,927	23.0
3.98	190,646	9.3%	6.4%	$5,719	25.4
5.29	207,552	10.2%	7.0%	$6,227	27.9
6.59	219,179	10.7%	7.4%	$6,575	30.8

Insulation could also be added to the exterior surface of the exterior walls. The total non-window exterior wall area is 3,446 m^2. Three benefits of adding insulation to the exterior wall are: the work does not need to disturb the tenants suites, tenants do not loose floor area in their suites, and insulation would cover the areas where thermal bridging occurs through the concrete floors. Table 3.30 shows the resulting energy savings and associated costs of progressively adding 1 inch of polyurethane insulation to the exterior surface of the building. It does not include the cost of an exterior surface and payback periods are only for the cost of the insulation.

Table 3.30: Energy savings associated with adding insulation to exterior surface

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
1.30	150,363	7.4%	5.1%	$4,511	7.7
2.61	211,851	10.4%	7.2%	$6,356	11.0
3.91	245,509	12.0%	8.3%	$7,365	14.2
5.21	266,806	13.1%	9.0%	$8,004	17.5
6.52	281,495	13.8%	9.5%	$8,445	20.7

It is likely that if the building owners were to perform an exterior wall retrofit they would want to continue to have an exterior surface of the same quality as the existing brick. One alternative method to achieve a brick finish is to use a Regina made product called Panbrick. This product has a 12.7 mm brick exterior surface mounted to a 41.3 mm R12 polyurethane panel with 9.5 mm plywood backing. The total thermal resistance of a PanBrick panel is quoted to be R13 (RSI 2.3).

Table 3.31 shows the estimated cost and payback period associated with the use of polyurethane insulation and a PanBrick finish. The cost to purchase a PanBrick panel is $\$93.90/m^2$ ($\$8.45/ft^2$) [37]. Based on the cost to install bricks on an exterior wall, the cost to install the panels on the exterior wall was estimated to be $\$44.40/m^2$ ($\$4.00/ft^2$) [36].

Table 3.31: Energy savings associated with adding PanBrick and additional polyurethane insulation to the exterior surface

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
2.29	200,486	9.8%	6.8%	$6,015	76.8
3.59	238,797	11.7%	8.1%	$7,164	69.3
4.90	262,379	12.8%	8.9%	$7,871	67.6
6.20	278,358	13.6%	9.4%	$8,351	67.9

Payback periods for the interior and exterior insulation retrofits are rough estimates. They do show, however, that if it is desired to keep the same quality of exterior finish it will cost approximately 3 times more to add insulation to the exterior surface as opposed to the interior surface. The cost would be even greater if brick was used as the exterior surface rather than the PanBrick product. In addition to high cost, a second drawback to using the PanBrick product is that it has not been approved for installations greater than 3 story's. Using it along the entire vertical surface of the building would require additional investigation and approval from a structural engineer. A final factor to consider regarding the addition of insulation is that if solar panels of some kind were added to the South wall there would not be a need to add an expensive exterior surface such as brick. This would make insulating the exterior surface of the South wall much more affordable.

Addition of Insulation to the Roofs

This section investigates the addition polyurethane insulation to either the interior or exterior surface of the building's roofs. When insulation was installed on the interior surface, the finish was painted gypsum. When added to the exterior, the finish was non-galvanized painted steel decking. Insulation was added 1" at a time and there was no need to account for thermal bridging. The total surface area of the flat roof section is 329 m^2, the total area of the sloped metal roofs is 724 m^2. Table presents the savings for adding insulation to the interior surface of the flat penthouse roof. The cost of the insulation and interior finish was assumed to be the same as the values used for the interior wall retrofit.

Table 3.32: Savings and payback period for adding polyurethane insulation to the interior surface of the flat penthouse roof

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
1.38	1,428	0.1%	0.0%	$43	49.4
2.68	2,121	0.1%	0.1%	$64	45.3
3.98	2,721	0.1%	0.1%	$82	44.8
5.29	3,050	0.1%	0.1%	$91	48.3
6.59	3,382	0.2%	0.1%	$101	51.1

Tables 3.33 and 3.34 present the savings for adding insulation to the interior and exterior surfaces of the sloped roofs in the main floor suites, 10th floor suites, and main floor recreation areas. The cost of the steel deck roofing was assumed to be $40/m² ($3.72/ft²) [36]. While the payback periods of adding insulation to the exterior of the sloped metal roofs appear to be undesirable, a retrofit to the exterior surface of these roofs may already be necessary because of the significant moisture penetration these roof areas sometimes experience.

Table 3.33: Savings and payback period for adding insulation to the exterior of the sloped metal suite roofs

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
1.38	18,514	0.9%	0.6%	$555	55.5
2.68	26,182	1.3%	0.9%	$785	47.2
3.98	30,805	1.5%	1.0%	$924	46.8
5.29	33,778	1.7%	1.1%	$1,013	48.8
6.59	35,891	1.8%	1.2%	$1,077	51.8

Table 3.34: Savings and payback period for adding insulation to the interior of the sloped metal suite roofs

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
1.38	18,514	0.9%	0.6%	$555	30.9
2.68	26,182	1.3%	0.9%	$785	29.8
3.98	30,805	1.5%	1.0%	$924	32.1
5.29	33,778	1.7%	1.1%	$1,013	35.4
6.59	35,891	1.8%	1.2%	$1,077	39.1

Addition of Insulation to the Crawlspace Walls

Two approaches to insulating the crawlspace were investigated. The first was insulating the interior surface of the entire exterior wall of the crawlspace and the second was insulating only the walls around the finished mechanical and storage rooms. When insulation was added to the entire exterior wall area the crawlspace in the computer model was still being ventilated and heated. The total wall area of the exterior walls in the crawlspace is 265 m^2. When insulation was added to the exterior walls of the mechanical and storage rooms the unoccupied/unfinished areas of the crawlspace were not being ventilated or heated. The total exterior wall area of the mechanical/storage rooms in the crawlspace is 91 m^2.

Table 3.35 shows the results from progressively adding layers of R5 insulation to the interior surface of the exterior foundation walls.

Table 3.35 Crawlspace insulation and savings – heated crawlspace

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
0.88	20,683	1.0%	0.7%	$621	3.0
1.76	24,824	1.2%	0.8%	$745	4.9
2.64	26,669	1.3%	0.9%	$800	6.9
3.52	28,028	1.4%	0.9%	$841	8.7

Table 3.36 shows the results of adding layers of R5 insulation to the exterior walls of the mechanical/storage rooms in the crawlspace. Values of R5-R20 were the only available options in the computer model for underground walls.

Table 3.36 Crawlspace insulation and savings – only mechanical & storage rooms in the crawlspace are heated

Additional Thermal Resistance [RSI]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Natural Gas Savings [$/Yr]	Payback Period [Years]
0.88	4,665	0.2%	0.2%	$140	4.5
1.76	5,837	0.3%	0.2%	$175	7.2
2.64	6,490	0.3%	0.2%	$195	9.7
3.52	6,845	0.3%	0.2%	$205	12.3

Window Replacement

This section presents savings that would result from replacement of the windows in KEP. The thermal performance of the proposed windows was found using the built in library in the Hot2000 program. The one exception is the Thermotech windows which were found using manufacturers data [43]. The windows in Table3.37 created using Hot2000 assumed insulating spacers, fiberglass frames, 13mm of Argon gas, and sliders with sash for operable windows.

Table 3.37: Window types and their properties

		Small (2.4 m^2 - 1.2 x 2)				Large (3.2m^2 - 1.6 x 2)			
		Operable		Fixed		Operable		Fixed	
		RSI	SHGC	RSI	SHGC	RSI	SHGC	RSI	SHGC
1	Triple, Clear	0.61	0.52	0.60	0.60	0.54	0.60	0.60	0.61
2	Triple, 1 Layer of Low-e 0.04	0.85	0.36	0.90	0.41	0.87	0.37	0.91	0.42
3	ThermoTech ER 15	0.97	0.47	1.03	0.54	1.00	0.53	1.05	0.55
4	Triple, 2 Layers of Low-e 0.04	1.05	0.22	1.17	0.25	1.08	0.23	1.20	0.25

Table 3.38 presents 5 options for replacing the windows in KEP. Option 5 indicates that the ThermoTech windows were used on the South side of the building and triple pane windows with two low-e coatings were placed on the East, West, and North side of the building.

Table 3.38: Window retrofit options

Window Type	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Cost [$/m2]	Payback Period [Years]
Triple, Clear	141,123	6.9%	4.8%	$4,234	380	54.6
Triple, 1 Layer of Low-e 0.04	186,352	9.1%	6.3%	$5,591	420	45.7
ThermoTech ER 15	214,178	10.5%	7.2%	$6,425	500	47.3
Triple, 2 Layers of Low-e 0.04	200,574	9.8%	6.8%	$6,017	450	45.5
ThermoTech S, Triple 2 Layers on N	211,802	10.4%	7.2%	$6,354	480	45.9

Reducing the Total Building Infiltration Rate

In 2004 the Saskatchewan Research Council oversaw a retrofit in KEP that reduced natural gas consumption by 3.2%. The total cost of the measures was approximately $6,000, resulting in a simple payback period of 3 years. When the computer model was used to determine the average infiltration rate before and after the retrofit it was found that this retrofit corresponded to a 9.4% reduction in infiltration rate (from 0.32 L/s·m^2 to 0.29 L/s·m^2). From the SRC retrofit and model matching it was assumed that a minimum reduction of approximately 10% in the infiltration rate can be achieved in the building.

Table 3.39 presents the natural gas and cost savings that would result from reducing the infiltration in the building. It does not include a payback period column because beyond the air sealing and weatherstripping measures just mentioned, it can be difficult to directly associate a cost that will directly result in a known reduction in infiltration. Estimating the impact a retrofit will have is the first challenge, and the second is that reductions in infiltration can arise as an added benefit from another retrofit. Two primary examples are the retrofitting of exterior walls and replacement of windows.

Table 3.39: Potential infiltration savings

Percent Reduction [%]	Infiltration Rate [L/s/m^2]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]
9.4%	0.29	27,415	1.3%	0.9%	$822
25%	0.24	73,111	3.6%	2.5%	$2,193
50%	0.16	148,909	7.3%	5.0%	$4,467
75%	0.08	224,659	11.0%	7.6%	$6,740
100%	0.00	290,155	14.2%	9.8%	$8,705

The replacement of windows could not only reduce the infiltration rate when they are closed, but windows could also be installed that do not open as much as the current ones. Tenant control of the windows can have a significant impact upon infiltration rates and another retrofit that could result in a significant reduction in infiltration is monitoring of individual suites and charging tenants based upon their energy consumption. This practice could potentially reduce the frequency of tenants keeping their windows open during the winter.

Table 3.39 also shows a small discrepancy between the measured results and the computer model results. When infiltration is reduced by 9.4%, the resulting savings are 1.3%. It was expected that the natural gas savings would be equal to the 3.2% savings measured as a result of the retrofit implemented by SRC. There are three main reasons for this discrepancy. The first is that infiltration can only be entered into the computer model using two decimal places. A perfect match between model and data does not occur at exactly 0.32 and 0.29 L/s·m^2 and therefore accuracy of model-data matching for infiltration was limited. The second is that calculating the percent savings in total natural gas consumption requires the inclusion of consumption due to domestic hot water use and the assumption that on an annual basis it will be constant. In reality, annual domestic hot water use is not constant. The assumption that it is can introduce an uncertainty into the calculation of savings associated with reduction in infiltration levels. Finally, the measured data is fitted with linear trend lines that have associated uncertainties.

Reduction of Outdoor Air and Recirculation Rates

The previous chapter dealing with electrical retrofits outlined how the outdoor air flow rate in the above ground floors of the building could be reduced by approximately 21%. It also provided electrical savings for flow rate reductions of 7%, 14%, and 21%. Table 3.40 shows the natural gas savings for these same percent reductions in above ground outdoor air flow rates, along with cost savings and estimated payback periods. The cost of reducing the outdoor air flow rate for the above ground floors was assumed to be $700 for air balancing services (based on invoices found for previous air balancing services) and $300 for additional services. The labour cost to stop the crawlspace system from providing outdoor air and recirculating air inside the crawlspace was assumed to be $500. The table lists results both including and excluding the option of no longer ventilating the unfinished crawlspace areas. Not included in the payback estimations for these retrofits is the potential for a significant cost associated with remediating the crawlspace to ensure that moisture no longer enters.

Table 3.40: Natural gas savings from reducing outdoor air rates in building

Retrofit	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Payback Period [Years]
Removal of Crawl Space (CS)	63,356	3.1%	2.1%	0.3
3076 L/s - 7% reduction in above ground outdoor air flow	42,871	2.1%	1.4%	0.8
2844 L/s - 14% reduction reduction in above ground outdoor air flow	85,619	4.2%	2.9%	0.4
2622 L/s - 21% reduction in above ground outdoor air flow	121,616	6.0%	4.1%	0.3
2622 L/s - 21% reduction in above ground outdoor air flow and no ventilation in CS	184,972	5.2%	3.6%	0.3

Increasing Heat Recovery Effectiveness

This section presents results for installing new heat recovery systems. Table 3.41 shows incremental savings from installing systems with increasing effectiveness. Low and high temperature effectiveness values were assumed in order to approximate the effect of defrosting controls. A "low temperature" was specified as below -15ºC, the same setting used when modeling the base buildings. This is not a thorough analysis of how the heat recovery system would actually operate. Greater detail on the performance of the final heat recovery system recommended for the building is presented in Chapter 7. The savings presented in Table 3.41 result from increasing the effectiveness of the system from 36% (the effectiveness of the current system).

Table 3.41: Heat recovery effectiveness

Low Temperature Effectiveness [%]	High Temperature Effectiveness [%]	Increase in Max Effectiveness [%]	Natural Gas Savings [kWh/Year]	Natural Gas Savings [%]	Total Building Energy Savings [%]
55%	60%	24%	308,135	15.1%	10.4%
65%	70%	34%	398,618	19.5%	13.5%
75%	80%	44%	471,947	23.1%	15.9%
85%	90%	54%	593,795	29.1%	20.1%

Table 3.42 shows the cost assumed for each retrofit and their corresponding payback periods. The capital cost for each system is also listed. A typically assumed cost for heat recovery is $6 per L/s [38]. For a 3,300 L/s system this would be $19,800, much higher than the $12,200 estimate obtained from a second source [36]. The cost increases as effectiveness increases in Table 3.42 were assumed in order to account for effectiveness values that are greater than normal. The retrofits were modeled without reducing the outdoor air flow rate from 3,307 L/s. Note that even if the cost was doubled to $12 per L/s, the 60% effective system would still have a simple payback period of less than 5 years.

Table 3.42: Utility cost associated with replacing heat recovery system

Low Temperature Effectiveness [%]	High Temperature Effectiveness [%]	Increase in Max Effectiveness [%]	Natural Gas Savings [$/Year]	Cost [$/(L/s)]	Payback Period [Years]
55%	60%	24%	$9,244	6.00	2.1
65%	70%	34%	$11,959	6.25	1.7
75%	80%	44%	$14,158	6.50	1.5
85%	90%	54%	$17,814	6.75	1.3

Installation of High Efficiency Condensing Boilers

This section shows the savings that could be achieved by disconnecting the current 20 boilers and installing condensing boilers. The current boilers in KEP were designed to operate with a minimum return temperature of 60ºC. Newer condensing boilers allow for lower return temperatures which results in greater boiler efficiency. Efficiencies as high as 97% for a natural gas hot water boiler can be obtained if the return water temperature is reduced to 27ºC.

Table 3.43 lists the thermal efficiency entered into the model and the resulting natural gas and total energy savings. A boiler with 100% efficiency is presented out of interest sake. The cost of the boilers was found by reducing the number of boilers to 6 and assuming a base replacement cost $5,000 for a gas fired boiler with the same input rate as the existing boilers [36]. To account for purchasing a higher efficiency condensing unit, this base cost was then multiplied by a cost multiplier. The number of boilers was reduced to 6 because the system already has twice the necessary capacity and as retrofits are implemented the boilers will be in even less demand. Also included in the cost estimate is the labour required to remove the 10 of the existing boilers. The cost was assumed to be $610/Boiler [36]. In a replacement such as this there may be many other additional costs but there may also be salvage value for the boilers that are being removed. The natural gas savings in Table 3.43 also include the savings that occur from no longer having 20 continuously lit pilot lights (51,343 kWh/Year).

Table 3.43: Condensing boiler savings

Boiler Efficiency [%]	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Boiler Cost Multiplier	Savings [$/Year]	Payback [Years]
75%	139,893	4.3%	3.0%	1.2	$4,197	10.0
85%	282,798	11.3%	7.8%	1.4	$8,484	5.7
95%	396,084	16.9%	11.6%	1.6	$11,883	4.6
100%	443,676	19.2%	13.3%	1.8	$13,310	4.5

Thermostat Control

This section presents savings associated with setting and replacing the thermostats in the building. There is currently a building in Saskatoon that requires all tenants to use a setback thermostat in their suites. Table 3.44 presents savings from reducing the desired building temperature from 24ºC to 22ºC and also including potential impacts from installing night time setback thermostats. In the table, all setback retrofits include reducing the maximum building and ventilation temperature to 22ºC. The evening setback period was 12am-6am. It was assumed that each thermostat would cost $50 to purchase and $50 to install. It was assumed that 5 would be needed for the building and 116 for the suites.

Table 3.44: Effect of temperature control

Retrofit	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Payback Period [Years]
Reduce winter temperature to 22ºC	87,083	4.3%	2.9%	$2,612	0.0
Setback building to 19ºC in evening	101,473	5.0%	3.4%	$3,044	0.2
Setback suites to 19ºC in evening	109,561	5.4%	3.7%	$3,287	3.5
Setback both suites and building to 19ºC in evening	128,750	6.3%	4.4%	$3,863	3.1
Setback suites and building to 19ºC, and reduce stairwell temperature to 20ºC	132,441	6.5%	4.5%	$3,973	3.0
Setback building to 17ºC in evening	104,993	5.1%	3.5%	$3,150	0.2
Setback suites to 17ºC in evening	111,715	5.5%	3.8%	$3,351	3.5

Marginal savings occur when the setback temperature is reduced below 19ºC. This is because ventilation is continuously provided to the building at a temperature of 22ºC and as a result the building temperature remains high even if the thermostat is set to a low temperature. The ventilation air temperature could be reduced during the evening, but minimal savings result from this change because of the presence of heat recovery in the ventilation air and the relatively low efficiency of the boilers. Optimum setback temperature is dependent on the mechanical systems in the building and the final design will discuss this in greater detail.

Replacement of DHW Tanks

This section presents savings that could be obtained by replacing the existing domestic hot water tanks with higher efficiency models. Table 3.45 presents energy saving and simple payback periods for tank replacement. The base cost of a replacement tank was assumed to be $1,000 [36] and to obtain a final cost for a high efficiency condensing unit as a replacement this base cost was multiplied by the DHW cost multipliers seen in Table 3.45. All three tanks were replaced. A cost of $790/tank was assumed for the removal of of the current tanks [36] and an additional $500/tank was added for piping and additional labour. The natural gas savings in Table 3.45 also include the savings that occur from no longer having 3 continuously lit pilot lights.

Table 3.45: Savings, cost, and payback period associated with replacing DHW tanks

Retrofit	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Tank Cost Multiplier	Payback Period [Years]
Increase efficiency to 75%	31,374	1.2%	0.8%	$941	2.0	10.5
Increase efficiency to 80%	68,365	3.0%	2.0%	$2,051	2.5	5.5
Increase efficiency to 85%	108,491	4.9%	3.4%	$3,255	3.0	4.0
Increase efficiency to 90%	140,419	6.5%	4.5%	$4,213	3.5	3.4
Increase efficiency to 95%	168,907	7.9%	5.4%	$5,067	4.0	3.1

Reducing Output Capacity of the DHW Tanks

The computer model determines DHW standing losses based on the size of the tank compared to its load. The output capacity of the DHW tanks in the building is 440 kW (3 tanks that each have capacities of 147 kW). Table 3.46 shows the savings that would result from decreasing the capacity of the DHW system. At 100 kW the DHW system was no longer able to meet the peak DHW load in the building. This indicates that only one DHW tank would be needed in the building. Disconnecting the other two would save $3,386 each year.

Table 3.46: Reducing DHW tank output capacity

Retrofit	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Savings [$/Yr]	Peak Load Still Met? [Yes/No]
DHW Output Capacity: 300 kW	84,560	4.1%	2.9%	$8,456	Yes
DHW Output Capacity: 200 kW	103,611	5.1%	3.5%	$10,361	Yes
DHW Output Capacity: 150 kW	112,870	5.5%	3.8%	$11,287	Yes
DHW Output Capacity: 100 kW	116,319	5.7%	3.9%	$11,632	No

Reducing Suite DHW Load

In the base building the suite domestic hot water use is 113.4 L/Day per suite. Low flow shower heads are commercially available that can reduce shower hot water use by 50% [40]. Showers were assumed to use 25% of the suite DHW [41]. Therefore changing the shower heads in all the suites could result in a DHW reduction of 12.5%, or 14.2 L/Day. Low-flow faucet aerators are also available that can reduce the flow of water from your tap by 25-50% [42]. Faucets were assumed to use 33% of the DHW in a suite [41]. Therefore assuming a 50% reduction, total DHW could be reduced by 18.7 L/Day. If these two fixtures were replaced, the remaining DHW for the suites would be 80.5 L/Day. If 10% of the remaining consumption could also be reduced through the use of an energy monitoring device that provides feedback to the tenants, an additional 8.05 L/Day could be saved. The final DHW use in the suites would be 72.45 L/Day, a 36.1% reduction. In the computer model this would correspond to a maximum suite load of 561.0 W/Occ in the suites. Table 3.47 shows the savings that could be achieved from each of these retrofits. The low flow shower-heads and faucets were assumed to cost $50 to purchase and install. The energy monitoring devices were each assumed to cost $150 to purchase and $200 to install.

Table 3.47: Energy savings from reducing DHW use in suites

Retrofit	Natural Gas Savings [kWh/Yr]	Natural Gas Savings [%]	Total Building Energy Savings [%]	Savings [$/Year]	Payback Period [Years]
Low Flow Showerheads	59,745	2.9%	2.0%	$1,792	3.2
Low Flow Faucets	80,688	4.0%	2.7%	$2,421	2.4
Monitoring Devices	32,440	1.6%	1.1%	$973	41.7
Three Retrofits Combined	174,767	8.6%	5.9%	$5,243	10.0

Reducing Outdoor Air Rates During the Evening

It was previously presented in the electrical section of this appendix that there would be savings associated with lowering the ventilation rate during the evening between the hours of 12pm and 6am. Initially this same retrofit was investigated in order to reduce natural gas consumption but it was found that natural gas consumption would increase if the ventilation rate was reduced. This is because the heat recovery system in the ventilation air provides a considerable amount of heat to the building during the evening. When ventilation is reduced to the building, a greater amount of the heating load must be met by the boilers which have a maximum efficiency of 75%. Therefore reducing the ventilation rate in the evening may not result in positive benefits in the final design.

A3.3 VENTILATION AIR ENERGY RECOVERY

In order to verify that the transient simulation of the energy recovery wheels was calculating reasonable results it was progressively created and verified against the results from the EE4 model of the building. Figure 3.6 compares the natural gas consumption attributed to heating outdoor ventilation air when there is no energy recovery present in either the transient simulation and the EE4 model. The annual energy consumption estimated by the transient simulation at this stage of modeling was 0.7% less than the EE4 computer model of the building.

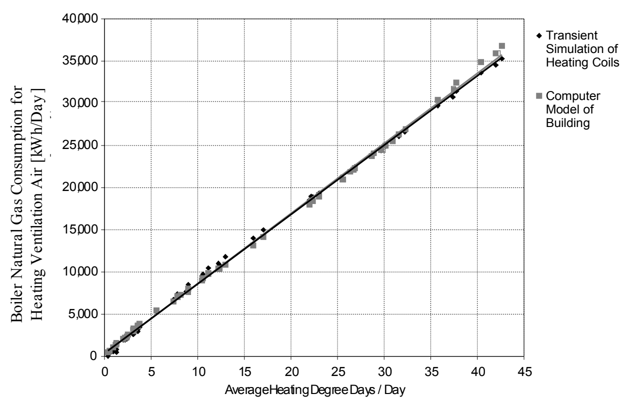

Figure 3.6: Model comparison with no heat recovery

Next, the transient simulation was modified to include a sensible heat recovery system that matched the heat recovery effectiveness values and control method used in the EE4 computer model of the building. Recall that based on the measured values presented in Chapter 5, the system's effectiveness was 36% outdoor air temperatures above -15ºC and 16% for temperatures equal to or below this temperature. Figure 3.7 compares the natural gas consumption attributed to heating outdoor ventilation air in the transient simulation and the EE4 computer model of the building when this system was included.

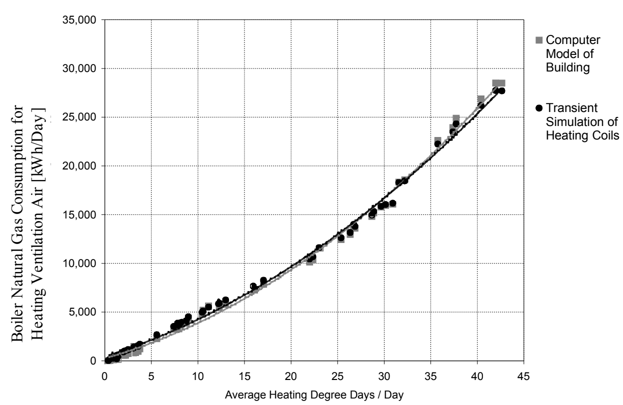

Figure 3.7: Model comparison when current heat recovery system is added

At this stage of modeling the total annual energy consumption predicted by the transient simulation was 0.7% greater than the computer model of the building. This transient model was also used to find the cooling contribution of the current heat recovery system (approximately 2,500 kWh/Year). The difference between the annual energy consumption calculated by the two models is believed to be due to small differences in supply and exhaust air density's.

After the heat recovery simulation was acceptably matched, the transient model was modified to have an energy recovery system. To ensure that frost did not form on the exhaust side of the system a psychometric chart was used to find the saturation point assuming that that indoor air temperature was 22ºC and the indoor air relative humidity was 25%. Using these conditions, it was found that frosting would occur when the exhaust air was reduced to -12ºC.

For a system with 90% effectiveness, an exhaust air temperature of -12ºC would occur when the outdoor air temperature dropped below -16ºC. Therefore from -16ºC to -40ºC the effectiveness was reduced in order to avoid frosting. At a temperature of -40ºC the effectiveness of the system would need to be 55% in order to reduce the exhaust air temperature to -12ºC. The effectiveness was therefore varied linearly from 55% at -40ºC to 90% at -16ºC. Figure 3.8 shows the reduction in natural gas consumption attributed to heating outdoor ventilation air when the 90% effective energy recovery system is installed.

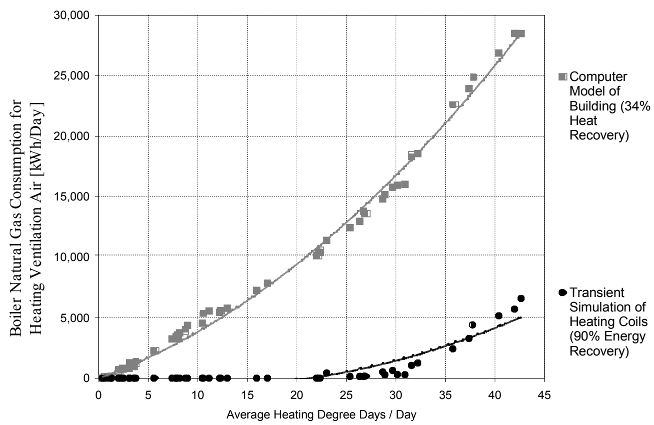

Figure 3.8: Temperature results from transient simulation of HR system

The increase in savings from increasing the HR effectiveness to 90% was approximately 421,000 kWh/Year for heating and 9,100 kWh/Year for cooling. Frosting controls in the transient simulation reduced the energy savings by approximately 20,500 kWh/Year.

<u>Appendix 3 References:</u>

1. The Energy Detective, 2007, http://www.theenergydetective.com/
2. Solplan Review, July 2005, Pay as You Go Electricity, The Independent Journal of Energy Conservation, Building Science, and Construction Practice, The Drawing-Room Graphics Service, pg 13
3. D. Parker and D. Hoak (Florida Solar Energy Center) and A. Meier and R. Brown

(Lawrence Berkeley National Laboratory), 2006, How Much Energy Are We Using? Potential of Residential Energy Demand Feedback Devices, Florida Solar Energy Center, University of Central Florida, Florida USA,

4. Wellspring Wireless, 2007, Promotional Advertisement, http://www.impactmovie.com/wellspring/
5. B. McNalley, 2006, What do we mean by pump efficiency?, McNalley Institute http://www.mcnallyinstitute.com/06-html/6-01.html
6. Keidel.com, 2001-2006 Centrifugal Pumps, http://www.keidel.com/mech/pumps-centrifugal.htm
7. European Commission, 2003, European Guide to Pump Efficiency for Single Stage Centrifugal Pumps, http://energyefficiency.jrc.cec.eu.int/motorchallenge/pdf/EU_pumpguide_final.pdf
8. Personal communications, HVAC Sales (Regina, Saskatchewan), 2007
9. National Electrical Manufacturers Association, 2002, Nema Premium Motors, Product Scope and Nominal Efficiency Levels, http://www.nema.org/stds/complimentary-docs/upload/MG1premium.pdf
10. Natural Resources Canada, 2004, CANMOST Software Listing Price, Government of Canada, http://oee.rncan.gc.ca/industrial/equipment/software/intro.cfm?attr=24
11. United States Department of Energy, Sept 2005, When to purchase NEMA Premium Efficiency Motors, Energy Tips – Motor Systems, United States Government http://www1.eere.energy.gov/industry/bestpractices/pdfs/whentopurchase_nema_motor_systemts1.pdf
12. Natural Resources Canada, 2002, Use of Variable Frequency Drives for Fan and Pump Control, Government of Canada, http://oee.nrcan.gc.ca/Publications/infosource/Pub/ici/eii/M92-242-2002-11E.pdf
13. Washing State University Energy Program, 2003, Energy Efficiency Fact Sheet, Adjustable Speed Motor Drives, http://www.energy.wsu.edu/documents/engineering/motors/MotorDrvs.pdf
14. Schneider Electric USA, 2006, Boosting the Energy Efficiency of HVAC Systems With Variable Speed Drives, Data Bulletin, http://ecatalog.squared.com/pubs/Motor%20Control/AC%20Drives/Class%208839%20M-Flex/8800DB0601.pdf
15. A.Thumann and W.J. Younger, Handbook of Energy Audits, 6th Edition, The Fairmonst Press, Page 246
16. ASHRAE, 2001, ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia
17. J. Weale, P.E., and P. Rumsey, P.E., 2005, Laboratories for the 21st Centrury: Best Practices, Low-Pressure-Drop HVAC Design for Laboratories, U.S. Environmental Protection Agency, U.S Department of Energy, http://www.labs21century.gov/pdf/bp_lowpressure_508.pdf

18. R. D. Montgomery, P.E., and R. Baker, Nov 2006, Study Verifies Coil Cleaning Saves Energy, ASHRAE Journal, Nov 2006, pg 34

19. R. Besant, P.Eng, Fellow ASHRAE, and C. Simonson, Ph.D, P.Eng, Associate Member, ASHRAE, Air-to-Air Exchangers, ASHRAE Journal, April 2003

20. Upper Peninsula Power Company, 2006, HVAC: Maintaining Fans, http://www.uppco.com/business/PDF/HVAC_05.pdf

21. F.C. McQuiston, J. D. Parker, J.D. Spitler, 2000, Heating, Ventilating, and Air Conditioning Analysis and Design, John Wiley & Sons, pg 402

22. BC Hydro, 2004, Power Smart Tips & Practices: Fans, http://www.bchydro.com/business/investigate/investigate804.html

23. Natural Resources Canada, 2004, Technical Fact Sheet, Premium Efficiency Motors, Government of Canada, http://oee.nrcan.gc.ca/Publications/infosource/Pub/ici/eii/pdf/M144-21-2003E.pdf

24. Nextag, Search for Refrigerators, Feb 2007, http://www.nextag.com/All--a-refrigerator+size-_-8.0+-+12.0+cu.ft.--zzenergy+star+refrigeratorzB2z5---html

25. United States Department of Energy, 2006, How to Buy an Energy-Efficient Compact Fluorescent Lamp, United States Government http://www.eere.energy.gov/femp/procurement/eep_compact_fluor_lamp.cfm

26. Dr. R. Dumont, 1997, De-Lamping for Energy Savings, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

27. Dr. R. Dumont, 1997, Exit Sign Energy Efficiency Upgrade, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

28. LITEMOR, 2007, Home Depot Product Pricing List, LITEMOR Lighting Guide

29. Dr. R. Dumont, 1997, Improved Efficiency Fluorescent Lamps and Ballast, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

30. Dr. R. Dumont, 1997, Fluorescent Fixture Reflectors, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

31. Personal communications, Gescan Division of Sonepar (Saskatoon, SK), Feb 26 2007, 306-931-0077

32. Personal communication, Wesco (Saskatoon, SK), 2007, 306-242-1296

33. BC Hydro, 2004, Power Factor Correction, http://www.bchydro.com/business/investigate/investigate834.html

34. Dr. R. Dumont, 1997, Reducing Electricity Demand Using Power Factor Correction, E-Notes - Energy Efficiency Notes, Saskatchewan Research Council

35. L M Photonics Ltd, 2002, Power Factor and Power Factor Correction, http://www.lmphotonics.com/pwrfact.htm

36. RSMeans, 2002, Building Construction Cost Data, 60th Annual Edition, RSMeans Company Inc., Kingston, MA

37. Personal communications, R. Holzkaemper, 2007, PanBrick employee

38. Professor C. Simonson, 2006, ME 491 Class Notes, College of Mechanical Engineering, University of Saskatchewan

39. ASHRAE, 2000, ASHRAE HVAC Systems and Equipment Handbook, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta Georgia, page 27.4

40. BC Hydro, August 2004, Power Smart Tips & Products, Low Flow Shower Heads, http://www.bchydro.com/powersmart/elibrary/elibrary699.html

41. D. Hill (Canadian Mortgage and Housing Corporation) & A. Pride (Minto Developments Inc.), 2005, City of Cornwall Social Housing Division, Top 10 Energy and Water Saving Tips in Multi-Unit Residential Buildings, Powerpoint Presentation

42. Environment Canada, 2006, Water Saving Devices, Government of Canada, http://www.ec.gc.ca/water/en/info/pubs/brochure/e_iwdww2.htm

43. Thermotech Windows, 2007, Product Specifications, http://www.thermotechfiberglass.com/products.htm

APPENDIX 4: RETROFIT COST ESTIMATE SUMMARY

This appendix provides a summary of the sources and assumptions behind the cost estimates of building retrofits. The total estimated cost of all of the proposed retrofits was approximately $3,050,000. The fifth column in the table lists references that appear in the main body of this thesis. Estimates without references are from the author. References without a chapter number are provided at the end of this appendix.

Table A4.1: Price estimate summary page 1

R#	Building Retrofit	Capital Cost [$]	Source	REF
1	Discontinue use of North sidewalk heat tape system	$100	Estimated cost for labour.	-
2	Set building thermostat to 22ºC (in both suites and common areas)	$100	Estimated cost for labour.	-
3	Set stairwell, storage, and mechanical room temperatures to 18ºC	$100	Estimated cost for labour.	-
4	Set crawlspace thermostat to 10ºC	$200	Estimated cost for labour.	-
5	Replace all incandescent bulbs with 13 W compact fluorescent or LED bulbs (in both suites and common areas)	$4,000	Litemore pricing guide from Home Depot and SRC estimates from Dr. R. Dumont's E-Notes.	7.3
6	Reduce ventilation rates to ASHRAE standard 62-2001 minimum levels (2,622 L/s) on above ground floors and reduce recirculation rate in recreation areas	$2,500	Based on previous receipts for air balancing services (located in the mechanical binder for the building) and $1,000 in assumed additional costs.	7.8
7	Remove unnecessary incandescent and fluorescent fixtures	$500	Estimated cost for labour.	-
8	Install power factor correction	$1,500	SRC estimate sourced from their 2003 BEM Audit of KEP.	7.5
9	Reduce supply air temperature from 23ºC to 22ºC	$20	Estimated cost for labour.	-
10	Reduce crawlspace ventilation rates by 65%	$500	Estimated cost for labour.	-
11	Install variable frequency drives on heating and cooling recirculation pumps	$3,700	$250/kW - Natural Resources Canada publication on variable frequency drives.	7
12	Reduce pressure drop in the ducting by cleaning and sealing central supply shaft (25% savings) and cleaning and sealing the exhaust ducts (25% savings)	$1,000	Estimated cost for labour and a small amount of duct sealing materials.	7.7
13	Replace fluorescent fixtures with more efficient ballasts and bulbs and retrofit double bulb fluorescent fixtures to use a single bulb with a silver reflector	$15,000	Litemore pricing guide from Home Depot for bulbs, reflectors, and shunts. Assumed a labour cost of $12 per fixture.	1
14	Install setback thermostats in building common areas and set evening setback temperature to 18ºC	$650	The cost of 5 thermostats ($50 each) plus $250 assumed for their installation.	-
15	Replace washing machines and clothes dryers with higher efficiency front loaded models	$16,000	Purchase cost found online, costs from difference Canadian suppliers were averaged. $1,000 x 8 washing machines + $1,000 x 8 clothes dryers.	2
16	Reduce stairwell and hallway lighting to 20% from 12pm-7am and install occupancy controls	$3,000	Personal communications with a local lighting contractor.	3,4
17	Install day lighting controls in recreation and foyer areas	$2,000	Personal communications with a local lighting contractor.	3,4
18	Install block heater control system monitor block heater consumption and charging renters based on their consumption (additional 10% savings)	$16,000	Cost of a block heater controller from the Intelligent Parking Lot Controller Corp., is $150. Multiply by 32 parking stalls + $100 to install each meter. Electrical metering devices (The Energy Detective) can be purchased for $150. Multiply by 32 parking stalls + $100 to install each meter.	7.14, 7.18
19	Install occupancy lighting controls in crawlspace, mechanical rooms, laundry rooms, public washrooms, and storage rooms	$3,000	Personal communications with a local lighting contractor.	3,4
20	Reduce the pressure drop in the ceiling mounted lounge/recreation area AHU's by cleaning coils and ducts, maintenance, and duct sealing (main floor ΔP reduced by 25% & second floor ΔP reduced by 25%)	$400	Estimated cost for labour.	-
21	Increase heat recovery effectiveness of the crawlspace HRV to 85%	$3,000	$6/(L/s) is a typical cost and this was increased for assumed additional labour and materials.	7.32
23	Reduce suite receptacle consumption by 20% (not including refrigerator consumption) Reduce suite lighting consumption by 15% Reduce window mounted air conditioner consumption by 50%	$103,240	Personal communications with Wellspring Wireless representative ($890/Meter).	7.21

Table A4.2: Price estimate summary page 2

R#	Building Retrofit	Capital Cost [$]	Source	REF
23	Replace suite refigerators	$58,000	Purchase cost found online, costs from difference Canadian suppliers were averaged. $500 x 116 refrigerators (fridges are small and it was assumed a bulk purchasing deal could be achieved).	7
24	Replace heating and cooling recirculation pump motors with higher efficiency models	$2,500	CANMOST motor slection tool from Natural Resources Canada - Internal price library.	5
25	Replace crawlspace ventilation motors with higher efficiency motors.	$1,000	CANMOST motor slection tool from Natural Resources Canada - Internal price library.	5
26	Replace crawlspace fans with higher efficiency models	$2,000	Estimated cost for labour and materials.	-
27	Replace heating and cooling circulation pumps with higher efficiency (70%) models	$4,000	Personal communications with a mechanical supplier in Regina.	6
28	Reduce unspecified building receptacle consumption by 10% and install digital controls	$75,000	Personal communications with Dave Palibroda at Integrated Designs	-
29-31, 35	Remove existing central supply AHU	27,000	RSMeans estimate for removal of heavy mechanical equipment.	7.1
	Install low face velocity supply AHU		RSMeans data for an air handling unit with heating and cooling, with a flow rate of 3.8 m3/s (41% greater than necessary). $10,000 per unit x 2 units	7.1
	Place new supply AHU on opposite side of the mechanical room and install new air intake for this unit (70% savings in mechanical room ducting ΔP).		Estimated cost for labour, materials and a half day crane rental.	7.3
32	Install premium efficiency motors	$2,800	CANMOST motor slection tool from Natural Resources Canada - Internal price library.	5
33	Increase fan efficiency to 80%	$4,200	RSMeans data for a centrifugal airfoil fan complete with motor and drive (3.8 m3/s) is $2,650. Cost of a 5.6 kW motor is $556. Motors were removed from the cost estimate. $2650 x 2 - $556 x 2 = $4,100	7.1
34	Place central supply motor inside airstream	$200	Estimated cost for labour.	-
36-41	Removing run-around glycol heat recovery system (includes disconnecting the glycol circulation pump)	39,775	RSMeans estimate for removal of heavy mechanical equipment.	7.1
	Install two energy recovery wheels with effectiveness values of 81%. Total system effectiveness is 90%		$6/(L/s) is a typical cost (although much higher than RSMeans data) and $12/(L/s) was assumed because there are two wheels.	7.32
	Install two 200 W motors that will operate the two energy recovery wheels for approximately 8,100 hours per year		CANMOST motor slection tool from Natural Resources Canada - Internal price library.	5
	Cooling contribution of HR			
	Capital savings from downsizing replacement air conditioning unit		Cooling is $175/kW - From Professor Simonson's ME 491 class notes.	7.32
	Installation of equipment		Estimated cost for labour, materials, and a half day crane rental.	7.3
42	Reduce suite DHW load by installing low-flow shower-heads	119,356	Showeheards are $25 to purchase and they were assumed to be $25 to install. Faucets are $25 to purchase and they were assumed to be $25 to install. The installed cost of the waters meters were obtained from a Wellspring Wireless estimate ($890/meter).	-
	Reduce suite DHW load by installing aerating faucets			-
	Install water monitoring devices in suites to reduce tenant DHW consumption by an additional 10%			7.21
43, 44	Remove one existing DHW tank	15,000	RSMeans estimate for removal of heavy mechanical equipment.	7.1
	Purchase and install one 150 kW, 85% efficient, DHW tank		RSMeans estimate for a gas fired domestic hot water heater.	7.1
45	Install a solar DHW system sized to provide 99% of the DHW load	309,800	Cost based on NRCan case study. $670/m^2.	7.37
46	Add 51 mm of polyurethane insulation to the exterior surface of the South exterior wall		RSMeans cost data for polyurethane insulation. Rounded up.	7.1
47	Insulate crawlspace walls with R10 insulation	$5,000	RSMeans cost data for polyurethane insulation. Rounded up.	7.1
48	Above Baseboard Heaters	$65,000	RSMeans cost data for aluminum foil radiant barrier, polyurethane insulation, gypsum, and painting. Rounded up.	7.1
49	Above Baseboards - South Solar	$31,000	RSMeans cost data for aluminum foil radiant barrier, polyurethane insulation, gypsum, and painting. Rounded up.	7.1
50	Stairwells, Storage, and Mechanical Rooms	$27,000	RSMeans cost data for polyurethane insulation, gypsum, and painting. Rounded up.	7.1
51	Sloped Metal Roofs	$42,000	RSMeans cost data for polyurethane insulation, gypsum, and painting. Rounded up.	7.1

Table A4.3: Price estimate summary page 3

R#	Building Retrofit	Capital Cost [$]	Source	REF
52	Replace South windows with triple pane, low-e windows (ThermoTech ER 15) and North windows with quadruple pane, low-e, insulated windows (ThermoTech ER 6)	$486,400	Typically a cost of $\$500/m^2$ is assumed for windows. A quote was obtained from Adams Lumber and the average price of triple pane windows was $\$482/m^2$. Price was increased to $\$800/m^2$ for higher quality windows and installation costs.	7.49, 8
53	Replace doors with steel polyurethane filled well insulated doors	$5,500	$500 per door x 11 doors.	-
54	Air seal leakage paths and compartmentalize floors in building (10% savings in infiltration)	$6,000	Actual cost of retrofit from SRC project report.	11
55	Reduce infiltration by an additional 40% (50% in total)	$77,420	Estimated cost for labour and materials needed to ensure high quality installation of the windows and insulation + $495/Meter for Wellsprings Wireless monitoring device in wall mounted heaters.	7.21
56	Purchase and install 2 condensing boilers	$27,000	Quoted price for two, 95.2% AFUE, Viessmann boilers from Dynamic Agencies was $19,000. Additional costs were assumed for installation.	7.46, 9
57	Replace current air conditioner with a new 85 kW unit that has a COP 4.2	$10,000	Cooling is $175/kW - From Professor Simonson's ME 491 class notes.	7.32
58, 59	Install a solar water heating system for heating the outdoor ventilation air	271,500	Cost based on NRCan case study. $\$670/m^2$.	7.37
	Add 51 mm of polyurethane insulation to the exterior surface of the South exterior wall		RSMeans cost data for polyurethane insulation. Rounded up.	7.1
60	Install a 88 kW of photovoltaic system	$1,232,000	$14/W, Kelln Solar (Saskatchewan Solar Company) cost estimate for the net zero home in North Battleford. Includes inverters and all other necessary equipment.	10
Total		**$3,050,461**		

References:

1. The Home Depot, 2007, Litemore Lighting Pricing Guide
2. Sears Canada, Clothes dryer price listings, http://www.sears.ca/gp/search/ref=sr/102-8256468-3216903?field-keywords=dryer&url=node%3D15860851&Go.x=0&Go.y=0&index=marketplace&page=1&sn=1&size=12
3. Personal communications with Wesco (Saskatoon, SK), 2007, 306-242-1296
4. Personal communications with Gescan Division of Sonepar (Saskatoon, SK), 2007, 306-931-0077
5. Natural Resources Canada, 2006, CANMost Motor Selection Tool, Government of Canada, http://oee.nrcan.gc.ca/industrial/equipment/software/intro.cfm?attr=24
6. Personal communications with HVAC Sales (Regina, SK), 2007, 306-721-7980
7. Nextag, Search for Refrigerators, Feb 2007, http://www.nextag.com/All--a-refrigerator+size-_-8.0+-+12.0+cu.ft.--zzenergy+star+refrigeratorzB2z5---html
8. Personal communications, Adams Lumber (Saskatoon, SK), 2007, 306-652-5393
9. Personal communications, Dynamic Agencies (Saskatoon, SK), 2007, 306-343-1901
10. Personal communications, K. Winder, 2007, Saskatchewan Research Council
11. Jerry Makohon, Dr. R. Dumont, L. Snodgrass, Demonstration Project: Tune-Up Guide For Multi-Unit Residential Buildings, 2006, Saskatchewan Research Council