Assessment of Heat Recovery Ventilators for Multi-Unit Residential Buildings in BC

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CEEN 596

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Assessment of Heat Recovery Ventilators for Multi-Unit Residential Buildings in BC

A case study on the residential Sail building on UBC campus

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1.0 Executive Summary

A high level detailed analysis of ventilation heat recovery technologies for the Sail Building was conducted. The Sail building is to be constructed on UBC campus by Adera developments, with the completion of the 172 suite apartment expected to be in August 2013.

The original plan for ventilation was to have passive supply vents with mechanical exhaust in each suite. Fresh air is passively drawn from outside into each bedroom via an inlet vent installed on the exterior wall near the ceiling. Suite air is exhausted on an 8hr/day timed basis through bathroom exhaust fans. Corridor ventilation is provided separately by an air handling unit on a central supply basis. The new ventilation plan was to provide balanced supply and exhaust ventilation within each unit, on a decentralized basis. A selection framework was devised which considered five important attributes in the decision making process of selecting the right technology. A ventilation heat recovery unit with a plate type heat exchanger was considered the best fit for the Sail building. The 155MAX HRV (heat recovery ventilator) manufactured by Airia Brands was chosen as the unit to provide ventilation in each suite. The 155MAX unit in particular had high heat exchanger efficiency and a low Watts/CFM value.

The new more efficient ventilation system would save 1600 GJ (445,000 kWh) of natural gas therefore avoiding 83 tonnes of CO_2 annually. The unit would consume 18,400 kWh (66 GJ) of electricity, as each unit requires electricity to run. The total incremental cost of the new ventilation system was estimated to be $97,900. The annual building energy modelled utility savings is predicted to be $12,200. Using a 25 year project life and 8% discount rate the NPV for implementing the new ventilation technology is $32,500. The cost benefit ratio is above 1 at 1.33. The cost of conserved energy is 0.33 $/GJ far lower than 9.94 $/GJ, which is the current market price of natural gas. With positive financial indicators a decision was given to invest in the new heat recovery ventilation system as it was found to be financial viable, while also resulting in a better way to provide higher indoor air quality for residents.

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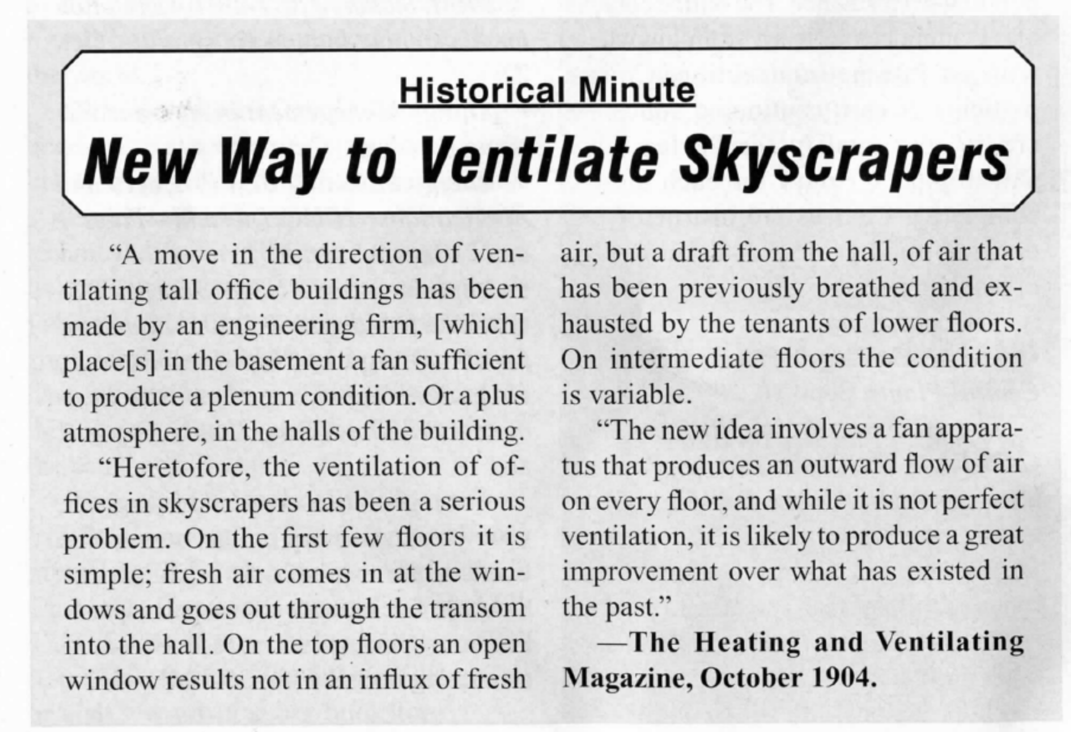
2.0 Introduction

2.1 Ventilation

We spend approximately 90% of our time within buildings [1]. Be it our home, office, or apartment, making sure air within these spaces is clean and fresh is paramount. Ventilation provides occupants with a healthy environment but also maintains the health of the building by minimising the risk of damp conditions resulting in mildew growth. The main reasons for ventilation in buildings are listed below:

- To provide oxygen to enable occupants to breath
- To remove waste carbon dioxide, moisture and odour from the activities of occupants within the space
- To remove other trace gases and particulates from building materials and coverings (carpets for example)
- To keep odours within reasonable bounds
- To provide cooling
- To allow a psychological connection between the indoor and outdoor realm

The earliest known reference to ventilation is from an ancient roman architect Vitruvius Pollio, dating back to approximately 80-15 BC. He said towns should be located "without marshes in the neighborhood, for when the morning breezes blow toward the town at sunrise, if they bring with them mists from marshes and, mingled with the mist, the poisonous breath of the creatures of the marshes to be wafted into the bodies of the inhabitants, they will make the site unhealthy" [2]. By the 11th and 12th century a general understanding of the need for adequate indoor ventilation can be assumed to date from the time when open fires for cooking and heating were moved indoors. Smoke from fires inside dwellings exited through cracks and holes in roofs by the use of chimneys. By the industrial revolution most physicians believed polluted external air was responsible for numerous chronic diseases. By 1866, ventilation had progressed to the point that a company named B.F. Sturtevant Co. was selling ventilation fans, and by 1884, Dr. John S. Billings, U.S. deputy surgeon general, published “The Principles of Ventilation and Heating and Their Practical Application”, a comprehensive text providing standards and specifications for ventilating primarily large public buildings [3]. The first mention of mechanical ventilation occurred in 1904 in the form of a magazine article referring to a new way to ventilate sky scrapers (shown in Figure 1). Nowadays we have a wealth of knowledge to establish codes and standards on ventilation.



Historical Minute

New Way to Ventilate Skyscrapers

“A move in the direction of ventilating tall office buildings has been made by an engineering firm, [which] place[s] in the basement a fan sufficient to produce a plenum condition. Or a plus atmosphere, in the halls of the building.

“Heretofore, the ventilation of offices in skyscrapers has been a serious problem. On the first few floors it is simple; fresh air comes in at the windows and goes out through the transom into the hall. On the top floors an open window results not in an influx of fresh air, but a draft from the hall, of air that has been previously breathed and exhausted by the tenants of lower floors. On intermediate floors the condition is variable.

“The new idea involves a fan apparatus that produces an outward flow of air on every floor, and while it is not perfect ventilation, it is likely to produce a great improvement over what has existed in the past.”

—The Heating and Ventilating Magazine, October 1904.

Figure 1 - New way to ventilate Skyscrapers

Division B, Part 6.2.1.1 of the BC building code 2012 relies on ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality* for specification of required ventilation for commercial and residential buildings. The BC building code states “the rates at which outdoor air is supplied in buildings by ventilation systems shall be not less than the rates required by ANSI/ASHRAE 62, Ventilation for Acceptable Indoor Air Quality.” In particular for ventilation, the relationship between law acts, codes, standards and methods for verification can be seen in Figure 2.

Consitution of Canada

- States the regulation of building construction and systesms within them as a provincial responsibility.

National Building Code 2010

- Objective is to prevent illness and loss of amenity

Provides a model building code for provinces to adapt.

BC Building Code 2012

- Sets ventilation requirements to maintain air purity and control air pollutants

Based on the National Building Code model, the code dictates specific regulation within British Columbia.

Standards

- ANSI/ASHRAE Standard 62.1.2010
- ANSI/ASHRAE Standard 62.2.2010

The two standards referred in the BC building code that set the functional requirement for ventilation.

Verification Methods

- ANSI/ASHRAE HO2674 Method for testing ventilation rates

Set by the standards to ensure a procedure to test compliance with designed ventilation rates.

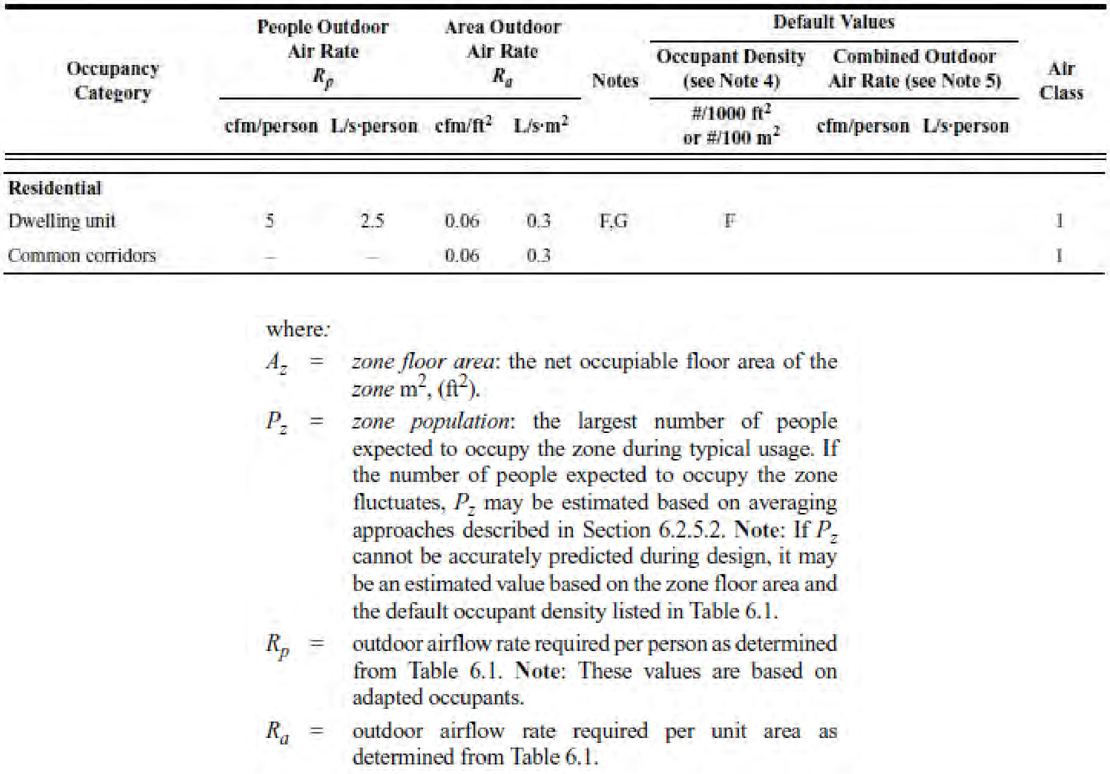
Figure 2 - Building Law, Codes & Standards Diagram

The outdoor air ventilation rate (V_{bz}) specified in the ANSI/ASHRAE Standard 62.1 is based on a per person and per area basis. This is true when calculating supply air ventilation. Ventilation can also be provided by extracting air mechanically within a space. Mechanical extraction is usually done using bathroom extraction fans. The air that replaces the extracted air within a space is then passively drawn in. The ANSI/ASHRAE Standard 62.1 states extracted air meet be high enough to provide 0.35 air changes per hour within a space [4]. Therefore a choice with regards to how a building is ventilated is provided, either it can be my mechanical supply or mechanical extraction with passive supply vents.

The equation for outdoor air supply rate is below:

$$V_{bz} = R_p\, P_z + \, R_a\, A_z$$

Equation 1 - Ventilation Rate [4]



Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Residential									
Dwelling unit	5	2.5	0.06	0.3	F,G	F			1
Common corridors	–	–	0.06	0.3					1

where:

A_z = *zone floor area*: the net occupiable floor area of the *zone* m^2, (ft^2).

P_z = *zone population*: the largest number of people expected to occupy the zone during typical usage. If the number of people expected to occupy the zone fluctuates, P_z may be estimated based on averaging approaches described in Section 6.2.5.2. Note: If P_z cannot be accurately predicted during design, it may be an estimated value based on the zone floor area and the default occupant density listed in Table 6.1.

R_p = outdoor airflow rate required per person as determined from Table 6.1. Note: These values are based on adapted occupants.

R_a = outdoor airflow rate required per unit area as determined from Table 6.1.

Figure 3 - Outdoor Air Supply Rate Equation Nomenlecture

The amount of fresh air we need to breathe is relatively small (0.3 l/s) compared to the amount needed to dilute and displace CO_2 and odours (13 l/s). Figure 4 compares the rate of air required for different functions. The majority of ASHRAE's specified amount of fresh air required to ventilate a space is therefore more attributed to increasing air quality, and not to providing adequate access to oxygen.

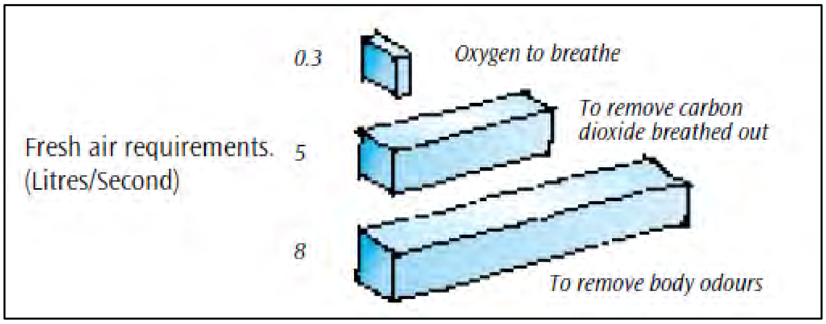


Figure 4 - Fresh Air Requirements [5]

When we compare ventilation design between single family homes and apartment buildings, we can intuitively judge apartment buildings are more complex to ventilate. The main reason being most apartments have limited exposure to outside walls and windows. Furthermore natural physical forces that dictate the movement of air become more pronounced in taller buildings. A different ANSI/ASHRAE standard accounts for the single family homes or what is determined to be low rise residential buildings (3 stories or less). These ventilation rates are based on the number of bedrooms in the ventilated space, the number of occupants, the area of the ventilated spaces and the outdoor air quality.

The air flows and their distribution in a given building are caused by physical forces of pressure differences evoked by wind, thermal buoyancy, distribution of small openings within the building envelope and occupant behaviour. Figure 6 below shows the relationship of air flow influenced by these physical forces.

The main physical forces that are important in the case of the sail building are infiltration, exfiltration, and stack effect. The unintentional and uncontrollable flow of air through cracks and leaks into the building envelope is called infiltration. The unintentional and uncontrollable flow of air out of a buildings envelope is called exfiltration. Figure 5 shows all relative air flows within an apartment setting.

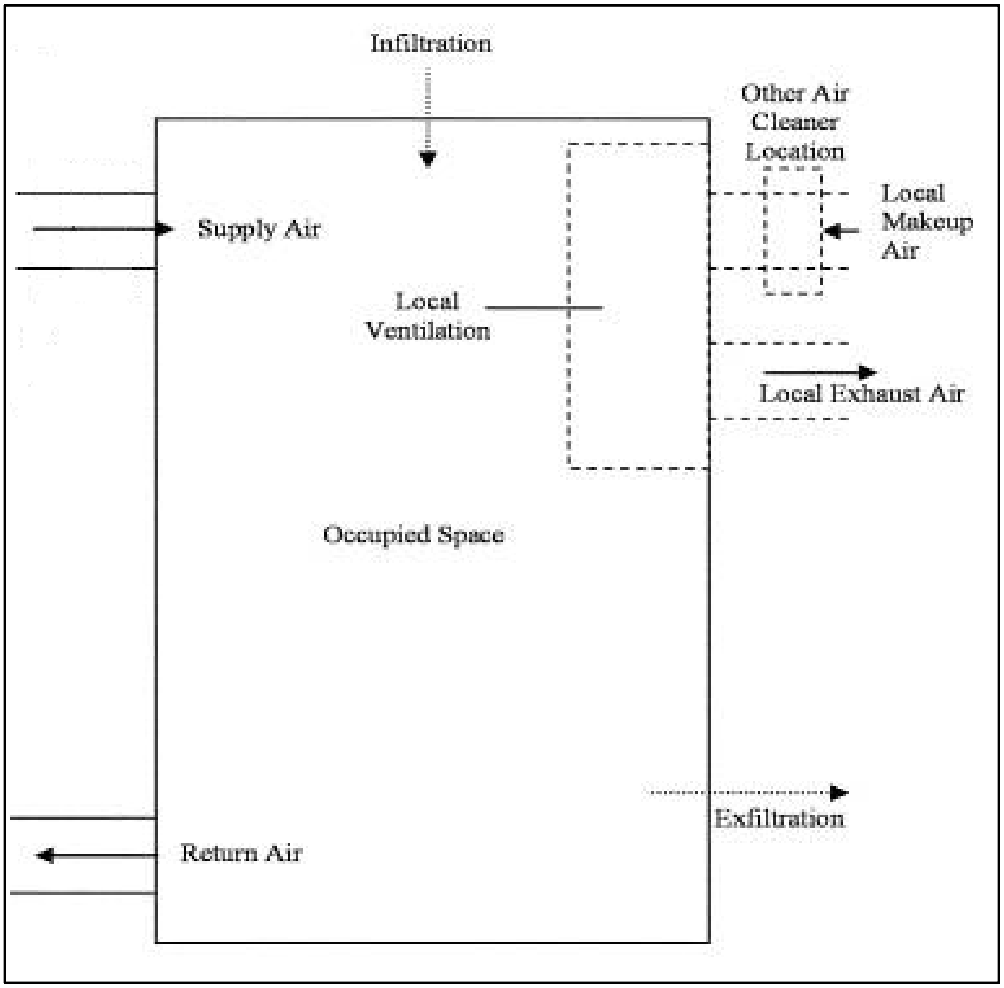


Figure 5 - Air Flows within an Apartment

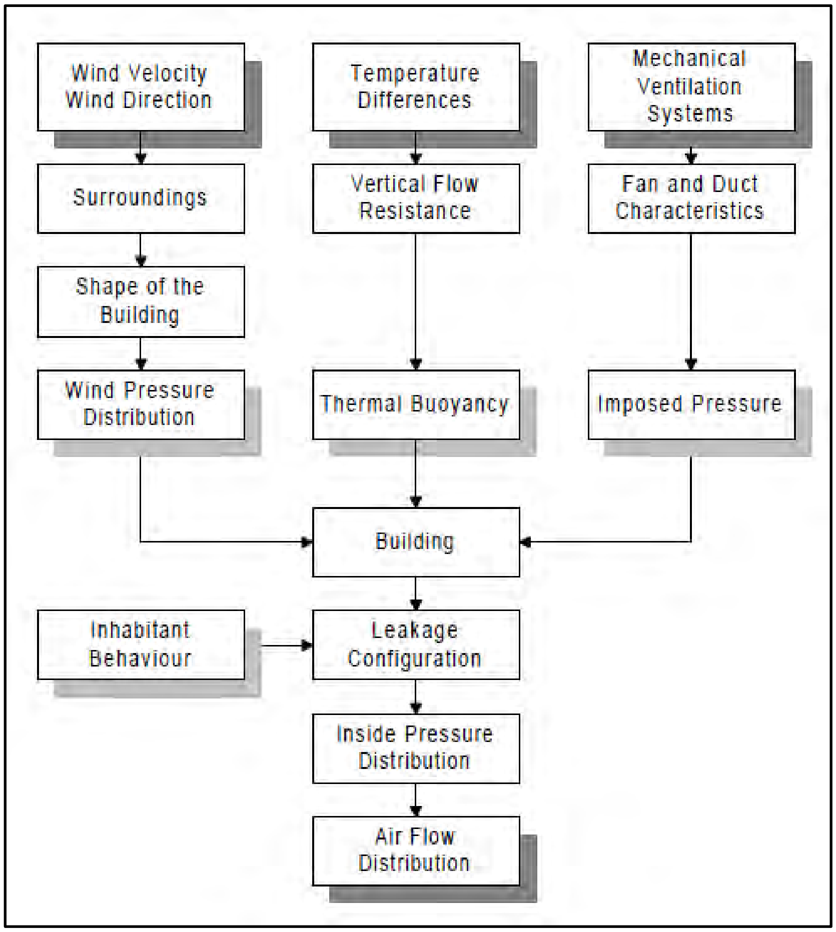


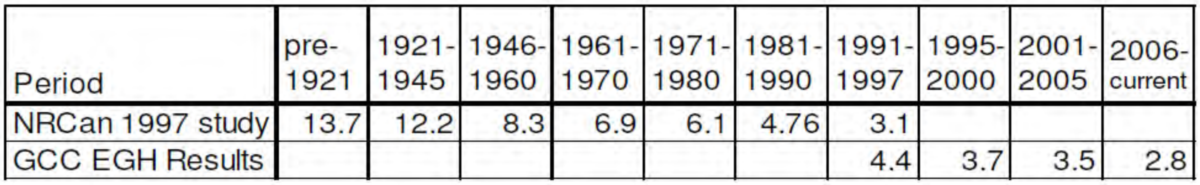
Figure 6 - Air Flow Distribution in Buildings [6]

Stack effect only occurs in high rise buildings and is due to air flow moving up within a building due the difference in air density inside a building relative to the density of the outside air. The effect is more pronounced in the winter and can cause the lower floor to become depressurised while the upper floors are pressurised as the warm air moves upwards within a building. Many studies have shown that the wind effect is far more dominant than the stack effect in inducing airflow [7]. Hence, the application of natural cross ventilation by wind in picking up fresh air and delivering to ventilated spaces has been the preferred choice by architects and building designers. The practice has been used to generate indoor air movement and improve a buildings thermal environment for a long time.

Low-rise buildings often use natural ventilation and the effect of exfiltration and infiltration to ventilate their homes through the use of operable windows. High-rise buildings (over 3 stories) often use mechanical ventilation systems in the form of fans, air-inlets and ducts. Mechanical ventilation is used extensively in high rise buildings and will most likely continue to be in the future as the most appropriate way to provide fresh air and ventilate a building. The mechanical system is capable of providing a controlled rate of fresh air exchange.

Air tightness is an important characteristic of a building and represents how leaky a building is relative to its size. The unintentional flows in and out of the building can cause an energy penalty, as warm air in the heating season is lost to the environment. Typical multi unit residential buildings (MURBs) show an average leakage rate of 3-4 l/s*m^2 which is 30 - 40 times higher than the desirable leakage rate set by the Canadian national building code of 0.1 l/s*m^2 required to keep humidity levels between 27 – 55 % [8]. The finding shows areas of significant improvement to air tightness that can be achieved. Energy standards for residential buildings fall under part 3 of the BC building code and are required to follow ASHRAE 90.1 standards for energy efficient building practices which do not have specific requirements for minimum air tightness value. As it is difficult to quantify air leakage through a building envelope with regards to larger multi-unit residential buildings like the Sail building, ASHRAE 90.1 only provides qualitative requirements for air sealing of interfaces and joints within the building enclosure. Windows and doors are the exception as prescriptive performance values are referenced.

A trend towards more airtight building enclosures as can be seen in Figure 7. The data is shown for air changes per hour at 50 Pa. Performance issues such as water penetration control and emphasis on energy efficiency are considered to have driven the reduction in air leakage rates. However, improved airtightness means that it is more critical that the building ventilation system is both properly designed and is operating appropriately to ensure provisions of acceptable indoor air quality within apartments.



Period	pre-1921	1921-1945	1946-1960	1961-1970	1971-1980	1981-1990	1991-1997	1995-2000	2001-2005	2006-current
NRCan 1997 study	13.7	12.2	8.3	6.9	6.1	4.76	3.1			
GCC EGH Results							4.4	3.7	3.5	2.8

Figure 7 - Historical Air Leakage Rates [9]

Many multifamily buildings do not consistently provide families with clean fresh air. A recent case study by RDH at Central Park Place residential building in Burnaby showed on average only 35% -62% [10] of fresh air supply actually entering each apartment [11]. While apartments have windows that can be open to the environment, this does not provide a complete ventilation solution. Also the option of opening windows is not always an option to the variability of weather and high frequency of rain and snow in most parts of Canada.

Multifamily homes, especially newly designed more air tight buildings, require mechanical ventilation and fans to exhaust pollutants generated inside the building such as moisture, cooking odours and chemical from cleaning products. Clean fresh air is pulled in from outside and filtered using a screen set by the ASHREA standard 62.1.2010 to have minimum efficiency reporting value (MERV) of no less than 6. This means the filter should catch 35-49% of particle with average size between 3 – 10 microns [12]. The pink area in Figure 8 below shows the particulate matter typical MERV 6 filters protects against. The area in green and pink shows the particulate matter MERV 13 filters protect against, which are typically used in ventilation heat recovery systems. MERV 13 filters catch 75 – 90% of particles with an average size between 0.3 to 10 microns. It is evident the MERV 6 filters do not cover the breadth of different molds, spores, and bacteria that are important to reduce for healthy living. There is also a stipulation in the ASHRAE standard that requires filters to be replaced a regular intervals to maintain efficiency. After the outdoor air is filtered it is heated or cooled to help maintain a healthy living space.

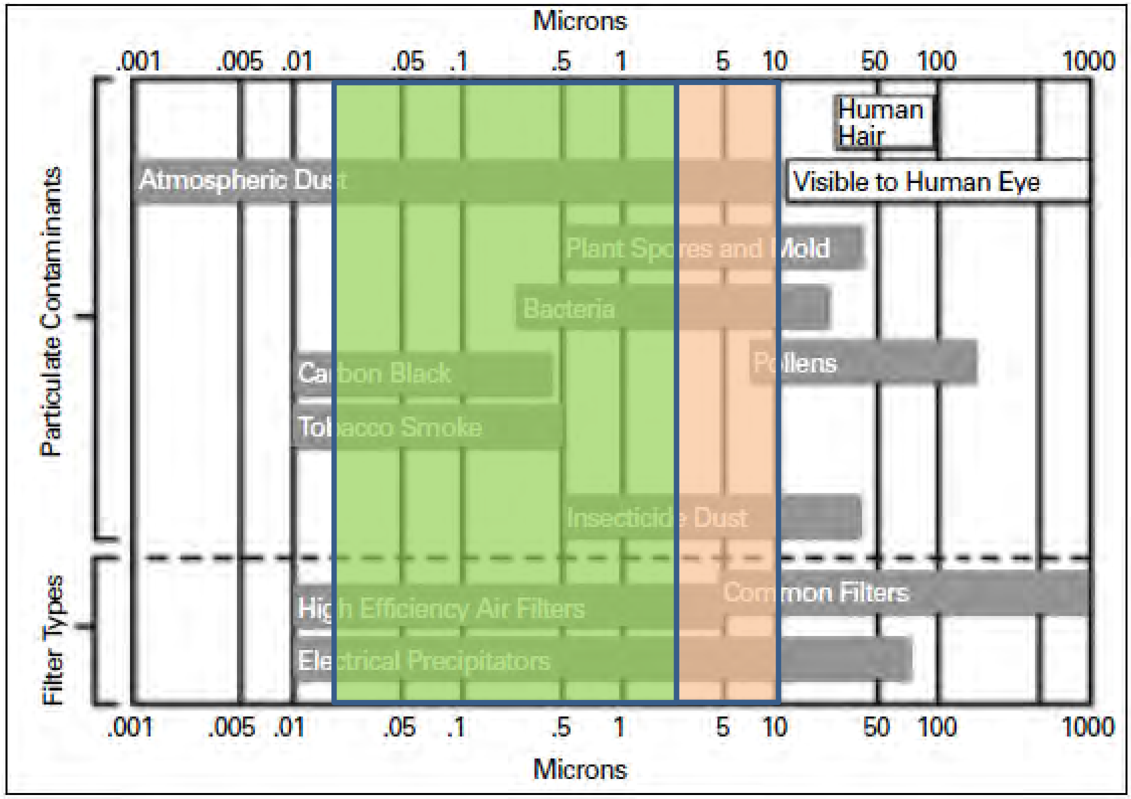


Figure 8 - Common Particle Contaminants

The outdoor filtered fresh air is used to displace and reduce contaminants and allergens inside the building. The most common type of ventilation in multifamily residential homes and what is proposed to be built for the Sail building is termed central supply ventilation. Fresh air is supplied by a central air handing unit usually placed on a roof to all the floors of the building. The air flows down a ventilation shaft close to the elevator shaft and delivers a set flow to each corridor. The supply infiltrates the corridor and each apartment by flowing under the slit in each door. Air is exhausted from individual suites by means of exhaust fans, through air leaks and occupants behavior in opening windows. The main advantage of the pressurized corridor method is to keep indoor suite odours in each suite. Figure 9 and Figure 10 shows the path of ventilated air to each apartment building.

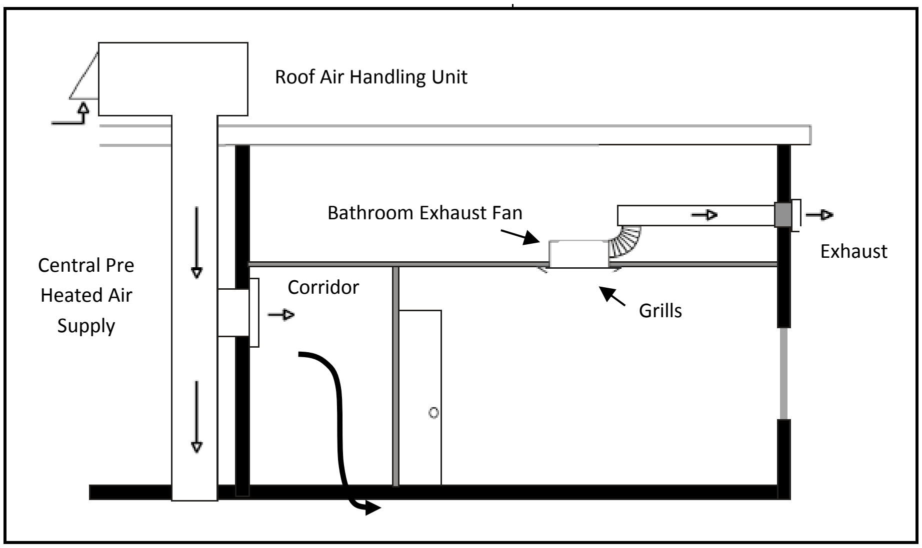


Figure 9 - Central Supply Ventilation

There are a number of issues with the current model of positive corridor supply ventilation. These include:

- Air flowing through the corridors may or may not find its way to all the apartments on that floor
- The slit in the apartment door may be blocked off
- The incoming air flow enters the dirtiest part of the apartment where the main door entry is located. This is where occupants wipe there shoes and take them off
- Pressure imbalances due to cross wind and stack effect cause the path of desired airflow from corridor vent to apartment to be disturbed
- Fresh air supplied to each corridor may more easily flow through each elevator and other shaft openings
- Greater probability of leakages in the long shaft and duct path to each corridor

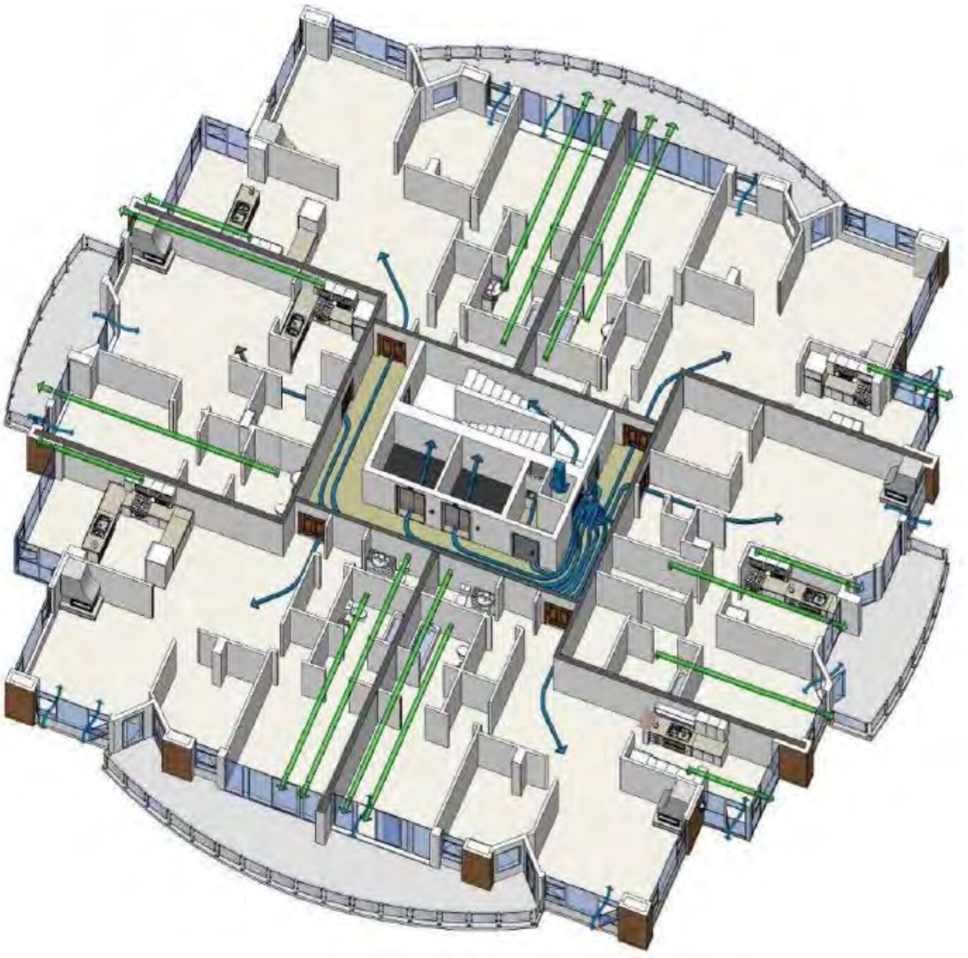


Figure 10 - Air flow Path of Central Ventilation System [13]

The outside intake air is heated usually to a minimum of 18°C in the winter months by the use of an air handling unit. As there are a number of inherent inefficiencies in the positive pressure air supply method, significant energy costs are incurred.

The existence of anthropogenic global warming due to climate change has led to a consensus to reduce greenhouse gas emissions (GHG) among governments, individuals and institutions [14]. It is safe to say the existence of anthropogenic global warming is a key issue in pushing forward the tenants of sustainable living. It has become apparent in recent year's energy efficient technologies in buildings have become increasingly desirable, due to the emphasis placed on sustainability. Improved energy efficiency is often the most economic and readily available means of improving energy security and reducing greenhouse gas emissions

In terms of building energy consumption British Columbia's Energy Efficient Buildings Strategy established targets for significant energy and emission reductions in new and existing buildings by the year 2020. In order to create permanent change within the market the strategy is to promoted market transformation by introduction, adoption and eventual regulation of new energy efficient building designs and technologies. Other policy instruments of supporting and expanding demand side energy management initiatives are also detailed in the plan to help achieve the 33% reduction in BC GHG emissions by 2020. The national Eco ENERGY and provincial Live Smart BC incentives and rebate programs are ways the government is trying to encourage adoption of energy efficient technologies within the residential building sector.

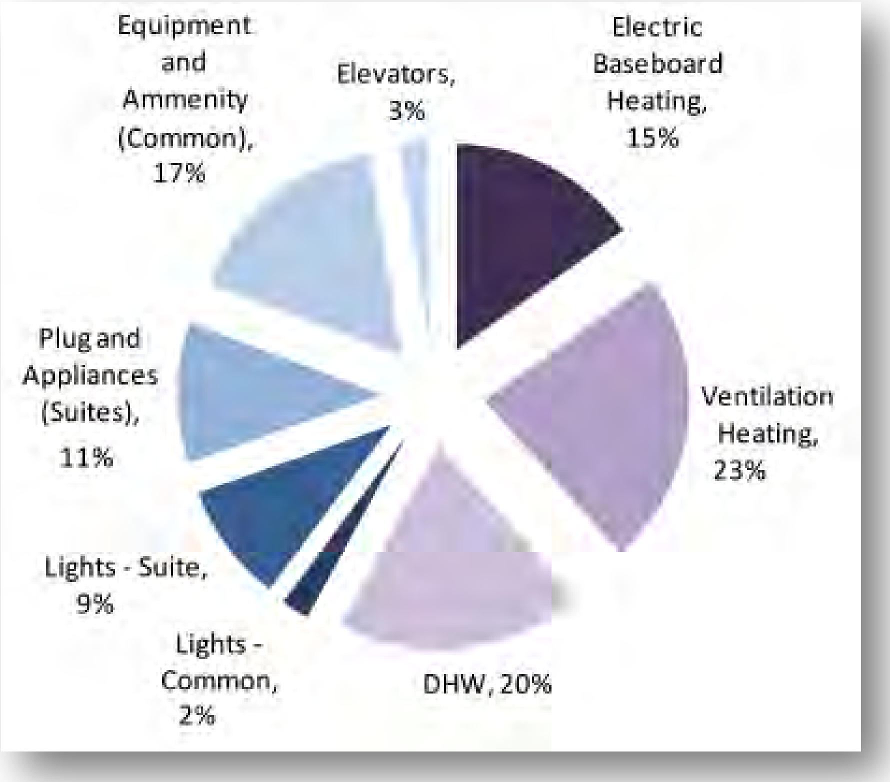
Building energy consumption within most developed countries has increased as a result of economic growth [15]. The residential sector accounts for 17% of the total energy consumed within Canada [16], accounting for 1,422 Petajoules of energy. 650 Petajoules of energy was used in the form of burning natural gas for heat and ventilation purposes. Cumulatively speaking, there is great potential for energy savings by implementing heat recovery technologies to reduce gas use within houses and apartments.

Figure 11 shows that gas used to heat air for ventilation purposes account for 23% of a MURB's energy consumption, for buildings without fireplaces and 20% for buildings with fireplaces. Heating and ventilation systems (HVAC) are the single largest energy consuming component of an apartment building, and therefore represents the largest potential for energy savings by implementing energy efficient technologies.

On average a typical high rise building would spend $1200/suite per month on electricity and gas. In the case of the Sail building with 172 suites this would be $206,400. The average building energy performance index for a mid to high rise building in lower mainland BC is 213 kWh/m^2/yr. The proportions of fuel used for energy is equally split between gas and electricity (50% of the energy derived from burning gas). Half of that gas burned is used for heating supply air used to ventilate the building.

A way in which to recover some of the heat wasted in ventilation is to use a heat recovery ventilator (HRV). The concept recovers heat energy in the exhaust air that is expelled from a building. The recovered heat energy is used to pre heat the fresh air coming into the building, by the use of a heat exchanger core, which can be a multitude of different designs. Two blower fans are used to move the fresh and stale air streams. A diagram of the system can be viewed in Figure 12. It has been estimated an 80% efficient HRV can recover 33.8% [13] of the ventilation heating energy used within a multi-unit residential building, which is in the region of $16,000 for a building similar to the Sail development.

Without Fireplace



With Fireplace

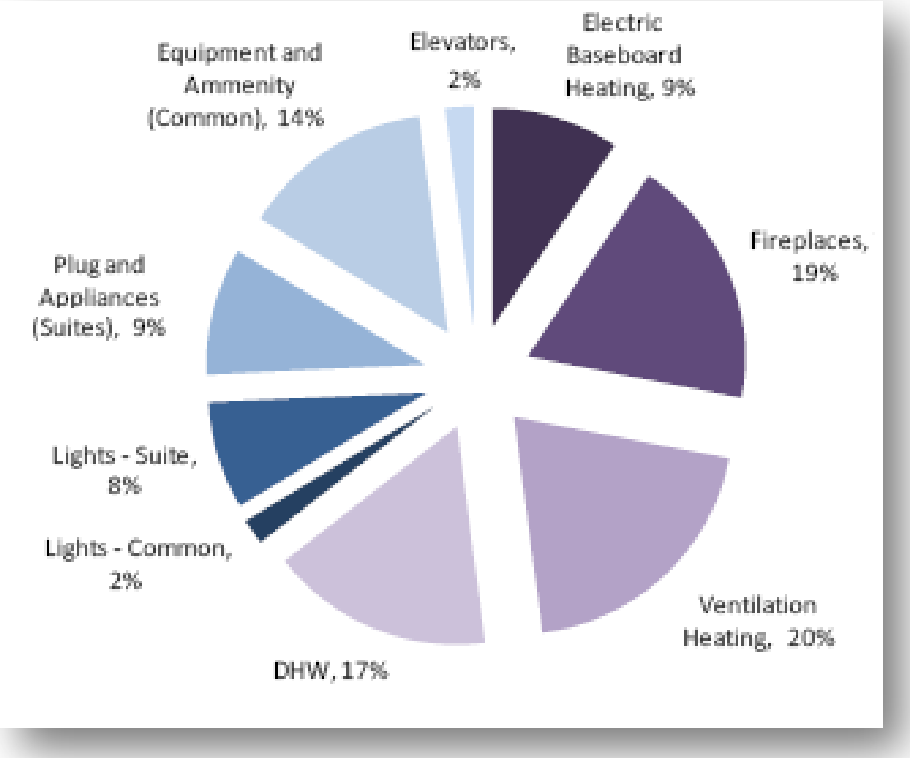


Figure 11 - Distribution of Typical Apartment Building Energy Consumption [17]

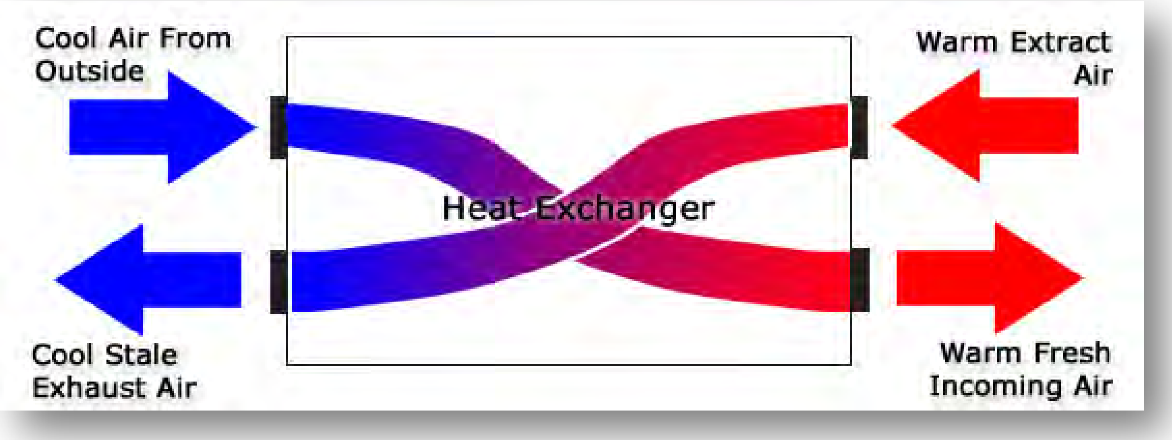


Figure 12 - Diagram of Heat Recovery Ventilation System

In literature heat recovery ventilation systems are known as heat recovery ventilators (HRV) for sensible heat transfer or enthalpy recovery ventilators (ERV) if transferring sensible and latent heat (moisture). Either system can be installed on top of an existing air handing unit infrastructure within a building. What defines whether the system is a HRV or ERV is the type of heat exchanger core used within the system.

The advantages of using HRV or ERV are lower utility costs due to increased efficiency, greater building temperature control, lower building GHG emissions and improved air quality. The level of efficiency achieved by installing such equipment is dependent on the characteristics of the building chosen. The air tightness of a building is an important factor affecting the amount of recovered heat. The larger the air leakage rate within a buildings envelope, the lower the flow of exhaust air going through the HRV. Therefore the available amount of heat recovery would be lower. If electricity rather than gas is used to heat the incoming fresh supply air in a central HVAC system the expected energy savings may be lower due to increased electrical load of blowers used in HRV compared to the heat energy saved. As the difference in heat/enthalpy recovery ventilators comes down to the design of the heat exchanger, four main heat exchanger designs are explained below. These heat exchanger technologies are used as the central part of a heat recovery ventilator system and are currently available on the market.

2.2 Purpose

The purpose of the chosen CEEN 596 topic was to evaluate the feasibility of using heat recovery ventilation systems to save energy in a multi-unit residential apartment (MURB). The project explored the most appropriate type of heat recovery ventilation system suited to a typical MURB setting. The Sail building currently under construction by Adera on UBC Campus (see Figure 47 location details) will be targeted as a case study example to determine the potential reduction in utility energy use. The feasibility will consider the savings in utility consumption and other forgone costs compared to the additional financial cost of installing and operating a heat recovery ventilation system within the Sail building.

2.3 Objective

The objective of the report was to answer the following points:

- Define most appropriate HRV design for the installation into a multi-unit residential building
- Determine current Sail building utility costs for heating and ventilation
- Determine the cost of instillation of the HRV into each suite and the potential reduction in building utility cost
- Investigate the financial feasibility in adopting the HRV ventilation design into the Sail building

2.4 Background

Adera developments have positioned itself in the last 10 years as a green building developer, by leading adoption of sustainable building practices. Adera is the largest builder of green homes in BC. The Canadian Home Builders' Association has recognized Adera as Built Green Builder of the Year for three consecutive years (2009-2011). Tom Awram was interested in investigating whether or not to HRV should have been an option to the list of green building design additions they currently go through in order to increase building energy efficiency and reduce building utility consumption.

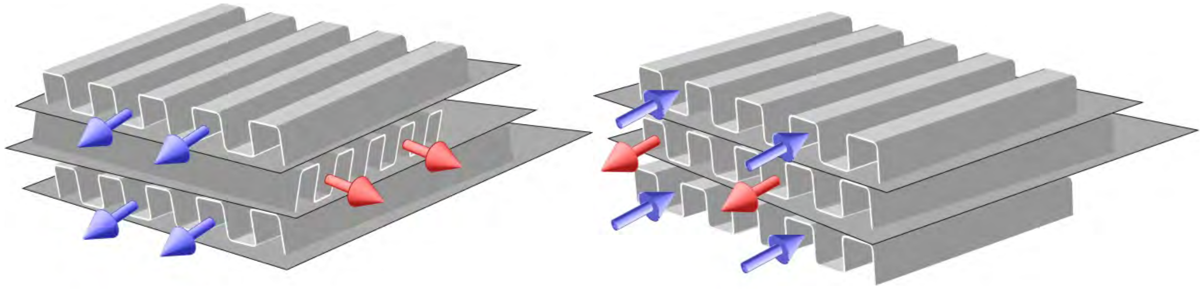
The Sail project has begun construction and will be completed for occupancy in August 2013. Therefore a retrospective analysis on the project will be conducted to focus on the "what if" question of how much it would of cost to implement a HRV system and what would have been the utility savings. The answer to these questions is useful for Adera as a developer to understand what is the best bang for their buck, in terms of reducing energy consumption with respect to cost of implementation. It is not financially beneficial for a developer to invest in technologies with a payback period of greater than 4 years. Strata councils could fund projects through a lease agreement with the developers to implement a particular technology that is expected to have a 7 – 10 years payback period. This is somewhat unusual as in most cases the developer is not sure when the building will have greater than 50% occupancy. The developer is making decisions based on what sustainable building technologies are looked upon favourably from its particular market demographic. There is a financial motive to reduce building construction costs to ensure higher profits are realized when the suites are sold within the building.

2.5 Literature Review

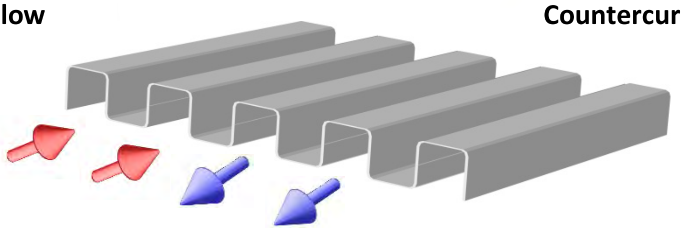
2.5.1 Fixed Plate

The heat exchanger core is constructed in a plate design providing channels for both fresh and stale air streams to flow past each other. The exchanger surface is constructed of thin plates stacked one on top of each other with a measured gap in between for air to flow. Experiments have shown the gap height is an important characteristic of any HRV [18]. For a given fan power the larger the gap height, the higher the total heat transfer rate. This relationship stands true up to a certain height, after which increasing the height reduces the overall performance of the HRV. Determining the optimal height is dependent on the temperature difference between the incoming and outgoing air, the pressure drop within the system and the fan speed.

The heat exchanger core can also be constructed in a permeable membrane cube design with several air channels. The core operates by transferring thermal energy from the outgoing air to the incoming air via the heat exchanger surface. The three main flow regimes are either cross flow, countercurrent or parallel flow, and are shown in the diagram below.



Cross Flow **Countercurrent Flow**



Parallel Flow

Figure 13 - Flow Regimes

The material for the core itself can vary greatly from thin aluminum sheets and treated corrugated cardboard to a porous plastic membrane. The material of the heat exchanger core dictates whether you have a HRV or ERV as sensible and latent heat can be transferred by membrane cores. Using a plastic thin film plate heat exchanger core working under cross flow regime vibrates the thin plastic film within the core, which actually increases the total heat transfer rate [19]. It is postulated the vibration action continually removes the film condensation of water moisture that occurs on the thin plastic sheet within heat exchanger core due to the action of latent heat transfer from outgoing air to the thin plastic wall. Therefore the continual removal of the film condensate helps to lower the resistance to the heat flux and causes an increase in total heat transfer rate. Traditionally the fixed plate design is the most common design type for heat exchangers seen in the process and manufacturing industry. Hence it has been adopted by many companies in the ventilation industry with regards to the HRV core. Fixed plate heat exchanger cores typically have an efficiency of 55-60% for sensible heating and 65-75% for latent heat transfer. Systems with fixed plate heat exchanger cores can be seen in the figures below.

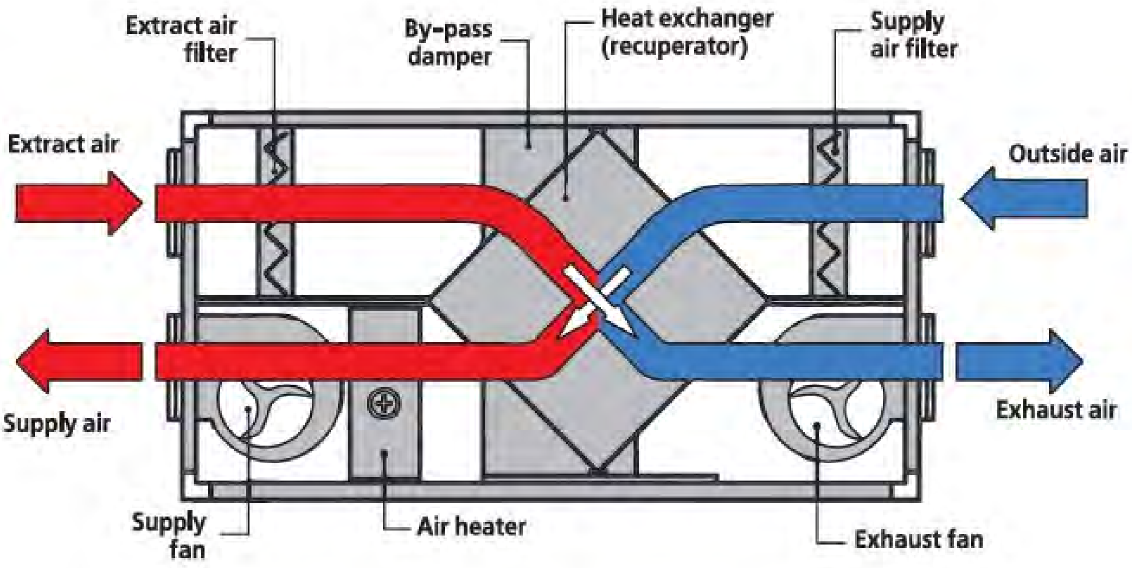


Figure 14 - Fixed Plate Core HRV/ERV [20]

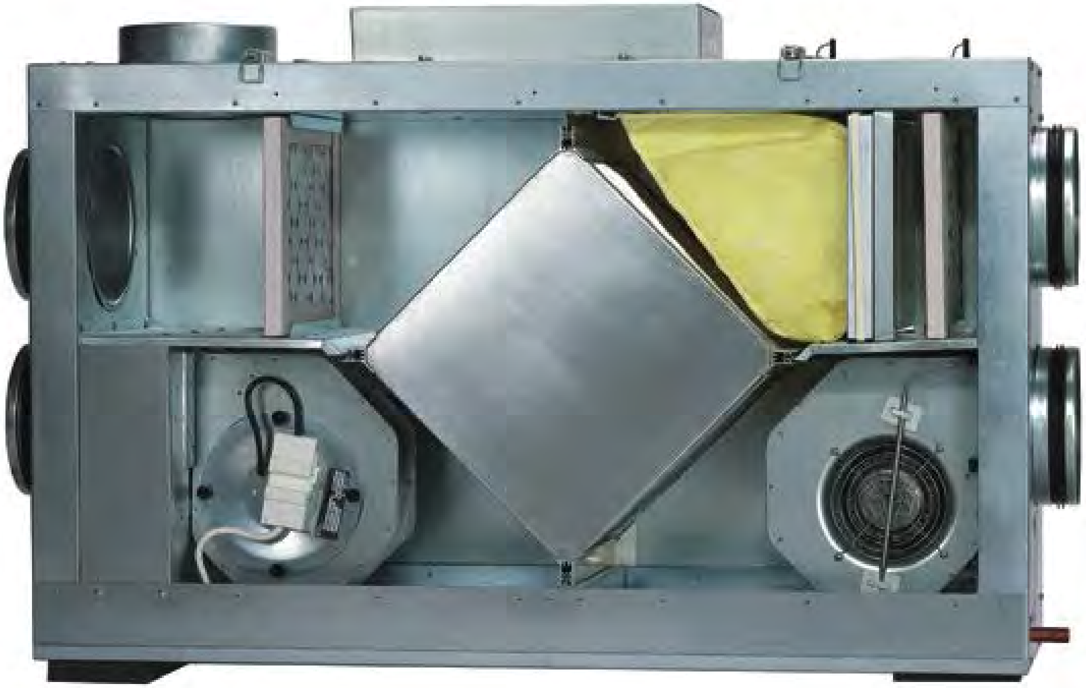


Figure 15 - Real Life Fixed Plate HRV Helios KWLC 650 unit

2.5.2 Heat Pipe

The heat pipe design uses a sealed system made from a material with high thermal conductivity such as copper or aluminium, which contains an evaporating fluid at low pressure. A partial pressure is set within the pipes, which is near the vapour pressure of the working fluid within the pipe. Therefore the latent heat of vaporisation transfers thermal heat as the working fluid changes phase. The setup is advantageous when you require thermal transfer over a long distance with a corresponding small temperature difference.

The unit is essentially separated into two systems one side acting as the evaporator with the other end as a condenser, creating a cyclical Carnot cycle. The working fluid in liquid phase is heated by the warm exhaust air and changes to vapour. The exhaust air exits the system at a lower temperature. The vapour within the pipe then travels to the condensing side where it is cooled by the fresh incoming air changing phase back into liquid. The incoming fresh air is heated by the action of the vapour changing phase to liquid. A wick structure is placed around the outside wall of the pipe to provide capillary action pumping for the working fluid in liquid state to move back to the evaporating side. A diagram of the heat exchanger can be seen below.

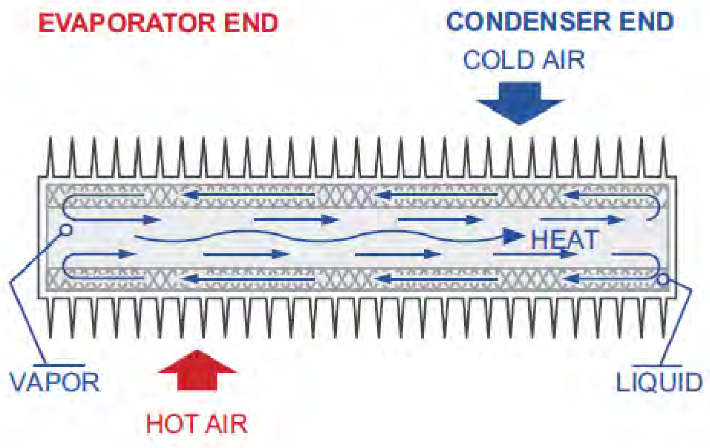


Figure 16 - Heat Pipe HRV

The heat pipe heat exchanger design doesn't have any moving parts and provides low flow resistance and therefore pressure drop. The heat pipe heat exchanger shown in Figure 17 is part of a larger system that is similar in design to the fixed plate HRV/ERV. Both designs have blowers and filters to move and filter the air before it is heated. The dangers of cross contamination are low due to the flow direction of the exhaust and fresh air. The effectiveness of the system is determined by two main characteristics flow velocity of air past the heat exchanger and the thermal contact of the air with the fins on the heat exchanger. Experimental work indicated that at low air velocities the pressure loss decreases, while increased pressure losses are observed at higher air flow velocities [21]. Typical expected efficiency is in the range of 45-55%.

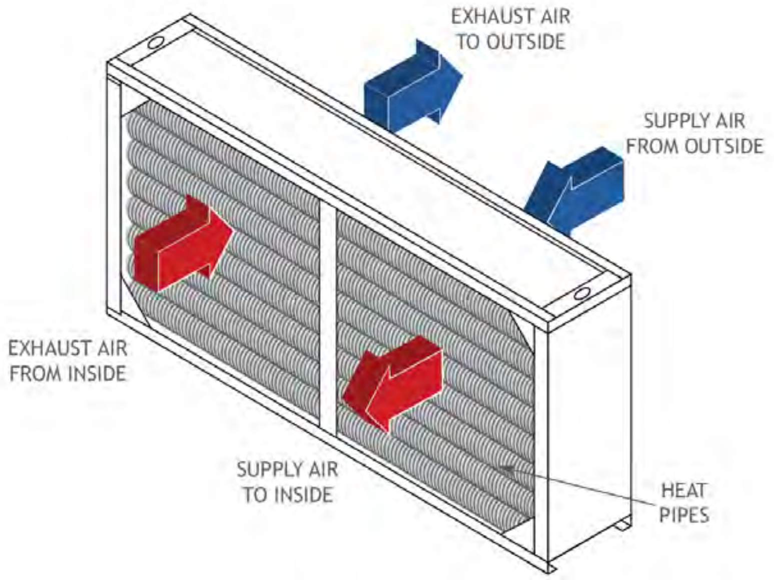


Figure 17 - Heat Pipe Heat Exchanger

2.5.3 Rotating thermal wheel

In this case the heat exchanger is in the shape of a circular rotor consisting of a honeycomb permeable membrane, which rotates past two air flows: the exhaust and fresh air. The heat exchange membrane is typically manufactured from aluminium, but can also be made from plastics and synthetic fibres with hygroscopic coating giving rise to high adsorption rates of water vapour. Latent and sensible heat is recovered by drawing outside air across half of the enthalpy wheel and drawing exhaust air across the other half. As the wheel rotates sensible heat is picked up from the exhaust air stream in half a rotation and given up to the fresh air stream in the other half of the rotation. Latent heat is transferred by the permeable membrane of the rotor providing a structure for the moisture within the exhaust air to be entrained within the rotor and picked up by the fresh air flow in the next half of the rotation. Sensible and latent heat transfer is simultaneous and gives an overall high efficiency within the ranges of 80-90%.

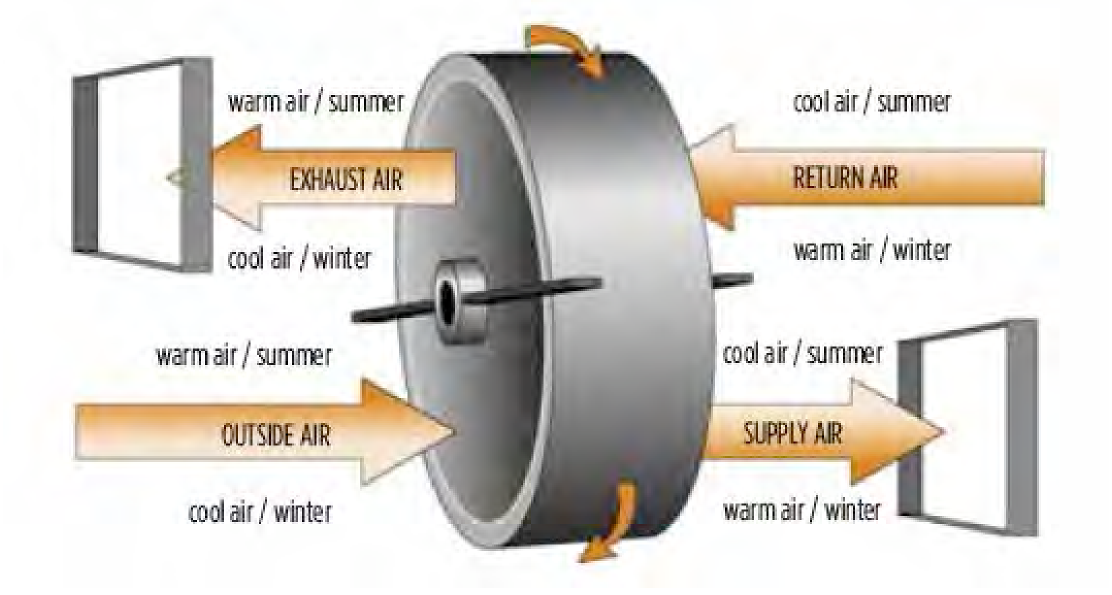


Figure 18 - Rotating Thermal Wheel ERV

The rotor is driven by a motor at low speeds of 3-15 rpm in a belt drive system. The unique advantage of the rotating wheel is the capability of recovering both latent and sensible heat. The shallower depth of the heat exchange membrane compared to a fixed plate heat exchanger has the advantage of experiencing lower pressure drop through the thermal wheel. The pressure drop across the thermal wheel may be increased by 30% by the level of uptake of moisture within the membrane rotor. The design only permits cross flow air past the thermal wheel.

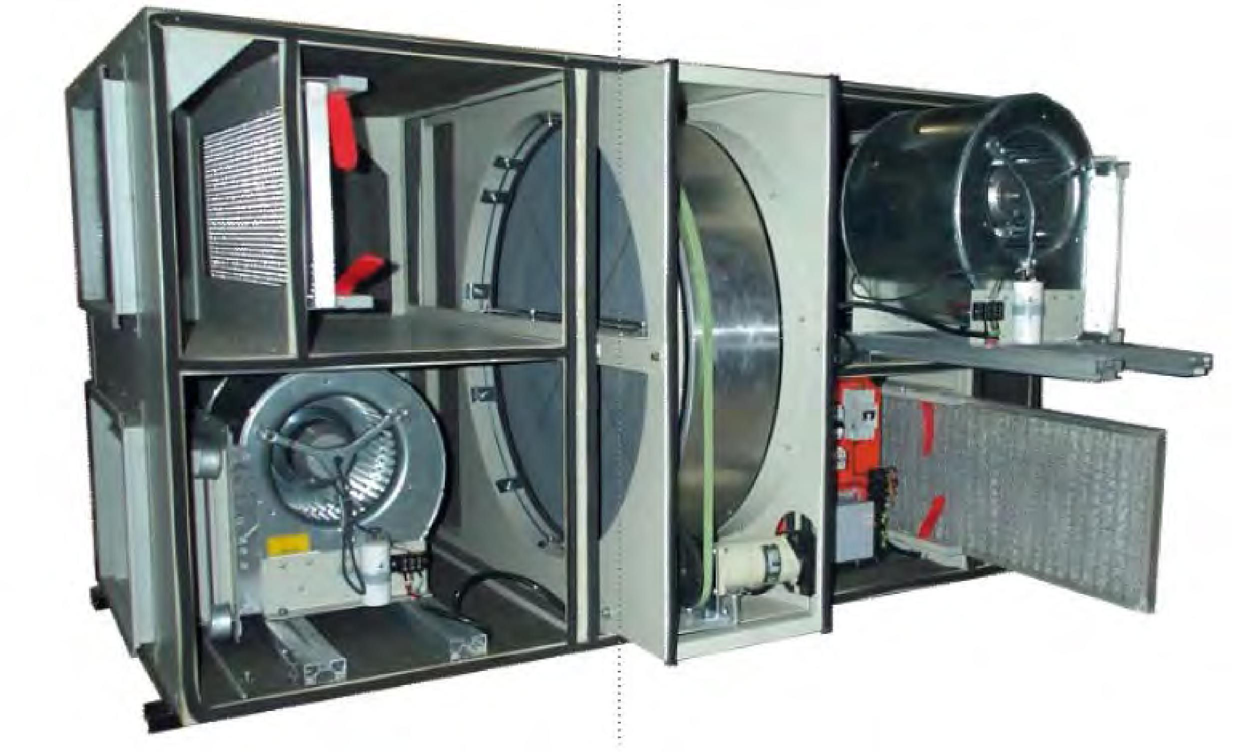


Figure 19 - Real Life Rotating Thermal Wheel Nuaire T1-TWB Unit

The disadvantage in the restriction of air flow regimes and the rotating action of the wheel gives way to higher possibilities of cross contamination. The two main ways cross contamination occurs in thermal wheels is in the form of leakage and carryover. Fouling of the thermal wheel may be an issue as it becomes very difficult to impossible to clean the permeable membrane effectively. With more moving parts the system as a whole can be noisier compared to other simpler system discussed. The small motor used to move the rotor uses electricity, therefore the electrical consumptions is slightly higher.

2.5.4 Runaround

The term run around refers to two recuperative heat exchangers that are physically separated but connected by a piped circuit, which contains a working fluid acting as an intermediate heat transfer medium. The working fluid is used to transfer heat between fresh air (supply air flow) and stale air (exhaust air flow) flows. The recuperative heat exchanges are placed individually in each air stream. Exhaust air flows past coils in the first heat exchanger heating the working fluid within, which is usually water. The water warmed by the exhaust air is pumped to the second recuperative heat exchanger placed in the fresh air stream, where by the fresh air stream gains heat as its passes over the warm coils in the second recuperative heat exchanger. A diagram of the system can be seen in Figure 20 below.

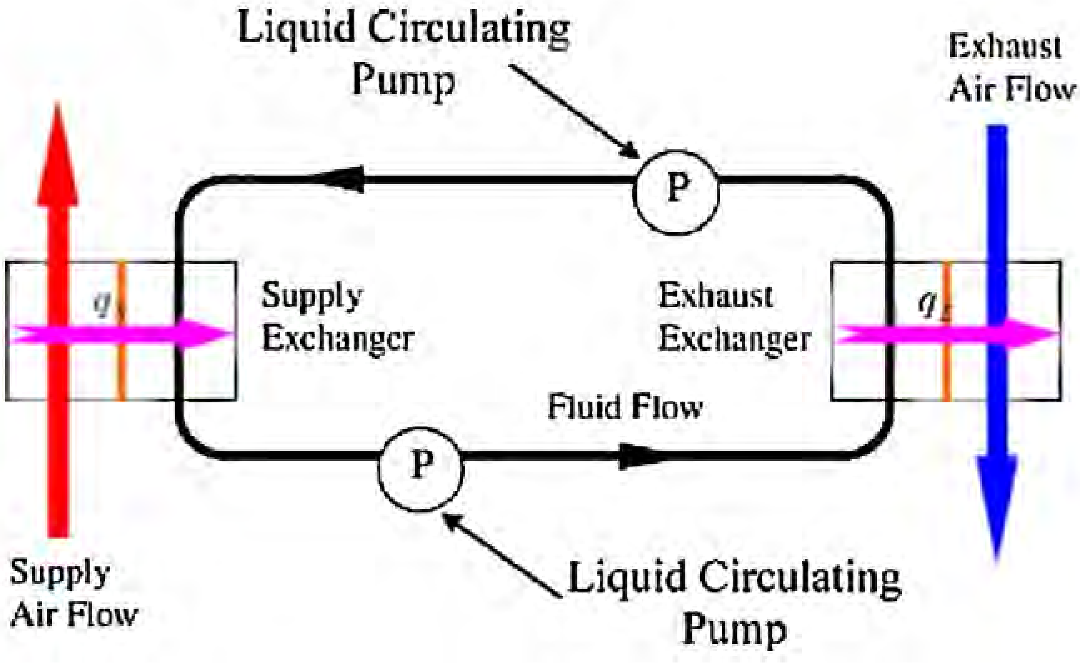


Figure 20 - Runaround Heat Exchanger

The design of the recuperative heat exchanger itself is not unique and can use any two of the heat exchanger designs mentioned above. The unique aspect of the runaround system is the fresh air (supply air) and stale air (exhaust air) flow's ducts do not have to be in the same physical location. Therefore they can be in different places within a building, giving it flexibility in retrofitting applications. The optimum circulating rate of the working fluid around the pipework circuit changes with airflow rates of the exhaust and supply air [22]. The length of the pipework used to connect both recuperative heat exchangers is an important characteristic of the system. The longer the piping circuit, the lower the available heat transfer rate due to heat losses to the environment (friction losses of the working fluid increase as it moves along the pipe). One main disadvantage is the use of a working fluid as the heat transfer medium. The pumping of the working fluid and the electrical consumption of ancillary equipment reduces the system efficiency. Typically efficiency range between 44-65%.

2.5.5 Comparison

The range of effectiveness when considering the four main types of heat exchangers detailed above is in the region of 60 – 85% [23]. The systems respective advantages and disadvantages can be seen in Figure 22. Figure 22 shows fixed plate and rotating wheel designs give higher maiming efficiency ratings. Figure 21 shows at varying pressure and air flow rates, rotating wheel is seen to be the best design to give the highest effectiveness values. The dotted line in Figure 21 shows the relationship with increasing air flow rate to pressure loss, while the solid line refers to the increasing effectiveness with regards to increasing air flow rates. The building characteristic where the heat recovery ventilator will be implemented is important in determining the best possible design to be chosen. Currently BC building code efficiency standard is to implement a HRV technology with a minimum rated efficiency of 60%. This means heat pipes for residential application would not meet this standard. Further investigation for most appropriate design for the sail building application is to be detailed in the methodology section.

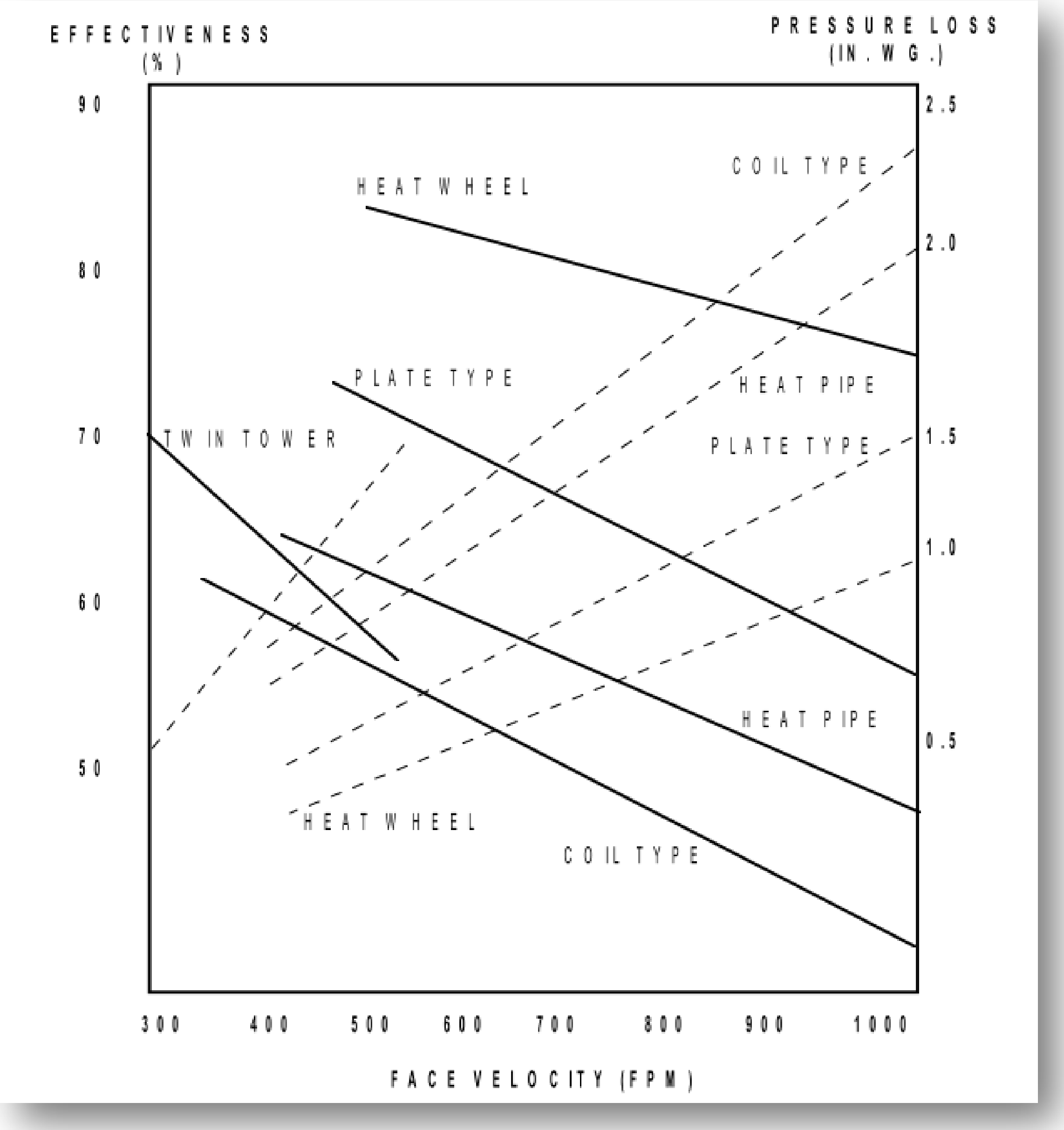
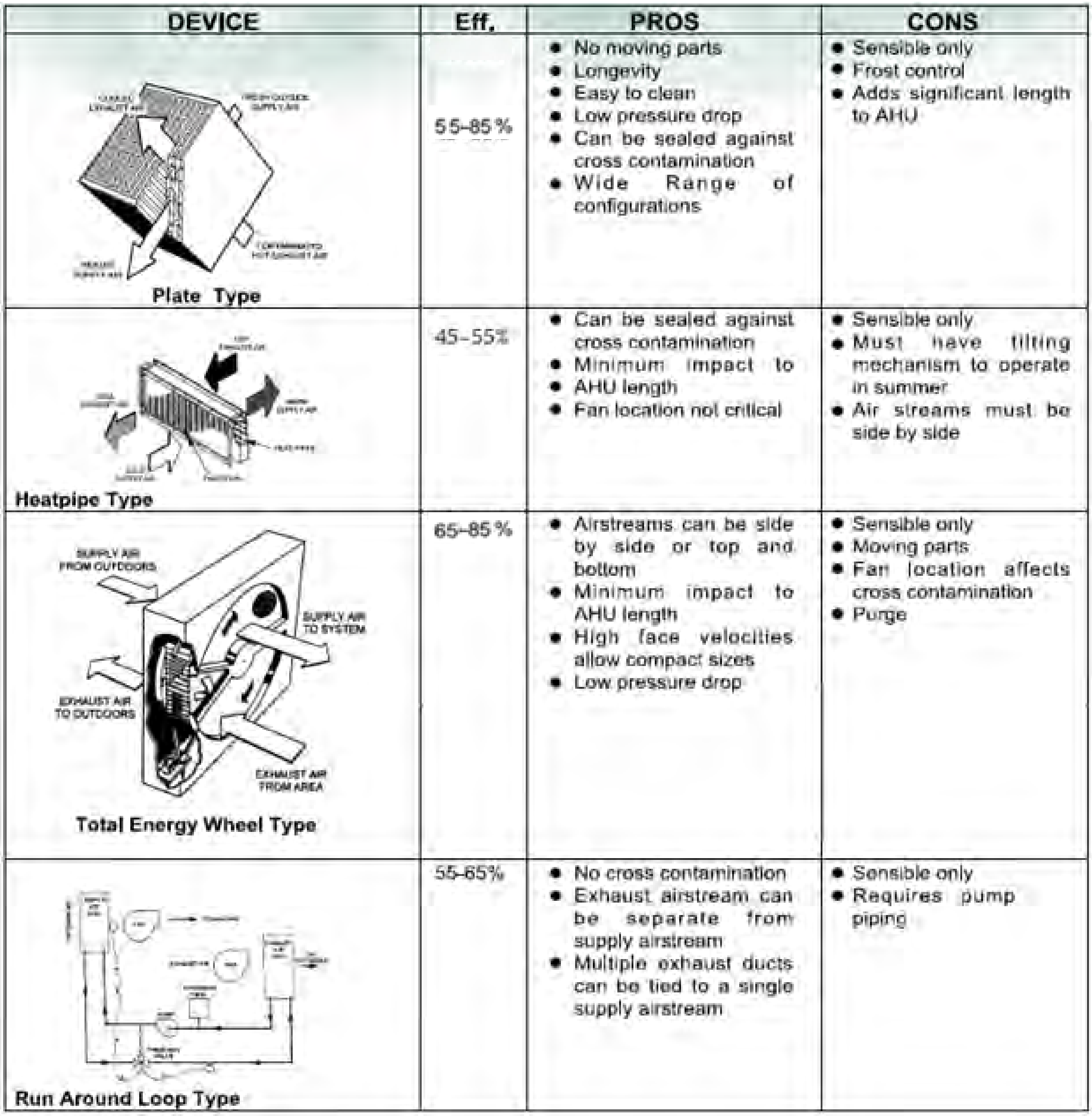


Figure 21 - Effectiveness of Various Types of Heat Recovery Ventilators [31]



DEVICE	Eff.	PROS	CONS
Plate Type	55-85 %	No moving parts Longevity Easy to clean Low pressure drop Can be sealed against cross contamination Wide Range of configurations	Sensible only Frost control Adds significant length to AHU
Heatpipe Type	45-55%	Can be sealed against cross contamination Minimum impact to AHU length Fan location not critical	Sensible only Must have tilting mechanism to operate in summer Air streams must be side by side
Total Energy Wheel Type	65-85 %	Airstreams can be side by side or top and bottom Minimum impact to AHU length High face velocities allow compact sizes Low pressure drop	Sensible only Moving parts Fan location affects cross contamination Purge
Run Around Loop Type	55-65%	No cross contamination Exhaust airstream can be separate from supply airstream Multiple exhaust ducts can be tied to a single supply airstream	Sensible only Requires pump piping

Figure 22 - Comparison of Different Heat Recovery Systems [24]

3.0 Methodology

In order to determine the answers set by the objective of the report, the first step was to select the appropriate heat exchanger design within the range of heat recovery ventilation technologies currently available. For the Sail building the objective is based on a hypothetical quasi-retrofit installation as the investigation on the use of ventilation heat recovery has been approached after the initial architectural design of the building. Therefore some of the choices for the existing ventilation system have already been made, which limit the type of heat recovery system that can be adopted over the existing infrastructure due to cost.

In particular the Sail building has been constructed for passive supply vents with mechanical exhaust in each suite. Fresh air is passively drawn from outside into each bedroom and the living room via inlets installed on the exterior walls near the ceiling. Suite exhaust is removed on an 8hr/day timed basis through the bathrooms. Corridor ventilation is provided separately by central supply ventilation. This means the architectural design of the building does not have a central exhaust system. The option of installing a central exhaust system within the Sail building would increase the cost of a heat recovery ventilation system significantly. Therefore, options for the type of heat recovery technologies are limited to units that would work best in a decentralized system.

Even with the limitation with regards to heat recovery selection for the Sail building, a selection framework was constructed to help anyone with deciding the best type of decentralized heat recovery technology for a multi-unit residential building.

The selection framework is based on a points system that has been generated by qualitative analysis of attributes for different heat recovery ventilation technologies. The framework is posed as a guide to help building managers, strata council members or developer focus on the best type of decentralized heat recovery technology for their building.

The framework was developed using five key attributes that are considered to be important to the decision maker with regards to decentralized ventilation [25].

The attributes in the decision framework are:

- Capital Cost (The market price of each equipment)
- Comfort (whether the technology recovers only sensible or latent heat as well)
- Size of equipment (The volume the equipment would occupy in the suite)
- Maximum Efficiency (The maximum possible sensible efficiency achievable)
- Operation Costs (The relative electrical consumption of the unit on a per CFM basis)

Each attribute was given a score out of 10, with 10 being the most desirable component of that attribute and 1 being the least desirable. Depending on who the decision maker is (e.g. resident, strata council member or developer) weighting factors are assigned based on how the decision maker ranks the attributes from 1st to 5th.

Weighting factors are used to skew the points gained in the selection framework to highlight the best design for a decision makers particular set of preferences. The points gained for each attribute is multiplied by that attributes weighting factor. The system with the highest number of points is determined to be the most appropriate technology for that building. Further investigation should then be conducted to determine energy savings potential with the selected technology.

Once the type of heat recovery technology is selected, the next step is to determine the cost savings of the new ventilation system. In order to achieve this goal a building energy model was used to determine the reduction in energy consumption and corresponding savings. Before the energy model was generated, an estimation of the savings based on reduction of heat load attributed to the new ventilation system was conducted. The calculated estimation gave a reference to the level of accuracy to the building energy model results. It helped to understand if the energy model savings were in the right region. For the estimation method two scenarios were developed, the base case which estimated the ventilation heat loss that would currently exist and the new ventilation system case where the AHU would be removed and HRV installed in each suite on a decentralized basis. The difference between the ventilation heat loss from these two scenarios would be equal to the utility savings by implementing the new ventilation system.

An energy model of the building was developed by Stantec under direction of Adera Developments. The model was created using EE4 software, which uses the DOE 2.1 E building simulation engine. The model was created as part of the requirements of the National Building Code 2011 in demonstrating the energy use within the Sail building will be 25% lower than the Model National Energy Code for Buildings 1997 requirements. The Stantec EE4 building model was used as the base case where no changes to the building ventilation system were conducted. Another EE4 model of the building was constructed that represented the implementation of the new decentralized heat recovery ventilation system. The difference in energy consumption between the two models would yield the energy savings accounted for by the new ventilation system.

Both building energy models take into account a variety of variables to understand the heat load requirements of the Sail building. These variables includes outside air temperature, stack effect, wind velocity, glass to wall ratio, occupancy, equipment, and solar heat gains within the building. Both building energy models use 1996 weather data for Vancouver lower mainland to determine annual energy consumption. This is done by calculating the utility requirements on an hour by hour basis for one full year. This gave an accurate prediction of the annual energy consumption for the whole building for the base case and the new ventilation heat recovery case.

Once the type of HRV/ERV technology was selected and the annual savings in energy were modelled, the next step was to determine the cost of implementing the heat recovery ventilation system in the Sail building. This was achieved by understand the number of elements that go towards each type of cost. The relationship of each element towards the cost of implementation of the new technology can be seen in Figure 23 below.

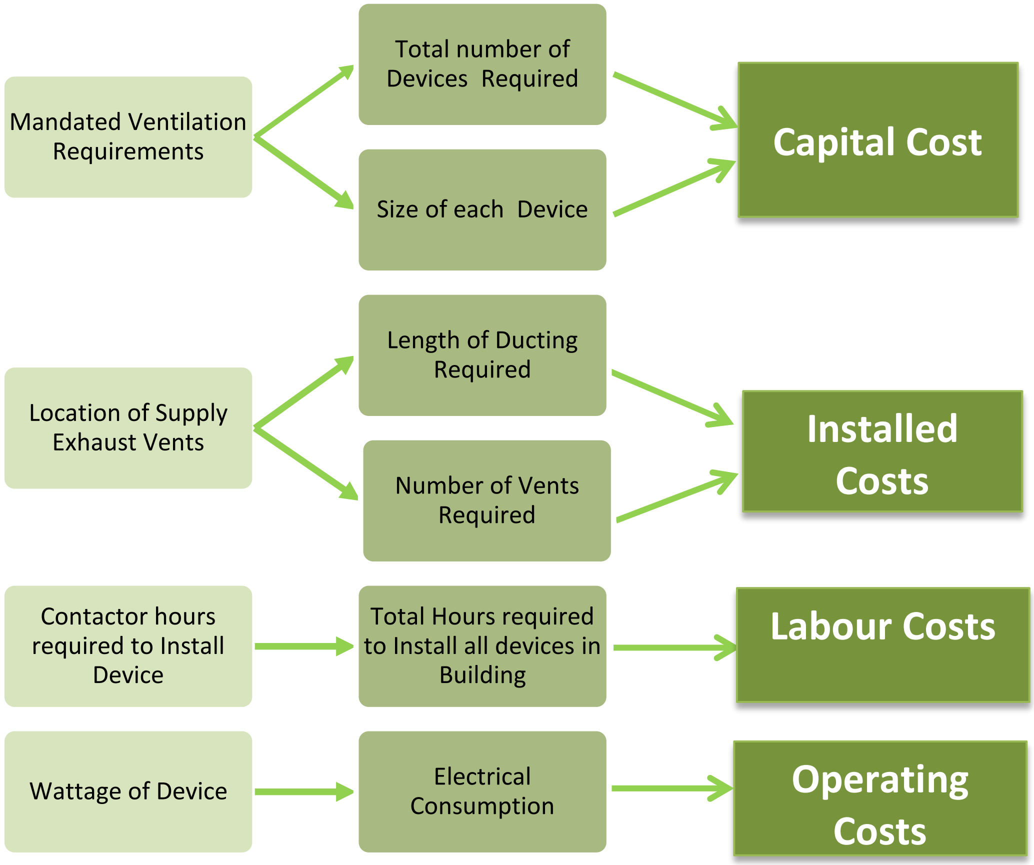


Figure 23 – Implementation Cost Association Diagram

Supply ventilation requirements were calculated using the Ashrae 62.1 2012 specification that are required to be followed by the BC building code. The ventilation requirements were calculated for each suite in order to understand the size of the HRV/ERV required, and the associated cost.

In order to determine the elements of the implementation cost in Figure 23, a layout of each HRV/ERV system for each suite in the Sail building was constructed. The Sail building has 172 suites which are comprised of five distinctly different suites in terms of layout spread across two separate buildings. The suite types are:

- 1Bedroom + 1 Bathroom (9 suites)
- 1Bedroom + Den +1 Bathrooms (15 Suites)
- 1 Bedroom + Den + 2 Bathrooms (11 Suites) or 2 Bedroom + 2 Bathrooms (60 Suites)
- 2 Bedroom+ + Den +2 Bathrooms (34 Suites)
- 3 Bedroom+ 2 Bathrooms (43 Suites)

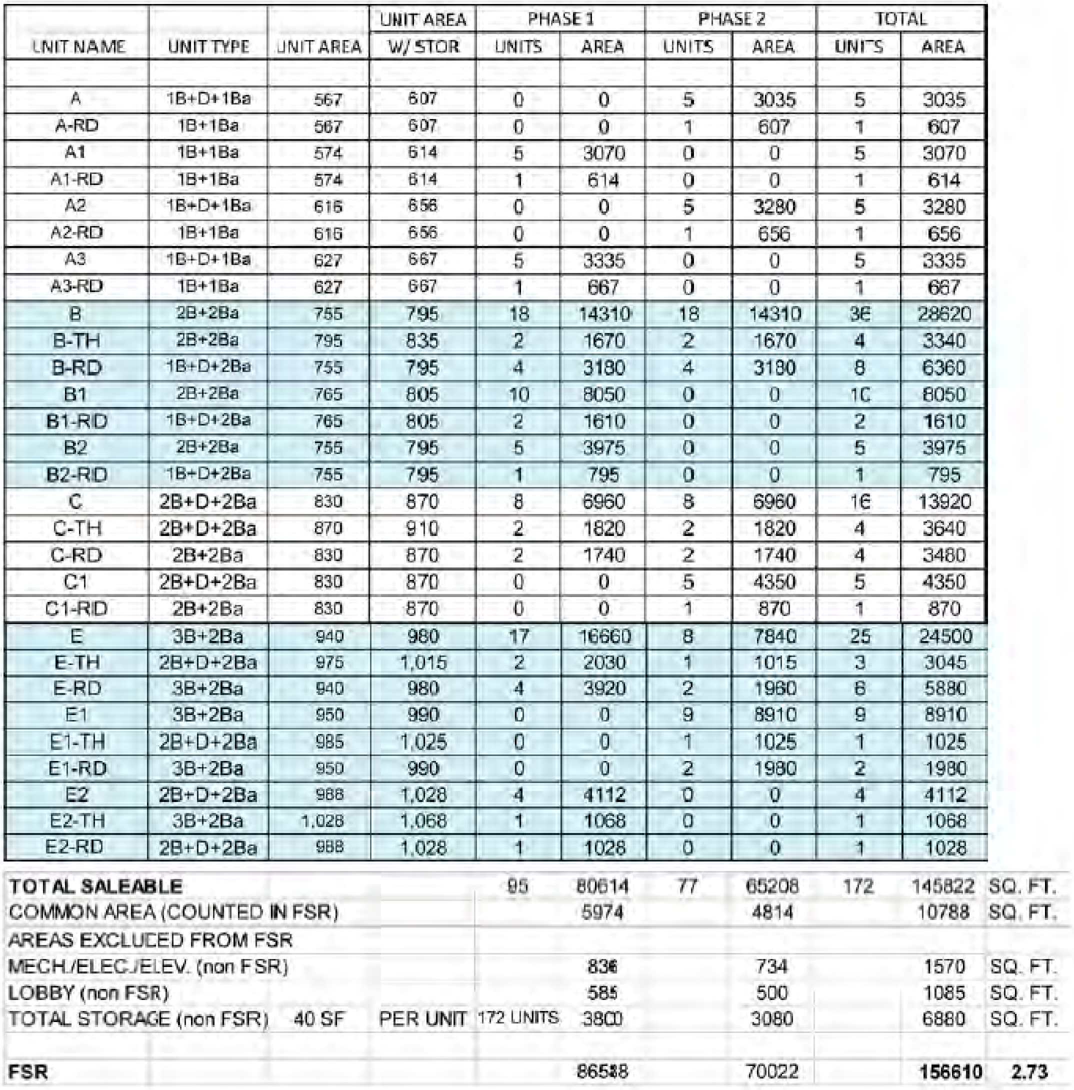
There is no difference in the layout between the 1 Bedroom + Den + 2 Bathrooms and 2 Bedroom + 2 Bathrooms. It is assumed the 1 Bedroom + Den + 2 Bathroom suites are a more luxurious 1 bedroom suite, sold as 1 bedroom penthouse. Each HRV/ERV installation was catered to each of the five suites as no duct run could cross each other due to limited space in the ceiling. The duct run and placement of vents had to be unique to each apartment layout. This gave a realistic approach to understanding the cost associated with ducting and with the size of the HRV/ERV. The ducting diagram also gave an estimation of the man hours required to install each heat recovery ventilation unit for each suite type.

By determining the total cost of implementation and the annual energy savings using the procedures explained above, we can calculate the NPV, IRR and cost benefit ratio on the incremental cost of the new ventilation system. These factors would help determine the financial viability of the project. A decision on whether to invest in the heat recovery technology in the hypothetical Sail building scenario will then be given.

4.0 Data Sources

Architectural floor plans of the Sail building were used in most of the analysis in determination of ventilation requirements, ducting layout and building information. The key piece of building information taken from the architectural drawing used in calculations of ventilation requirements in Table 6 & Table 7 can be seen in Table 1 below.

Table 1 - Architectural Key Building Information



UNIT NAME	UNIT TYPE	UNIT AREA	UNIT AREA W/ STOR	PHASE 1 UNITS	PHASE 1 AREA	PHASE 2 UNITS	PHASE 2 AREA	TOTAL UNITS	TOTAL AREA	
A	1B+D+1Ba	567	607	0	0	5	3035	5	3035	
A-RD	1B+1Ba	567	607	0	0	1	607	1	607	
A1	1B+1Ba	574	614	5	3070	0	0	5	3070	
A1-RD	1B+1Ba	574	614	1	614	0	0	1	614	
A2	1B+D+1Ba	616	656	0	0	5	3280	5	3280	
A2-RD	1B+1Ba	616	656	0	0	1	656	1	656	
A3	1B+D+1Ba	627	667	5	3335	0	0	5	3335	
A3-RD	1B+1Ba	627	667	1	667	0	0	1	667	
B	2B+2Ba	755	795	18	14310	18	14310	36	28620	
B-TH	2B+2Ba	795	835	2	1670	2	1670	4	3340	
B-RD	1B+D+2Ba	755	795	4	3180	4	3180	8	6360	
B1	2B+2Ba	765	805	10	8050	0	0	10	8050	
B1-RD	1B+D+2Ba	765	805	2	1610	0	0	2	1610	
B2	2B+2Ba	755	795	5	3975	0	0	5	3975	
B2-RD	1B+D+2Ba	755	795	1	795	0	0	1	795	
C	2B+D+2Ba	830	870	8	6960	8	6960	16	13920	
C-TH	2B+D+2Ba	870	910	2	1820	2	1820	4	3640	
C-RD	2B+2Ba	830	870	2	1740	2	1740	4	3480	
C1	2B+D+2Ba	830	870	0	0	5	4350	5	4350	
C1-RD	2B+2Ba	830	870	0	0	1	870	1	870	
E	3B+2Ba	940	980	17	16660	8	7840	25	24500	
E-TH	2B+D+2Ba	975	1,015	2	2030	1	1015	3	3045	
E-RD	3B+2Ba	940	980	4	3920	2	1960	6	5880	
E1	3B+2Ba	950	990	0	0	9	8910	9	8910	
E1-TH	2B+D+2Ba	985	1,025	0	0	1	1025	1	1025	
E1-RD	3B+2Ba	950	990	0	0	2	1980	2	1980	
E2	2B+D+2Ba	988	1,028	4	4112	0	0	4	4112	
E2-TH	3B+2Ba	1,028	1,068	1	1068	0	0	1	1068	
E2-RD	2B+D+2Ba	988	1,028	1	1028	0	0	1	1028	
TOTAL SALEABLE				95	80614	77	65208	172	145822	SQ. FT.
COMMON AREA (COUNTED IN FSR)					5974		4814		10788	SQ. FT.
AREAS EXCLUDED FROM FSR										
MECH./ELEC./ELEV. (non FSR)					836		734		1570	SQ. FT.
LOBBY (non FSR)					585		500		1085	SQ. FT.
TOTAL STORAGE (non FSR)		40 SF	PER UNIT	172 UNITS	3800		3080		6880	SQ. FT.
FSR					86588		70022		**156610**	**2.73**

The parameters used for the EE4 building energy model can be viewed in Table 2.

Table 2 - EE4 Building Energy Model Parameters

Occupancy Density	24.1 m^2/occ
Roof R-value	5.09 °C·m^2/W (R-28.9)
Walls R-value	3.22 °C·m^2/W (R-18.3)
Windows U-value	1.99 W/°C/m^2 (U-0.35)
Window/Wall Ratio:	33.60%
Lighting power density	8.64 W/m^2 (0.80 W/ft2)
Plug load density	4.45 W/m^2 (0.41 W/ft2)
Unintended Infiltration Rate	0.17 ACH
Ambient Indoor Air Temperature	20°C
Ventilation Balance point	18°C
155MAX HRV Effectiveness	85%
155MAX Electrical Consumption	60 W
Air Handling Unit Electrical Consumption	2800 W
Air Handling Unit Supply Air Flow	5060 CFM
Weather File	1996 BC lower Mainland
Number of Floors	6
Gas Rate	9.94 $/GJ
Electricity Rate	0.069 $/kWh

5.0 Results

5.1 Selection Framework

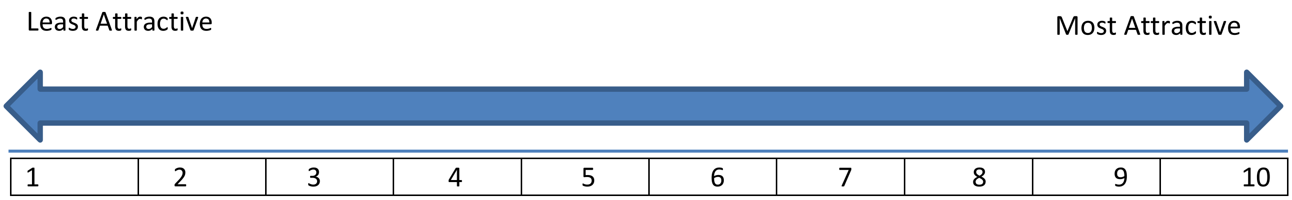


Table 3 - Points Based Comparison of Heat Recovery Technologies

Attribute	Plate Type	Rotary Wheel	Heat Pipe	Runaround
Capital Cost	8.0	6.5	4.0	3.0
Comfort	1.0	10.0	1.0	1.0
Size of equipment	9.0	4.0	5.0	2.0
Maximum Efficiency	8.0	8.5	5.5	6.5
Operation cost	8.0	5.0	10.0	2.0

Table 4 - Weighting Factors

	Decentralized Ventilation System Weighting Factors	
Attribute	Developer	Resident
Capital Cost	0.5	0.05
Comfort	0.05	0.5
Size of equipment	0.15	0.2
Maximum Efficiency	0.2	0.1
Operation cost	0.1	0.15
	1.00	1.00

Table 5 - Selection Framework

Developer Selection Framework						
Rank	Developer Weighting Factors	Attributes	HRV	Rotary Wheel	Heat Pipe	Runaround
1	0.5	Capital Cost	4	3.25	2	1.5
2	0.2	Maximum Efficiency	1.6	1.7	1.1	1.3
3	0.15	Size of equipment	1.35	0.6	0.75	0.3
4	0.1	Operation cost	0.8	0.5	1	0.2
5	0.05	Comfort	0.05	0.5	0.05	0.05
		Totals	**7.8**	6.55	4.9	3.35
Resident Selection Framework						
Rank	Resident Weighting Factors	Attributes	HRV	Rotary Wheel	Heat Pipe	Runaround
1	0.5	Comfort	0.5	5	0.5	0.5
2	0.2	Size of equipment	1.8	0.8	1	0.4
3	0.15	Operation cost	1.2	0.75	1.5	0.3
4	0.1	Maximum Efficiency	0.8	0.85	0.55	0.65
5	0.05	Capital Cost	0.4	0.325	0.2	0.15
		Totals	4.7	**7.725**	3.75	2

5.2 Ventilation Requirements

Table 6 - Ventilation Requirement per Suite

Suite Code	Unit Type	Total Suites	Occupancy per suite	Suite Area (sq.ft)	Supply Ventilation Rate	
					L/s	CFM
A	1B+D+1BA	5	2	567	20.8	44.1
A-RD	1B+1BA	1	2	567	20.8	44.1
A1	1B+1BA	5	2	574	21.0	44.5
A1-RD	1B+1BA	1	2	574	21.0	44.5
A2	1B+D+1BA	5	2	616	22.2	47.0
A2-RD	1B+1BA	1	2	616	22.2	47.0
A3	1B+D+1BA	5	2	627	22.5	47.6
A3-RD	1B+1BA	1	2	627	22.5	47.6
B	2B+2BA	36	3	795	29.7	62.8
B-TH	2B+2BA	4	3	835	30.8	65.2
B-RD	1B+D+2BA	8	2	795	27.2	57.5
B1	2B+2BA	10	3	805	29.9	63.4
B1-RD	1B+D+2BA	2	2	805	27.4	58.1
B2	2B+2BA	5	3	795	29.7	62.8
B2-RD	1B+D+2BA	1	2	795	27.2	57.5
C	2B+D+2BA	16	3	830	30.6	64.9
C-TH	2B+D+2BA	4	3	870	31.7	67.3
C-RD	2B+2BA	4	3	830	30.6	64.9
C1	2B+D+2BA	5	3	830	30.6	64.9
C1-RD	2B+2BA	1	3	830	30.6	64.9
E	3B+2BA	25	4	940	36.2	76.7
E-TH	2B+D+2BA	3	3	975	34.7	73.5
E-RD	3B+2BA	6	4	940	36.2	76.7
E1	3B+2BA	9	4	950	36.5	77.3
E1-TH	2B+D+2BA	1	3	985	35.0	74.1
E1-RD	3B+2BA	2	4	950	36.5	77.3
E2	2B+D+2BA	4	3	988	35.0	74.2
E2-TH	3B+2BA	1	4	1028	38.7	81.9
E2-RD	2B+D+2BA	1	3	988	35.0	74.2
		172				

Table 7 - Ventilation Rate Change

Suite Code	Unit Type	Total Suites	Volume per Suite m^3	Bathroom per Suite	Old Air Changes per Hour	New Air Changes per Hour	Old System Ventilation Rate, L/s	New System Ventilation Rate, L/s	Difference
A	1B+D+1BA	5	164.348	1	0.35	0.46	15.98	20.80	23%
A-RD	1B+1BA	1	164.348	1	0.35	0.46	15.98	20.80	23%
A1	1B+1BA	5	166.377	1	0.35	0.45	15.98	21.00	24%
A1-RD	1B+1BA	1	166.377	1	0.35	0.45	15.98	21.00	24%
A2	1B+D+1BA	5	178.551	1	0.32	0.45	15.98	22.17	28%
A2-RD	1B+1BA	1	178.551	1	0.32	0.45	15.98	22.17	28%
A3	1B+D+1BA	5	181.739	1	0.32	0.45	15.98	22.47	29%
A3-RD	1B+1BA	1	181.739	1	0.32	0.45	15.98	22.47	29%
B	2B+2BA	36	230.435	2	0.50	0.46	31.96	29.66	-8%
B-TH	2B+2BA	4	242.029	2	0.48	0.46	31.96	30.77	-4%
B-RD	1B+D+2BA	8	230.435	2	0.50	0.42	31.96	27.16	-18%
B1	2B+2BA	10	233.333	2	0.49	0.46	31.96	29.94	-7%
B1-RD	1B+D+2BA	2	233.333	2	0.49	0.42	31.96	27.44	-16%
B2	2B+2BA	5	230.435	2	0.50	0.46	31.96	29.66	-8%
B2-RD	1B+D+2BA	1	230.435	2	0.50	0.42	31.96	27.16	-18%
C	2B+D+2BA	16	240.580	2	0.48	0.46	31.96	30.63	-4%
C-TH	2B+D+2BA	4	252.174	2	0.46	0.45	31.96	31.75	-1%
C-RD	2B+2BA	4	240.580	2	0.48	0.46	31.96	30.63	-4%
C1	2B+D+2BA	5	240.580	2	0.48	0.46	31.96	30.63	-4%
C1-RD	2B+2BA	1	240.580	2	0.48	0.46	31.96	30.63	-4%
E	3B+2BA	25	272.464	2	0.42	0.48	31.96	36.20	12%
E-TH	2B+D+2BA	3	282.609	2	0.41	0.44	31.96	34.67	8%
E-RD	3B+2BA	6	272.464	2	0.42	0.48	31.96	36.20	12%
E1	3B+2BA	9	275.362	2	0.42	0.48	31.96	36.48	12%
E1-TH	2B+D+2BA	1	285.507	2	0.40	0.44	31.96	34.95	9%
E1-RD	3B+2BA	2	275.362	2	0.42	0.48	31.96	36.48	12%
E2	2B+D+2BA	4	286.377	2	0.40	0.44	31.96	35.04	9%
E2-TH	3B+2BA	1	297.971	2	0.39	0.47	31.96	38.65	17%
E2-RD	2B+D+2BA	1	286.377	2	0.40	0.44	31.96	35.04	9%
							5113.043	5255.987	3%

* Equations used to calculate Table 6 & Table 7 can be view in appendix B.

5.3 HRV Selection

Table 8 - HRV Running Cost Comparison

	HRV Unit	Watts at Desired CFM	Cost, $
95 Max	129	89	131,580
155 Max	43	60	45,150

Electrical Use 95MAX HRV, kWh/yr	100,574
Electrical Use 155MAX HRV, kWh/yr	25,601
Electrical Consumption Using Mix of HRV, kWh/yr	123,346
Total Capital Cost using mix of HRV, $	176,730
Total Capital Cost using on 155MAX HRV, $	180,600
Electrical Consumption Using All Big HRV, kWh/yr	90,403
Reduction in Energy use using all BIG HRV	27%
Electrical Savings Kwh/yr	32,943
Electricity Rate, $/kWh	0.069
Annual Savings, $	2,273
Extra Capital Expenditure, $	3,870
Capital Cost Difference ratio	1.02

*Equations used to calculate Table 8 can be view in the appendix C.

5.4 Comparison of Estimated Verses Modelled Savings

Table 9 - HRV Cost Saving Comparison

Building Model Method Utility Savings	
Gas Savings, GJ	1,664.33
Electricity Savings, Kwh	-18,436.94
Estimation Method Utility Savings	
Gas Savings, GJ	1,061.36
Electricity Savings, Kwh	-18,422.61
	Utility Costs, $
Old Ventilation System Sail Energy Model	108,955
New Ventilation System Sail Energy Model	96,738
Savings by Installing Heat Recovery Ventilation	12,217
Energy Savings by Estimation Method	9,278.75
Energy Savings by Building Energy Model	12,217.00
% Difference	24%

5.5 HRV Supply and Extract Vent Placement

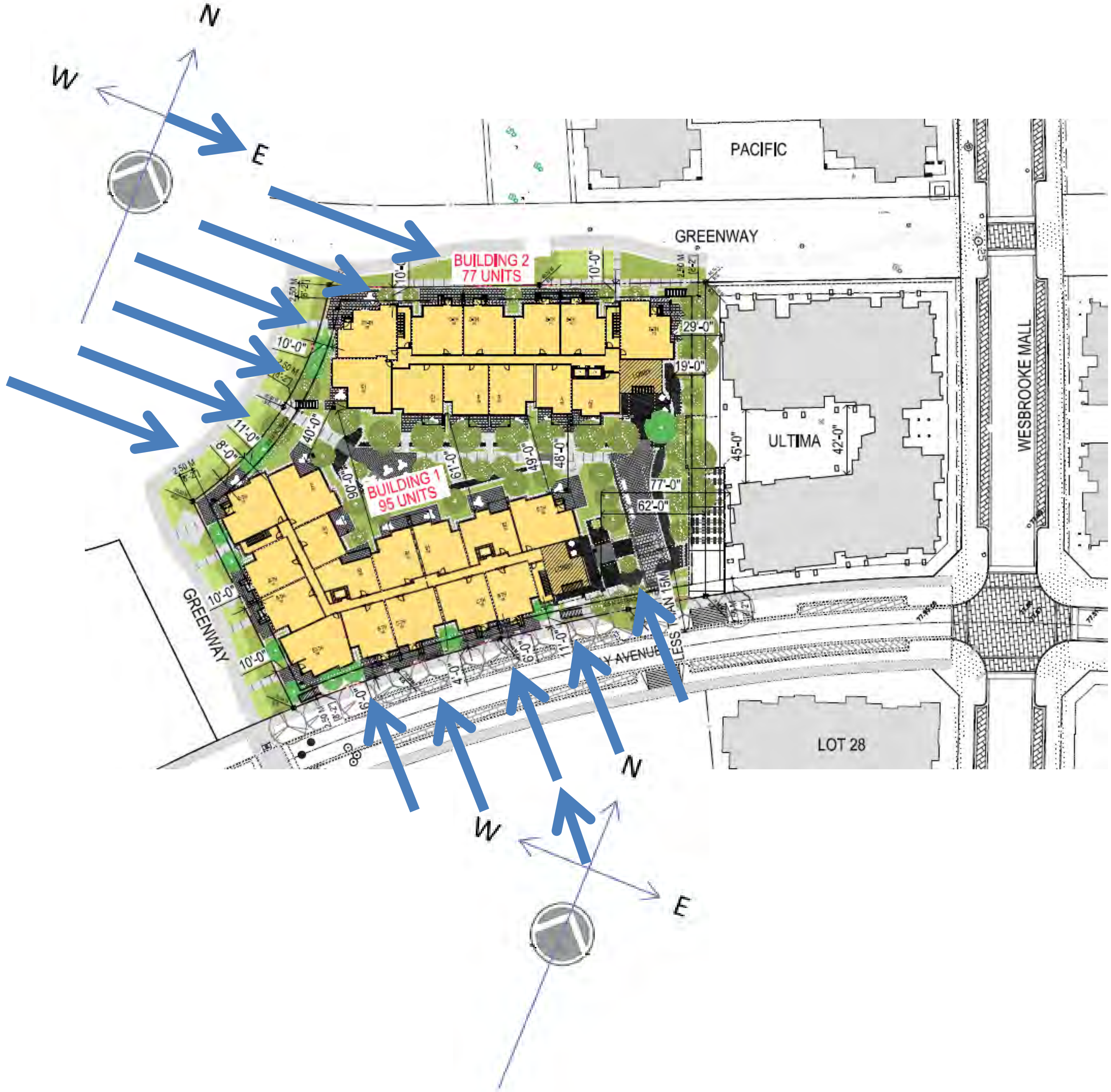


Figure 24 - Annual Wind Direction

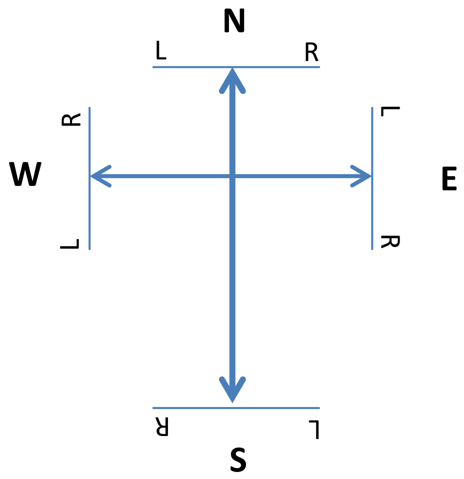


Figure 25 - Wind Direction Key

Table 10 - Outside Supply and Exhaust Vent Placement

	North Side		East Side		South Side		West Side	
	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust	Supply	Exhaust
Building 1	Left	Right	Left	Right	Left	Right	Left	Right
Building 2	Left	Right	Right	Left	Left	Right	Left	Right

5.6 Implementation Cost & Financial Analysis

Table 11 - Financial Analysis of HRV system

Assumptions	
Total Ducting Required, Meters	19985.70
Labour Cost, $/hr	50.00
Duct cost, $/ft	0.90
HRV Cost, $/unit	1050.00
AHU Cost $/unit	9500.00
Existing ducting cost per suite, $	500.00
Suite bathroom Exhaust fan cost, $/unit	89.00
Sheet Metal Shaft cost, $	5000.00
Vent Cost, $/unit	4.90

Old Ventilation System Capital Cost		
AHU	$	28,500.00
Suite ducting	$	86,000.00
Sheet Metal Shaft	$	10,000.00
Suite bathroom Exhaust fans	$	28,480.00
labour	$	10,000.00
Total Installed Capital Cost	$	162,980.00
New Ventilation system Capital cost		
HRV	$	180,600.00
Labour	$	15,000.00
Ducting	$	58,750.62
Vents	$	6,507.20
Total Installed Capital Cost	$	260,857.82
Incremental Capital cost for new system	$	97,877.82
Estimation Savings	$	9,278.75
Energy Model Savings	$	12,217.00

	New Ventilation System	
	Estimate	Energy Model
NPV	$1,170.77	$32,535.92
IRR	8%	12%
Cost Benefits Ratio	1.01	1.33
Payback Period, Year	11	8

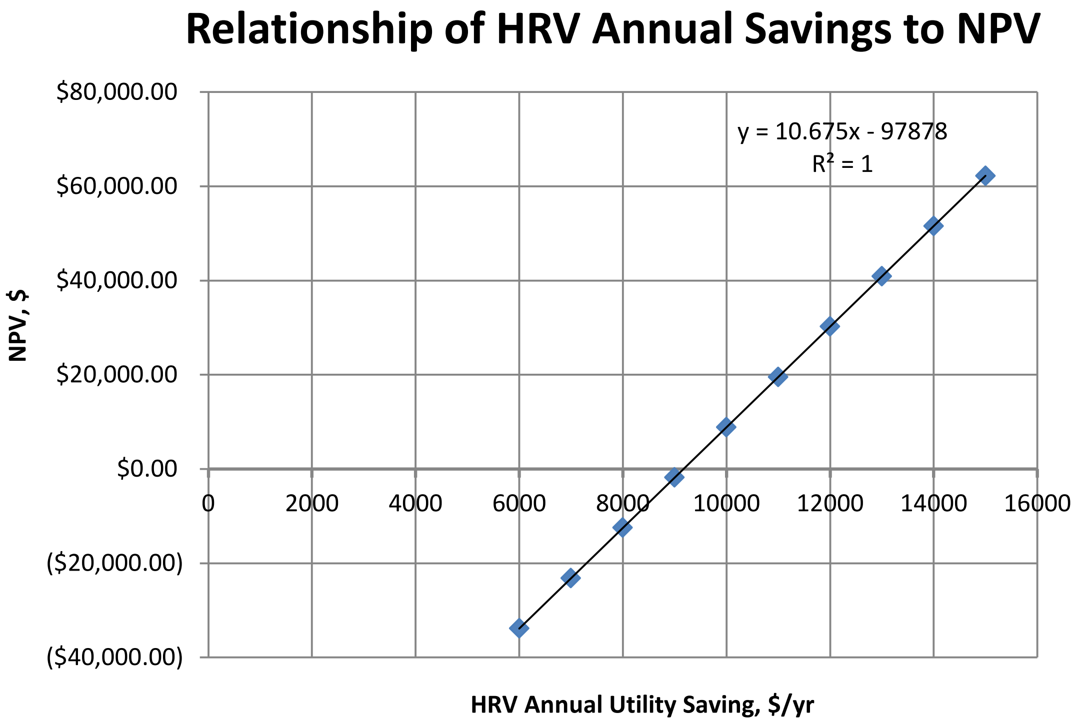


Figure 26 - NPV Graph

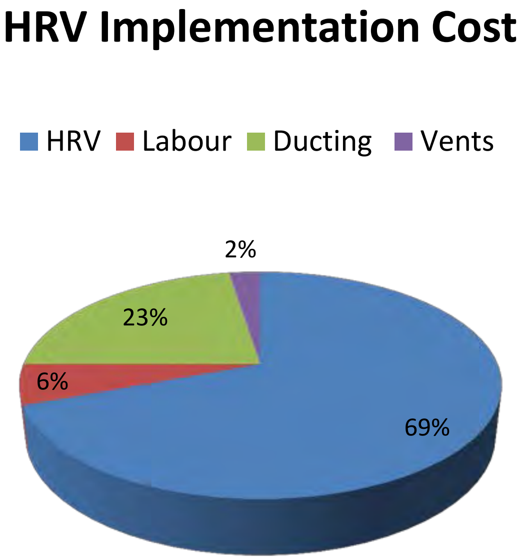


Figure 27 – HRV Implementation Cost

6.0 Discussion

6.1 Selection Framework

The type of heat recovery ventilation technology to use in the Sail building was limited to decentralized systems. This is due to the same reason mentioned in the methodology, as the option of exhausting suites centrally was not chosen when the Sail building was designed. Each suite exhausts air to the outdoors individually using a dedicated ducting system for the dryer, bathrooms and kitchen range hood. Therefore using a central heat recovery unit was uneconomical as you would need to pay significantly more to reroute all the exhaust ductwork for each suite to a central location.

For buildings that do have central supply and exhaust locations, central heat recovery systems would need to be reviewed using different attributes. The points based comparison table used would therefore need to be re-generated with the new list of attributes selected.

The information used to generate the points for each attribute can be view in appendix A. The ranking of developer attributes was conducted by specifically choosing what would be important from a developer’s point of view. Input was gathered from a number of different developers who cited capital cost, efficiency of equipment and floor space taken by the device as highly important attributes when deciding on which technology to install within each suite. Similarly a number of residents who had bought similar suites within the UBC neighbourhood were consulted. The same process was applied in deciding on the ranking of resident’s attributes, where comfort, operation cost and size of equipment were conveyed to be important. An assumption was made that the developer would provide the technology in regards to the capital cost of the equipment and the resident would be in charge of paying for the operation of the equipment. While the decision of what technology to adopt in the case of the

Sail building is to be done from a developer’s perspective, it was deemed important to view the results of the selection framework as if it was a resident led decision.

From a developer’s perspective it is shown in Table 5 that a plate type heat exchanger technology, scoring 7.8 points, would be the best suited technology for the decentralized heat recovery ventilation system for the Sail building. From a resident’s perspective, the same table shows that a thermal wheel, scoring 7.725 points, would be the best option for the Sail building.

From Table 4 the weighting factors show the main differences in preference between developer and resident when deciding on a technology. As the thermal wheel comes a close second with regards to the developer choice scoring 6.55 points, it could be considered a second technology to evaluate if it turns out the plate type design does not result in savings.

A negative aspect of the selection framework would be the limitation in assigning equal weighting factors to a particular attribute. The ranking of attributes will always result in unequal weighting factors applied to each attribute points. It was deemed important to rank the attributes and apply a weighting factor as a way to highlighting the best suited technology for a particular set of preference.

6.2 Ventilation Requirements

The equation used to calculate the ventilation requirements can be viewed in appendix B. It can be seen the ventilation rate varies from 44 to 82 CFM, based on the size of the suite and its occupancy. A plate type heat recovery ventilation unit would need to be sized to deliver at minimum of 82 CFM.

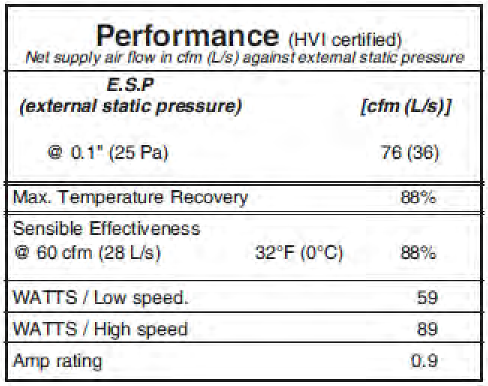
As there is an inherent difference in the new way the Sail building is to be ventilated, it was important to understand the increase in ventilation rates when compared to the original design.

Originally the Sail building was to be ventilated by mechanical extraction. Ashrae 62.1 specification requires a minimum of 0.35 air changes per hour in the suite if air is to be mechanically extracted. Fresh air was then to be provided by infiltration through a passive vent usually placed in the bedroom. This was to be accomplished by setting a timer on the bathroom extract fans to allow them to be on for 8 hours a day.

Alternatively, the new system would directly deliver fresh air into each bedroom and living space and extract stale air from bathrooms continuously. Apart from the inherent benefits of this approach, this ventilation method is thought of as a balanced system with air exchange rates ultimately not differing too much from the original design. Table 7 shows an overall increase of 3% of air changes per hour on a building wide level. Overall, although there is fundamentally a higher amount of air changes per hour, which would mean higher ventilation heat loss, the difference is relatively small. The benefits in terms of delivering fresh air and providing better air quality outweigh the slight increase in ventilation requirements.

6.3 HRV Selection

The Home Ventilating Institute provides third party verification for testing performance of heat recovery ventilation units on the market today. The units are tested based on CAN/CSA C439, Standard Laboratory Methods of Test for Rating the Performance of Heat/Energy-Recovery Ventilators. Certification of the units is provided for products which are tested. Approximately 362 different units are available on the market from varying manufacturers based on the HVI certified product directory [26]. By reviewing the product list in the HVI directory and checking the performance data, two units stand out in regard to high efficiency and correctly sized supply and exhaust flow characteristics. These are the Lifebreath 95 Max and 155 Max, made by Airia brands.

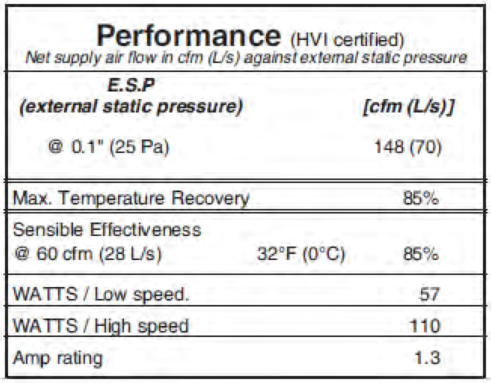


Performance (HVI certified)
Net supply air flow in cfm (L/s) against external static pressure

E.S.P (external static pressure)		*[cfm (L/s)]*
@ 0.1" (25 Pa)		76 (36)
Max. Temperature Recovery		88%
Sensible Effectiveness @ 60 cfm (28 L/s)	32°F (0°C)	88%
WATTS / Low speed.		59
WATTS / High speed		89
Amp rating		0.9

Unit Price $1020 [30]

Figure 29 - 95 MAX HRV



Performance (HVI certified)
Net supply air flow in cfm (L/s) against external static pressure

E.S.P (external static pressure)		*[cfm (L/s)]*
@ 0.1" (25 Pa)		148 (70)
Max. Temperature Recovery		85%
Sensible Effectiveness @ 60 cfm (28 L/s)	32°F (0°C)	85%
WATTS / Low speed.		57
WATTS / High speed		110
Amp rating		1.3

Unit Price $1050 [30]

Figure 28 - 155 MAX HRV

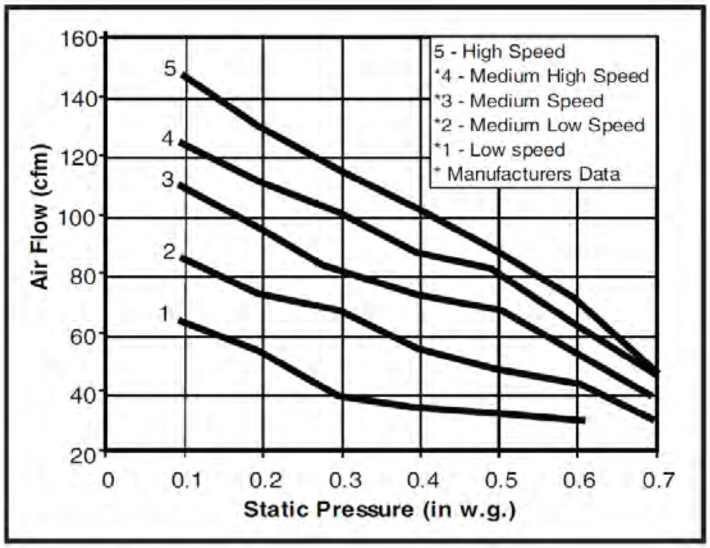


Figure 30 - 155MAX Fan Speed Settings

Both have a high efficiency (temperature recovery) between 85-88%. The majority of suites can use the 95 MAX HRV model for the ventilation rate required, while the rest can use the larger 155 MAX HRV model to cope with ventilation rates above 76 CFM.

But on closer inspection it can be seen the price difference is very small between both units. The majority of the smaller 95 MAX units will be running at higher fan speed consuming higher wattage of around 89W. The larger 155MAX units, on the other hand, run at lower fan speeds and consume 68W of electricity. It therefore it makes financial sense to install the larger 155MAX units in all the suites to reduce electrical consumption by 21W. It can be seen in Table 8 that the financial savings associated with this reduction in electrical consumption is $2,273 and it would cost $3,870 more in capital expenditure. The capital cost difference ratio is comparatively small at 1.02 and it seems worthwhile to invest. Also the larger unit provides more flexibly in motor speed settings compared to 95MAX model. For the savings estimation, the 155MAX unit with 85% efficiency and 68 watts typical consumption will be used with the EE4 building model.

The way the 155MAX unit is controlled is by a digital control display. The HRV unit is expected to be set on continuous ventilation mode and be running continuously. The digital control display lets to vary the speed of the fan, which dictates the ventilation rates that are delivered within the suite. When considering the range of ventilation requirements for all the suites in the sail building are between 44 – 81 CFM speed 1 & 2 would be suitable to set on the unit to provide adequate ventilation. The relationship of speed and CFM delivered can be seen in Figure 30.

The digital control display also has settings for controlling the humidity levels which will trigger the unit to go on when humidity levels are above the set point within the suite. The digital display control unit can be seen in figure jjj

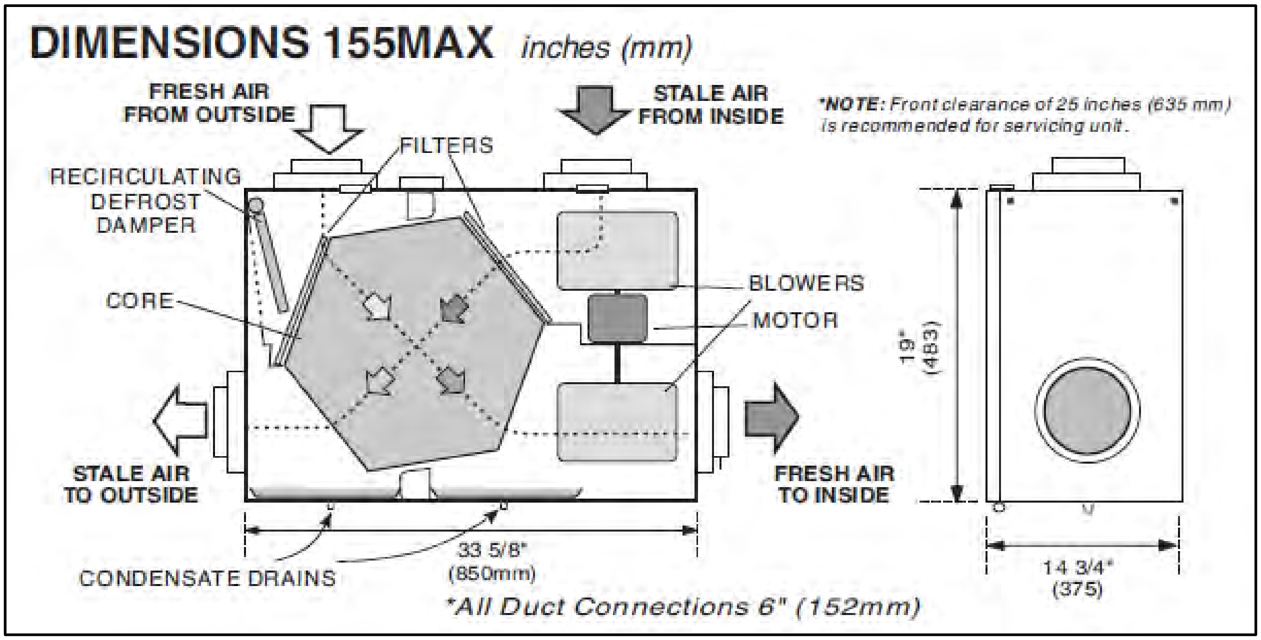


Figure 31 - Selected HRV Dimensions

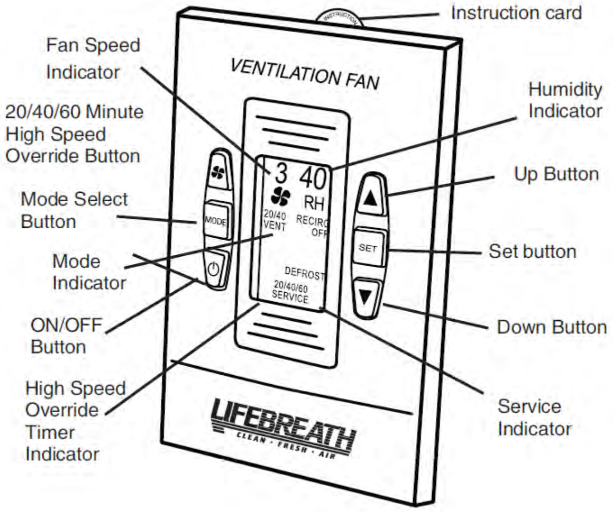


Figure 32 - 155MAX Digital Control Display

The laundry cupboard is the most appropriate place to install the HRV, as it is out of the way but still easily accessible for maintenance purposes. The cupboard space for all of five distinctive suite layouts is relatively the same. The dimension of the HRV unit can be seen in Figure 31. Using this data, the volume of the HRV is calculated at 0.15m^3. This would fit well in the cupboard space, which has a volume of 3.07m^3. It is expected to sit over the washing machine on a dedicated shelf unit.

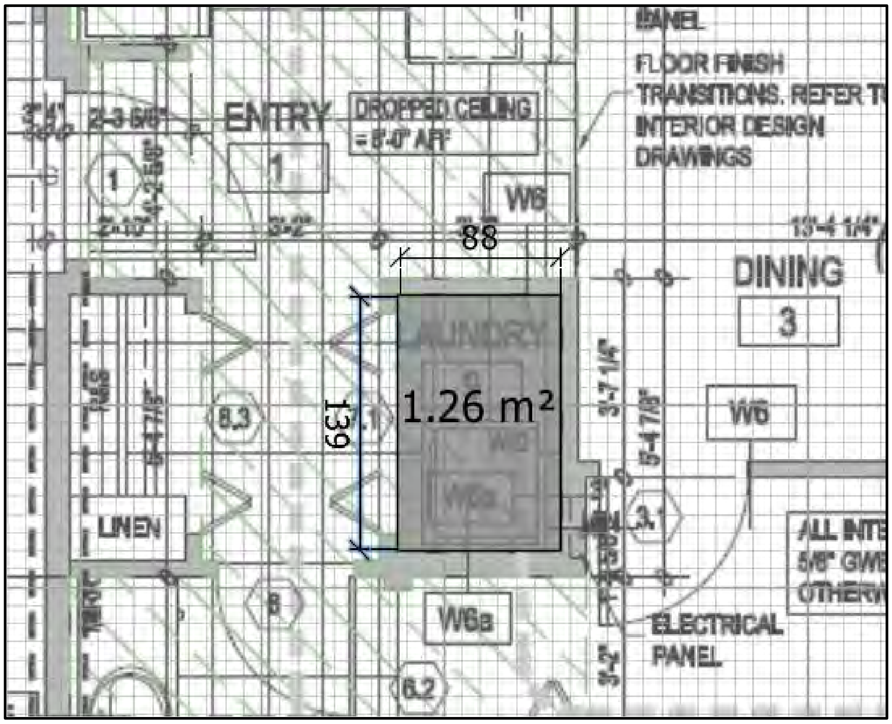


Figure 33 - Location of HRV within Apartment

6.4 Comparison of Estimated Savings Verses Modelled Savings

Now that the HRV is selected, an analysis of the energy savings can be calculated. It was deemed pertinent to calculate estimated savings before generating the building model as a way to determine if the building model energy savings are within reason.

The estimated savings and the modelled savings were both done in a comparative way. Both the methods looked at the existing plan for ventilation in the Sail building, and compared it against the new method to ventilate the Sail building, using heat recovery ventilation. Results in Table 9 show the estimated savings to be $9,279 while energy model savings were predicted to be $12,217. Both results are within the same region and differ by 24%. The main difference seems to be accounted for by the building model predicting higher natural gas savings of 603 GJ.

The difference may be due to different weather files used for both methods and how the data from the weather file was used in the calculation of ventilation heat loss.

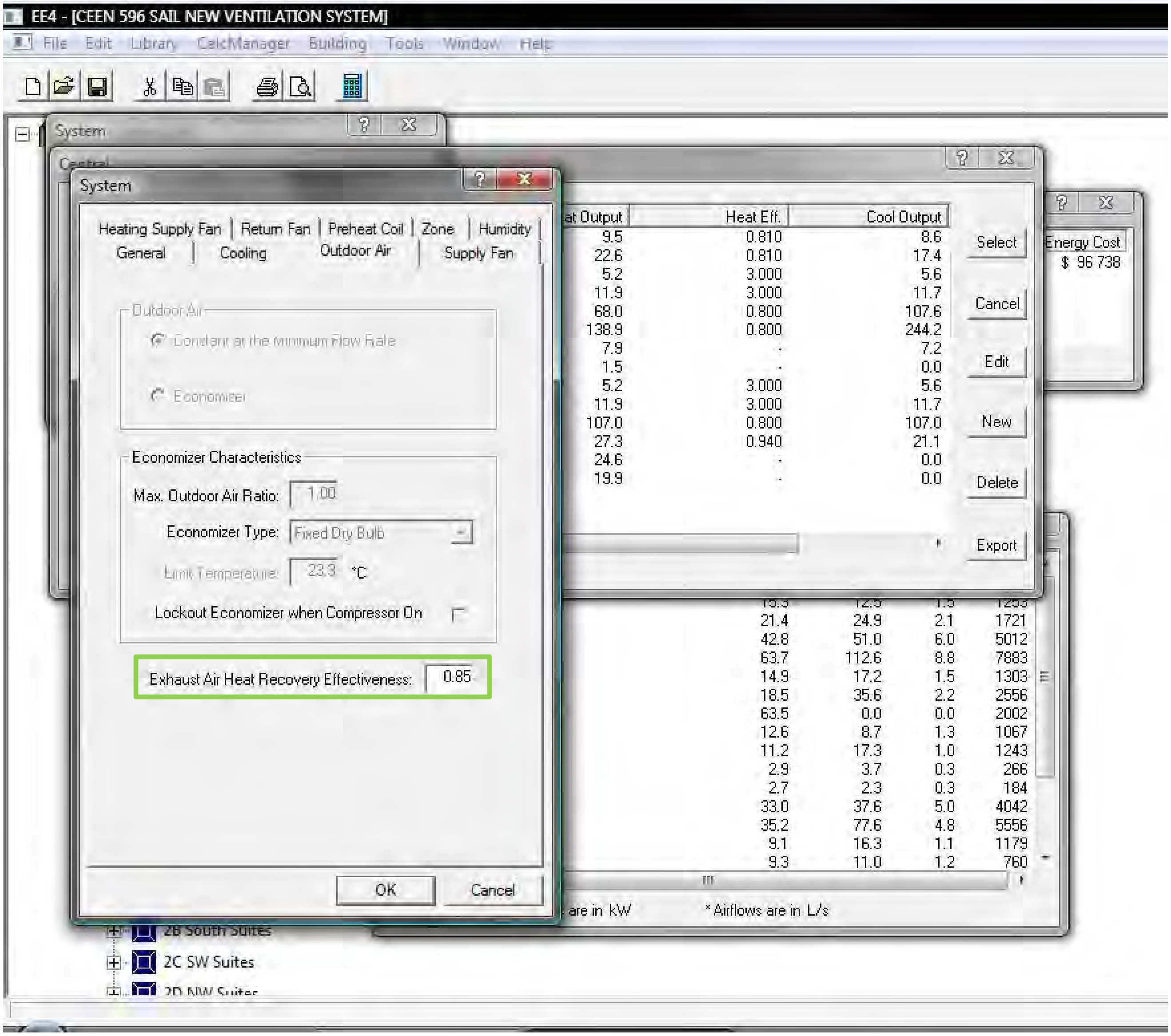
The estimation method only considered heat loss due to intentional infiltration through passive air vents within each suite, and heat loss due to supply ventilation to each corridor delivered by the air handling unit (AHU). The equations calculated heat loss for both AHU and infiltration on a monthly basis. Weather was factored into account by using heating degree days. This can be seen in Table 19 & Table 20. Equations can be viewed in appendix C. The new ventilation system for the estimation method and also the building energy model method assumed there would be no air handling unit providing ventilation to each corridor. Instead every odd numbered suite would have a dedicated supply vent to the corridor supplying fresh air. This was done as not every suite needs to provide supply air to the corridor. Only 50% of the suites on each floor are required to provide adequate ventilation to the corridor. The effect of not using an AHU in the new ventilation system can be seen in Table 21, where there is no energy consumption under the air handling unit cell.

The estimation method energy savings was calculated using the weather data for 2009 for Vancouver UBC location. The 2009 weather file was chosen as it was the best full set of data available from Environment Canada website [27]. The building energy model used 1996 weather data for lower mainland. A more recent weather data set couldn’t be used as access to upload a new weather file within the EE4 program was restricted. Also availability of a weather file in EE4 format to be able to upload was not found.

The overall weather in 1996 was colder than the 2009 weather data used in the estimated method, therefore a proportion of the 603 GJ difference can be assumed to be accounted for based on colder 1996 temperatures. Another important difference in the weather data both methods used is the building energy model method considered wind speed in the calculation of heat loss from a building wide perspective. Higher wind speeds results in larger heat loss through windows and exterior walls in mid to high rise buildings. This could account for another slice of the GJ difference.

The hypothesis for the majority of the difference is the base case in the building energy model method is a more accurate representation of the ventilation heat loss due to it incorporating unintended infiltration (cold airflow coming into the suite through windows, cracks and other joints). Due to the way ventilation is delivered in the base case by bathroom extract ventilation with passive supply vents, each suite is under slight negative pressure. In the building energy model method unintended infiltration is a variable that is estimated based on building airtightness, and material construction assumptions. The result of factoring in unintended infiltration is higher use of the radiant floor heating to maintain 21°C temperature in the suite. The hot water system burns gas to provide hot water for the radiant floor system. Therefore more GJ are used in the base case simulation method than in the estimated method. In the base case scenario for the estimated method only assumed intended infiltration coming through the passive vents. Therefore heat loss due to unintended infiltration was not accounted for which could be the main driving force behind the difference.

In order to model the 155MAX heat recovery ventilation unit in EE4, each suite was separated into a ventilation zone. There is no option for adding HRV equipment to each zone, therefore an air handling unit with heat recovery was used which acted as our 155MAX HRV. The electrical consumption and ventilation requirements displayed in Table 6 for each suite were set of the AHU to match the situation as if there was a 155MAX unit being used. In this way, it was possible to mimic a HRV without having the option of choosing a HRV within the EE4 equipment list. Figure 34 & Figure 35 shows how each AHU was customised to reflect the desired conditions for each suite.



Outdoor Air

○ Constant at the Minimum Flow Rate

○ Economizer

Economizer Characteristics

Max. Outdoor Air Ratio: 1.00

Economizer Type: Fixed Dry Bulb

Limit Temperature: 23.3 °C

Lockout Economizer when Compressor On ☐

Exhaust Air Heat Recovery Effectiveness: 0.85

at Output	Heat Eff.	Cool Output
9.5	0.810	8.6
22.6	0.810	17.4
5.2	3.000	5.6
11.9	3.000	11.7
68.0	0.800	107.6
138.9	0.800	244.2
7.9	-	7.2
1.5	-	0.0
5.2	3.000	5.6
11.9	3.000	11.7
107.0	0.800	107.0
27.3	0.940	21.1
24.6	-	0.0
19.9	-	0.0

Energy Cost

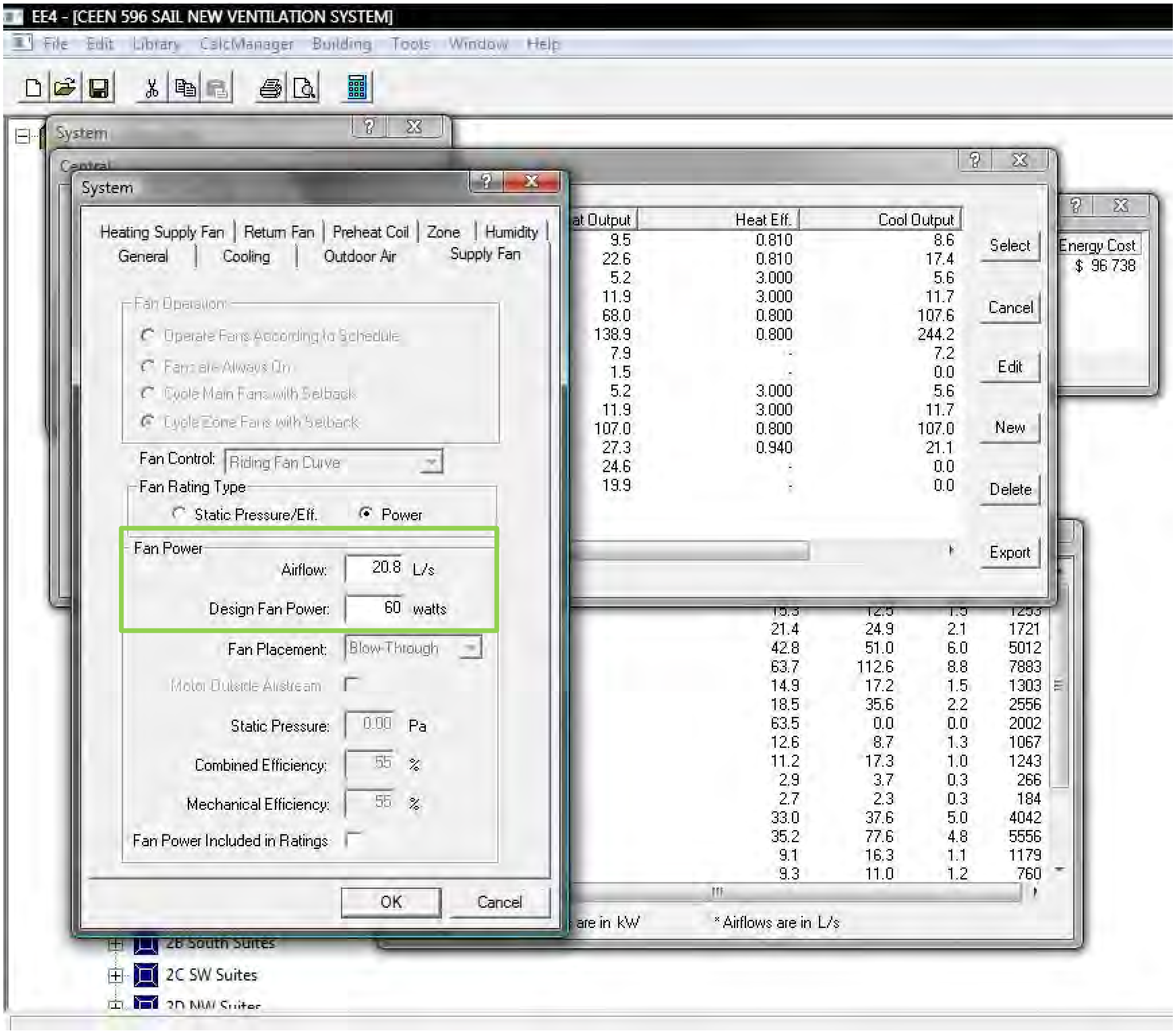
$ 96 738

21.4	24.9	2.1	1721
42.8	51.0	6.0	5012
63.7	112.6	8.8	7883
14.9	17.2	1.5	1303
18.5	35.6	2.2	2556
63.5	0.0	0.0	2002
12.6	8.7	1.3	1067
11.2	17.3	1.0	1243
2.9	3.7	0.3	266
2.7	2.3	0.3	184
33.0	37.6	5.0	4042
35.2	77.6	4.8	5556
9.1	16.3	1.1	1179
9.3	11.0	1.2	760

are in kW

* Airflows are in L/s

Figure 34 - Inputting HRV Effectiveness within Building Energy Model



Fan Operation
○ Operate Fans According to Schedule
○ Fans are Always On
○ Cycle Main Fans with Setback
● Cycle Zone Fans with Setback

Fan Control: Riding Fan Curve

Fan Rating Type
○ Static Pressure/Eff. ● Power

Fan Power
Airflow: 20.8 L/s
Design Fan Power: 60 watts

Fan Placement: Blow-Through
Motor Outside Airstream ☐
Static Pressure: 0.00 Pa
Combined Efficiency: 55 %
Mechanical Efficiency: 55 %
Fan Power Included in Ratings ☐

at Output	Heat Eff.	Cool Output
9.5	0.810	8.6
22.6	0.810	17.4
5.2	3.000	5.6
11.9	3.000	11.7
68.0	0.800	107.6
138.9	0.800	244.2
7.9	-	7.2
1.5	-	0.0
5.2	3.000	5.6
11.9	3.000	11.7
107.0	0.800	107.0
27.3	0.940	21.1
24.6	-	0.0
19.9	-	0.0

Energy Cost
$ 96 738

21.4	24.9	2.1	1721
42.8	51.0	6.0	5012
63.7	112.6	8.8	7883
14.9	17.2	1.5	1303
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35.2	77.6	4.8	5556
9.1	16.3	1.1	1179
9.3	11.0	1.2	760

are in kW
* Airflows are in L/s

Figure 35 - Inputting HRV Electrical Consumption and Air Supply Flow Rate

6.5 HRV Supply and Exhaust Vent Placement

Within the apartment effort has been made to have fresh air supply vents in all bedrooms and living rooms. Ducting diagrams for each suite type can be seen in the appendix F. Every other suite on each floor directs a fresh air supply duct to ventilate the corridor. In the case of building 1 eight suites on each floor collectively supply ventilation to the corridor. In Building 2 six out of the twelve suites on each floor provide ventilation to the corridor. The corridor for both buildings is under slight positive pressure, which gives the benefit of keeping cooking odours if they are any within each apartment

Ashrae 62.1 contains specific rules for placing outdoor supply and exhaust vents. The key rule which is pertinent to the Sail building is the supply and exhaust vents should be placed 3 meters away from each other. A computer drafting program was used to calculate the distance for each suites using architectural floor plans from Adera. The computer program was used to ensure the outside supply and extract ducts were placed 3 meters apart. The drafting program also helped in determining the length of the ducting required.

Additionally the concept of looking at annual wind direction in order to maximise fresh air pick up and provide an extra preventative measure against cross contamination was also applied. Table 10 shows the best location for supply and exhaust vents based on annual wind direction shown in Figure 24. The two most prevalent wind directions are east and north-west based on data for the Sail building location, which can be seen in Figure 51 in appendix H. With this in mind using the diagram key in Figure 25 vents were positioned based on what compass direction the side of the building was facing (north, east, south or west). The vents were positioned either left or right of the compass direction as a general rule for each apartment to ensure fresh air was most likely to be pick up and exhaust air was most likely to be diluted. Where wind directions would be competing, in regards to where the location of the vents would be placed the higher annual wind direction of east was chosen.

6.6 Implementation Cost and Financial Analysis

Ducting diagrams were generated for each of the five distinct suite layouts in the Sail building. A 3d model of the duct work which represents the difference before and after HRV installation can be seen in appendix F. The space in between the celling and the floor above was assumed to be 1 ft, as existing ductwork for the kitchen, laundry and bathrooms were planned to run across the celling within this space. The existing set up for each suite is to vent extracted air on the outside wall next to the balcony. When considering the HRV installation the bathroom ductwork for each suite can be removed as well as the bathroom exhaust fans. This is due to the HVR now delivering the air exhausting requirements. Also the ductwork for the laundry and the kitchen would need to be rerouted as the 1 ft space within the celling was not large enough to be able to cross the 8inch diameter ducting required by the HRV. As can be seen by the ducting diagram in Appendix F no duct line crosses another. A conscious effort was made in the new ventilation system to install fresh air supply ducts to every bedroom and living room in each suite.

The length of ducting required by installing the HRV into each unit would be the difference between removing unnecessary length of existing ducting and adding required length of HRV ducting. In order to keep the pressure drop across the HRV at 25 Pascal (0.1 in. w.g) the length of ductwork required was calculated on an equivalent length method. This meant 90° bends and tees would add an additional length to the new ductwork. The length of duct work required at a certain pressure would dictate the diameter of the duct pipework. Table 26 shows the corresponding duct lengths for bends and tees.

Table 23 & Table 24 show the determination of the duct length for each suite type. The total length of duct required can for the whole building can be seen to be 19,986 meters. The total number of vents was calculated by adding the supply and extract points for each HRV unit for each suite. Table 25 in appendix F shows the total amount of vents required are 984. The labour was determined by consulting heating and ventilation contractors. Adera's mechanical contractor suggested a good rule of thumb to assume it takes 1.5 longer to install all the HRV's than it would to install the original ventilation system in the Sail Building. Adera Developments commented that the current ventilation system is assumed to take 200 hours to install by the contactor, therefore the time in labour to install the HRV units would be 300 hours.

Once all of the elements for the implementation cost were known a financial analysis of the incremental cost was conducted. The cost of implementing the new ventilation system against the existing ventilation system was conducted. Table 11 shows details of the costing information and the result of the financial analysis. The incremental cost of installing HRV units in each suite would be $97,878. The annual modelled energy savings is predicted to be $12,217, resulting in a positive NPV of $32,535. The cost benefit ratio is above 1 at 1.33 showing a positive sign towards investing. The NPV was done over a 25 year lifetime, as the life span of the HRV and the ventilation system are considered to be very long. Airia brands manufactures of the HRV and Adera Developments expect their systems to last 25 years. A discount rate of 8% was used as this is the standard discount rate Adera development uses when considering financial investment decisions regarding new technologies within residential buildings.

An NPV of $1,171 was calculated when considering annual savings of $9,279 from the estimation method. The low value of NPV with regards to the estimated method savings poses questions as to whether or not the new system would be a worthwhile investment. If we look at the Cost benefit ratio we see a value very close to 1 of 1.01, which would further preclude us from considering investing in the new ventilation system. Figure 26 shows the change in NPV relative to the change in annual utility savings. The NPV becomes zero when the savings are less than $9,168.80. This limit is very close to the estimated savings of $9,279, which would mean any change in installation cost would render the project uneconomical based on the estimated savings. If we consider the financial assumptions are correct and the energy savings realised are equal to the modelled or higher the project is financially viable. Based on the building model savings it would only take an increase in installation costs of $3,101.2 to render the project uneconomical. This is essentially a variation of 3% in installation cost, which shows the sensitivity of the project in regards to accuracy required on financial assumptions used.

If we consider the cost of conserved energy (CCE) for implementing the new ventilation system, which was calculated using Equation 8 in appendix D we see it results in 0.33 $/GJ. The CCE is far lower than the current cost of gas at 9.94 $/GJ. Therefore we are spending far less in avoiding energy consumption by adopting the energy efficient change in the Sail building. As the CCE is less than the cost of buying energy, conservation makes economic sense.

In Figure 27 the majority of the implementation cost can be seen to be the capital cost of the HRV which is to be expected. What is surprising to see that ducting accounts for 23% of the cost of installing the equipment, due to the sheer amount of ducting required in total of over 19,000 meters.

As the benefit of the technology is experienced by the resident who purchases the suite a financing agreement provided by the developer could be used to make it financially worthwhile for Adera developments. Once greater than 50% resident occupancy has been reached the preliminary strata council members can pay an annual fee that would equal an acceptable interest rate on the capital expenditure Adera paid by installing the technology paid to Adera. A financing agreement would make it economically beneficial for the developer. In order for such an agreement to occur the developer would need to know if purchasers would want such a technology. As a large amount of apartments are sold before they are technically built, there is an opportunity to discuss with purchasers if they would like to enter into a financing agreement. All of the equations used to calculate financial indicators in Table 11 can be viewed in appendix D.

7.0 Conclusion

Building ventilation provides occupants with adequate fresh air to ensure a pleasant living environment. This can be done either through mechanical extract ventilation with passive supply vents like in the Sail building, or by balanced mechanical supply and exhaust ventilation like in the proposed new heat recovery ventilation system. The main advantages of having a heat recovery ventilation system providing dedicated fresh air to living rooms and bedrooms, is one of increasing air quality and comfort for residents, while reducing utility consumption.

The filters within the HRV unit are MERV 13, which are higher rating than what is typically used in large air handling units. Therefore technically the air entering into the building under the new ventilation system would contain less particulate matter, and be of higher quality. Better air quality has been proven to lead to improved health benefits for the resident. The range of particulate matter which is filtered can be seen by the green and pink region in Figure 8.

Estimated savings were calculated to verify the validity of the energy model predictions. The estimated savings can be considered the lower end of the possible energy savings achievable. The estimated savings were calculated to be $9,278 which varied by 24% from the modelled savings. The difference in the estimated energy model savings and the building energy model can be attributed to a number of factors in how both methods calculated the reduction in energy consumption. The first being the estimated method used 2009 weather data while the energy model savings used a different weather file (1996 lower mainland weather file). This was due to the restriction in updating the EE4 software with a more recent weather file. Another factor is the wind speed is incorporated in the calculation of building heat loss in the building energy method, whereas this is not account for in the estimation method. The effect of wind is considered to have a large impact as to the rate of heat a building will lose. Therefore the building would require higher energy consumption to maintain the temperature within each suite.

Also the energy model took into account unintended infiltration into the suite. Each suite is under slight negative pressure due to the way the suite is ventilated. Unintentional infiltration comes through cracks, joints, windows and other openings. The effect is a larger heat load on maintaining the temperature within the suite in the winter season. The modelled savings can be considered reasonable to achieve. Based on the way the building energy model factored in the vast number of variables in calculating the savings, it was considered a more accurate representation of the realistic savings that could be achieved. Therefore only the savings attributed to the building energy model method was used in the financial analysis on justifying a decision.

Adera developments were interested in understanding the cost and savings associated with implementing such a technology. An EE4 building energy model was developed to determine annual utility savings, which resulted in $12,200. The incremental financial cost of installing the new ventilation system would be $97,900. The cost benefit ratio and NPV both look positive at 1.33 and $32,500 respectively. The cost of conserved energy is 0.33 $/GJ far lower than the current cost of gas at 9.94 $/GJ. Therefore we are spending far less in avoiding energy consumption by adopting the energy efficient change in the Sail building. The financial decision would be to invest in the new ventilation heat recovery technology with a caution to ensure the installation costs are as accurate as possible at the time of implementation. It would only take a change of 3% to the installation cost for the project to be uneconomical. It could also be said even if the implementation of the new ventilation system was uneconomical the perceived benefits of healthier indoor living environment could provide a unique selling point compared to other properties on the market within the same location. The cost of implementation would be $570 per suite therefore due to the high property value of the suites ranging from $300,000 to $900,000 this would be an increase the property price by 0.19 to 0.06%. The amount of natural gas consumption that would be avoided with the new ventilation system is 1,664 GJ, as can be seen in Table 9. If we assume approximately 50.2Kg of CO_2 is generated for every GJ of gas burned the implementation of the new ventilation technology would result savings of 83 tonnes of CO_2 from being emitted into the atmosphere annually.

Based on the selection framework generated in Table 5 for decentralized heat recovery ventilation systems, the best heat exchanger design was a plate type. The most appropriate HRV was then selected to be 155MAX unit made by Airia Brands, as this unit has high efficiency and low watts/CFM. Each suite ventilation requirements differ due to size and occupancy levels as can be seen in Table 6. There was a question of whether to use more than one size of HRV. The decision to choose a larger HRV 155MAX unit for all suites turned out to be beneficial. Electrical savings by running a larger unit which consumes lower wattage were $2,273. This accounts for 19% of the total annual savings that were predicted to be achieved by the building model.

The financial viability of the new ventilation system becomes more desirable the higher the savings, as can be seen in the NPV graph in Figure 26. As the gradient of the line is quite sharp a small change in the implementation cost or realized savings would result in a large change in the economics feasibility of the project. Although both the estimated savings and the modelled savings both have positive NPV, the project would be considered higher risk if the realized savings turns out to be closer to the estimated savings. It was noted that in the planned ventilation system for some the suites would not be ventilated to the appropriate requirements of 0.35 ACH (air changes per hour) required by the BC building Code. The suites affected are A2, A2-RD, A3 & A3-RD. The suites can be seen in Table 7 to be under ventilated at 0.32 ACH. The bathroom extract fan would need to be required to be on for more than the designed 8 hour/day. Adera developments have been consulted on this point. The ducting cost was seen to be a surprising large component of the installed cost of the new ventilation system. Figure 27 shows duct work represents 23% of the total installed cost. Ensuring accurate costing information for the ducting will help ensure installed cost has a higher degree of accuracy.

8.0 Significance of Work

The decision to invest in heat recovery ventilation technology can be based on two fundamental differing goals. The first goal of increasing air quality and comfort for residents, the second being savings money through reduction in utility consumption. It is important to understand the type of goal you wish to achieve as trying to achieve both will present you with conflicting preference.

In the case of the sail building a plate type sensible heat recovery unit was selected to be the technology to be used. There are other designs of ventilation heat recovery devices which can recover latent heat. These ERV devices would provide more comfort for the resident as they control the humidity within the space. At the selection stage ERV were not selected as it scored poorly on cost in the selection framework, due to it being one of more expensive type of technologies.

The financial viability of installing a new heat recovery system against a traditional system is highly specific to the building characteristic and assumptions used for determining implementation costs. This results in difficulty in replicating similar energy savings for other similar type of residential buildings.

The main advantages of each type of heat recovery technology can be seen below:

- Runaround systems are good for retrofit applications when central exhaust and supply vents are at different locations in buildings.
- Heat pipes require no maintenance and they do not have any moving parts but require the supply and exhaust ventilation ducts to be physically close to each other.
- Thermal wheels work best for larger centrally supplied and exhausted systems as greater efficiencies can be achieved with economies of scale.
- Plate type heat exchangers are the most flexible technology as they can be adapted to work on a decentralised suite basis. The core can also be exchanged for a type that recovers latent heat.

9.0 Limitations of Study & Recommendations for Further Work

The work conducted considered a detail look at the best technology for the Sail building. The answer to the type of technology used in terms of heat recovery ventilation has limited value or applicability for different multiunit residential buildings. The result of the financial viability may be different for another building that has different building characteristics. The impact of building characteristics on the energy model has significant influence on the annual utility savings.

Effort was conducted to ensure the lowest market price for equipment was used in the HRV installation cost calculations. The financial assumptions used in Table 11 can vary; therefore there is a time component to the validity of the financial assessment conducted.

Maintenance costs were not considered for the life of the HRV as unreliable data with regards to the estimation of these maintenance cost was not available. Usually filters would need to be changed typically twice a year, but in the case of the 155MAX model the filters can be cleaned and then put back in to the unit [28]. The lifetime of the heat exchanger was considered to be the same as the lifetime of the product. Therefore it was assumed little to no maintenance charges would arise from using a HRV. As this is quite different to the way typical ventilation systems are maintained usually with annual mechanical service contacts. It was deemed necessary to be conservative and exclude maintenance from both systems. Gaining accurate information to the maintenance costs of both technologies would provide better accuracy in the financial savings that could be achieved with the new ventilation system.

The increased health impacts were not quantified. This can be considered to be one of the most important reasons to invest in the heat recovery technology. If the residents are elderly, suffer from asthma or other ailment, better ventilation is expected to help increase wellness [29].

The time required to commission and balance the HRV system was not considered due to the uncertainty in the amount of actual time required to conduct such a task building wide. Similarly the time taken to commission and test the original ventilation system was not considered in the labour cost.

In the new ventilation system it can be seen there is a reduction in heat load conservatively speaking of 1,664 GJ, by the absence of requiring an air handling unit. The air handling unit provides central supply ventilation to each corridor in the original ventilation system. Air is heated by the AHU system using hot water coils. The radiant floor heating and ventilation heating systems are in a sense coupled together. Both systems use hot water as the medium to provide heat and rely on the hot water system to be sized correctly for both requirements. As the heat load requirement for the air handling unit does not exist anymore in the new ventilation system, it is safe to assume the hot water system is now oversized. Therefore savings could be realised by resizing the hot water system. The money that would be saved by going to a smaller hot water heating system was not accounted for in the new ventilation financial analysis. This would be an interesting point for further work to be conducted, to see how much of a difference it would make.

A further investigation into the sensitivity of natural gas and electricity prices would help understand the risk associated with potential changes in utility rates. As natural gas is currently at a historic low greater potential for savings may be realised in the 25 years of the project life, if natural gas rates increase within that time.

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11.0 Appendix A – Selection Framework

11.1 Capital Cost

- For a typical residential application a small Plate type heat recovery ventilators are considered to be the cheapest. This is due to market availability and therefore market competition. Also the simpler design in heat exchanger technology results in lower manufacturing cost.
- For a thermal wheel the capital costs are associated to be higher due to the additional rotary equipment required for a typical installation. The material for the heat exchanger also drives up the price as latent heat recovery technology is more expensive.
- Heat pipe are the simplest technology in design but require expensive manufacturing costs due to the vacuum required with in the heat pipe.
- Runaround coils are considered the most expensive due to the additional ancillary equipment required in the design. More components are required Due to the nature of the design of how heat is recovered.

For a typical residential apartment application the cost of each technology was gained from supplier interviews. Quotes were compared to a price range and the appropriate points were given.

Table 12 - Capital Cost Points

Price Range, $	Points Given
0-999	10
999-1499	8
1500-1749	7
1750-1999	4
over 2000	3

Table 13 – Capital Points Continued

	Supplier Quotes per unit, $				
Technology	Quote 1	Quote 2	Quote 3	Average Quote, $	Points Received
HRV	1099.00	1049.00	1199.00	1115.67	8
Rotary Wheel	1575.00	1399.00	1449.00	1474.33	7
Heat Pipe	1850.00	2100.00	1950.00	1966.67	4
Runaround	2500.00	2300.00	1999.00	2266.33	3

11.2 Comfort

The aspect of delivered comfort to the resident within the ventilated space was determined by the type of heat recovery possible. It was assumed technologies that recover sensible and latent heat would provide a ventilated space with relative humidity control. Points were given based on Table 14.

Table 14 - Comfort Points

Type of Heat Recovery	**Points Given**
Sensible Recovery	1
Sensible & Latent Recovery	10
Technology	Points Received
HRV	1
Rotary Wheel	10
Heat Pipe	1
Runaround	1

11.3 Size

The physical size of each technology was compared on the volume the equipment would take in the suite. The average of three different variations of the same technology was used to determine the average volume used within a suite.

Table 15 - Size Points

Volume of each Technology	Points Given
0-0.09	10
0.1-0.19	9
0.2-0.24	5
0.25-0.29	4
>0.3	2

	Volume per unit, m^3				
Technology	Unit 1	Unit 2	Unit 3	Average Volume, m3	Points Received
HRV	0.12	0.13	0.16	0.14	9
Rotary Wheel	0.21	0.25	0.21	0.22	5
Heat Pipe	0.22	0.26	0.28	0.25	4
Runaround	0.29	0.32	0.46	0.36	2

11.4 Maximum Efficiency

The total maximum effective efficiency (total plus any latent heat transfer) from Figure 22 was used to determine how many points were given to each technology.

Table 16 - Maximum Efficiency Points

Efficiency, %	Points Given
100	10
95	9.5
90	9
85	8.5
80	8
75	7.5
70	7
65	6.5
60	6
55	5.5
50	5
<49	1

Table 17 - Maximum Efficiency Points Continued

Technology	Points Received
HRV	8
Rotary Wheel	8.5
Heat Pipe	5.5
Runaround	6.5

11.5 Operation Costs

The operation cost points were given by comparing the average watts per CFM for each technology. Three variations of the same technology were used to determine the average electrical consumption of that technology. Corresponding points in Table 18 were given depending on the watts per CFM value.

Table 18 - Operation Points Cost

Electrical Consumption, Watts/CFM	Points Given
0 to 1.2	10
1.21 to 1.34	8
1.35 to 1.39	7
1.4 to 1.49	5
over 1.5	2

	Electrical Consumption, Watts/CFM				
Technology	Unit 1	Unit 2	Unit 3	Average Electrical Consumption, Watts/CFM	Points Received
HRV	1.34	1.36	1.32	1.34	8
Rotary Wheel	1.40	1.38	1.33	1.37	5
Heat Pipe	0.00	0.00	0.00	0.00	10
Runaround	1.45	1.55	1.62	1.54	2

12.0 Appendix B – Ventilation Calculation

12.1 Supply Ventilation Rate

The supply ventilation was calculated using Ashraf 62.1 Equation below:

$$V_{bz} = R_p\, P_z + R_a\, A_z$$

Equation 1 - Ventilation Rate [4]

Where:

- V_{bz} = Supply ventilation rate (L/s)
- R_p = Outdoor airflow rate per person (2.5 L/s /occupant [4])
- P_z = Zone Population (Occupancy per suite in Table 6)
- R_a = Outdoor airflow rate required per unit area (0.3 L/s/m^2 [4])
- A_z = Unit Area (Suite Area in Table 6)

12.2 New and Old Air Exchange Rate Equation

The old air exchange rate in Table 7 was calculated using the equation below:

$$Q(ach/hr) = \frac{q(l/s).3600}{V(m^3).1000}$$

Equation 2 - Air Exchange Rate

Where:

- Q (ach/hr) = New or Old air exchange rate
- q (L/s) = Rated Exhaust Ventilation, or Supply Ventilation Rate in Table 7
- V (m^3) = Volume of Suite in Table 7

13.0 Appendix C – Estimated Savings

$$Q = V * \rho_{air} * C_p * (Ti - To) * 60$$

Where:

- $Q_{sensible}$ is sensible heat load in (Btu/hr)
- V = volumetric air flow rate in (cfm)
- ρ_{air} is the density of the air in (lbm/ft³)
- C_p = specific heat capacity of air at constant pressure in (Btu/lbm -F)
- Ti = indoor air temperature in (°F)
- To = outdoor air temperature in (°F)

Equation 3 - Ventilation Heat loss

$$E_{annual} = \frac{(Q_{design})(DD)(24)(C_d)}{1{,}000{,}000(\Delta T_{design})}$$

where:

E_{annual} = estimated annual heating energy *required by the building* **(MMBtu)**

NOTE: 1 MMBtu = 1,000,000 Btu

Q_{design} = design heating load of the building (Btu/hr)

DD = annual total heating degree days at the building location (degree days)

C_d = correction factor from Figure 2–26 (unitless)

ΔT_{design} = design temperature difference at which design heating load was determined (°F)

Equation 4 - Ventilation Annual Heat Loss

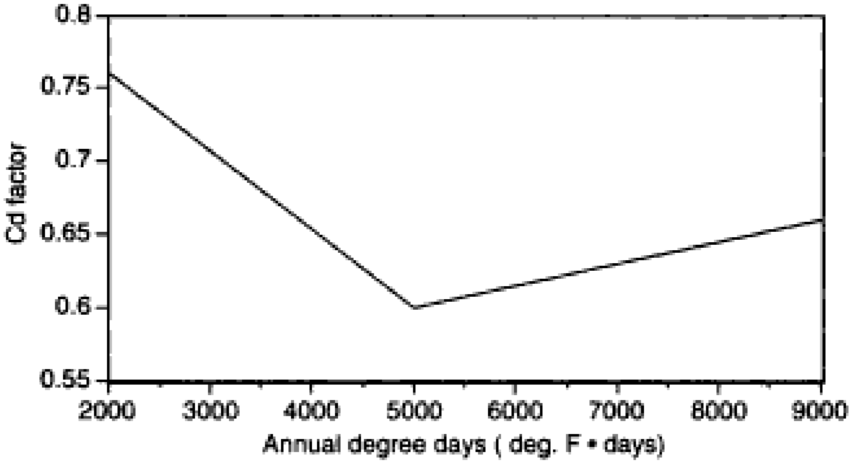


Figure 36 - HDD Correction Factor

13.1 Estimated Savings Table

Table 19 – Old Ventilation System Heat Loss

Air Infiltration Heat Loss Calculations	
Volumetric Air infiltration rate, CFM	10833
Density of Air, lbm/ft³	0.0752
Specific Heat Capacity of air, Btu/lbm –F	0.24
indoor air temp, °F	69.8

Vancouver UBC Location 2009 Weather data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Outdoor Air Temp, °C	3.6	4.9	6.6	9.1	12.3	14.7	16.9	17.1	14.5	10.3	6.1	3.8
Set point °C	18	18	18	18	18	18	18	18	18	18	18	18
HDD/month	446.8	382	385.8	252.7	179.3	110.3	26.5	10.6	80	232.2	313.6	440.4
Average Outdoor Air Temp, °F	38.48	40.82	43.88	48.38	54.14	58.46	62.42	62.78	58.1	50.54	42.98	38.84
Heat Loss no HRV, BTU/HR	367,409.88	339,959.72	304,063.35	251,274.57	183,704.94	133,027.71	86,573.59	82,350.49	137,250.82	225,935.96	314,621.10	363,186.78
Monthly Heat loss no HRV, BTU/Month	125,792,133.19	107,548,332.32	108,618,184.84	71,145,192.61	50,480,146.56	31,053,877.11	7,460,813.63	2,984,325.45	22,523,210.96	65,373,619.80	88,290,986.95	123,990,276.32

Total Building Air Infiltration Heat Loss	
Annual Heat Loss no HRV, BTU/yr	805,261,099.73
Hot Water boiler Efficiency	95%
Total Annual Heat Loss, BTU/yr	**847,643,262.88**

Table 20 – Old Ventilation System Heat Loss Continued

Air handling Unit Heat Loss	
Volumetric Air infiltration rate, CFM	5060.0
Density of air, lbm/ft³	0.0752
Specific Heat Capacity of air, Btu/lbm –F	0.24
indoor air temp, F	69.8
Cd factor	0.73

Vancouver UBC Location 2009 Weather data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Outdoor Air Temp, °C	3.6	4.9	6.6	9.1	12.3	14.7	16.9	17.1	14.5	10.3	6.1	3.8
Set point °C	18	18	18	18	18	18	18	18	18	18	18	18
HDD/month	446.8	382	385.8	252.7	179.3	110.3	26.5	10.6	80	232.2	313.6	440.4
Average Outdoor Air Temp, °F	38.48	40.82	43.88	48.38	54.14	58.46	62.42	62.78	58.1	50.54	42.98	38.84
Heat Loss no HRV, BTU/HR	171,613.96	158,792.22	142,025.34	117,368.17	85,806.98	62,136.09	40,437.77	38,465.20	64,108.66	105,532.72	146,956.78	169,641.38
Monthly Heat loss no HRV, BTU/Month	42,892,179.60	36,671,469.58	37,036,264.30	24,258,849.11	17,212,551.03	10,588,646.84	2,543,963.20	1,017,585.28	7,679,888.92	22,290,877.58	30,105,164.55	2,277,788.49

Total Building Air Infiltration Heat Loss	
Annual Heat Loss no HRV, BTU/yr	274,575,228.49
Hot Water boiler Efficiency	95%
Total Annual Heat Loss, BTU/yr	**289,026,556.30**

Table 21 – New Ventilation System Heat Loss

Air Infiltration Heat Loss Calculations With HRV

Volumetric Air infiltration rate, cfm	11137.0
Density of air lbm/ft³	0.0752
Specific Heat Capacity of air, Btu/lbm –F	0.24
indoor air temp, F	69.8
Heat Recovery, %	75%

Vancouver UBC Location 2009 Weather data	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average Outdoor Air Temp, °C	3.6	4.9	6.6	9.1	12.3	14.7	16.9	17.1	14.5	10.3	6.1	3.8
Set point °C	18	18	18	18	18	18	18	18	18	18	18	18
HDD/month	446.8	382	385.8	252.7	179.3	110.3	26.5	10.6	80	232.2	313.6	440.4
Average Outdoor Air Temp, °F	38.48	40.82	43.88	48.38	54.14	58.46	62.42	62.78	58.1	50.54	42.98	38.84
Heat Loss with HRV, BTU/HR	56,658.04	52,424.97	46,889.41	38,748.89	28,329.02	20,514.12	13,350.46	12,699.22	21,165.36	34,841.44	48,517.52	56,006.80
Monthly Heat loss With HRV, BTU/Month	19,398,324.39	16,584,959.53	16,749,940.80	10,971,254.64	7,784,511.11	4,788,798.52	1,150,527.30	460,210.92	3,473,289.95	10,081,224.09	13,615,296.62	19,120,461.19

Total Building Air Infiltration Heat Loss

Annual Heat Loss with HRV, BTU/yr	124,178,799.05
Hot Water boiler Efficiency	95%
Total Annual Heat Loss With HRV, BTU/yr	**130,714,525.32**

13.2 Summary of Estimated Savings

Table 22 – Summary of Estimated Savings

Old Ventilation System

AHU	
AHU Gas Consumption BTU/YR	289,026,556.30
AHU Electrical Consumption, kWh	24,528.00
Building Ventilation Heat Loss	
Air Infiltration Gas Consumption, BTU/YR	847,715,640.80
Air Infiltration Electrical Consumption, kWh	47,452.59
New Ventilation System	
AHU	
AHU Gas Consumption BTU/YR	0
AHU Electrical Consumption, kWh	0
Building Ventilation Heat Loss	
HRV Gas Consumption BTU/YR	130,714,525.32
HRV Electrical Consumption, kWh	90,403.20
Gas Savings, BTU/YR	1,006,027,671.78
BTU TO GJ conversion Factor	0.000001055
Gas Savings, GJ	1,061.36
Electricity Savings, kWh	-18,422.61
Gas Rate $/GJ	9.94
Electricity Rate, $/kWh	0.069
Total Estimated Savings	9,278.75

14.0 Appendix D – Equations for Financial Analysis

The equation used to calculate financial indicators in Table 11 to help determine investment decision can be seen below.

$$Simple\ Payback\ (yr) = \frac{Capital\ Cost\ (\$)}{Annual\ Energy\ Savings\ (\frac{\$}{yr})}$$

Equation 5 - Simple Payback

Where:

$Simple\ Payback$ = Number of years to recover the incremental capital cost of new ventilation system (8 years)

$Capital\ Cost$ = Incremental Capital cost for new ventilation system ($97,877.82)

$Annual\ Energy\ Savings$ = The reduction in building utility costs by implementing new ventilation system (12,217 $/yr)

$$NPV = \sum_{t=0}^{n} \frac{(Benefits(\$) - Costs(\$))_t}{(1+r)^t}$$

Equation 6 - NPV Equation

Where:

NPV = Net present value of the project (32,535.92)

$Benefits$ = The reduction in building utility costs by implementing new ventilation system ($12,217)

$Costs$ = Incremental Capital cost for new ventilation system ($97,877.82)

r = Discount rate (8%)

t = Project lifetime (25)

$$CBR = \frac{Net\ Present\ Value_{Benefits}(\$)}{Net\ Present\ Value_{Costs}(\$)}$$

Equation 7 - Cost Benefit Ratio Equation

Where:

CBR = Cost Benefit Ratio (1.33)

$Net\ Present\ Value_{Benefits}$ = The net present value of total annual utility savings within the 25 year lifetime of the project ($130,413.74)

$Net\ Present\ Value_{Costs}$ = The net present value of the Incremental Capital cost for new ventilation system ($97,877.82)

$$Cost\ of\ Conserved\ Energy\ (\frac{\$}{GJ}) = \frac{Annualized\ Surcost(\$)}{Net\ Annual\ Energy\ Saving(GJ)}$$

Equation 8 - Cost of Conserved Energy Equation

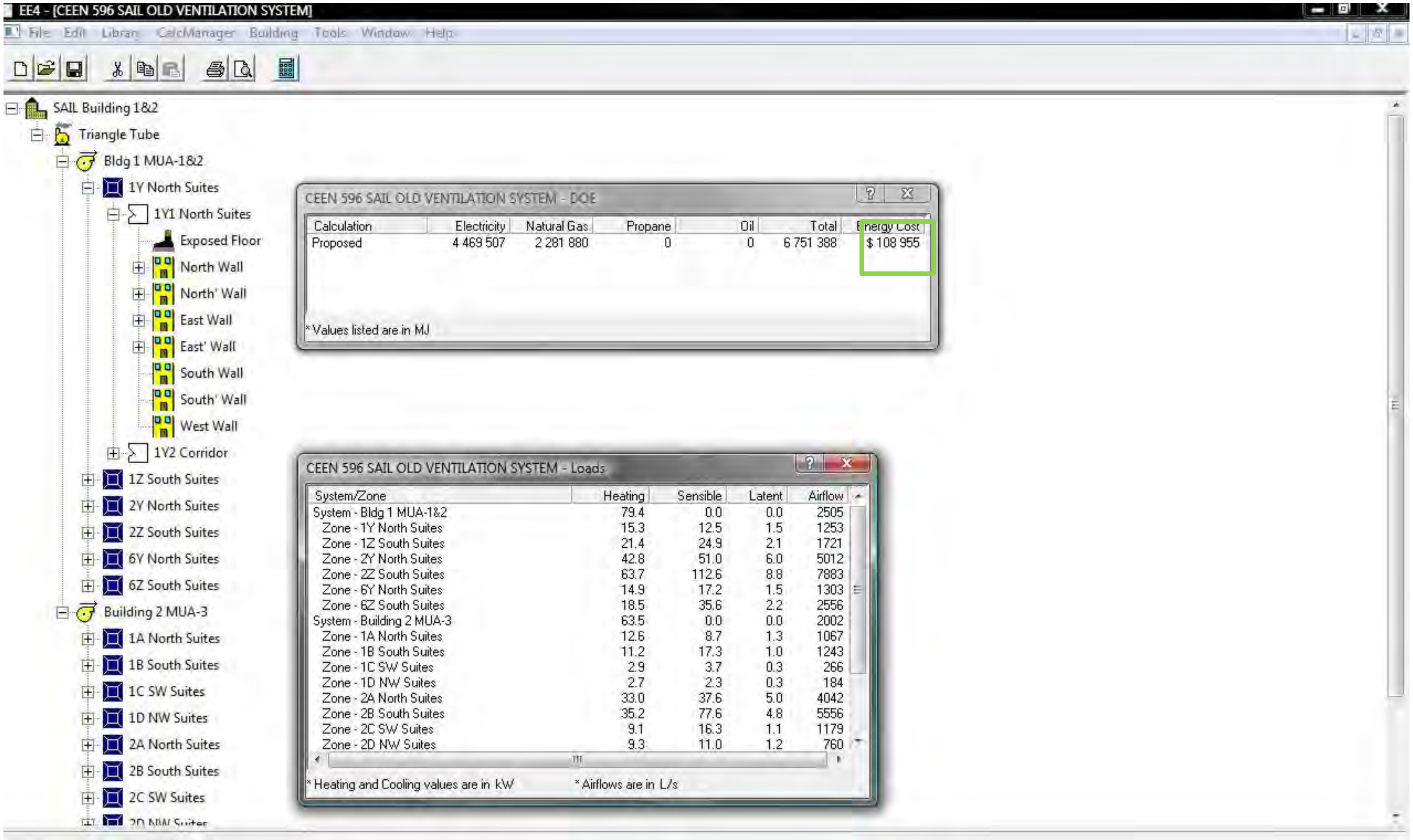
Where:

$Cost\ of\ Conserved\ Energy$ = The cost of avoiding buying a GJ of gas (0.33)

$Annualized\ Surcost$ = The annualized net present value of the incremental capital cost of the new ventilation system over the 25 year lifetime of the project ($9,971)

$Net\ Annual\ Energy\ Saving$ = The overall reduction in building utility energy consumption gained by implementing the new ventilation system (15347 GJ)

15.0 Appendix E – Summary of Building Energy Model Savings



CEEN 596 SAIL OLD VENTILATION SYSTEM - DOE

Calculation	Electricity	Natural Gas	Propane	Oil	Total	Energy Cost
Proposed	4 469 507	2 281 880	0	0	6 751 388	$ 108 955

*Values listed are in MJ

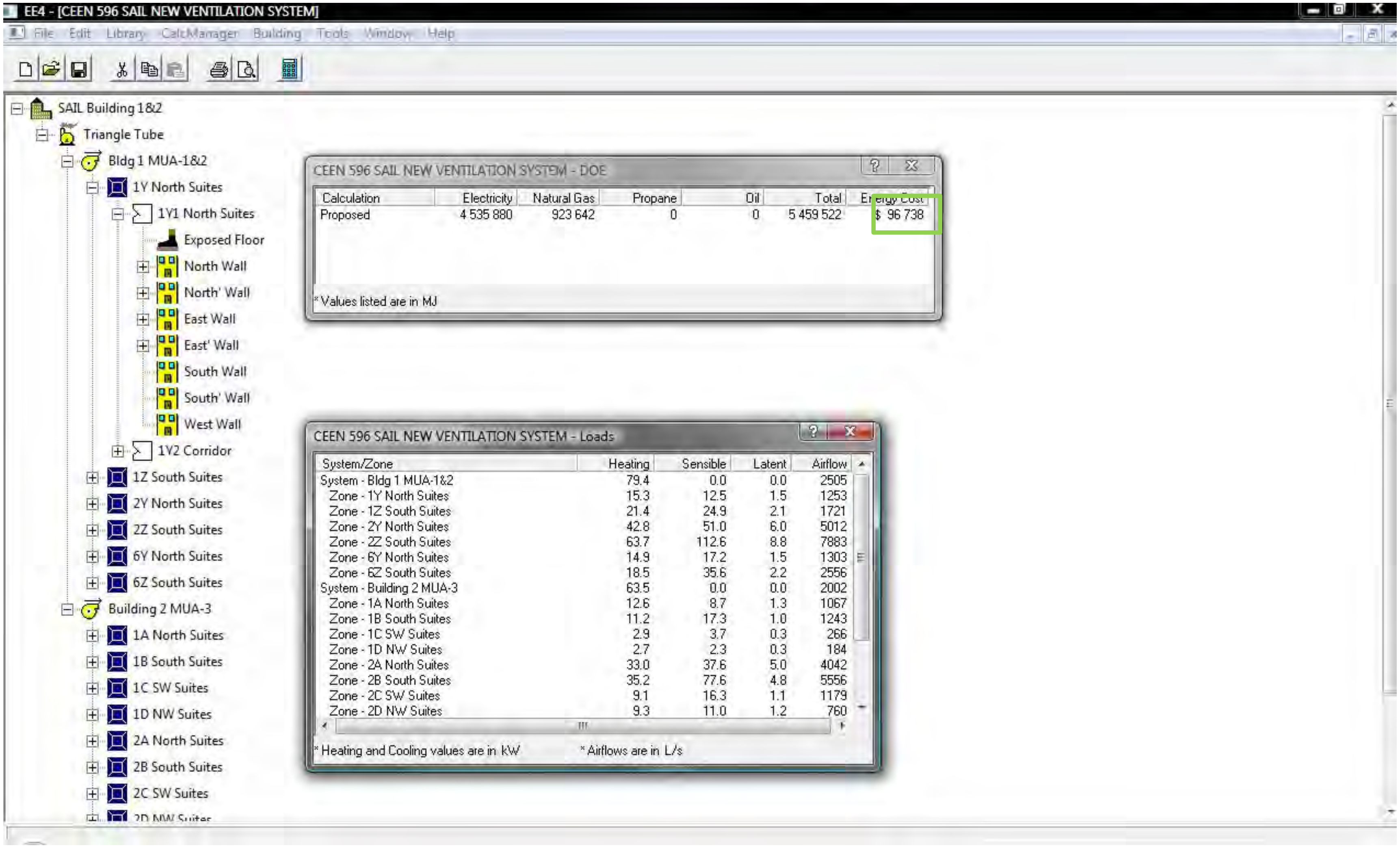
CEEN 596 SAIL OLD VENTILATION SYSTEM - Loads

System/Zone	Heating	Sensible	Latent	Airflow
System - Bldg 1 MUA-1&2	79.4	0.0	0.0	2505
Zone - 1Y North Suites	15.3	12.5	1.5	1253
Zone - 1Z South Suites	21.4	24.9	2.1	1721
Zone - 2Y North Suites	42.8	51.0	6.0	5012
Zone - 2Z South Suites	63.7	112.6	8.8	7883
Zone - 6Y North Suites	14.9	17.2	1.5	1303
Zone - 6Z South Suites	18.5	35.6	2.2	2556
System - Building 2 MUA-3	63.5	0.0	0.0	2002
Zone - 1A North Suites	12.6	8.7	1.3	1067
Zone - 1B South Suites	11.2	17.3	1.0	1243
Zone - 1C SW Suites	2.9	3.7	0.3	266
Zone - 1D NW Suites	2.7	2.3	0.3	184
Zone - 2A North Suites	33.0	37.6	5.0	4042
Zone - 2B South Suites	35.2	77.6	4.8	5556
Zone - 2C SW Suites	9.1	16.3	1.1	1179
Zone - 2D NW Suites	9.3	11.0	1.2	760

* Heating and Cooling values are in kW

* Airflows are in L/s

Figure 37 – Old Ventilation System Building Energy Model



CEEN 596 SAIL NEW VENTILATION SYSTEM - DOE

Calculation	Electricity	Natural Gas	Propane	Oil	Total	Energy Cost
Proposed	4 535 880	923 642	0	0	5 459 522	$ 96 738

* Values listed are in MJ

CEEN 596 SAIL NEW VENTILATION SYSTEM - Loads

System/Zone	Heating	Sensible	Latent	Airflow
System - Bldg 1 MUA-1&2	79.4	0.0	0.0	2505
Zone - 1Y North Suites	15.3	12.5	1.5	1253
Zone - 1Z South Suites	21.4	24.9	2.1	1721
Zone - 2Y North Suites	42.8	51.0	6.0	5012
Zone - 2Z South Suites	63.7	112.6	8.8	7883
Zone - 6Y North Suites	14.9	17.2	1.5	1303
Zone - 6Z South Suites	18.5	35.6	2.2	2556
System - Building 2 MUA-3	63.5	0.0	0.0	2002
Zone - 1A North Suites	12.6	8.7	1.3	1067
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Zone - 1C SW Suites	2.9	3.7	0.3	266
Zone - 1D NW Suites	2.7	2.3	0.3	184
Zone - 2A North Suites	33.0	37.6	5.0	4042
Zone - 2B South Suites	35.2	77.6	4.8	5556
Zone - 2C SW Suites	9.1	16.3	1.1	1179
Zone - 2D NW Suites	9.3	11.0	1.2	760

* Heating and Cooling values are in kW * Airflows are in L/s

Figure 38 – New Ventilation System Building Energy Model

16.0 Appendix F – Ducting

Table 23 – Duct Length Calculations

	Existing Duct Length cm				Modification to Existing Duct Length				Total Duct Length before HRV, cm	Total Duct Length After HRV, cm	Saving in Length, meters
Suite Type	kitchen	Laundry	bath 1	bath 2	kitchen	Laundry	bath 1	bath 2			
1B+1BA	1146	519	598	0	975	770	0	0	2263	1745	5.18
1B+D+1BA	912	832	773	0	875	1323	0	0	2517	2198	3.19
1B+D+2BA	1274	890	830	885	1329	713	0	0	3879	2042	18.37
2B+2BA	1274	890	830	885	1329	713	0	0	3879	2042	18.37
2B+D+2BA	1280	438	637	923	772	444	0	0	3278	1216	20.62
3B+2BA	76	502	920	1039	76	502	0	0	2537	578	19.59

	HRV Duct Length, cm				Bends				Effective Duct length at 0.1 in w.g, cm		Total Duct Length Required per Suite, meters	Pipe Diameter 1+2, Inch	Pipe Diameter 3+4, Inch
Suite Type	🟦	🟦	🟥	🟧	elbow 90		Tee		1+2	3+4			
	1	2	3	4	1+2	3+4	1+2	3+4					
1B+1BA	798	693	342	806	1	5	1	0	5758.2	5110.4	108.686	8	8
1B+D+1BA	699	1012	165	1002	1	4	1	0	5978.2	4824.6	108.028	8	8
1B+D+2BA	848	1707	828	654	3	5	0	1	5907.8	6968.4	128.762	8	8
2B+2BA	848	1707	828	654	3	5	0	1	5907.8	6968.4	128.762	8	8
2B+D+2BA	588	1506	750	462	2	4	2	1	8190	6393.6	145.836	8	8
3B+2BA	590	1796	358	464	0	1	3	1	9396.4	5089.2	144.856	8	8

Table 24 – Duct Length Calculation Continued

Suite Type	**Total Duct Length per Suite, meters**	**Number of Suites**	**Total duct length per Suite Type, meters**
1B+1BA	108.686	9	978.17
1B+D+1BA	108.028	15	1620.42
1B+D+2BA	128.762	11	1416.38
2B+2BA	128.762	60	7725.72
2B+D+2BA	145.836	34	4958.42
3B+2BA	144.856	43	6228.81
			22927.9
Suite Type	**Saving in Length of existing duct work, meters**	**Number of Suites**	**Total duct length per Suite Type, meters**
1B+1BA	5.18	9	46.62
1B+D+1BA	3.19	15	47.85
1B+D+2BA	18.37	11	202.07
2B+2BA	18.37	60	1102.2
2B+D+2BA	20.62	34	701.08
3B+2BA	19.59	43	842.37
			2942.19
	Savings of Length of Existing Duct work, Meters		2942.19
	New Length of Duct work required due to HRV, Meters		22927.9
	Total Required duct work, Meters		19985.7

Table 25 – Vent Calculation

Suite Type	Number of Units	Number of vents Required per Suite	Total Number of Vents Required
1B+1BA	9	4	36
1B+D+1BA	15	4	60
1B+D+2BA	11	6	66
2B+2BA	60	6	360
2B+D+2BA	34	6	204
3B+2BA	43	6	258
	172		984

Table 26 - Equivalent Duct Length

	Equivalent length, cm	
	ft	cm
Vents	40	1219.2
elbow	10	304.8
Tee	50	1524

16.1 Ducting Diagram Key

Figure 39 - Ducting Diagram

- Supply Air Entering (1) 🟦
- Supply Air Leaving (2) 🟦
- Exhaust Air Entering (3) 🟥
- Exhaust Air Leaving (4) 🟥
- Kitchen and Laundry Duct ⬛

16.2 Ducting Diagrams

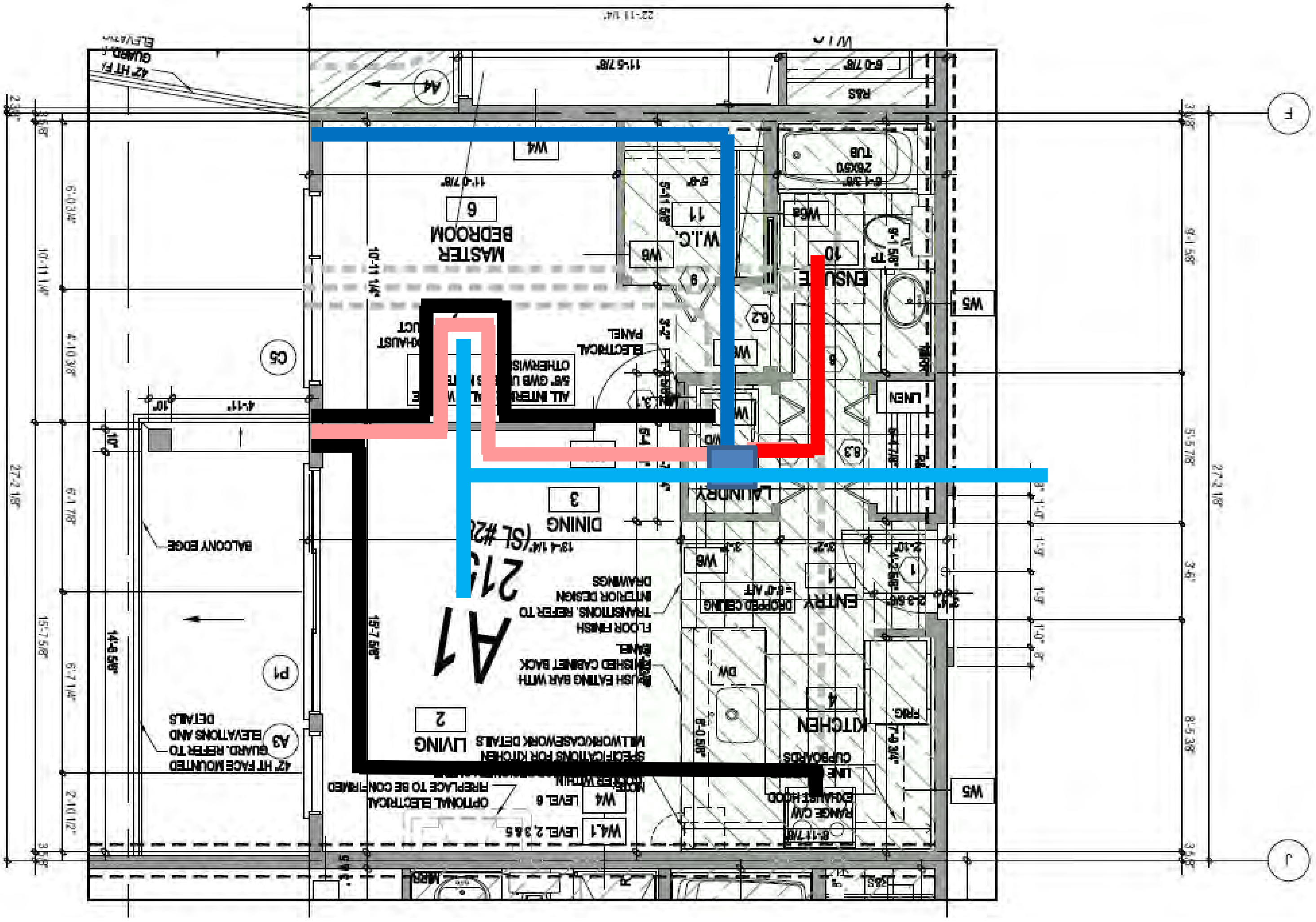

Figure 40 - Ducting Diagram – 1B+1BA

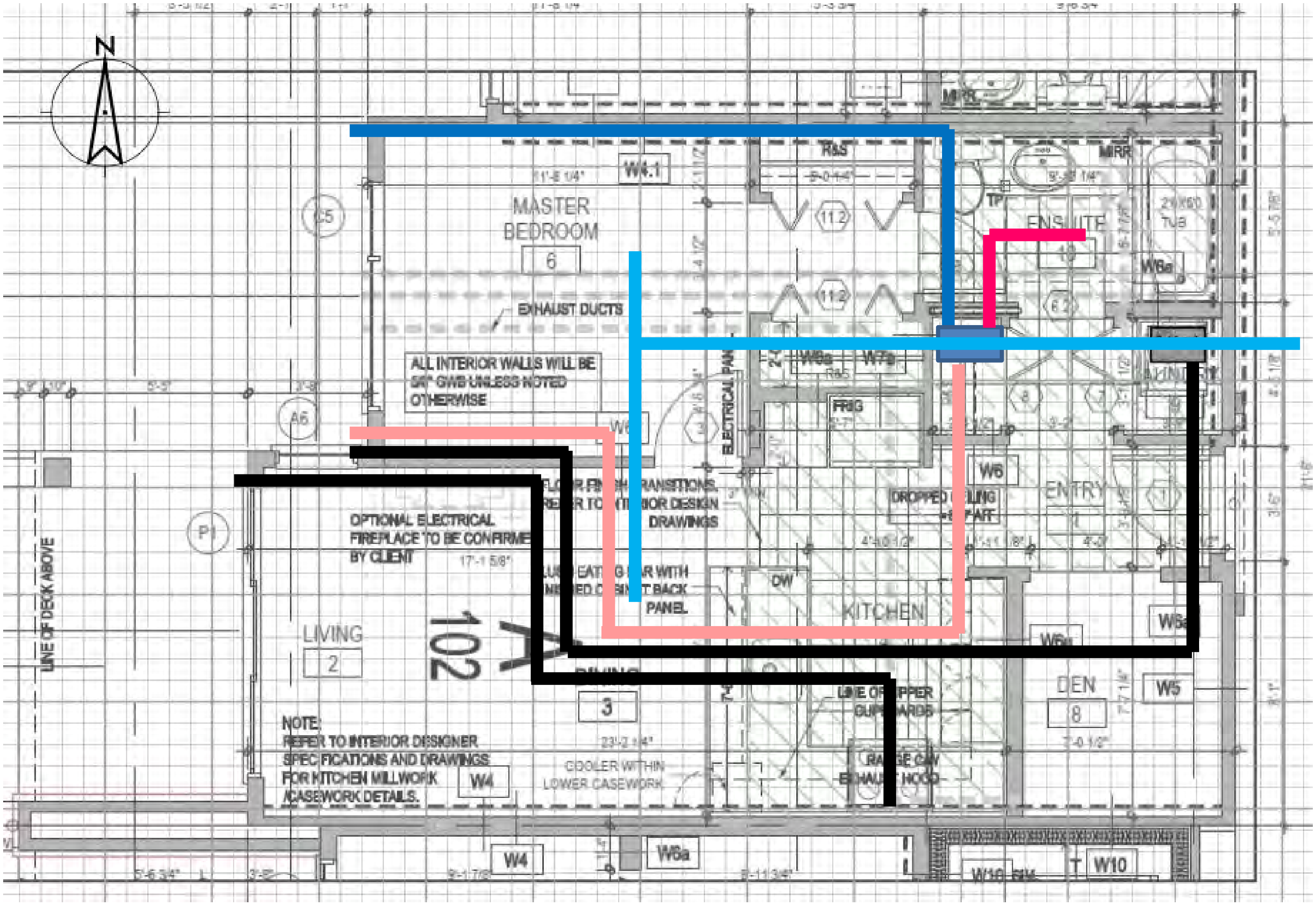

Figure 41 - Ducting Diagram – 1B +DEN+1BA

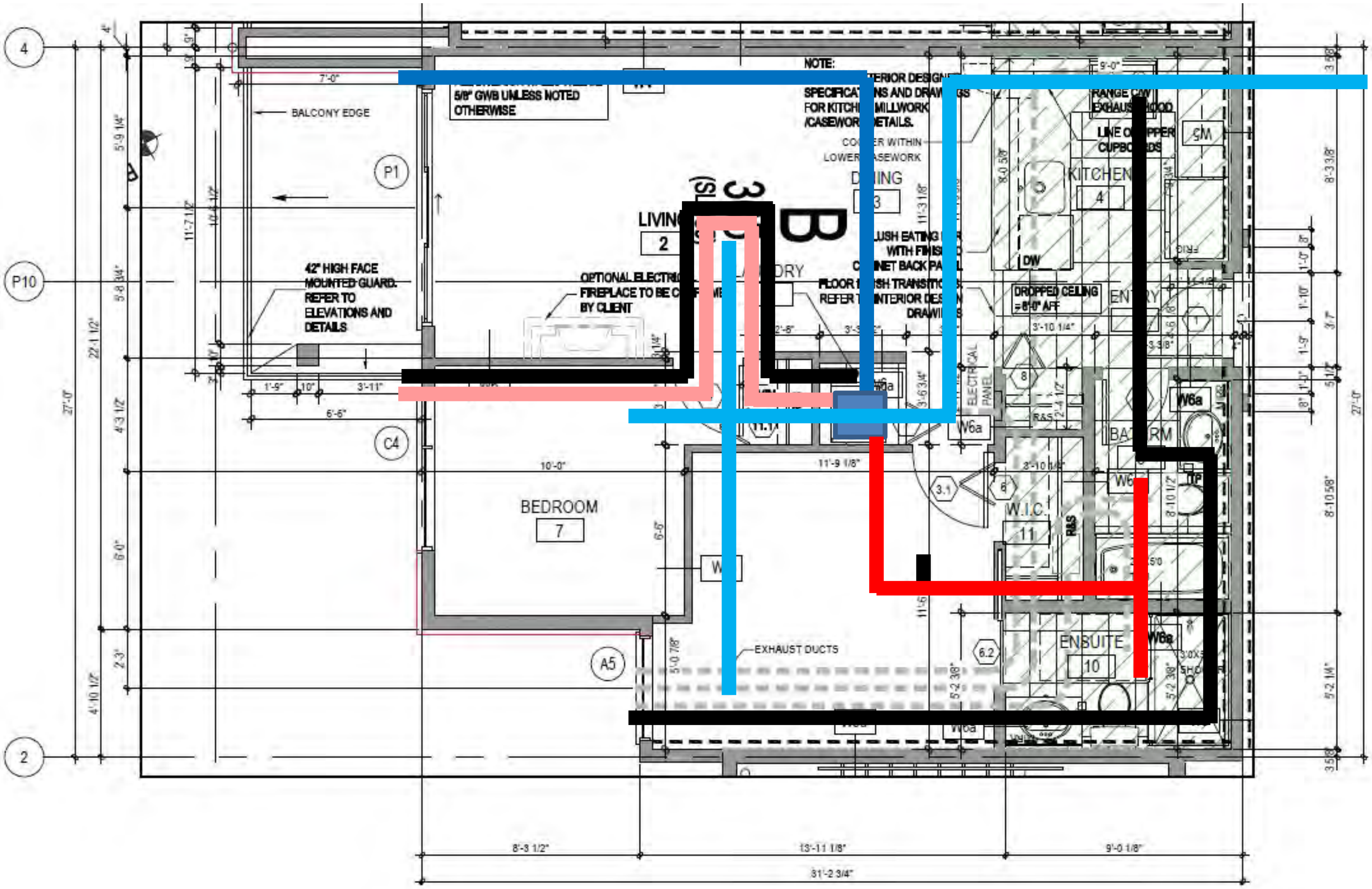

Figure 42 - Ducting Diagram – 1B+DEN+2BA or 2B+2BA

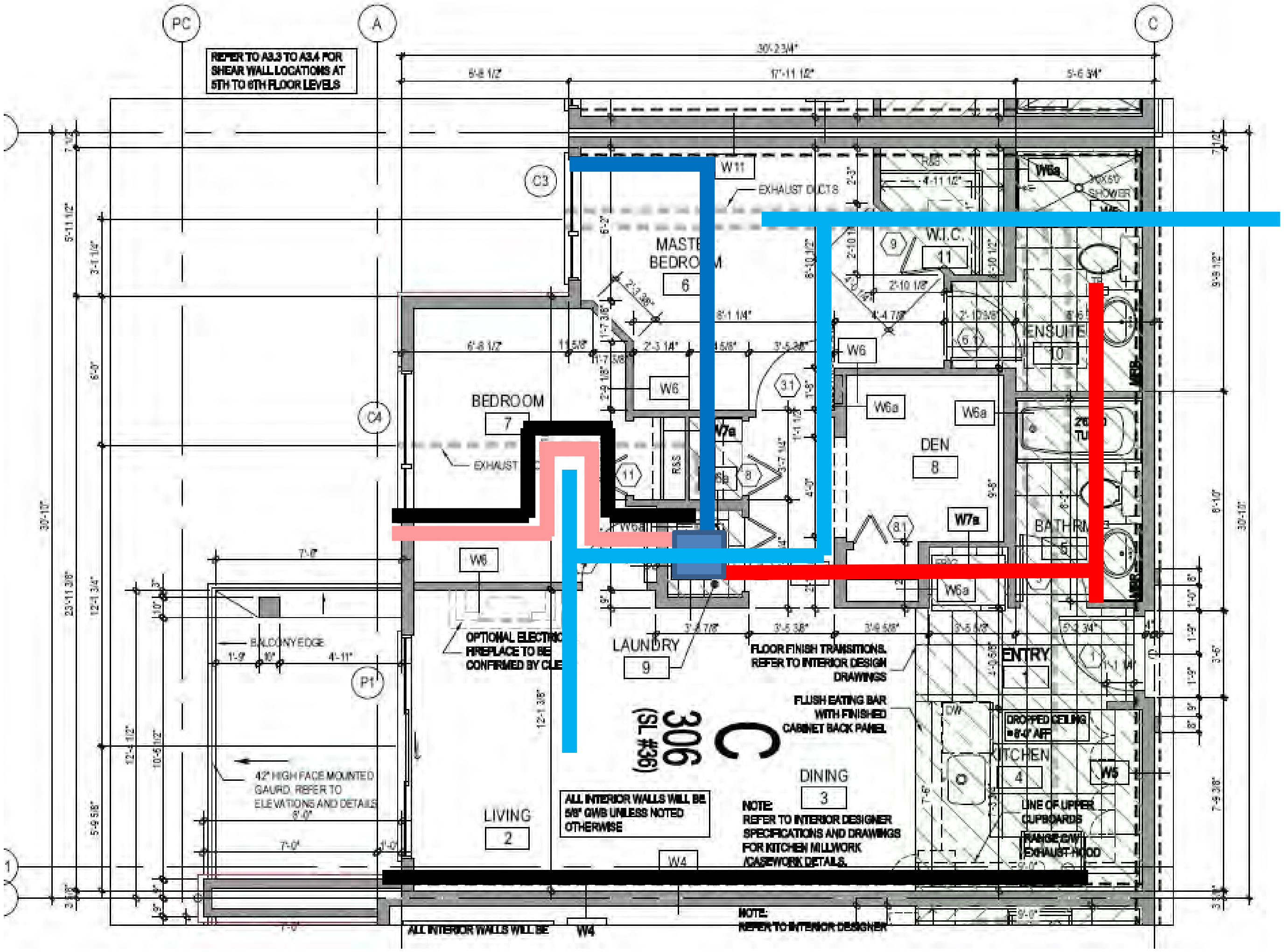

Figure 43 - Ducting Diagram – 2B+DEN+2BA

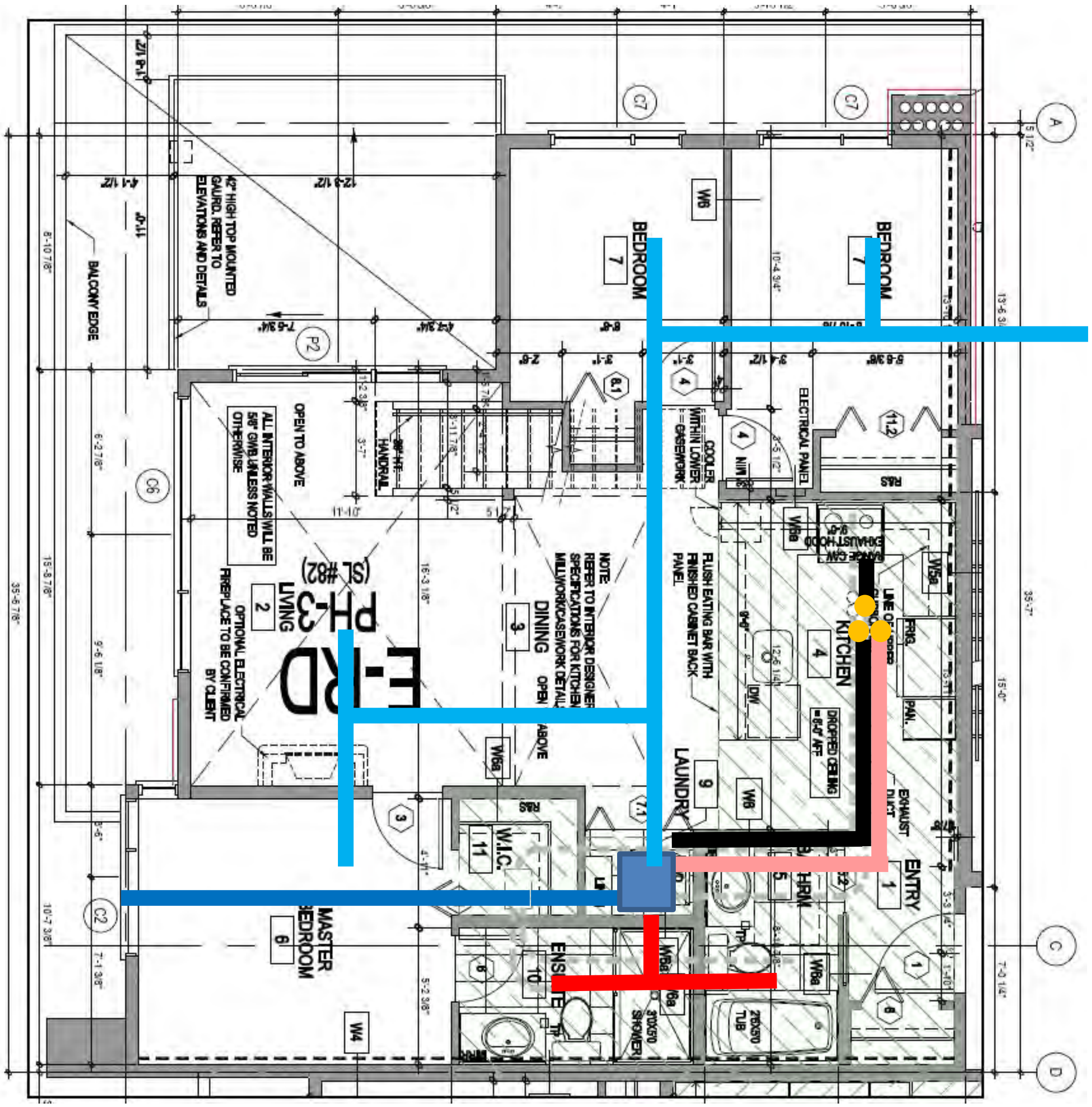

Figure 44 - Ducting Diagram – 3B+2BA

Figure 45 - 1 Bedroom Suite Ducting before HRV Installation

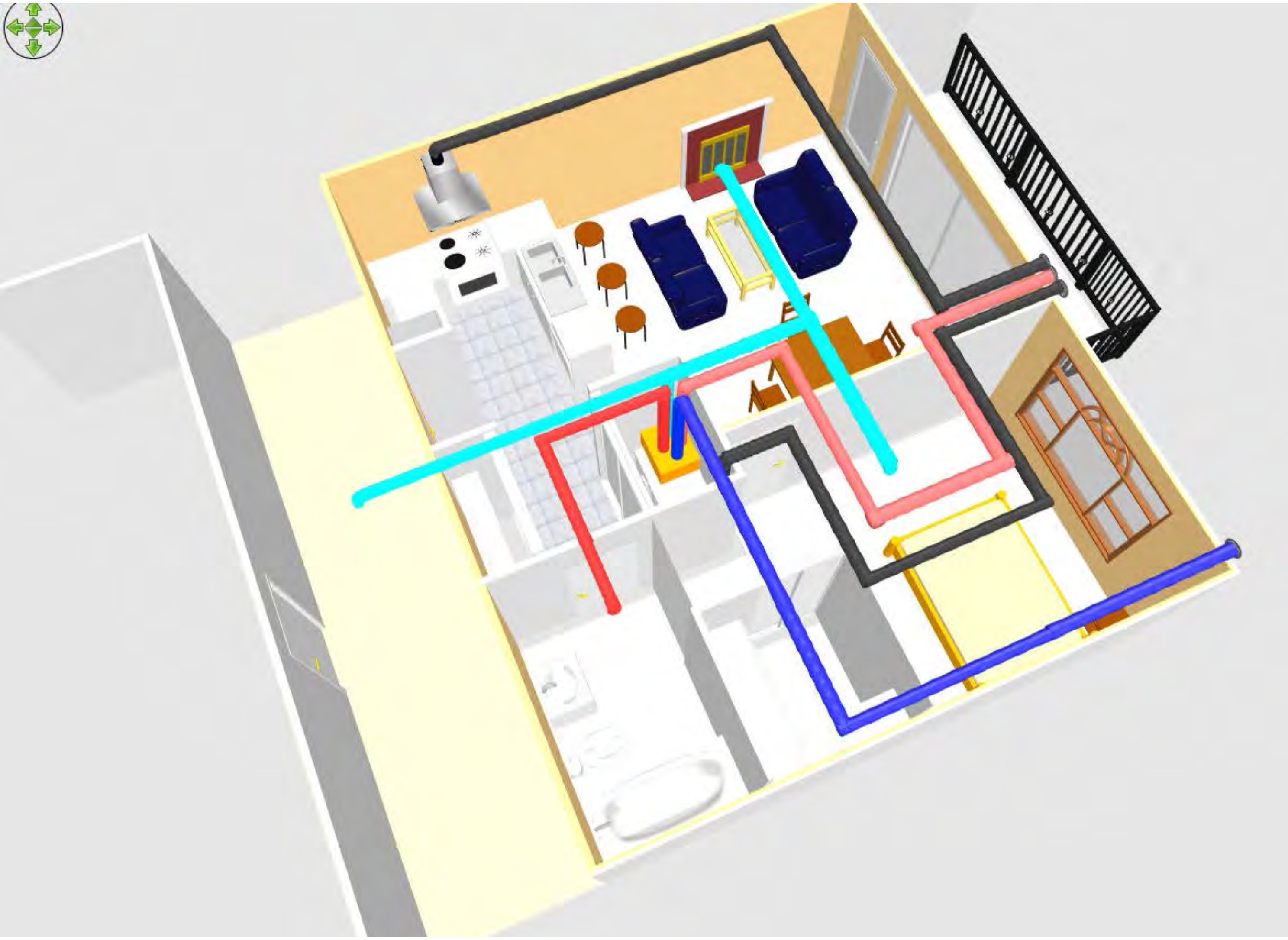

Figure 46 - 1 Bedroom Suite Ducting after Installation

17.0 Appendix G – Sail Building Location & Plans

Figure 47 – Location of The Sail building on Campus

Figure 48 -3D Representation of the Sail Building

Figure 49 - Sail Building Ariel Plans

18.0 Appendix H – Wind Direction

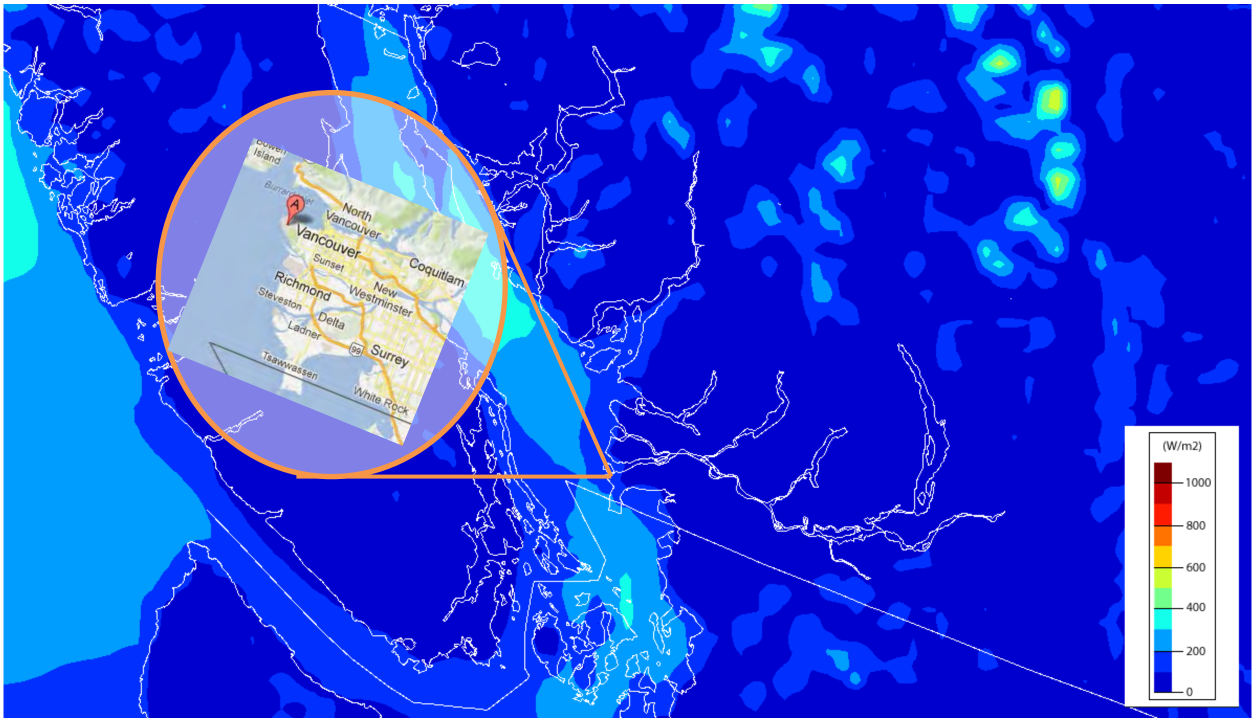

Figure 50 – Annual Wind Speed

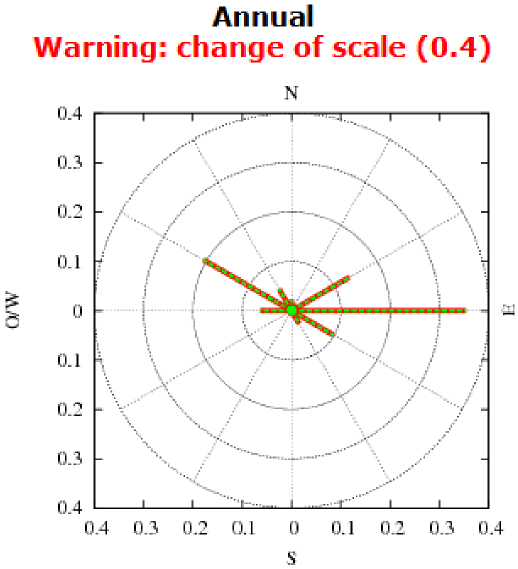

Figure 51 – Annual Wind Direction for UBC location

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