Energy Performance and Life Cycle Costing of Ventilation

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Contents

SUMMARY

Lot E and Site B are two projects under construction with two different ventilation systems. Due to the fact that space conditioning has dominated a great portion of energy consumption, our client - UBC Properties Trust, would like to determine the pros and cons of both ventilation systems for future reference. According to client's request, we did some studies on both ventilation systems on regulation complexity, energy consumption performance, strategies used in the industry, architectural structure, and life cycle costing.

For regulation complexity, 2012 British Columbia Building Code was reviewed. Both designs have met the criterion of the code. Comparing with mechanical ventilation system, natural ventilation system has more requirements. The most significant difference of requirements for natural ventilation system or combination of natural and mechanical ventilation were applied in occupant load during normal use, permits required for use of large openings in the building envelope even during the winter and restriction of occupancy of seasonal buildings. Thus, requirements and regulation for natural ventilation system is more complicated.

For information of energy performance of residential buildings in Vancouver, a report about energy consumption in mid- and high-rise residential building in British Columbia published by RDH Building Engineering Ltd. was reviewed. In their study, consumption data from 39 samples were analyzed. As a result, the average energy consumption is 213kWh/m^2/yr, and average energy consumption for space conditioning is 37%. Since ventilation system has the most effect on space heating energy consumption, simulation with data from 13 samples shows that with a constant make-up air flow rate, annual space heat consumption can goes up to 108.4 kWh/m^2/yr in an environment with high leaky rate (windows open) and it can goes down to 96.7 kWh/m^2/yr in an environment with tight rate. Knowing natural ventilation system tends to have a higher air leakage rate, it is believed that mechanical ventilation would perform better on saving annual space heat consumption.

Previous studies gave us some strategies that may improve the energy efficiency and consumption for residential buildings. There are three most efficient ways which are improving

glazing and wall assemblies, control airflow including make-up air ventilation strategies, and control air leakage. The study also provided some practical improvements. Varying makeup air temperature set-point between 13 to 23 degrees results in a significant difference in energy consumption. The architectural design for natural ventilation has more restricts in floor area, exposed wall area, window to wall ratio, overall wall and roof R-values, window U-value and window solar heat gain coefficient. Decreasing ventilation air flow rates up to 60% of the nominal flow rate would be optimal. Finally, it is very practical to provide heating and ventilation directly to each suite. Using the in-suite approach is more economical considering the cost for ductwork and fire-dampers.

The mechanical drawings were reviewed, compared, and checked for conformance to best practices. Lot E had significantly less ducting requirements, which saved material and space use. Also, each apartment was isolated from the main ventilation system, reducing fire risk and stabilizing energy requirements. It had at least three times as many exterior penetrations as Site B, which will likely increase air leakage. Lot E also had more pieces of equipment, which will likely require more maintenance time. One possible improvement for Site B would be to incorporate the dryer exhaust into the HRV, which, while intermittent, presents a significant heat recovery potential.

Reports of energy modeling for both projects were reviewed. For Site B, EUI of the building design is 136.6 kWh/m^2/year and it meets the energy efficiency target for REAP gold plus certification. The result of Lot E modeling shows that EUI of Lot E (base design) is 176.5 kWh/m^2/year which is higher than REAP gold certification EUI target 163.8 kWh/m^2/year. Cost calculations with respect to lifetime of ventilation systems (20 years) for the two projects were carried out. Using Net Present Value (NPV) calculations at nominal discount rate of 5% and inflation of 2% the real discount rate was calculated to be 3%. The maintenance cost and yearly energy cost (District Energy System rates) were accounted for. The NPV values were normalized by dividing the results by residential area. This made the results directly comparable (NPV/m^2). The residential area was used, rather than total building because the residential ventilation systems are being compared. The results favor the ventilation system Lot E.

1. **INTRODUCTION**

1.1 Project Information

The purpose of this project is to compare and contrast two different residential ventilation systems – centralized HRV (Site B project) and passive ventilation (Lot E).

Site B (Central) is a 6 storey mixed-use building with 98 residential units on levels 2-6 ranging from studios to 3 bedroom units and 7 CRUs on the ground level. There is a level of underground parking; levels P1 – L1 are of concrete construction and L2-6 are of wood frame construction. This project is located in the UBLVD neighbourhood at 6015 University Boulevard and will be connected to UBC District Energy at project completion.

Lot E (Village Square) is a 6 storey mixed-use building with 90 residential units ranging from studios to 3 bedroom units and 8 CRUs on levels 1 and 2. There are 2 levels of underground parking; levels P2 – L2 are of concrete construction and L3-6 are of wood frame construction. This project is located in the Wesbrook Village Neighbourhood at 3338 Webber Lane and will be connected to the south campus District Energy system managed by Corix at project completion.

By doing this research, we aim to support UBC's environmental sustainability goals of reducing energy, materials, and carbon by encouraging sustainable event practices.

1.2 Research Scope

In this research, we addressed the pros and cons for design implications, initial/upfront costs and ongoing (post-occupancy) maintenance costs between the two ventilation system designs. We proposed suggestions for better energy efficiency and consumption in residential buildings regarding to different ventilation systems.

1.3 Tasks

Our main tasks include three parts:

1. Review of design drawings (and applicable design standards/codes pertaining to ventilation) liaising with mechanical consultants and architects to understand design and associated impact to architectural design
2. Review construction costs and operating costs associated with both systems, perform life-cycle analysis as necessary.
3. Review common practice in the industry for similar projects and analyze performance/feedback in terms of energy efficiency, value for money, ease of temperature control etc.

2. VENTILATION BACKGROUND

Ventilation is the process of supplying air to and/or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature. It is an important contributor to the health and comfort of an indoor environment. Specifically, ventilation serves two primary purposes:

1. To provide fresh air for occupants to breathe.
2. To dilute or remove contaminants.

These contaminants can include any of the following:

a. Moisture generated by people, pets, and plants, and by activities such as cooking and showering.
b. Contaminants and odours generated by interior sources including people, plants, cooking, household cleaners, and off-gassing of interior finishes and furnishings.
c. Contaminants from exterior air including dust, particulates, allergens, and mould.

Poor indoor air quality has reported impacts on human health, particularly for the young, the elderly, and those with sensitivities. Impacts can include increased asthma, headaches, and fatigue. Health Canada publishes Residential Indoor Air Quality Guidelines, which advise on recommended exposure limits for a range of indoor pollutants, including benzene, carbon monoxide, fine particulate matter, formaldehyde, mould, naphthalene, nitrogen dioxide, ozone, and toluene 1 - all of which can be found in residences. While source control is an essential first step toward limiting exposure to indoor pollutants 2, adequate ventilation (paired with filtration) is a critical means of establishing and maintaining indoor air quality.

There are two traditional approaches to providing ventilation to a space:

1. Natural (passive) ventilation, where airflow is driven by natural pressure differentials through open windows, doors, grilles, and other planned penetrations.
2. Mechanical ventilation, where airflow is planned and controlled using fans and associated ductwork, grilles, diffusers and vents.

2.1 Centralized HRV

HRVs simultaneously supply and exhaust equal quantities of air to and from a building or suite while transferring heat between the two air streams (with minimal mixing of air in the two streams). This reduces the energy consumption associated with heating or cooling ventilation air while providing a balanced ventilation system. Heat recovery also helps condition the incoming outdoor air to temperatures that are more acceptable to the occupants. (BC Housing, 2015)

HRVs typically consist of the following components:

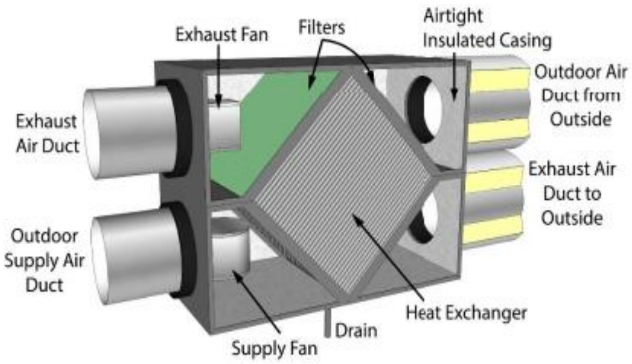


Figure 1. Parts of a heat recovery ventilator

a. An airtight insulated case
b. Supply and exhaust fans
c. Outdoor air inlet from outside (shown with insulated duct connected)

d. Outdoor supply air outlet (shown with duct connected)
e. Exhaust air inlet (shown with duct connected)
f. Exhaust air outlet to outside (shown with insulated duct connected)
g. Heat exchanger
h. Condensate drain pan connecting to a drain
i. Sensors and controls
j. Removable /cleanable filters
k. In some cases motorized dampers to aid in defrost

2.2 Passive Ventilation

Natural ventilation can save energy by reducing fan power for ventilation, or providing “free” cooling in shoulder seasons (typically spring and autumn or at night during the summer in diurnal climates, when outside temperatures are cooler than interior spaces). A natural ventilation system can be as simple as a single operable window that can be used for local ventilation to one room, or as complicated as a group of operable windows and passive air vents strategically located to provide ventilation to an entire building or suite. While natural ventilation through operable windows may provide a complementary means of ventilation for MURBs, most codes require a mechanical ventilation system as the primary means. While operable windows provide occupants with some control over the temperature and ventilation within a space, they can significantly increase energy consumption if they are open when it is too cold or too warm outside. (BC Housing, 2015)

Opening windows in cool and cold weather can also lead to uncomfortable temperatures, and can reduce the effectiveness of an HRV or ERV system if one is present. Finally, providing ventilation air through windows does not enable the removal of exterior air contaminants, as a mechanical system with filtration would.

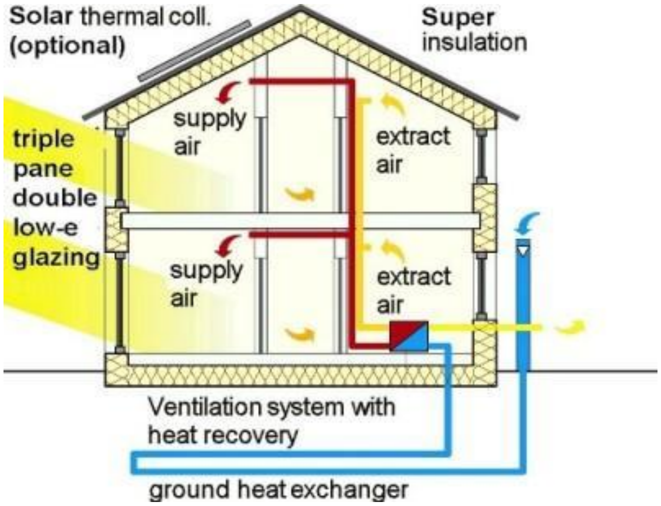


Figure 2. Passive ventilation

3. METHODOLOGY

3.1 The BC Building Code

We referred to the 2012 British Columbia Building Code in this report. The 2012 British Columbia Building and Plumbing Code (BCBC) is an objective-based code which identifies the minimum standard within the Province of British Columbia for buildings to which this Code applies. Building, Plumbing and Fire Codes (collectively referred to as the 2012 BC Codes) are regularly updated and this edition of the BC Codes succeeds the 2006 edition. (Government of British Columbia, 2012)

3.2 Vancouver Building Trends and Performance Trends at UBC

3.2.1 Performance Trend of Residential Buildings in Vancouver

Since project Site B is the first residential building on UBC campus has proposed to use centralized HRV system, more data about the performance of HRV needs to be gathered. Thus, the Energy Consumption and Conservation in Mid- and High- Rise Residential in British

Columbia report which was written by RDH building engineering Ltd. was reviewed. (RDH, 2012)

3.2.1.1 Distribution of Energy Consumption

In the reviewed report, consumption data from 39 non-combustible construction MURBs located in the Lower Mainland of BC, Victoria, BC were analyzed to assess the current level of energy consumption. They have used the following steps to analyze the data:

1. Gather at least 10 years of gas and electricity billing data from 1998 to 2008 from BC Hydro and Fortis BC.

2. Study the effect of climate on heating consumptions in the first 10 years

3. Capture at least 2 to 3 years of data after building enclosure upgrade

4. Compare pre and post- rehabilitation energy consumption

3.2.1.2 Energy Model Simulation

For a further and more detailed study, RDH building engineering Ltd. chose 13 samples as representatives of larger building set. Energy model was performed by the software program FAST (Facility Analysis and Simulation Tool) with mechanical and architectural information collected for the 13 samples. Since the metered energy consumption data was collected for the study mentioned in previous section, input the metered data can enhance the accuracy of the simulation result, and those result will be called “meter calibrated” model. In the simulation, it is assumed that make-up air system operates at 100% of its rated air flow capacity at leaky rate (high value in cfm/sf) and it operates at 80% of rated air flow capacity at tight rate (low or 0 cfm/sf). Range of airtightness was set between 0 to 0.4 cfm/sf and the values between were scaled linearly.

3.2.2 Performance Trend of Buildings in UBC

Due to the fact that the two projects (Site B and Lot E) that are investigated will be located in UBC area, so a study of the energy consumption performance of other buildings in the same area would be a useful information for future consumption behavior prediction and design trend.

In order to collect the energy consumption of buildings in the UBC area, a core component of UBC’s energy management and building performance monitoring called ION Historian was used. This database is publicly accessible and it provides real-time and long-term trending of energy and water consumption data for majority of UBC Vancouver campus buildings. However, this database does not contain energy consumption for any residential building in UBC campus. We believe that the trending of data of those non-residential buildings can provide some insight of effect of both ventilation systems. (http://ion.energy.ubc.ca/ion/)

Procedure for data gathering from ION Historian:

Step 1: Location specification

In the ION front page, there is a main campus diagram. The whole campus was divided into 7 sections. Based on the location of the targeted building, click the corresponding area on the diagram. Then, click on the meter icon of the targeted building, and the building’s real-time electrical energy meter diagram will be displayed.

Figure 3. ION front page

Step 2: Choosing data

For the purpose of this study, long-term trending data was needed. Thus, click on the web reports icon on the bottom left.

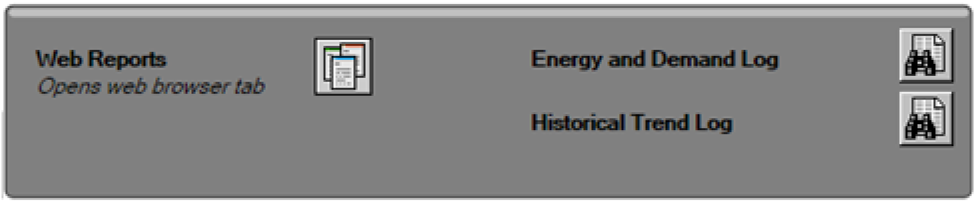
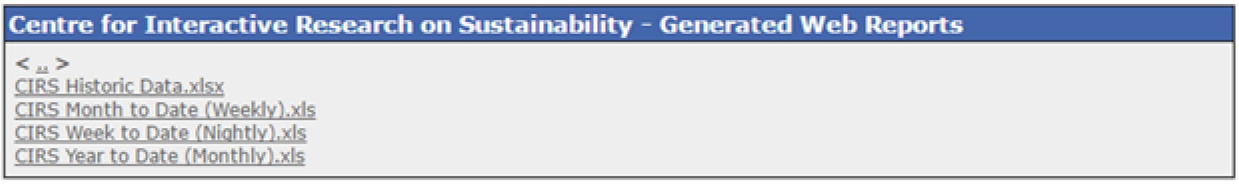


Figure 4. Web reports icon

Then, click Historic Data.xlsx for annual data.



Centre for Interactive Research on Sustainability - Generated Web Reports

< .. >
CIRS Historic Data.xlsx
CIRS Month to Date (Weekly).xls
CIRS Week to Date (Nightly).xls
CIRS Year to Date (Monthly).xls

Figure 5. Generated web reports

Step 3: Result

Based on the design of the building, various energy and water consumption data will be available in a excel sheet.

Step 4: Analyze

Some of the buildings in this study use steam for space heating. Thus, for analysis purposes, usage of steam will be converted to energy with equation 1 lb steam = 1.055NJ. Due to the fact that the value displayed in the previous spreadsheet are cumulative, so the value for annual consumption will be the difference between consumption on 1 Jan and 31Dec.

3.3 A Review of Common and Best Practices in the Industry

The research report “Energy Consumption and Conservation in Mid- and High-Rise Residential

Buildings in British Columbia” (RDH, 2012) provided us some data for energy consumption by ventilation systems and improvement strategies.

The report investigated the energy consumption and efficiency of multi-unit residential buildings (MURBs) in British Columbia before and after comprehensive building enclosure rehabilitation. It examined and assessed the actual energy-related performance of the in-service building, and to determine the energy impact of the building enclosure improvements.

The research is used to determine better building enclosure design strategies to reduce energy consumption, while considering the other building functions for both new and existing buildings. Detailed energy consumption data was provided by the local gas and electric utility suppliers for a sample set of private-sector condominiums constructed over the past 40 years. Consumption data from 39 non-combustible construction MURBs located in the Lower Mainland of BC, and Victoria, BC were analyzed to assess the current levels of energy consumption.

3.4 Mechanical Drawings

The mechanical drawings of each building were provided by the client. The drawings detail the layout of the building’s heating and ventilation system and provide insight into notable differences between the two systems. We compared the drawings and highlighted notable differences such as terms of duct size and location, amount of mechanical equipment, and safety concerns. (Worden, 2015)

3.5 Energy Modeling of Site B and Lot E

3.5.1 Energy modeling for site B

The new site B development on University Boulevard for UBC Properties Trust consists of a six storey mixed use building with 68,016ft^2 of residential space and 10,621ft^2 of commercial over a single storey parkade. (Williams Engineering, 2015)

3.5.1.1 Modeling Methodology

The energy modeling was done to provide necessary documentation to meet REAP Energy and Atmosphere Energy Efficiency Targets. The energy model was created using EE4 (Version 1.7 build 2), a program developed by Natural Resources Canada (NRCan). This software is based on the DOE 2.1e simulation engine, which calculates energy consumption on an hourly basis based on the detailed set of inputs that includes the following:

a. Building orientation
b. Building configuration
c. Window to wall ratio
d. Type of glazing
e. Type of building materials and construction
f. Internal and external shading
g. Internal lighting types and schedules
h. Heating and cooling loads and schedules
i. Zone temperature set point and schedules
j. Terminal equipment characteristics and performance
k. Central system characteristics and performance
l. Energy type and cost

3.5.1.2 Climate Data

Climate data for Vancouver B.C was used for this report. This data describes a typical meteorogical year and includes hourly values for many parameters including:

a. Dry bulb temperature
b. Dew point temperature
c. Relative Humidity
d. Solar Radiation
e. Wind speed and direction
f. Cloud cover

3.5.1.3 Occupancy Schedule

The majority of the building follows a multifamily residential occupancy. The following is the typical daily occupancy profile:

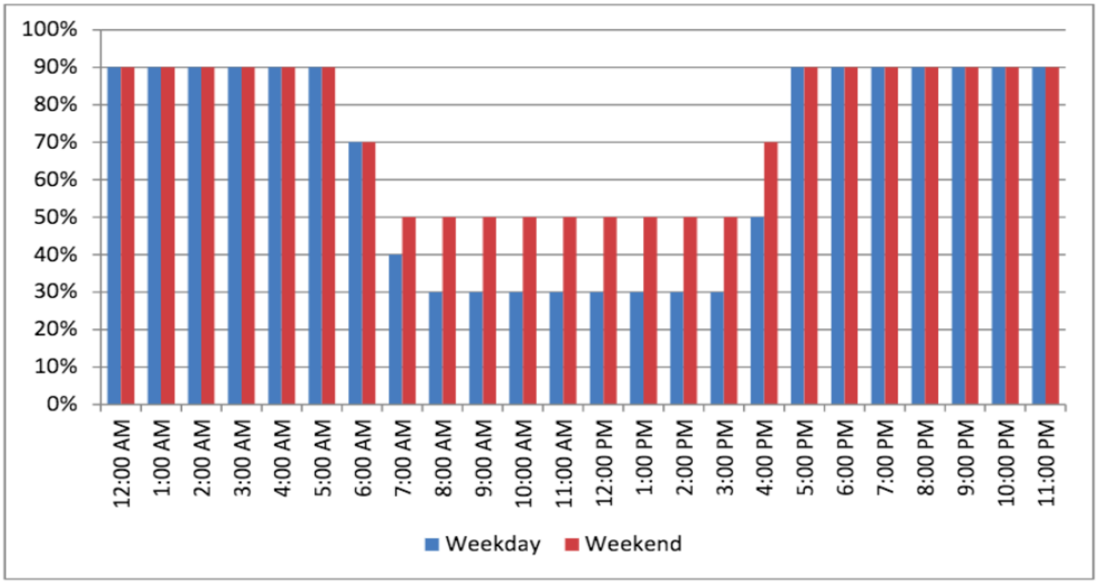


Figure 6. Daily occupancy profile

The occupancy is typical to any multifamily residential occupancy. The peak loads are during the morning and night except the office hours. However, the loads during the weekends are higher than weekdays.

3.5.1.4 Modeling procedures under REAP

The energy model generated follows the modeling procedures outlined in the most recent version of NRCan's EE4 Modelling Guide and UBC's Energy Modelling Guidelines.

The following table provides a summary of the modeling input parameters, as well as a quantitative summary of the energy conservation measures (ECMs).

Table 1. Envelope

Floor Area	78,637 ft^2
Number of storeys	6
Roof Construction	6" Rigid Insulation Roof Overall Building: R-32.3
Wall construction	2x6 Wood Framed Batt Insulation Wall Overall Building: R-16.9
Glazing Properties	Low-E Double Glazed, Argon – Filled, Thermally broken

	Aluminum Windows: U-0.35 SHGC-0.32 Low-E Double Glazed, Argon filled, Vinyl Windows: U-0.28 shgc-0.31
Skylight U-value	N/A
Window/Wall Ratio	North 44.1%, East 29.3%, South 51.1%, West 44.9% Total 44.4%

Table 2. Internal Loads

Interior Lighting Power Density	0.90 W/ft^2
Lighting Controls	Occupancy Sensors in Public Areas
Peak Occupancy	Residential: 177 People Commercial: 38 People
Appliance / Receptacle	0.42 W/ft^2

Table 3. Operating conditions

Indoor Design Temperatures	Heating Setpoint: 72 F Cooling Setpoint: 75 F
Indoor Humidity Levels	No Control
Ventilation Airflow	6,925 CFM (39 CFM/occ)
DHW Requirements	Lavatories: 1.0 GPM, Sinks: 1.0 GPM, Showers: 1.5 GPM

Table 4. Mechanical systems

Residential Heating / Cooling System	Radiant Floor Heating No Cooling
Residential Ventilation System	100% Q/A Central Air Handling Unit with Hydronic Heating Coil
Commercial Heating / Cooling System	Split System Heat Pumps
Commercial Ventilation System	Direct Outdoor Air Connection
Supply Fan Power	Residential: 6,265 Watts Commercial: 2,433 Watts
Return Fan Power	None
Air Economizer	None
Heat Recovery	None

Table 5. Central plant

DHW System	Heat Exchanger to District Energy System
DHW Efficiency	N/A
Pump Control	Variable Speed
Heating Plant	Heat Exchanger to District Energy System
Heat Efficiency	N/A
Cooling System	None
Cooling Efficiency	N/A

3.5.1.5 Narrative of Energy Conservation Measures

The design team adopted numerous energy conservation measures (ECM's) in the design in order to strengthen the potential of this project to achieve REAP certification. Below is a description of the major ECMs.

a. High performance glazing and building insulation
b. Decreased lighting power density and occupancy sensors in common areas
c. Low-flow plumbing fixtures
d. Radiant floor heating to decrease fan energy

3.5.2 Energy modeling for Lot E

The building is planned for UBC Lot E on the university's South Campus is a 6-storey mixed use residential-commercial building that is complemented with two levels of underground parkade. The commercial portion, with a total area approximately 2,510 m^2 (27,000 ft^2), occupies most of levels 1 and 2. The residential portion, with a total area of approximately 7,435 m^2 (80,000 ft^2), occupies levels 3 to 6 and a portion of levels 1 and 2. The below grade area accommodates 2 levels of parkade, storage rooms and other service areas and has a total floor area of approximately 4,926 m^2 (53,000 ft^2). (Stantec, 2015)

There are 4 different wall types used in the project. Levels 1 and 2 (podium) are of concrete structure with metal frame wall. Level 3 through 6 are wood frame structure. The wood frame walls consist of 2x6 wood studs at 16'' filled with 5.5'' of batt insulation equivalent to RSI-3.87 (m^{2}K)/W (R-22 (Hfft^2)/BTU) nominal. Additional layers include gypsum wallboard, sheathings, membranes and air space. According to Appendix A of ASHRAE 90.1-2010, the effective R-value for this wall assembly can be estimated to be RSI-2.8 (R-15.9). This meets the REAP mandatory thermal performance requirement of RSI-2.75 (R-15.6) for exterior walls. The steel stud walls also have RSI-3.87 (R-22) nominal batt insulation between 6’’ studs, and 1.5’’ of continuous rigid insulation of RSI-1.06 (R-6). Additional layers such as gypsum board, sheathing effective R-value for this wall assembly can be estimated to be RSI-2.75 (R-15.6). This meets the REAP mandatory thermal performance requirement of RSI-2.75 (R-15.6) for exterior walls.

Below grade walls (underground parkade) are of reinforced concrete without any insulation. The roof of the building will be insulated with 6 inches of rigid insulation to an effective R-value of RSI-5.28 (R-30). The Window-to-Wall Ratio (WWR) of the building is approximately 41%. The windows in the wood – frame structure are at this point proposed to be of the Centra 2900 series with effective an effective U-value of USI-1.42 W/(m^2 K) (U-0.25). The concrete podium portion is assumed to have metal-framing windows with an overall U-value of USI-2.55 (U-0.45). The solar Heat Gain Coefficient (SHGC) is assumed to be 33% for all windows.

Table 6. REAP minimum envelope requirements

Envelope	**REAP thermal performance requirement**	**Base design**
Roof	RSI-4.93 (R-28) for flat roof	RSI-5.28 (R-30)
Exterior wall	Effective RSI-2.75 (R-15.6) for above grade walls	RSI-2.80 (R-15.9) for wood-frame walls RSI-2.75 (R-15.6) for steel-stud walls
Floor	RSI-2.75 (R-15.6) for slab floors	RSI-3.52 (R-20)
Minimum Glazing Thermal Performance	Maximum U-value of U-0.35 for non-metal framed windows U-0.45 for metal framed windows	U-0.25 for non-metal framing (Levels 3 through 6) U-0.45 for metal framing (Levels 1 and 2)

3.5.2.1 Modeling methodology

Energy analysis using simulation software can be very valuable throughout the design of new building projects to estimate the energy use of a building based on the local climate characteristics, system choices, and geometry. The purpose of energy simulations is to assist owners and design teams in recognizing opportunities to reduce the energy use in their designs as well as to evaluate the effectiveness of proposed energy conservation measures (ECM’s).

Simulation tools used during the design process help bring all the architectural and engineering design elements together to predict how different building components will interact with each other and the environment. By understanding the relationship between individual building components and the building as a whole. The project can be carefully designed to provide greatest benefit for the lowest cost. Successful high performance buildings can only be achieved by understanding how building components interrelate under operating conditions.

The whole building energy simulation software used to model the building and energy systems in the present study is IES Virtual Environment (version 2014). IESVE software complies with ASHRAE standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, and has capabilities to apply the Energy Cost Budget method, and Performance Rating Method outlined in the Appendix G of AHRAE standard 90.1-2007.It is also approved by the CaGBC to perform energy modeling for LEED Energy and Atmosphere prerequisite 2 (EAp2) and credits EAc1, EAc2, EAc5 and EAc6. The Vancouver CWEC weather file (Canadian Weather Year for Energy Calculation) has been for modeling. UBC Energy Modeling Guidelines (issued by Halsall on March 20, 2013) have been followed for this energy modeling and simulation analysis.

3.5.2.2 Mechanical

HVAC: Residential suites are ventilated to meet British Columbia Building Code 2012. Ventilation air is ducted directly to each suite. Heating of the suites is provided by radiant floor heating system. Corridos are pressurized using a central heating coil that acts as a make up air unit. Commercial portion is heated using hot water coils and cooled using VRF system. Parkade is only ventilated, and not heated. Table 2 summarizes the air flow rates.

Table 7. Airflow rates

Space type	Ventilation rate	Reference
Micro units	14 l/s (30 cfm)	BCBC 2012
One bedroom suites	14 l/s (30 cfm)	BCBC 2012
Two bedroom suites	21 l/s (45 cfm)	BCBC 2012
Three bedroom suites	21 l/s (45 cfm)	BCBC 2012
Corridors	378 l/s (800 cfm) each	Pressurization, Mechanical Design
Parkade	15,102 l/s (32,000 cfm)	ASHRAE 62.1-2007 requirement (3.79 l/m^2 or 0.75 cfm/ft^2)
Other spaces (such as storage rooms, amenity, etc.)	Defined per space type	To meet ASHRAE 62.1-2007 requirements
Commercial	Defined per space type	To meet ASHRAE 62.1-2007

Central Plant: Heating and Domestic Hot Water of the building will be provided by a new central District Energy System (DES) that is under construction on the UBC campus. As outlined in the UBC Energy Modeling Guideline, both the Method 1 and Method 2 approach of LEED Canada 2009 Interpretation Guide for District Energy Systems can be followed. Under Method 1, the energy model only accounts for the downstream equipment located within the project boundary. The energy provided by the DES modeled as purchased heat, which becomes effectively another fuel type. Following Method 1, the project will not benefit nor is it penalized for the efficiency of the DES.

Cooling of the commercial portion is provided by a VRF system. No cooling is provided for the suites.

3.5.2.3 Internal loads

Lighting: The lighting design is proposing Lighting Power Densities (LPD's) less than ASHRAE 90.1-2010 maximum allowances. LPD values are given in table 3.

Table 8. Lighting Power Density (LPD's) per space type

Space type	Base Design LPD (Stage 1) w/m^2 (w/ft^2)	ECM 8 LPD targets (Stage 2) w/m^2 (w/ft^2)
Suites	9.7 (0.90)	5.4 (0.50)
Corridors	6.5 (0.60)	4.9 (0.46)

Stairway	6.7 (0.62)	6.7 (0.62)
Electrical/Mechanical Rooms	8.6 (0.80)	8.6 (0.80)
Amenity spaces	7.9 (0.73)	6.5 (0.60)
Lobby	9.7 (0.90)	7.7 (0.72)
Lobby Elevator	6.2 (0.58)	5.4 (0.50)
Restrooms	8.6 (0.80)	6.5 (0.60)
Parkade	1.5 (0.14)	1.5 (0.14)
Storage Rooms	5.9 (0.55)	4.3 (0.40)
Vestibules	6.5 (0.60)	4.9 (0.46)
Offices	10.5 (0.98)	10.5 (0.98)
Rental	18.1 (1.68)	18.1 (1.68)
Restaurants	14.1 (1.31)	14.1 (1.31)

Peak exterior lighting is estimated at 4 kW and provided by electrical designer.

Miscellaneous equipment load: The UBC Energy Modeling Guide references MNECB and ENERGY STAR guidelines in order to define miscellaneous equipment loads. As a mandatory REAP requirement, clothes washers, refrigerators and dishwashers must meet ENERGY STAR performance criteria. Clothes dryers, and cooking appliances are assumed to be standard. Table 4 provides average annual energy consumption of new major appliances (source: NRCan; choosing and using appliances with EnerGuide, 2013).

Table 9. Annual energy consumption

Appliance type	**Annual energy consumption (kWh/year) - 2010**
Refrigerator – ENERGY STAR	369
Cooking appliance – Standard	499
Dishwasher – ENERGY STAR	309
Clothes washers – ENERGY STAR	148
Clothes Dryers – Standard	928
Total per suite	2,253

For the residential portion, UBC Energy Modeling Guide requires using a base value of 2.69w/m^2 (0.25 w/ft^2) to account for other non appliance process loads in the suites. The guide references MNECB 1977 modeling guide to define process loads for other residential spaces.

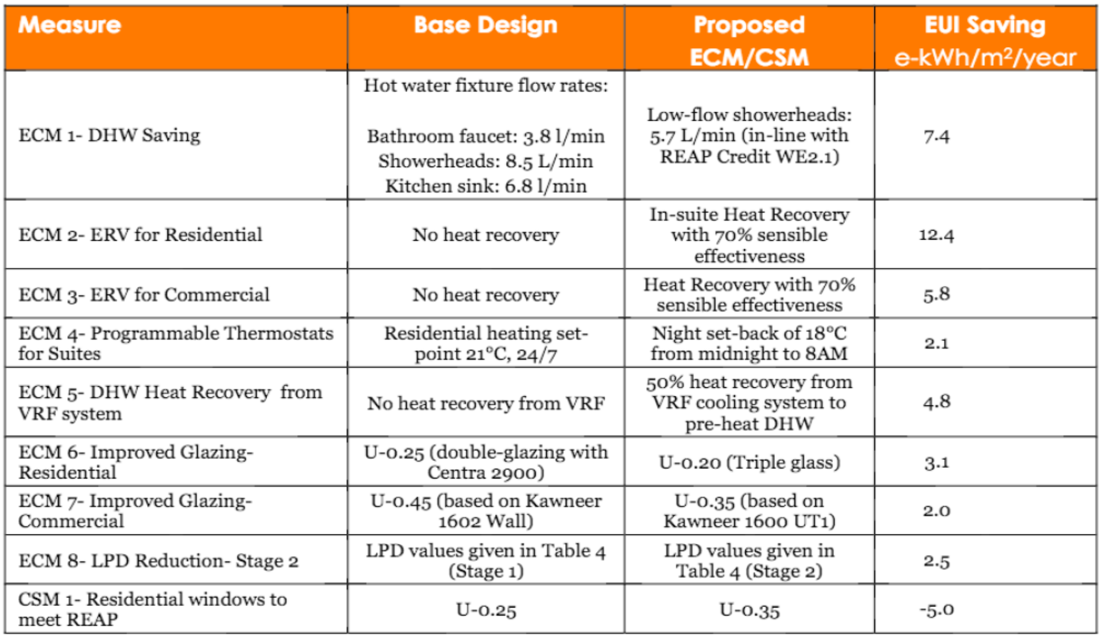
For commercial spaces, ASHRAE 90.1-2010 values are used as they are more recent than MNECB and better represent commercial plug loads.

Table 10. Equipment plug loads

Appliance type	Equipment load W/m^2 (W/ft^2)
Suites	2.69 (0.25)
Offices	16.14 (1.5)
Retail	5.38 (0.5)
Restaurant	5.38 (0.5)
Mechanical/Electrical Rooms	1.08 (0.1)
Washrooms	1.08 (0.1)
Corridors, Stairs, Storage Rooms	0

3.5.2.4 Energy Conservation Measures and Cost Saving Measures

The base design, with an overall EUI of 176.5 kWh/m^2/year exceeds the EUI target of 163.8 kWh/m^2/year. Considering major energy end uses ie. space heating, domestic hot water and interior lighting, various Energy Conservation Measures (ECM's) were studied. The impact of each ECM one EUI has been analyzed. As a Cost saving measure (CSM), the impact of a less performing glass for residential portion has also been evaluated. Design team considering the design intent and project budget, may select any individual or a combination of ECM's that awards a total of at least 12.7 kWh/m2/year of EUI reduction.



Measure	Base Design	Proposed ECM/CSM	EUI Saving e-kWh/m^2/year
ECM 1- DHW Saving	Hot water fixture flow rates: Bathroom faucet: 3.8 l/min Showerheads: 8.5 L/min Kitchen sink: 6.8 l/min	Low-flow showerheads: 5.7 L/min (in-line with REAP Credit WE2.1)	7.4
ECM 2- ERV for Residential	No heat recovery	In-suite Heat Recovery with 70% sensible effectiveness	12.4
ECM 3- ERV for Commercial	No heat recovery	Heat Recovery with 70% sensible effectiveness	5.8
ECM 4- Programmable Thermostats for Suites	Residential heating set-point 21°C, 24/7	Night set-back of 18°C from midnight to 8AM	2.1
ECM 5- DHW Heat Recovery from VRF system	No heat recovery from VRF	50% heat recovery from VRF cooling system to pre-heat DHW	4.8
ECM 6- Improved Glazing-Residential	U-0.25 (double-glazing with Centra 2900)	U-0.20 (Triple glass)	3.1
ECM 7- Improved Glazing-Commercial	U-0.45 (based on Kawneer 1602 Wall)	U-0.35 (based on Kawneer 1600 UT1)	2.0
ECM 8- LPD Reduction- Stage 2	LPD values given in Table 4 (Stage 1)	LPD values given in Table 4 (Stage 2)	2.5
CSM 1- Residential windows to meet REAP	U-0.25	U-0.35	-5.0

Figure 7. Base design and EUI saving

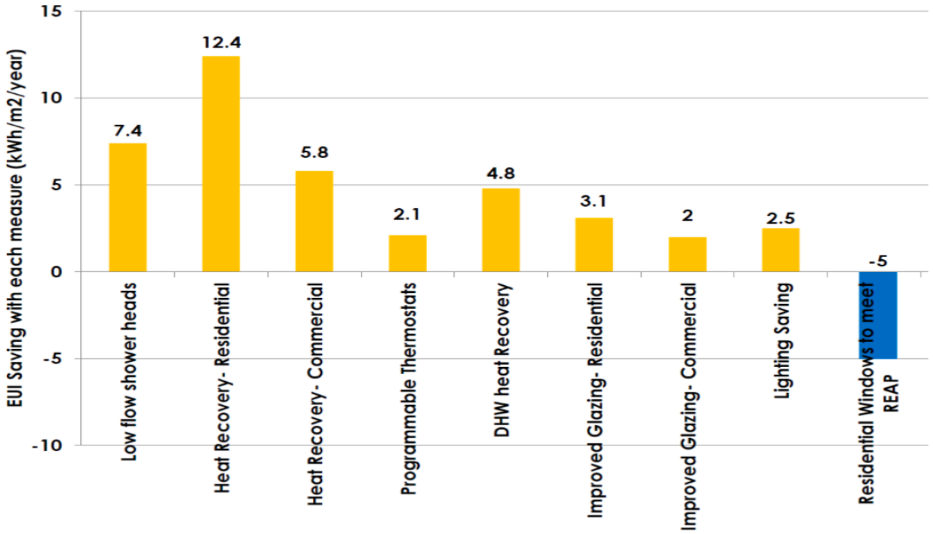
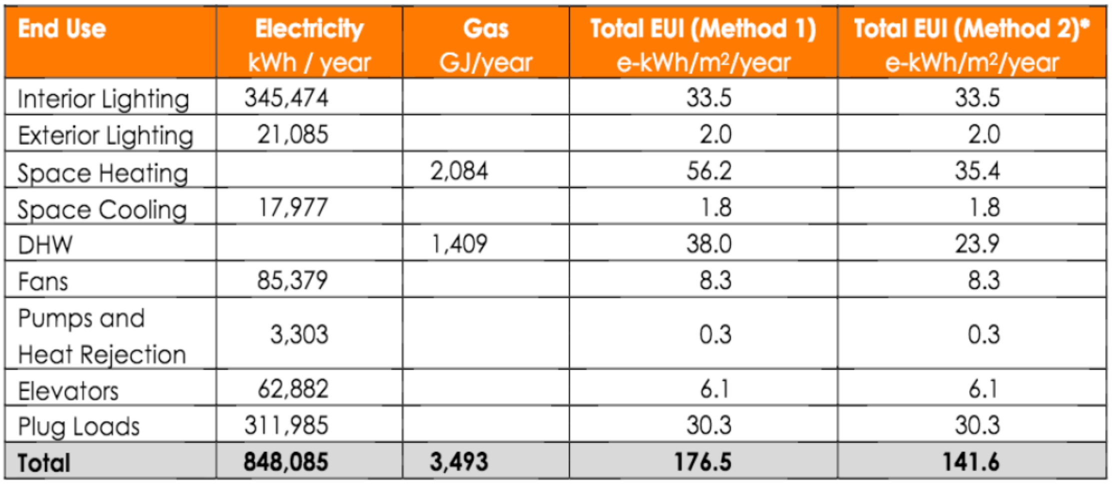


Figure 8. EUI savings associated with each ECM or CSM

In method 2 the DES plant is accounted for fully. It is pursued claiming credit for the performance of the final DES plant less the distribution losses. 37% of the space heating and DHW can be considered ‘free heat’, and therefore, subtracted from the EUI. Under method 2, the overall EUI is reduced to 141.6 kWh/m2/year.

Table 10. EUI method 1 and EUI method 2



End Use	**Electricity** kWh / year	**Gas** GJ/year	**Total EUI (Method 1)** e-kWh/m^2/year	**Total EUI (Method 2)*** e-kWh/m^2/year
Interior Lighting	345,474		33.5	33.5
Exterior Lighting	21,085		2.0	2.0
Space Heating		2,084	56.2	35.4
Space Cooling	17,977		1.8	1.8
DHW		1,409	38.0	23.9
Fans	85,379		8.3	8.3
Pumps and Heat Rejection	3,303		0.3	0.3
Elevators	62,882		6.1	6.1
Plug Loads	311,985		30.3	30.3
Total	**848,085**	**3,493**	**176.5**	**141.6**

*Space Heating and DHW load is multiplied by 0.63 to calculate the method 2 values.

4. RESULTS

4.1 Ventilation Requirements in BC Building Code

4.1.1 BC Building Code for Natural Ventilation

Except as permitted by Sentence (2), the ventilation required shall be provided by mechanical ventilation, except that it can be provided by natural ventilation or a combination of natural and mechanical ventilation in

a. Buildings of other than residential occupancy having an occupant load of not more than one person per 40 m^2 during normal use.
b. Buildings of industrial occupancy where the nature of the processes contained therein permits or requires the use of large openings in the building envelope even during the winter, and seasonal buildings not intended to be occupied during the winter.

Where climatic conditions permit, buildings containing occupancies other than residential occupancies may be ventilated by natural ventilation methods in lieu of mechanical ventilation where engineering data demonstrates that such a method will provide the required ventilation for the type of occupancy.

4.1.2 BC Building Code for Mechanical Ventilation

Mechanical Ventilation System Components:

1. A mechanical ventilation system shall include

a. A principal ventilation system that
    (1) provides supply air in accordance with Article 9.32.3.4., and
    (2) includes an exhaust fan that conforms with Article 9.32.3.5.,
b. the kitchen and bathroom exhaust fans that are required by Article 9.32.3.6., and

c. if the building includes a heated crawl space, the components that are required by Article 9.32.3.7.

2. Principal Ventilation System Supply Air

Except as provided in Sentence (6), a principal ventilation system shall mechanically provide supply air in accordance with Sentence (2), (3), (4) or (5).

3. Where the principal ventilation system is a ducted forced-air heating system, the ducted forced-air heating system shall

a. provide supply air through the ducting to each bedroom, and each floor level without a bedroom,

b. draw supply air from an outdoor inlet that is connected to the cabinet containing the furnace air circulating fan required by Clause (d) by ducting that measures, from that cabinet to the point at which the ducting intersects the return air plenum, between 3 m and 4.5 m in length, or if a flow control device is used, not more than 4.5 m in length.

c. draw supply air through ducting that is rigid ducting with an equivalent diameter of at least 100 mm, or flexible ducting with an equivalent diameter of at least 125 mm, and

d. have a furnace air circulating fan set to run continuously.

4. Where the principal ventilation system is a ducted forced-air heating system used in combination with a heat-recovery ventilator,

a. the ducted forced-air heating system shall conform to Clauses (2)(a), (c) and (d),

b. the heat-recovery ventilator shall draw supply air from an outdoor inlet into the return air plenum of the ducted forced-air heating system, and

c. the heat-recovery ventilator shall draw exhaust air, through dedicated ducting,

d. from one or more indoor inlets, at least one of which is located at least 2 m

e. above the floor of the uppermost floor level, and

f. at the capacity rating of the heat-recovery ventilator, which shall be no less than the air-flow rate specified in Table 9.32.3.5.

4. Where the principal ventilation system is a heat-recovery ventilator, the heat-recovery ventilator shall

a. provide supply air through dedicated ducting to

b. each bedroom, and

c. each floor level without a bedroom, and

d. draw exhaust air, through dedicated ducting, from one or more indoor inlets, at least one of which is located at least 2 m above the floor of the uppermost floor level, and at the capacity rating of the heat-recovery ventilator, which shall be no less than the air-flow rate specified in Table 9.32.3.5.

6. Where the principal ventilation system is a ducted central-recirculation ventilation system, the ducted central-recirculation ventilation system shall
   a. draw supply air from an outdoor inlet connected upstream of the fan, and
   b. draw air from each bedroom and deliver it to a common area, or a common area and deliver it to each bedroom.
7. A principal ventilation system need not conform to Sentence (1) if the principal ventilation system
   a. services a dwelling unit that is located where the January design temperature, on a 2.5% basis determined in conformance with Article 1.1.3.1., is greater than −20°C or has only 1 storey and a floor area of less than 168 m2 within the building envelope (see Appendix A), and does not have a ducted forced-air heating system, and
   b. provides supply air passively from outdoors through dedicated inlets that are located in each bedroom and at least one common area, are located at least 1 800 mm above the floor, and have an unobstructed vent area of not less than 25 cm^2.

4.2 Performance Trend of Building in Vancouver and UBC

4.2.1 Distribution of Energy Consumption in residential buildings in Vancouver

Knowing that the case studies in the report use MAU (make-up air unit) instead of centralized HRV, the value of energy consumption will definitely be different. Moreover, they are both mechanical ventilation, so it is believed the result of the report can still provide precise trending and can be used as a reference.

In the report written by RDH building engineering Ltd., it summarized a few statements about the average distribution of energy of those 39 cases. (RDH, 2012)

Average size of the MURBs in this study was 11,023 m^2 within a range of 2,142 to 19,563 m^2

- 49% of energy consumption is electricity (102kWh/ m^2/year)
    - 57% of electricity was used in suites
        - 38% used for electric heating
        - 62% used for appliances (plugs) and lighting
    - 43% of electricity was used in common areas
        - 100% used HVAC, elevators, lighting, plumbing, etc.

  <u>22% of total electricity consumption is used for space heat (4% to 36%)</u>

- 51% of energy consumption is gas (111kWh/ m^2/year)
    - 51% of the energy is used for space heat within make-up air unit
    - 49% of energy is used for domestic hot water

  <u>37% of the total energy consumption of the building is used for space conditioning (heating and ventilation)</u>

Thus, 37% of total energy consumption of the building is used for space conditioning which did not include cooling. This number can be used for as a reference in order to compare the efficiency of the design in Site B and Lot E with other designs within Vancouver area.

4.2.2 Effect of Ventilation System on Space Heat Consumption in Residential Building in Vancouver

The following two figures show the effect of airtightness and make-up air flow rate on space heat energy consumption in simulation.

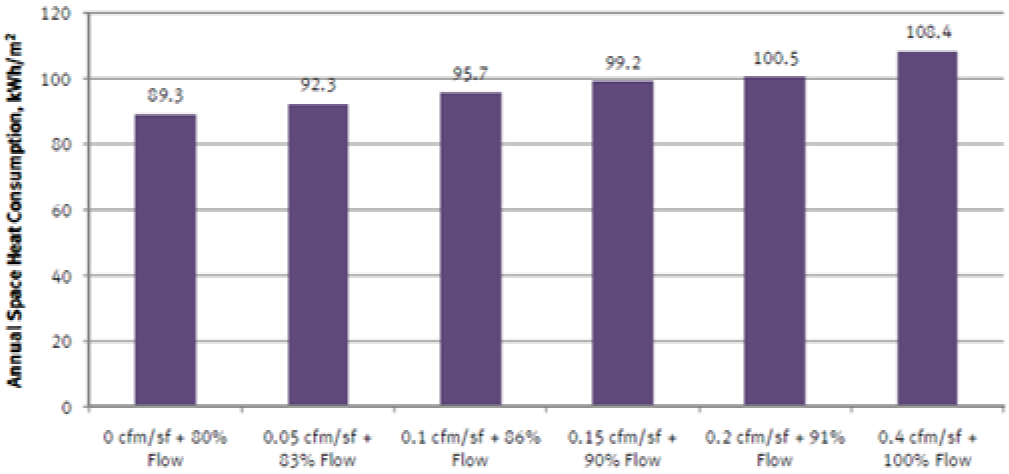


Figure 9. Space heat energy consumption of varying make-up flow rate with airtightness

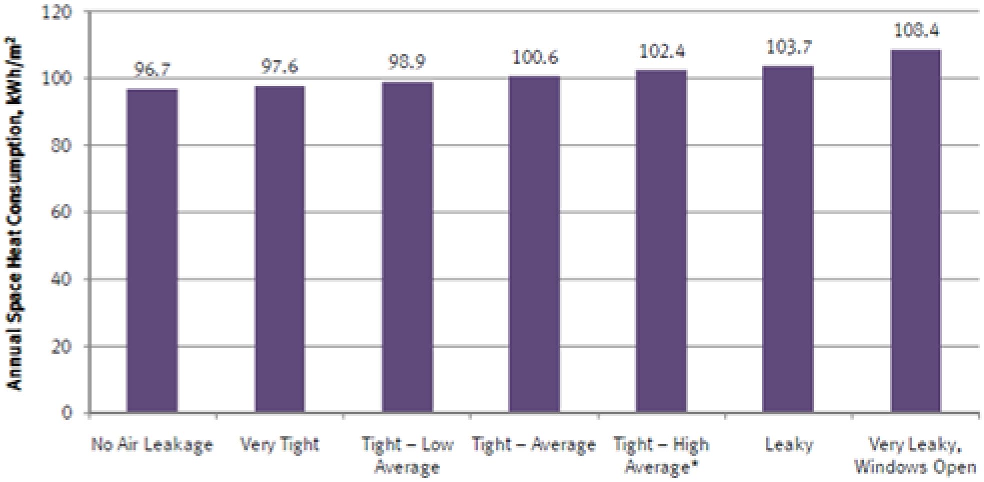


Figure 10. Space heat energy consumption of varying air tightness while make-up air remains constant

In figure 9, it shows the result of simulation where the make-up air flow rate increases as air tightness increases. It is assumed that at a leaky rate (0.4cfm/sf) the make-up air unit operates at a 100% of rated air flow capacity, in contrast, at a tight rate (0cfm/sf) the make-up air unit operates at 80% of rated air flow capacity. As a result, in a high leakage environment, the heat in the building will escape through building enclosure in a faster rate, which cause the space heating system to consume more energy in order to maintain a certain room temperature. Similar result can be seen in figure 10. In the second test, make-up air flow rate is set as constant, so that the impact of airtightness to space heat consumption can be earlier to observe. At a leaky rate, annual space heat consumption is around 108.4kWh/m2. However, the annual space heat consumption decreases to 96.7kWh/m2 at a tight rate. Therefore, it is conclusive that the higher the air tightness rate (cfm/sf), the higher the space heating consumption will be.

4.2.3 Energy Consumption Trend of Buildings on UBC Campus

The following tables summarized the total energy consumption of 6 buildings in UBC area. Data was collected from the Building Energy and Water Data base website. (University of British Columbia, 2016)

Aquatic Ecosystems Research Laboratory (AERL)

Usage:	Laboratory
Size:	5368 m^2
Year Built:	2011
Ventilation system:	Natural Ventilation

AERL	kWh Net start	Steam Net (lbs)	kWh	Steam (lbs)	Total Energy (kWh)	kWh per m2
2011	1,219,466	3,199,986	553,903	1,463,777	982,871	183
2012	1,773,369	4,663,763	545,754	1,116,691	873,007	163
2013	2,319,123	5,780,454	509,752	1,412,861	923,799	172
2014	2,828,875	7,193,315	498,328	1,483,353	933,033	174
2015	3,327,204	8,676,668				

Centre for Interactive Research on Sustainability (CIRS)

Usage:	Office and classroom
Size:	5675 m^2

Year Built: 2011

Ventilation system: Natural Ventilation

CIRS	kWh Net start	Steam Net (lbs)	kWh	Steam (lbs)	Total Energy (kWh)	kWh per m2
2011	-	-	220,821	-	220,821	39
2012	220,821	-	763,066	-	763,066	134
2013	983,887	-	781,974	-	781,974	138
2014	1,765,861	-	724,599	-	724,599	128
2015	2,490,460					

C. K. Choi Building (CHOI)

Usage: Office and classroom

Size: 3196 m^2

Year Built: 1996

Ventilation system: Natural Ventilation

CHOI	kWh Net start	Steam Net (lbs)	kWh	Steam	Total Energy (kWh)	kWh per m2
2011	356,956	2,503,253	161,451	1,191,420	510,603	160
2012	518,407	3,694,673	152,511	1,135,381	485,241	152
2013	670,918	4,830,054	133,013	1,146,857	469,106	147
2014	803,931	5,976,911	121,772	1,086,429	440,156	

						138
2015	925,703	7,063,340				

Irving K Barber Learning Centre (IBLC)

Usage: Library and classrooms

Size: 23226 m2

Year Built: 2008

Ventilation system: Mechanical Ventilation only

IBLC	kWh Net start	Steam Net (lbs)	kWh	Steam	Total Energy (kWh)	kWh per m2
2011	7,795,050	5,733,117	3,812,391	5,415,713	5,399,496	232
2012	11,607,441	11,148,830	3,597,690	5,366,931	5,170,499	223
2013	15,205,131	16,515,761	3,530,731	4,470,859	4,840,941	208
2014	18,735,861	20,986,620	3,501,050	4,586,586	4,845,175	209
2015	22,236,911	25,573,206				

Forest Sciences Centre (FSC)

Usage: Office, laboratory and classrooms

Size: 17505 m^2

Year Built: 1998

Ventilation system: Mechanical Ventilation only

FSC	kWh Net st start	Steam Net (lbs)	kWh	Steam	Total Energy (kWh)	kWh per m2

2011	9,976,699	8,107,520	4,681,017	26,916,154	12,568,945	718
2012	14,657,716	35,023,674	4,707,708	23,716,947	11,658,091	666
2013	9,365,562	58,740,621	4,452,934	24,161,033	11,533,459	659
2014	13,818,495	82,901,654	4,467,059	25,425,164	11,918,044	681
2015	1,650,062	108,326,818				

Earth Sciences Building (ESB)

Usage:	Office, laboratory, classrooms and lecture theatres
Size:	17500 m^2
Year Built:	2012
Ventilation system:	Mechanical Ventilation only

ESB	kWh Net st start	Steam Net (lbs)	kWh	Steam	Total Energy (kWh)	kWh per m2
2011	7,264,235	2,329,955	3,464,923	5,795,251	5,163,253	295
2012	10,729,158	8,125,206	3,106,616	5,899,637	4,835,537	276
2013	13,835,774	14,024,843	3,035,527	5,684,239	4,701,325	269
2014	16,871,301	19,709,082	3,206,416	- 19,709,082	-2,569,440	-
2015	20,077,717					

The following graph shows the performance trend of the chosen buildings in the past few years.

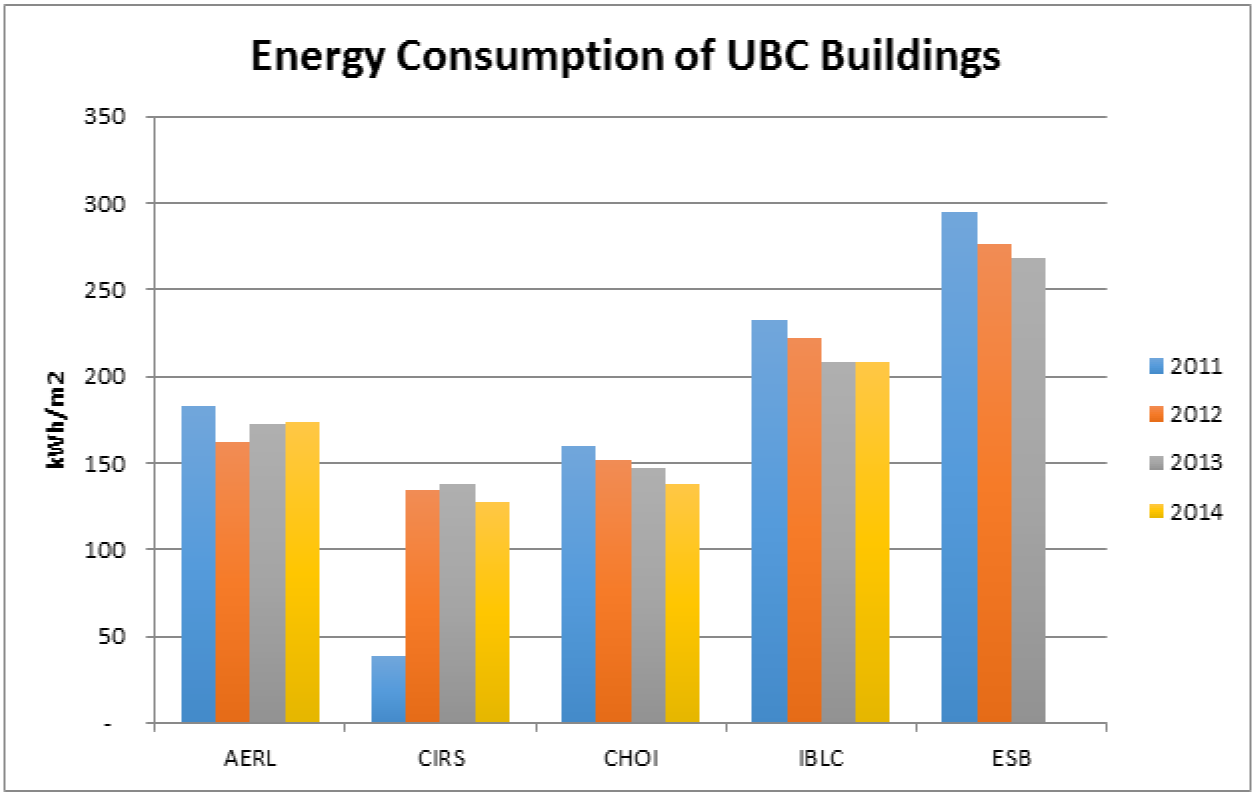


Figure 11. Total Energy Consumption of 5 buildings in UBC

Before comparing those 6 cases, some notes about the data and the way they are presented need to be clarified:

1. From figure 8, energy consumption of CIRS in 2011 is significantly less than the following years. This is because the CIRS building officially started operating in September 2011 which yields to the amount of ¼ of normal consumption.
2. Data of ESB in 2014 is not shown in the figure above since there was an error in the measurement. Metered data from the database has a negative value which indicated that the data is inappropriate and meaningless. Therefore it will not be used for analysis.
3. Data of Forest Science Centre (FSC) is not shown in figure 11 because of the value of energy consumption is much higher than the other 5 cases. In order to have better observation of the performance trending, figure above only shows data within a certain range.

Disclosure:

In this study, 6 buildings with various usages were chosen. Although the purposes and usages of each building is different, the trending of energy consumption can still provide some insights of the effect of ventilation systems. As mentioned in the previous section, the first 3 cases (AERL, CIRS and CHOI) use natural ventilation system and the other 3 cases (IBLC, FSC and ESB) operate with mechanical ventilation system. These 6 cases will be compared in terms of level of consumption, building usages and trend of design.

Looking closely at the performance trend of each building, the annual consumption for most of them is decreasing, expect for CIRS and AERL. Based on table xx, noticed that the electrical energy was decreasing in the past few years, which means that the consumption of steam for heating was increasing. Comparing with AERL, CIRS's consumption fluctuated a little but the values are fairly close. Based on the result from the database, noticed that it is difficult to point out the effect of natural ventilation on the trend of energy consumption because there are many other factors need to be considered such as weather and user behaviors. However, the trend of decreasing energy consumption in buildings with mechanical building could be caused by the optimization of building operation with the study of building usage behavior. In conclusion, there are many other factors need to be consider in order to point out which ventilation system has a better control on efficiency.

As listed in the previous section, the study included buildings with various usages. In general, buildings with laboratories, which contain huge equipment or operate in a longer hour, would consume more energy. For instance, FSC consumes in average 400kWh per m2 higher than the other two cases with mechanical ventilation because of its laboratories equipment. Similarly, AERL's energy consumption is higher than the other two cases with natural ventilation because AERL contains laboratories and the other two don't. Although both buildings have laboratories, the requirements and specifications of those labs can be significantly different. Therefore, the decision of applying natural ventilation or mechanical ventilation system purely depends on the load and usage of the area.

According to the result of all calculation, we noticed that the natural ventilation system is often used in the buildings with smaller area such as AERL, CIRS and CHOI with an average of 4745 m2. In contrast, mechanical ventilation system is chosen for buildings with greater area such ESB, FSC and IBLC with an average of 19,410m2. This trending may point out that the area of the building can be an important factor to consider when choosing the ventilation system. Number of buildings with natural ventilation in UBC is small, so more samples are needed in order to prove this design trend.

4.3 Common and Best Practices in the Industry

Some strategies that may improve the energy efficiency and consumption were recommended for those residential buildings. (RDH, 2012)

4.3.1 Strategies to improve energy efficiency and consumption

1. Improve thermal performance of building enclosure

These opportunities include improving glazing and wall assemblies. Much higher thermally performing windows and reasonable glazing ratios (i.e. less than 40% window area) are necessary. In terms of targets, glazing assemblies with R-values in the range of R-4 to R-6 (double to triple glazing within non-conductive frames, i.e. Energy Star Zone C & D windows) should be considered for use in mid- and high-rise buildings. More effective use of the same level of currently provided insulation (i.e. by the reduction of thermal bridging at cladding supports, and thermal breaks within balcony and projecting slabs etc.). Roofs and decks should also be insulated.

2. Control air flow including make-up air ventilation strategies

Better control of air flow within, and through buildings is a key factor in reducing energy consumption in this building type. Optimal airtightness levels for both the building enclosure and the whole building under in-service conditions should be determined. This highlights the need for in-suite and space heating and ventilation systems where occupants are directly responsible for their energy consumption without impact to the remainder of the building. The study findings identify the need to move away from the traditional pressurized corridor approach of MURB ventilation and de-couple ventilation from space heating. Separate in-suite ventilation and space heat systems should be considered. The energy simulations for a typical building showed significant benefits with the use of heat-recovery ventilators (either in-suite or ducted central systems). Direct ventilation systems with heat recovery can improve occupant comfort, even in temperate climates such as Vancouver. As part of the improvements to ventilation strategies, there is a need for suite compartmentalization to control stack and mechanical pressures across the building enclosure and across the ducts of in-suite systems.

3. Control air leakage

The use of operable windows (particularly in temperate climates) further invalidates most estimates of operating building pressures, building enclosure airtightness, and suite ventilation/heating distribution. Air is exhausted from individual suites by means of exhaust fans, through air leakage paths (both known and unknown) and occupants opening windows and exterior doors. The pressurized corridor distribution system is relatively ineffective at distributing ventilation air to suites – this ventilation system results in significant energy inefficiencies because the air is heated.

Air leakage results in natural ventilation (albeit with limited ventilation effectiveness and mixing) and is separate from mechanical ventilation. Mechanical ventilation systems induce pressures across the building enclosure which also result in air leakage, in addition to uncontrolled natural infiltration/exfiltration (caused by stack or wind pressures).

Architectural inputs for the energy model were obtained through the detailed quantity take-off process discussed previously. These included the floor area, exposed wall area, window to wall ratio, overall wall and roof R-values, window U-value and window solar heat gain coefficient.

Integrated building improvements adopted that include improvements to the thermal performance of the building enclosure (walls, roofs and windows), airtightness, space heating system, and ventilation strategies can reduce in space-conditioning (space heating and ventilation) loads from greater than 100 kWh/m^2/yr to less than 10 kWh/m^2/yr using the calibrated typical building model.

4.3.2 Best practices

The Impact of Mechanical Improvements.

1. Make-Up Air Temperature Set-point: Varying the make-up air temperature set-point between 74°F (23°C) and 55°F (13°C). Make-Up Air Flow Rate: Decreasing the make-up air flow rate to up to 60% of the nominal flow rate and increasing the make-up air flow rate to a rate typical in modern buildings. Site B building have mechanical systems, with centrally provided gas heated ventilation air to pressurized corridors, and electric baseboard heaters within suites. In terms of energy efficiency, ventilation strategies should be de-coupled from heating or at the very least recover the heat from ventilation air through a centralized system or in-suite systems.

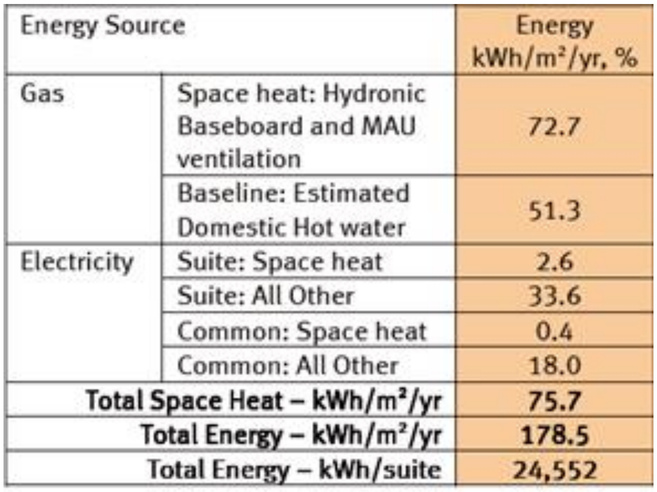
2. Suites compartmentalization: As a more energy efficient and effective ventilation strategy, it makes sense to provide heating and ventilation directly to each suite. This can be done with either centralized mechanical equipment or in-suite mechanical equipment. Typically the in-suite approach is more economical, as the cost for duct work, fire-dampers, odour control for a whole building ventilation approach (similar to a commercial building) is more expensive. In a temperate climate such as Vancouver, the use of in-suite balanced continuous supply and exhaust systems with option heat recovery ventilators (HRVs) can help provide ventilation air directly to the suites at a temperature which is acceptable for comfort year round. Therefore energy efficiency improvements made to central shared systems likely has the greatest potential benefit. Ventilation air is heated at a gas-fired rooftop make-up air unit and provided to the central corridors prior to flowing into the suites.

3. Architectural design for natural ventilation: The ventilation system is designed so that air flows into the suites through suite door undercuts as the corridor is intended to be positively pressurized with respect to the suites. However, this corridor pressurization is not always positive and significant amounts of fresh air flows through unsealed hallway doors into stairwells, shafts and the elevator shafts, resulting in less make-up air to the suites, particularly considering some of the door undercuts are reduced by the occupants. Moreover, the effect of wind and building stack effect results in negative pressures and associated reverse flow of suite air into the corridor space. Because of these noted issues with building flows and corridor

pressurization, the in-situ efficiency of supplying tempered ventilation air from the corridors to each of the suites is questionable in terms of both ventilation and heating effectiveness. The efficiency of the ventilation air delivered to the corridors is poor for several reasons including air leakage through shafts, stairwells, wind and stack-effect and blocked suite door undercuts – this results in poor heating efficiency of this gas space heat. However, the heated air that does get into the suite does reduce the amount of heat input from suite sources. For these reasons, it is likely that the useful space heat from the ventilation air is less than what the metering analysis indicates, but cannot be determined accurately without further information of the actual air flow distribution throughout this building.

4. Ventilation air flow rates. New residential buildings have ventilation air flow rates up to and exceeding 100 cfm/suite. The higher flow rates in these newer buildings with similar make-up air units of efficiency will result in significantly greater gas energy consumption.

Table 11. Summary of energy consumption for a typical residential building



Energy Source		Energy kWh/m²/yr, %
Gas	Space heat: Hydronic Baseboard and MAU ventilation	72.7
	Baseline: Estimated Domestic Hot water	51.3
Electricity	Suite: Space heat	2.6
	Suite: All Other	33.6
	Common: Space heat	0.4
	Common: All Other	18.0
Total Space Heat – kWh/m²/yr		**75.7**
Total Energy – kWh/m²/yr		**178.5**
Total Energy – kWh/suite		**24,552**

4.4 Mechanical Drawings

4.4.1 Overview

Lot E features naturally ventilated apartment units and mechanically ventilated hallways. Two rooftop air handling units that supply air to the hallways on every floor, except floor 1 through vertical ducts ranging in size from 16”x20” on the rooftop to 6”x6” in the basement. Fire dampers are placed at the exhaust into each hallway for a total of two fire dampers per floor. There are no ducts in the hallways themselves.

Each apartment is has several dedicated intake vents supplying air directly from outside. There is one exhaust vent for each bathroom and an additional two for the range and dryer. Overall there are at least 6 exterior penetrations per apartment. The main ducting is 12”x1” in-slab ‘ECCODUCT’, while the range and dryer exhaust ducts are circular and 6” and 5” in diameter, respectively. Heating is supplied via a radiant floor system. No fire dampers are installed in the apartments.

Site B features exclusively mechanical ventilation, provided by one large HRV on the rooftop. Supply and return air for floors 2-6 travels via two vertical ducts on opposite sides of the building. These ducts are larger than those in Lot E, ranging from 32”x30” at the top of the supply, to 12”x12” at the bottom of the return. Fire dampers are placed at the supply and return of each floor and the ducts continue along the hallway to each apartment. The hallway ducts are largest near the supply/return in the center of the building (28”x6”) and get smallest as they branch out to the edges (6”x6”).

Each apartment receives a supply and return from the ventilation system, where the return comes from the bathroom exhaust fan(s), and fire-dampers are placed where these ducts enter the apartment. The ducting in the apartments is mostly 8”x4”, however, as with Lot E, the range and dryer exhaust via circular, 6” and 5” diameter ducts. This makes for a total of two exterior penetrations. As with Lot E, apartment heating is supplied via a radiant floor system.

Both buildings have dedicated air-heating/cooling systems on floor 1. The refrigerant for these systems is supplied via outdoor condensers. Lot E also has dedicated HRVs for each CRU, whereas Site B does not include any air intake or exhaust system for the majority of CRUs (several have a filtered intake fan).

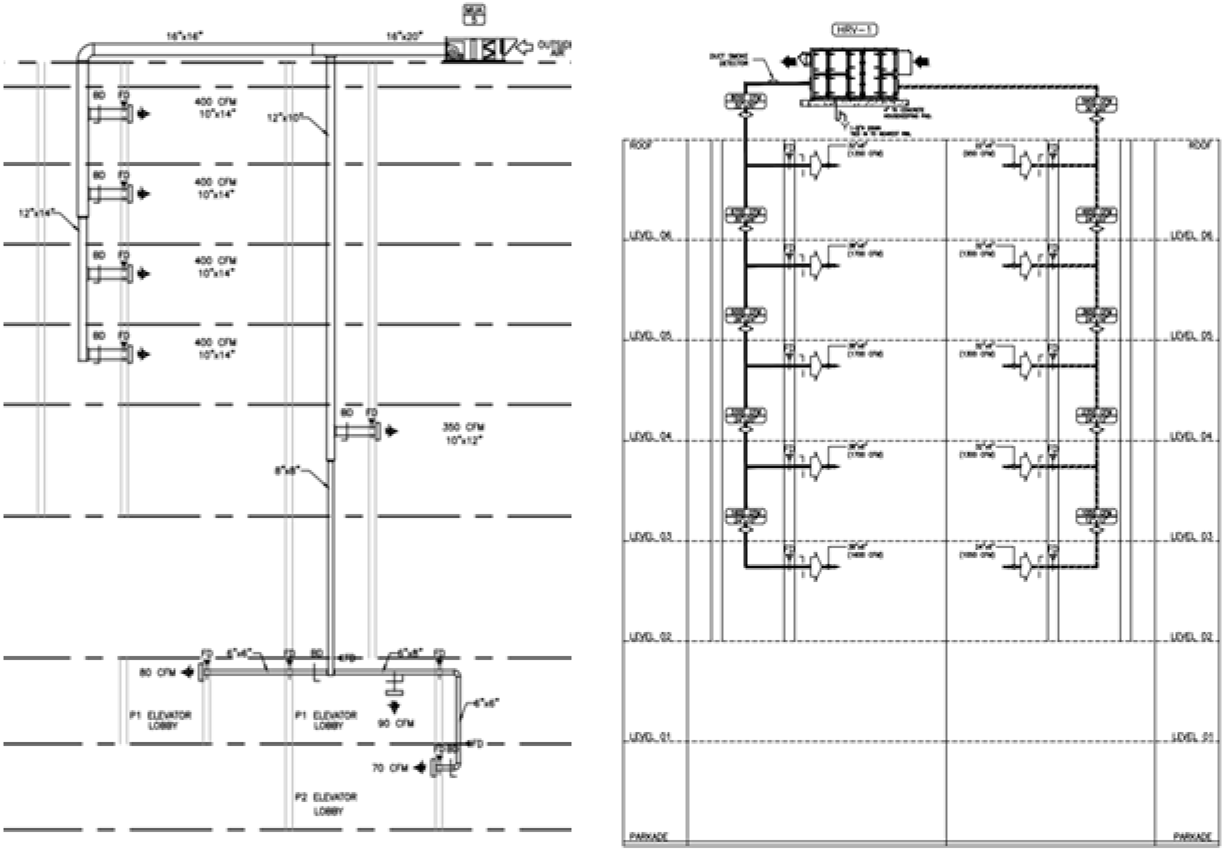


Figure 12. Building cross-section featuring air handling units for Lot E (left, only half of building shown) and Site B (right)

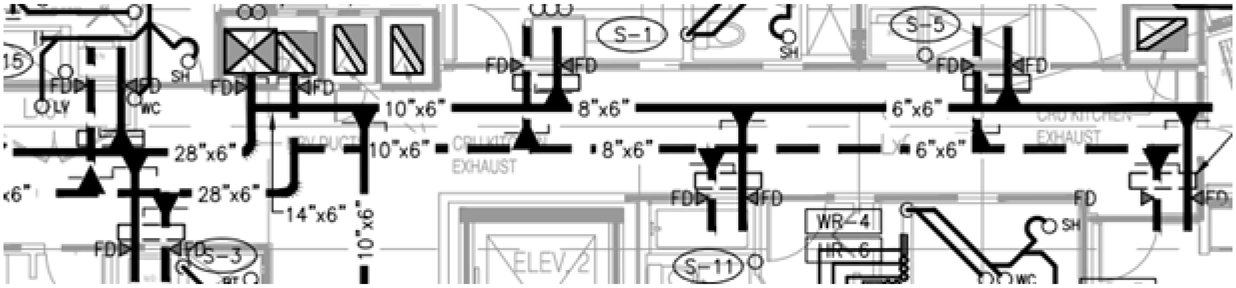


Figure 13. Hallway ducts in Site B

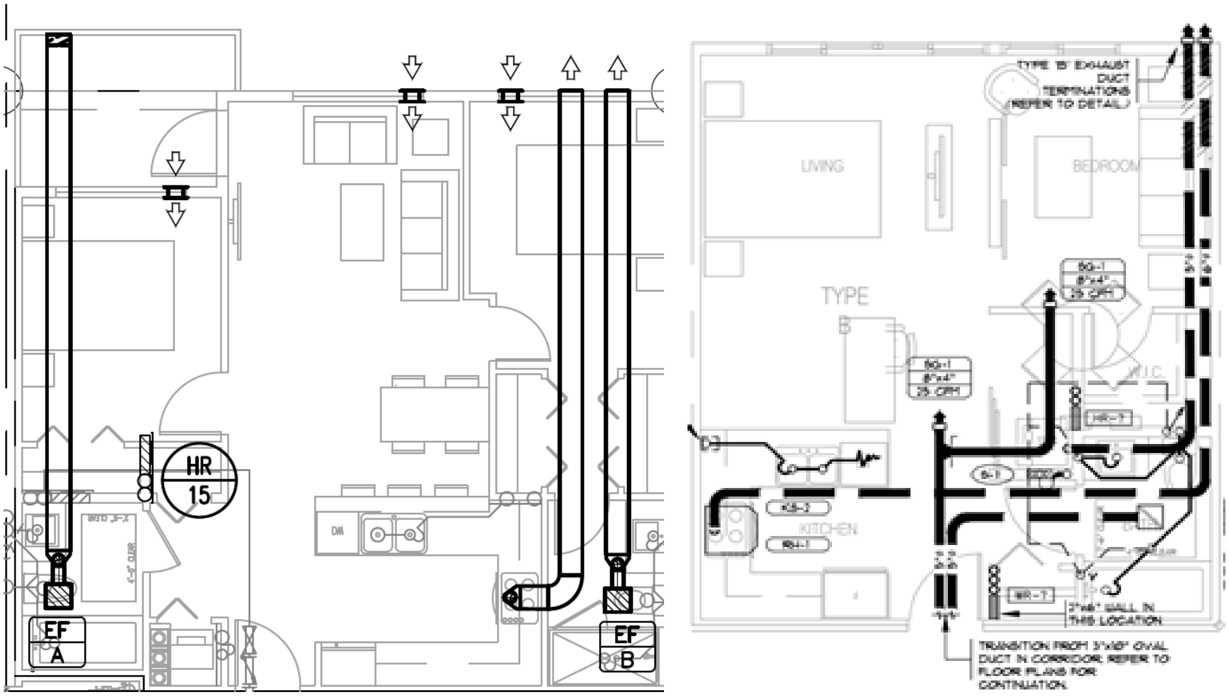


Figure 14. Apartment ventilation in Lot E (left) and Site B (right)

4.4.2 Comparison

The advantages of Lot E include smaller ducting and no ducting in the hallways, which minimizes material and space use. Also, each apartment is isolated from the main ventilation system, reducing the risk of fire spreading and saving money on fire dampers. The isolation of apartments also minimizes the impact that one poor inhabitant decisions, such as leaving a window open on a cold day, can have on overall building efficiency **(Best Practices, result #2)**.

On the other hand, Lot E has at lest three times as many exterior penetrations as Site B, which will likely increase air leakage and energy loss **(Best Practices, Result #3)**. Lot E also features several HRVs within its CRUs, which will save energy at the expense of additional maintenance costs. These HRVs should be placed in an accessible spot so their maintenance does not affect business operations within the CRUs.

Both buildings employ a radiant floor system, which decouples heating and ventilation and will likely save energy **(Best Practices, Result #2)**. One possible improvement for Site B would be to incorporate the dryer exhaust into the HRV, which, while intermittent, presents a significant heat recovery potential.

4.5 Life Cycle Costing of Ventilation systems

To compare the residential ventilation systems in Site B and Lot E, cost calculations with respect to lifetime of ventilation system (20 Years) was carried out. Using Net Present Value (NPV) calculations at nominal discount rate of 5% and inflation of 2% the real discount rate was calculated to be 3%. Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyze the profitability of a projected investment or project.

The following is the formula for calculating NPV:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

where

C_t = net cash inflow during the period t

C_o = total initial investment costs

r = discount rate, and

t = number of time periods

A positive net present value indicates that the projected earnings generated by a project or investment (in present dollars) exceeds the anticipated costs (also in present dollars). Generally, an investment with a positive NPV will be a profitable one and one with a negative NPV will result in a net loss. This concept is the basis for the Net Present Value Rule, which dictates that the only investments that should be made are those with positive NPV values.

4.5.1 Site B results

Since heating energy is the largest contributor to the total energy consumption, most of the savings is associated with the increased insulation and glazing performance.

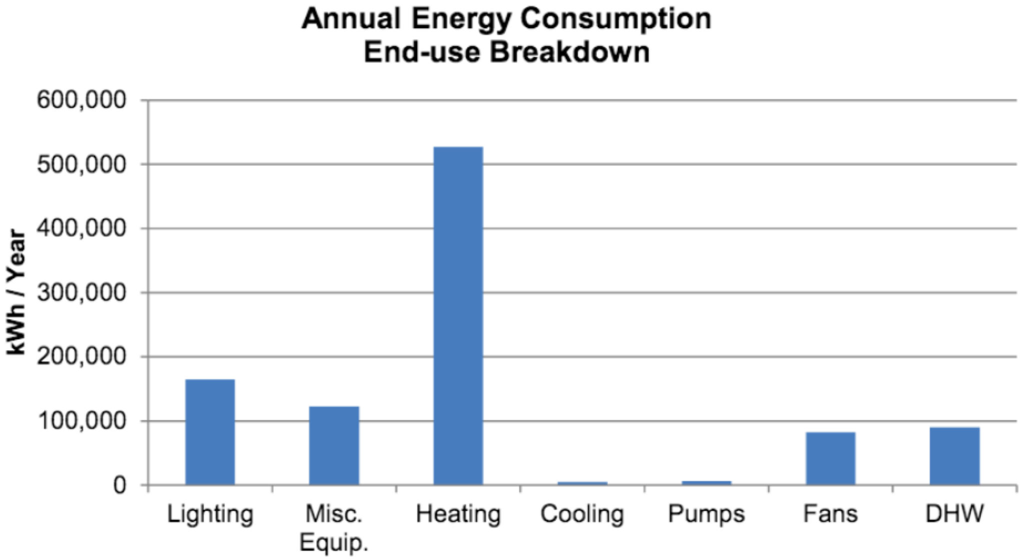


Figure 15. Annual Energy Consumption End – Use breakdown

4.5.1.2 Net Present Value for Site B

Total project cost of site B = $18M

Mechanical value = $3.3M (including HVAC)

Ventilation system capital cost (With installation) = $800,000

NPV calculation:

The space heating EUI of the residential unit = 56.2 kWh/m^2/year

Area of residential unit = 6319 m^2

Total energy consumption = 56.2 kWh/m^2/year x 6319 m^2

= 355,127.80 kWh/year

Total cost of energy consumption = 355,127.80 kWh/year x DES rates for 20 years (Cash outflow) - [1]

Nominal discount rate (Given) = 5%

Inflation (Given) = 2%

Real discount rate = (1.05/1.02)-1 = 0.0294 ~ 3%

Real discount rate is used because The nominal interest rate doesn't tell the whole story, because inflation reduces the lender's or investor's purchasing power so that they cannot buy the same amount of goods or services at payoff or maturity with a given amount of money as they can now. The real interest rate is so named because it states the "real" rate that the lender or investor receives after inflation is factored in; that is, the interest rate that exceeds the inflation rate.

Total maintenance cost of HVAC unit = $6000 per year (Cash outflow) - [2]

The maintenance cost is higher compared to Lot E because of the HRV system.

Total cash flows = -$ {[1]+[2]} (For 20 years)

Then, NPV is calculated using the ventilation system value, total cash flows and the real discount rate. The NPV values were normalized by dividing the results by residential area. This made the results directly comparable (NPV/m^2). It is shown in the figure below.

Therefore,

Net Present Value (NPV) = -$1,155,957.15

NPV/m^2 = -$182.93/$m^2$

4.5.2 Lot E Results

4.5.2.1 Base design

Since heating energy is the largest contributor to the total energy consumption.

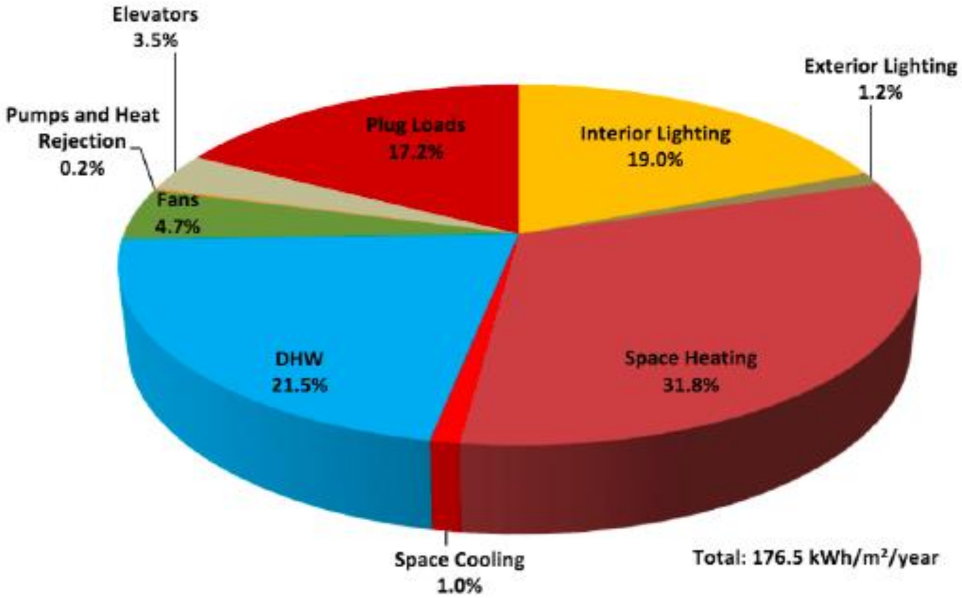


Figure 16. Contribution of energy end uses in overall energy consumption

4.5.2.2 Net Present Value for Lot E

Total project cost of site B = \$18M

Mechanical value = \$3.9M (including HVAC)

Ventilation system capital cost (With installation) = \$400,000

NPV calculation:

The space heating EUI of the residential unit = 72.1 kWh/m^2/year

Area of residential unit = 7435 m^2

Total energy consumption = 72.1 kWh/m^2/year x 7435 m^2

= 536,064 kWh/year

Total cost of energy consumption = 536,064 kWh/year x DES rates for 20 years (Cash outflow) - [1]

Nominal discount rate (Given) = 5%

Inflation (Given) = 2%

Real discount rate = (1.05/1.02)-1 = 0.0294 ~ 3%

Real discount rate is used because The nominal interest rate doesn’t tell the whole story, because inflation reduces the lender's or investor’s purchasing power so that they cannot buy the same amount of goods or services at payoff or maturity with a given amount of money as they can now. The real interest rate is so named because it states the “real” rate that the lender or investor receives after inflation is factored in; that is, the interest rate that exceeds the inflation rate.

Total maintenance cost of HVAC unit = \$4000 per year (Cash outflow) - [2]

Total cash flows = -\$ {[1]+[2]} (For 20 years)

Then, NPV is calculated using the ventilation system value, total cash flows and the real discount rate. The NPV values were normalized by dividing the results by residential area. This made the results directly comparable (NPV/m^2). It is shown in the figure below.

Therefore,

Net Present Value (NPV)	= -\$861,670.06
NPV/m^2	= -\$115.89/m^2

4.5.3 Life Cycle Cost Summary

Based on the NPV calculations Lot E provide a better NPV/m^2 (-\$115.89m^2) compared to Site B (-\$182.93 m^2). A positive net present value indicates that the projected earnings generated by a project or investment (in present dollars) exceeds the anticipated costs (also in present dollars). Generally, an investment with a positive NPV will be a profitable one and one with a negative NPV will result in a net loss. However, in the aforementioned projects both the NPV values are negative. Therefore, the project with less negative NPV value is more viable in this case.

Changing the maintenance costs: Even if Site B's maintenance cost is brought down to Lot E's maintenance cost the NPV/m^2 value favours Lot E. However, the maintenance cost of Site B will be higher than Lot E as Site B has HRV system and Lot E has passive ventilation.

Increasing the discount rates: It Changes the NPV rates positively, however slight changes in discount rates makes no difference in the decision.

Alongwith NPV, payback period could be determined if the capital cost of ECMs were known. Payback period determines the period of time required to recoup the funds expended in an investment.

5. CONCLUSIONS

By doing this research, we have a few findings listed as below:

1. The criterion for natural ventilation systems in BC building code (2012) has more restricts than mechanical ventilation systems.

2. Natural ventilation has higher air leakage rate which leads to greater energy consumption on space heating.

3. To enhance energy efficiency, we can improve glazing and wall assemblies, control airflow and air leakage. It is practical to vary make-up air temperature set-point and provide heating and ventilation directly to each suite.

4. The minimalist structure of Lot E will likely save enough money to justify its air leakage and lack of heat recovery.

5. Both the NPVs are negative. Lot E’s ventilation system has a lower capital cost and better NPV/sq.m compared to Site B. Hence investment in Lot E is favorable.

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