Thermal Effects of UBC Webber House Hydronic Hot Water Heating

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Executive summary

The new Webber House development in Wesbrook Village for UBC Properties Trust consists of a six story, 4,233 m^2 residential building with 36 suites over two parking levels.

The energy model for this building was established to explore the optimal thermostat temperature range with the ultimate goal of saving energy and achieving occupants' thermal comfort. Besides, the energy consumption end use was estimated.

The energy model was developed using Sketch up, Open studio and energy plus with ASHRAE 90.1-2010 Energy Standard.

Based on the results of the energy model, Scenario A not only can achieve highly thermal comfort for occupants, but also can provide up to 51% energy saving compared with Scenario B (upper bond).

Future work needs to be focused on the energy model adjustment. Some factors such as infiltration rate, lighting power density would have some impacts on heating consumption. Thus, to make the energy model more accurate, these numbers needs to be verified after operation.

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1. Introduction

1.1 Background

The new building Wesbrook Lot 3 Webber House (formerly Lot 45 Village Green) will be a 6-storey 4,233 m^2 Faculty/Staff Rental Housing in Wesbrook Place with 36 units on levels 1-6 ranging from 1 bedroom units to 4 bedroom units. (Nine types of units total). There will be two levels of underground parking. Levels P1 & P2 are of concrete construction and levels 1-6 are of wood frame construction. This project is located in Wesbrook Village at 3388 Webber Lane and now is still being processed and construction has not yet begun.

Figure 1 UBC LOT 3 Location

The new building will have a hydronic hot water heating system serving living space connected to district energy system being constructed by Corix. The spaces such as, the lobby, corridors and stairs will be served by electrical force flow heater. The heating water supply temperature will decrease from160 °F (71°C) (the temperature from district energy system) to 120 °F after crossing the heat exchanger to pre-heat heating water return from 120°F to 140°F for further domestic hot water supply use. The detailed hot water schematic is attached as appendix A.

There will be 6 radiant heating risers serving 36 dwelling units (9 types) through the building. The capacity of radiant heating system is 582400 BTU/HR, and 159 BTU/HR/M^2). The system was designed based on the worst scenario case, being the coldest day of the year at night with no heat input from any other sources (solar, people, equipment, etc.).Therefore, the actual condition would be better when internal loads, solar gains are considered. The detailed radiant heating riser schematic is attached as appendix B.

1.2 Purpose and Objectives

The purpose of this project is to establish the optimal thermostat temperature range to achieve energy saving while providing occupants' comfort. In order to achieve the objectives, an energy model was developed using Sketch Up, Open Studio and Energy Plus. To verify the reliability of the energy model, the actual building operation data from UBC Lot 22 Nobel House which has a similar radiant heating system was introduced. This study contains the following objectives:

- Review design drawings and understand the mechanical system
- Understand the effects of building envelope and architecture
- Note all factors as designed that impact the temperature level (such as materials, building orientation, internal loads, flow rate, etc.)

- Establish optimal thermostat temperature range to save energy and achieve occupants' thermal comfort
- Simulate the annual energy consumption end use(not include domestic hot water), and compare with the actual operation data of Nobel House
- Develop the sensitivity analysis to verify the effects from lighting and infiltration rate on heating consumption

1.3 Literature Review

To research the thermal effects of hydronic hot water radiant floor, the location of building, the building exposure, internal loads, building construction materials, water flow rates, supply and return temperature, average heat load flux, indoor room temperature and other parameters need to be taken into account. In terms of pipes, previous research shows that pipe type, diameter and the number of pipes do not have remarkable effect on radiant floor heating system performance. The more important design parameters are thickness and type of the cover due to dominance of radiation.(Sattari & Farhanieh, 2006) The spacing between pipes also affects the thermal performance. The average temperature of the floor surface increases with the decrease of pipe spacing, and the average heat flux surface of the floor would increase.(Du, 2014) For this project, the structure of living floor is wood frame. A research shows that the latent heat of the wood frame flooring is better than that of PVC flooring. The good latent heat capacity would contribute to maintaining a relatively high temperature for a long period once heating source is removed. (Seo, Jeon, Lee, & Kim, 2011)

Low temperature radiant system performance can also be affected by other parameters. A recent study shows that low temperature radiant model is sensitive to both construction parameters and system parameters. These input parameters include:

- Specification of the radiant system set point temperatures
- Scheduling of internal heat gains
- Specification of building element thermal properties

Energy plus can accurately predict low temperature radiant performance once these parameters can be accurately specified. (Chantrasrisalai, 2001)

To optimize thermostats' temperature setpoint and energy saving, not only the standard in accordance with ASHRAE needs to be met but also operative temperature, floor surface temperature, radiant temperature asymmetry and control system needs to be considered. Operative temperature can be simply approximated with average air and mean radiant temperature, and they are equally important in terms of thermal comfort. In the international standards, the recommended maximum floor surface temperature for heating is 29°C (84°F) in the occupied zone for rooms with sedentary and/or standing occupants wearing normal shoes.(Frank & Wright, 2002) Another research found that a night setback control strategy can be utilized as a means of saving energy even with the thermal mass to reheat. (Good, Ugursal, & Fung, 2005)

In this project, the optimal thermostats' temperature setpoint was developed to both satisfy the occupants and to save energy.

2. Modelling Methodology

2.1Modelling Software

The energy model was created using Sketch Up (version 2016), Open Studio (version 1.11.0) and Energy Plus (8.5.0). Sketch Up is a 3D modelling computer program for a wide range of drawing applications such as architectural, interior design, mechanical engineering. Open Studio is cross-platform (Windows, Mac, and Linux) collection of software tools to support whole building energy modeling using Energy Plus and advanced daylight analysis using Radiance. Energy Plus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting, and plug and process loads—and water use in buildings. Its development is funded by the U.S. Department of Energy Building Technologies Office. However, Energy Plus is code based, while Open Studio has a friendlier interface. Users can easily assign and design schedules, HVAC systems, and constructions, space types in Open Studio by dragging components or modules from the library. Besides, Open Studio can be easily plugged into Sketch Up, allowing users to quickly create geometry which is needed for simulation in Energy Plus, and therefore, there is a better interaction between Sketch Up and Open Studio.

From new construction program's energy modelling guideline released by BC Hydro, they required to use the following software to run the simulation for hydronic radiant heating:

a. IES VE and Energy Plus

b. Others: ESP-r, TRANSYS/TRNFLOW-acceptable, but not used in B.C.

Thus, Energy Plus as a professional building modelling software can ensure the accuracy. (BC.HYDRO, 2016) The simulation was based on a detailed set of inputs that includes the following:

- Building envelope (building orientation, wall and window materials, window to wall ratio)
- Spaces types
- Internal loads(Occupants, lighting, plug loads) and schedules
- Thermal zones
- HVAC system
- Heating setpoint schedules
- Climate Data

2.2 Building Envelope

2.2.1 Building orientation

The building orientation has an impact on the solar gain. The units faced to south have more solar gain than the units faced to north. The north axis of the new UBC LOT 3(Webber House) is 30 degree, read from architectural drawings.

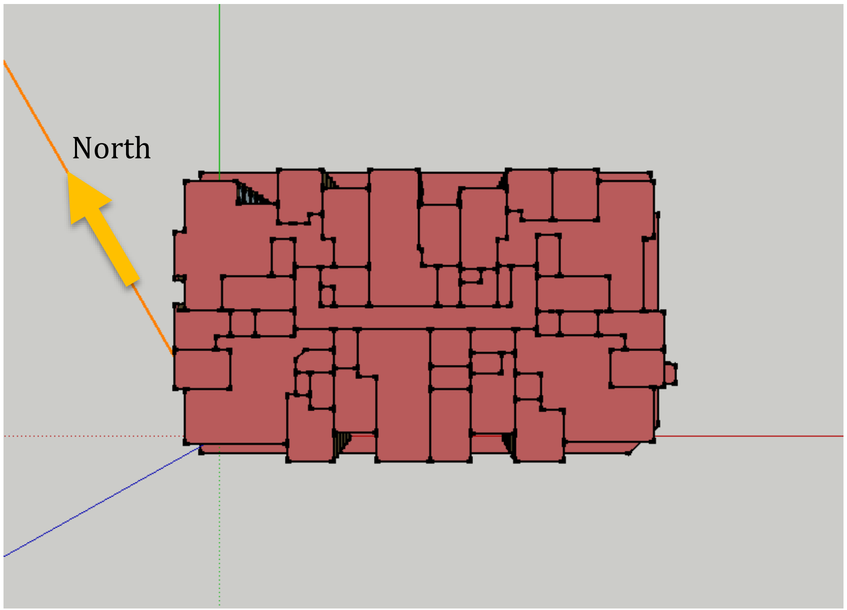


Figure 2 Model top view

2.2.2 Building materials

Different building materials have different thermal resistance. The higher the R-value is, the better the building insulation will achieve. Therefore, building materials decide the how much heat the building can keep within the units and the how much heat will loss through window, wall and roof to some extent. The building materials information was gained from architectural drawings and the construction contractors. For the roof construction, it was 4.5” rigid insulation roof, and R- value was 28.8 ft^2·°F·hr/Btu; For the wall construction, it was 2 x 6 wood framed batt insulation wall, and R-value was17.4 ft^2·°F·hr/Btu; For the glazing properties, low-e argon-filled double glazed vinyl windows were applied, the U-value was 0.266 BTU/(h °F ft^2). The window to wall ration is listed in the table below.

Table 1 Window to wall ratio

Description	Total (%)	North (%)	East (%)	South (%)	West (%)
Gross Window-Wall Ratio	22.36	23.4	21.21	24.61	19.25
Gross Window-Wall Ratio (Conditioned)	30.08	32.17	26.87	35.08	24.9

2.3 Space Types

2.3.1 Energy standard template

Before a space type was assigned to each model block, an energy standard template needed to be decided first. Open Studio has three ASHRAE energy standard templates. They are ASHARE 189.1-2009 (Standard for the Design of High-Performance Green Buildings), ASHARE 90.1-2007(Energy Standard for Buildings except Low-Rise Residential Buildings) and ASHARE 90.1-2010. Based on the energy modelling guideline from BC Hydro, ASHRAE 90.1 2010 was set in this simulation study. (BC.HYDRO, 2016) The reason we need to choose the energy template first is that once the template is confirmed, occupants, lighting, internal loads schedules will be assigned to each space type automatically by Open Studio, and these schedules are in line with the energy standard chosen.

2.3.2 Space types

In Open Studio, there are several building types, and under each building type, there are different space types.

Table 2 Space types

Building type	Space type	Rendering colour
Midrise Apartment	Apartment	Blue
Midrise Apartment	Corridor	Red
Office	Stair	Pink
Large Hotel	Lobby	Purple
Large Hotel	Storage(Parking)	Yellow

From the table above, it can be found that there are Midrise Apartment, Office and Large Hotel building types. The reason is that in Open Studio, there are only three space types under the midrise apartment building type, which are apartment, corridor, and office. For other space types, it is needed to find them under other building types. Therefore, stair was found under office, lobby and storage under large hotel. In open studio there is no space type for parking, so the most similar space type is storage, standing for parking space in this project. As mentioned before, once energy standard template and space types are decided, Open Studio will assign occupants schedule, lighting schedule, internal equipment schedule, and infiltration rate. For parking space, all schedules can be adjusted manually to match the actual situation.

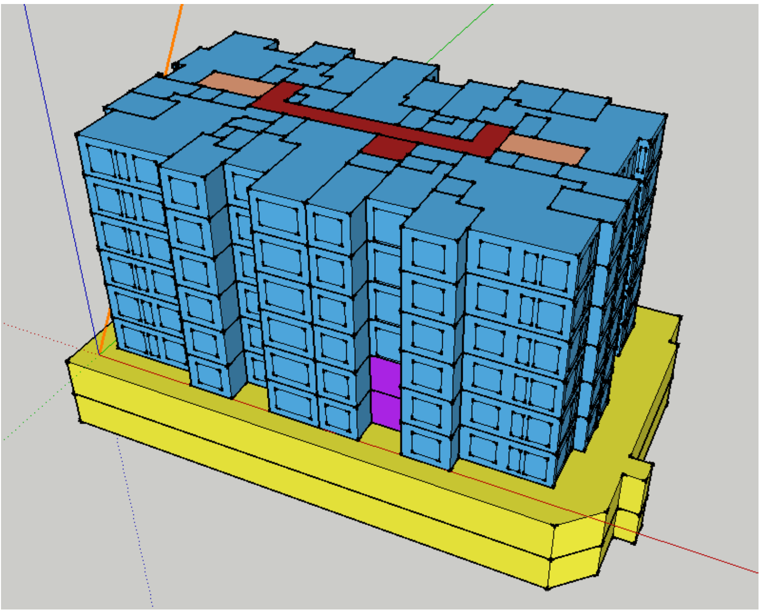


Figure 3 Model rendering by space types

2.4 Thermal Zones

In energy modelling process, the most critical simulation objects are thermal zones. Thermal zones are required to analyze the heat loss, heat gain, air temperature, mean radiant temperature, operative temperature, and relative humidity. Moreover, thermal zones as foundations are essential to establish the HVAC system. There were dominantly two kinds of thermal zones in this study, namely the conditioned space and the unconditioned space. For open spaces such as parking, corridors, lobby and stairs, they were considered as the unconditioned space, while all blocks under apartment space types were considered as the conditioned space.

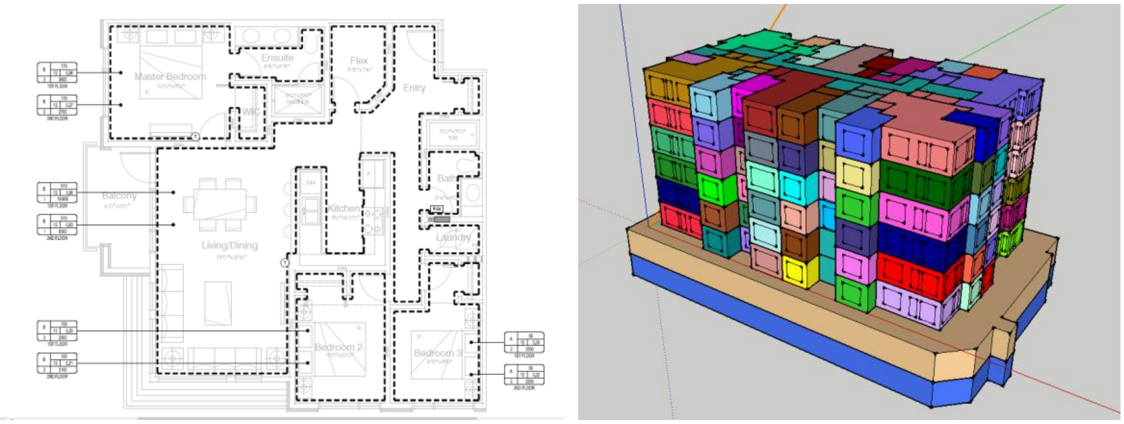


Figure 4 Typical unit type H floor plan (left); Model rendering by thermal zones (right)

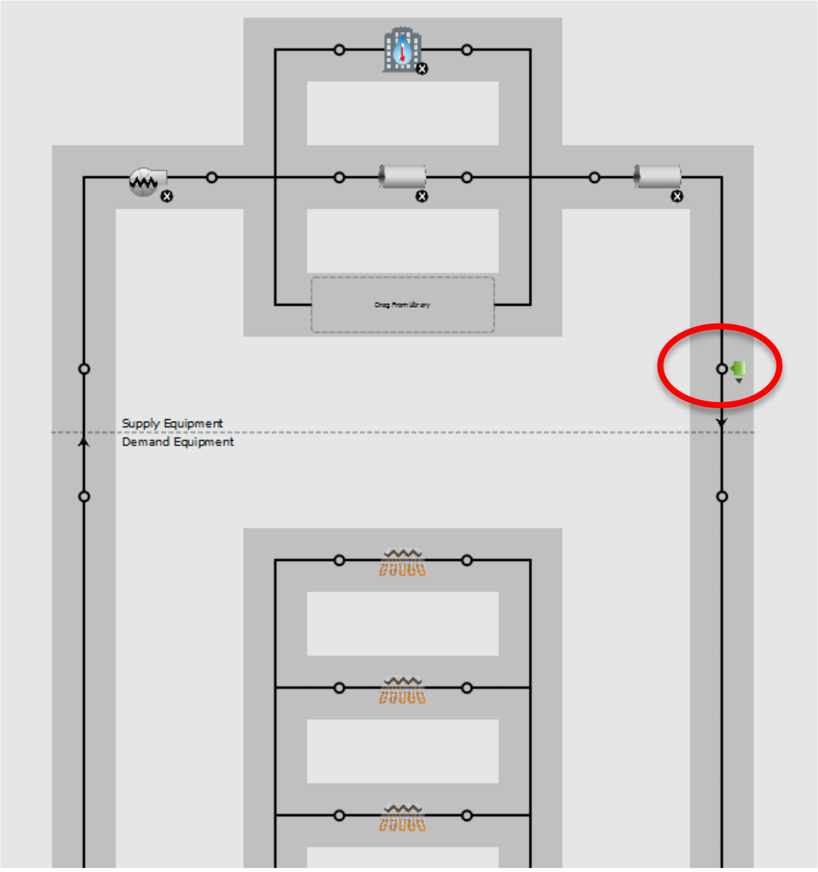
Figure 4 shows that how thermal zones were assigned. The left graph is a typical unit type H floor plan. As shown, there are four areas in unit H, three bedrooms, one living/dining room. Each area has a radiant heating layout under floor slab, and each area is exposed to different orientation. To simulate more accurately, four conditioned thermal zones were created to match four areas in unit H. However, in the mechanical design, there were only two thermal zones, one for all bedrooms, and the other for dining/living space. For all public space blocks, they were considered as one unconditioned space. For two parking spaces, they were considered as two unconditioned spaces as well. After creating all thermal zones, it showed like the right graph of Figure 4. There were 127 thermal zones in total, where 124 thermal zones were conditioned and 3 zones were unconditioned.

2.5 HVAC System

HVAC systems decide how to provide thermal comfort and acceptable indoor air quality. Different systems have different ways to transfer heat. In this project, a hydronic radiant heating system was designed. The benefits of radiant floor heating are listed as follows:

- Provide high level of thermal comfort(radiant systems engage with the body's dominant means of thermal transfer)
- Quiet operation
- Can be easily zoned
- Pipes are much smaller than ducts of forced air heating systems
- No interference with furniture placement

One major drawback of radiant floor heating systems is slow response time. It needs to take a while to warm up the space and reach the setpoint.



Setpoint manager

Figure 5 Radiant hot water loop

As shown on Figure 5, on the supply side, hot water came from district heating system. Before hot water flowed into the building, a setpoint manager can control the incoming flow temperature to maintain and the temperature at 50 °C constantly. After entering into the building, hot water was distributed to each conditioned thermal zone. The return water went back to district heating center, forming a closed loop.

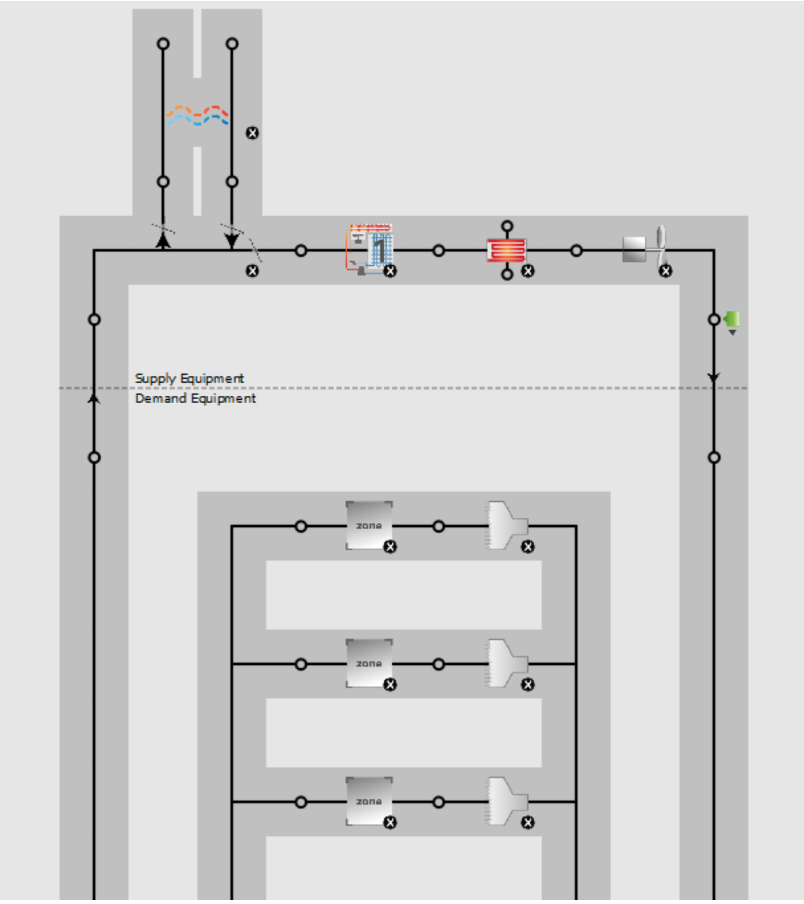


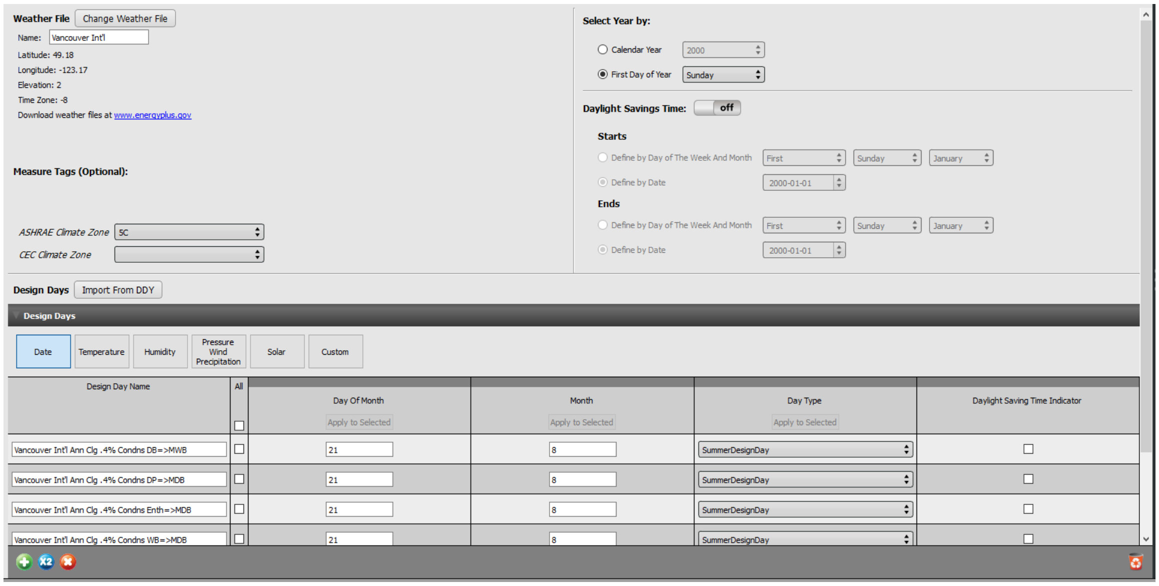
Figure 6 Ventilation loop

For ventilation design, each unit had a supply fan that sucked outdoor air from balcony and blew into rooms. However, it is very difficult to quantify the natural ventilation impact and it depends on personal behavior as well. Thus, to simply the simulation, a ventilation loop was introduced (Figure 6). The outdoor air passed through a cooling/heating coil to be cooled down/warmed up to 20 °C constantly. The loop did not have any function for heating or cooling spaces. It would only supply 20°C air to maintain the ventilation requirements.

Once all HVAC systems were designed, it was needed to go back thermal zones to assign zone equipment (here was radiant heating), and air loop to each thermal zone and link them to the HVAC loop. By doing that, a connection between thermal zones and HVAC system was established.

2.6 Climate Data

Since Open Studio is designed based on Energy Plus, it has access to download worldwide weather files on the Energy Plus site. According to ASHRAE climate zones, Vancouver is in climate zone 5C. (Ab, 2007) Design days can also be obtained through the library.



Name: Vancouver Int'l
Latitude: 49.18
Longitude: -123.17
Elevation: 2
Time Zone: -8
Download weather files at www.energyplus.gov

Measure Tags (Optional):
ASHRAE Climate Zone: 5C
CEC Climate Zone:

○ Calendar Year: 2000
● First Day of Year: Sunday

Daylight Savings Time: off

Starts
○ Define by Day of The Week And Month: First, Sunday, January
○ Define by Date: 2000-01-01

Ends
○ Define by Day of The Week And Month: First, Sunday, January
○ Define by Date: 2000-01-01

Design Day Name	All ☐	Day Of Month	Month	Day Type	Daylight Saving Time Indicator
Vancouver Int'l Ann Clg .4% Condns DB=>MWB	☐	21	8	SummerDesignDay	☐
Vancouver Int'l Ann Clg .4% Condns DP=>MDB	☐	21	8	SummerDesignDay	☐
Vancouver Int'l Ann Clg .4% Condns Enth=>MDB	☐	21	8	SummerDesignDay	☐
Vancouver Int'l Ann Clg .4% Condns WB=>MDB	☐	21	8	SummerDesignDay	☐

Figure 7 Climate data

3. Simulation

For this study, there were three scenarios to analyze radiant heating thermal effects.

- Scenario A: The ideal heating setpoint schedule with ASHRAE Energy standard 90.1-2010 (Base case)
- Scenario B: The upper bond heating setpoint schedule with ASHRAE Energy standard 90.1-2010
- Scenario C: Using Williams Engineering modelling assumptions

The only difference between scenario A and scenario B was the heating setpoint. Scenario A was aimed to see whether the ideal heating setpoint could provide occupants' thermal comfort and achieve energy saving. Scenario B was aimed to set the upper bond of energy consumption, and compare the difference of energy consumption between scenario A and B.

For scenario C, Williams Engineering also did an energy modelling for UBC Lot 3, but for a different purpose. They were aimed to provide the necessary documentations to meet REAP Energy and Atmosphere Credit 1.10. Besides, they used EE4 (version 1.7 build 2), a program developed by Natural Resources Canada (NRCan) for energy modelling. The intent of scenario C was to use inputs from WE modelling but run in the model by Energy Plus to see whether the result could match each other or not.

3.1 Scenario A

3.1.1 Inputs

3.1.1.1 Internal Loads

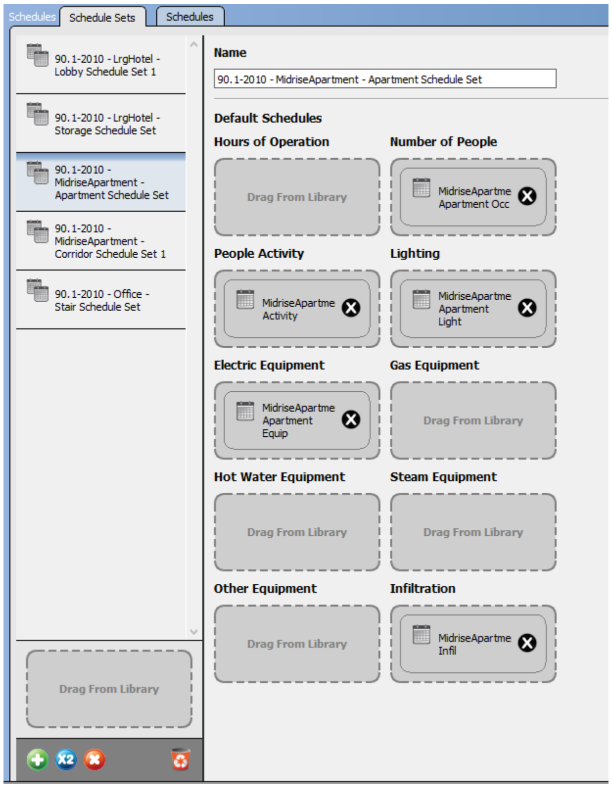
Internal loads consist of occupants' activity, interior lighting power density and plug load. The numbers are listed in the Table 3 below. All these numbers are in line with ASHRAE 90.1-2010 energy standard based on space types assigned. The only number that was changed manually was interior lighting power density of storage (parkade). Open studio assumed 6 W/m^2 for storage space, but it was quite high for parkade. According to ASHRAE energy standard 90.1-2010, the power density of parkade is 2 W/m^2. (BC.HYDRO, 2010)

Table 3 Internal loads of scenario A

Internal Loads			
	Occupants (people/m2)	**Interior Lighting Power Density (W/m2)**	**Plug loads (W/m2)**
Apartment	0.028	4.090286	3.875009
Corridor	N/A	7.104181	N/A
Stair	N/A	7.427098	N/A
Lobby	0.33	11.409745	N/A
Storage(Parkade)	N/A	2	N/A

3.1.1.2 Schedules

There were various schedules in the simulation such as occupancy schedule, people activity schedule, lighting schedule, equipment schedule (plug loads schedule), and infiltration rate.



Name: 90.1-2010 - MidriseApartment - Apartment Schedule Set

Default Schedules

Hours of Operation: Drag From Library
Number of People: MidriseApartme Apartment Occ
People Activity: MidriseApartme Activity
Lighting: MidriseApartme Apartment Light
Electric Equipment: MidriseApartme Apartment Equip
Gas Equipment: Drag From Library
Hot Water Equipment: Drag From Library
Steam Equipment: Drag From Library
Other Equipment: Drag From Library
Infiltration: MidriseApartme Infil

Figure 8 Typical schedule set for apartment

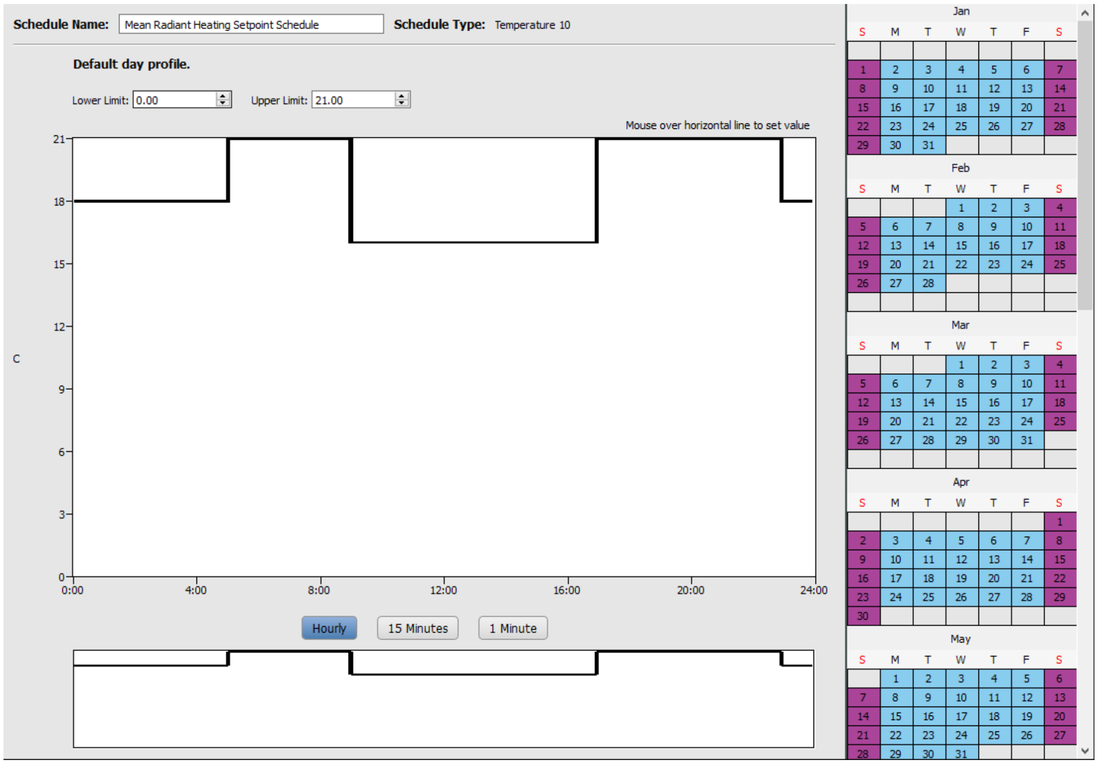
Open studio can automatically assign these schedules and loads once the energy template and space type are chosen. However, these schedules and loads can also be adjusted manually like internal loads to match the real operation situation.

Schedule Name: MidriseApartment Apartment Occ **Schedule Type:** Fraction

Default day profile.

Lower Limit: 0.00 Upper Limit: 1.00

(a)Apartment space weekdays occupancy schedule

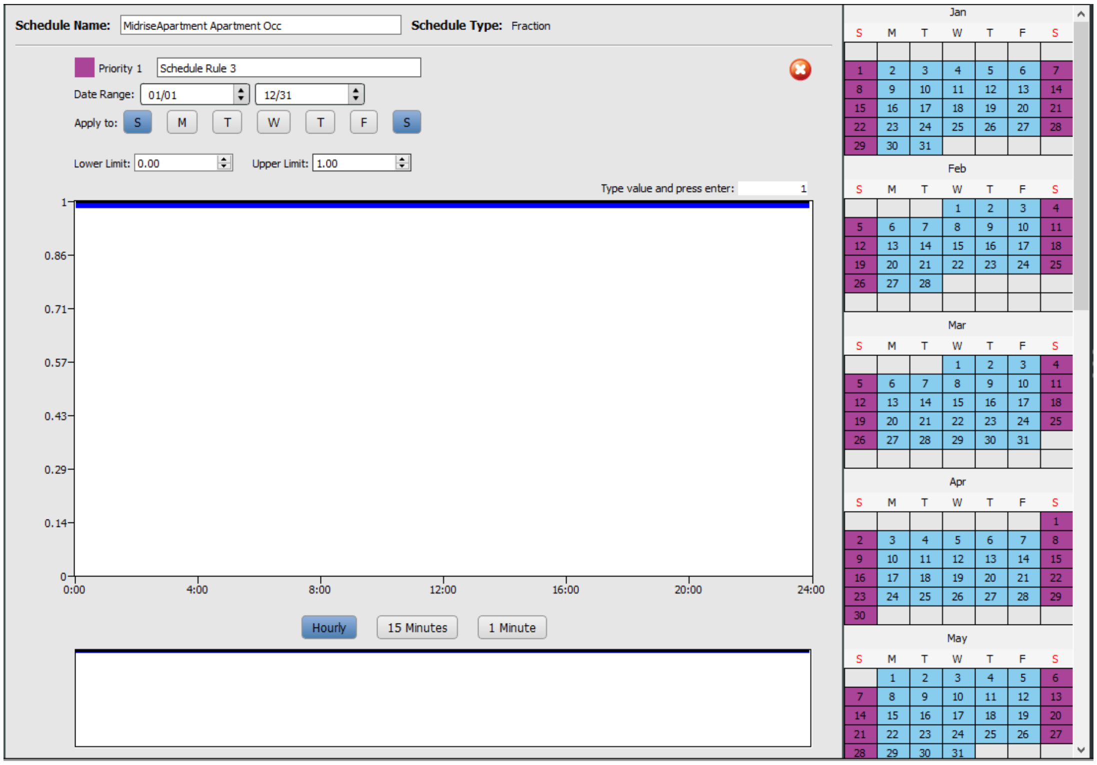


Schedule Name: Mean Radiant Heating Setpoint Schedule **Schedule Type:** Temperature 10

Default day profile.

Lower Limit: 0.00 Upper Limit: 21.00

(b)Apartment space weekdays heating setpoint schedule



Schedule Name: MidriseApartment Apartment Occ **Schedule Type:** Fraction

Priority 1 Schedule Rule 3

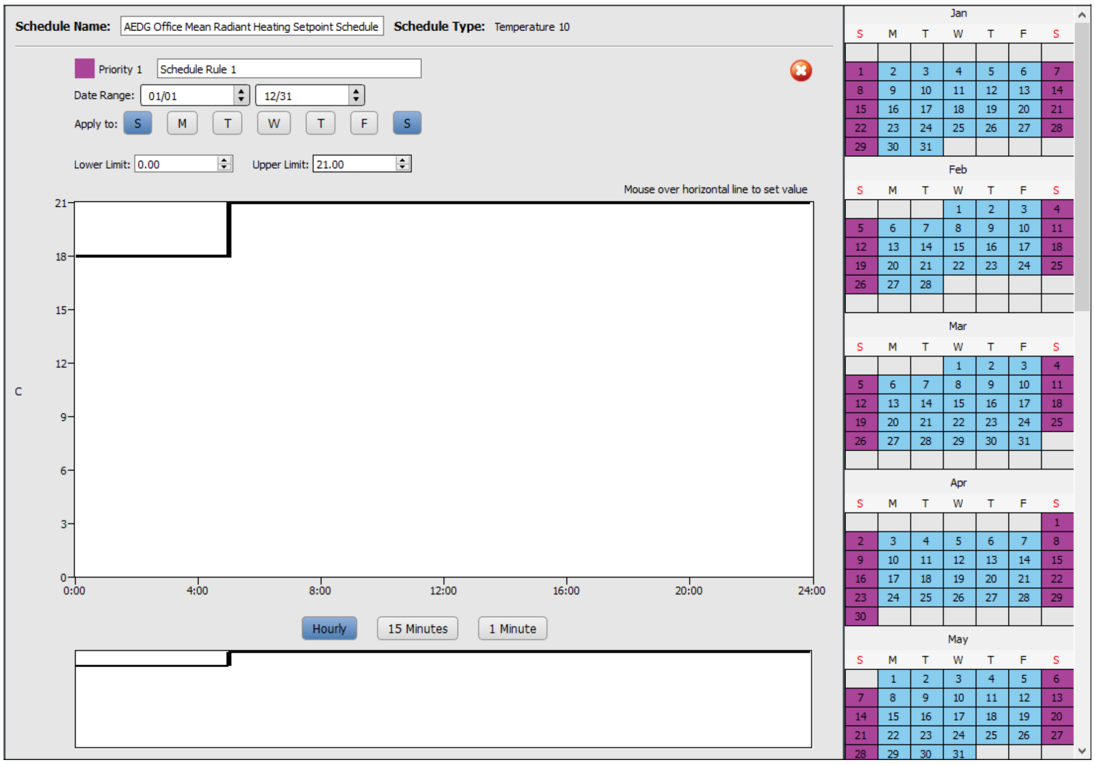
Date Range: 01/01 12/31

Apply to: S M T W T F S

Lower Limit: 0.00 Upper Limit: 1.00

Type value and press enter: 1

(c)Apartment space weekends occupancy schedule



Schedule Name: AEDG Office Mean Radiant Heating Setpoint Schedule **Schedule Type:** Temperature 10

Priority 1 Schedule Rule 1

Date Range: 01/01 12/31

Apply to: S M T W T F S

Lower Limit: 0.00 Upper Limit: 21.00

Mouse over horizontal line to set value

(d) Apartment space weekdays heating setpoint schedule

Figure 9 Scenario A Occupancy and heating setpoint schedules

From Figure 9, one set schedule was assigned for weekdays, another for weekends. The schedule type between occupancy and heating setpoint was different. Occupancy schedule used friction type, 1 standing for 100% occupied, 0.2 standing for 20% occupied, while heating setpoint schedule used temperature type, 21 standing for 21°C. The ideal setpoint range for Scenario A during weekdays was when units were occupied, it maintained the temperature at 21°C, and when units were unoccupied, it dropped the temperature down to 16 °C. Furthermore, from previous literature review, a 3°C setback could achieve energy saving when people sleep at night. For weekends, it is assumed that people would like to stay at home, and therefore the temperature maintained at 21°C except for sleeping time.

3.1.2 Results

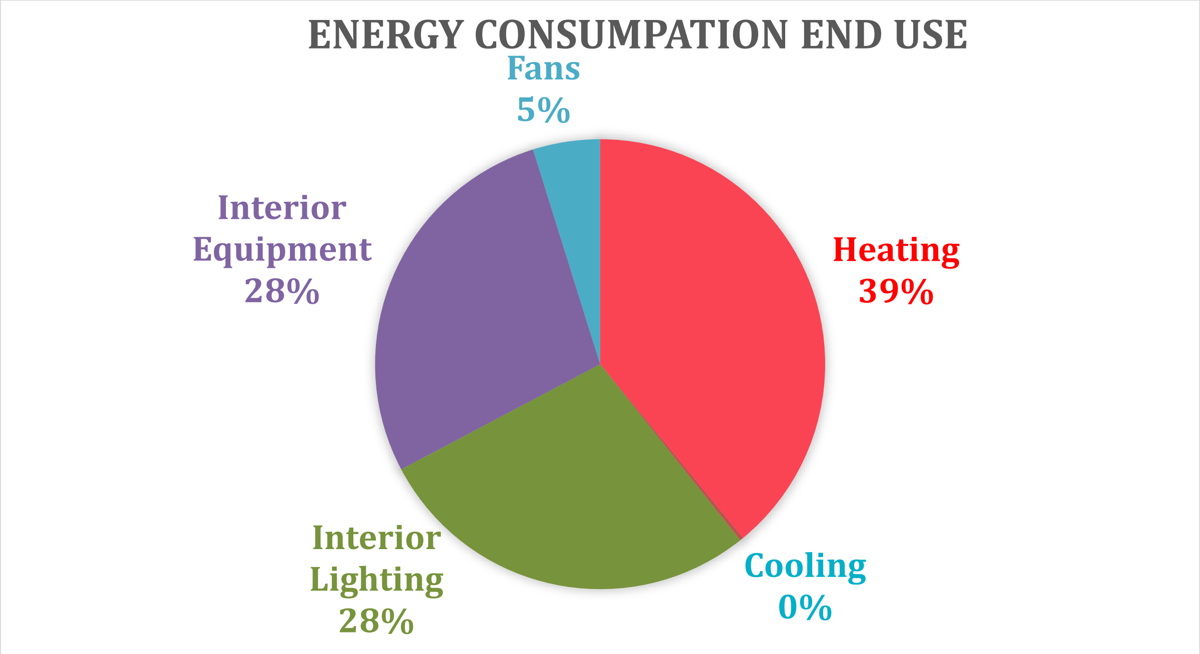


Figure 10 Annual energy consumption end use of scenario A

Table 4 Annual end use and energy use of scenario A

End Use	Annual Consumption (kBtu)	Energy use
Heating	395,581	District heating
Cooling	0	
Interior Lighting	282,990	Electricity
Interior Equipment	282,535	Electricity
Fans	48,832	Electricity
Pumps	171	Electricity
Total	1,010,109	Mixed

As shown on the Figure 9 and Table 4, heating accounted for 39% of total energy consumption. Interior lighting and interior equipment were the same, 28%. The reason why lighting was high is because when run the simulation, only heating in apartment spaces was considered, but lighting of units, public spaces and parking spaces were all taken into account.

Another simulation was run to analyze the energy consumption end use for dwelling units(apartment spaces) only.

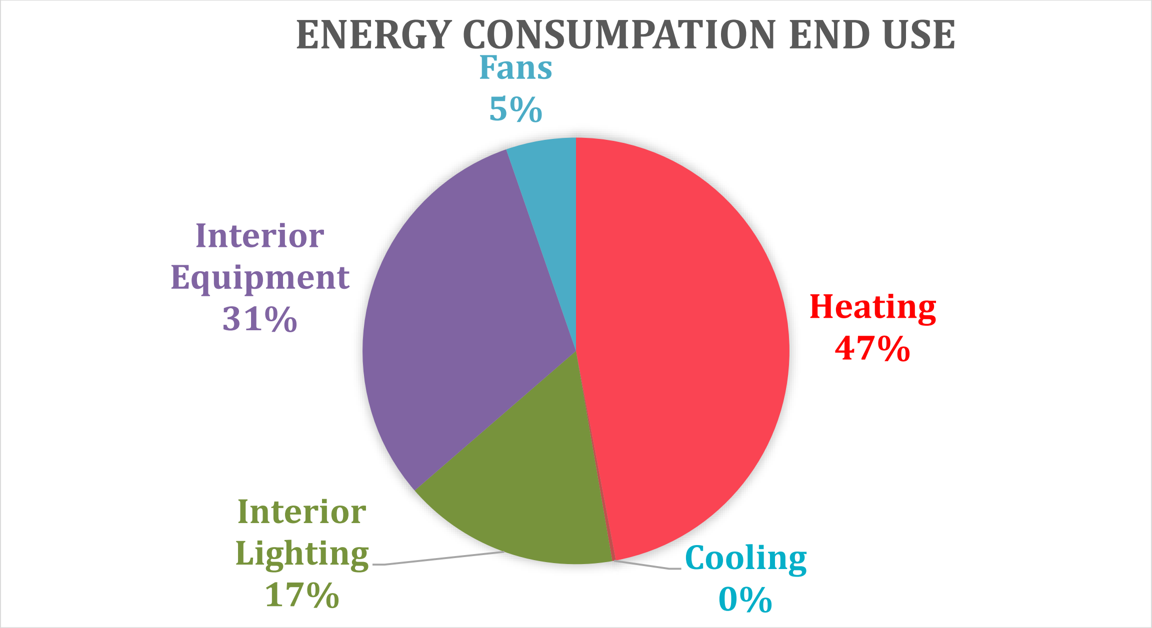


Figure 11 Annual energy consumption end use of scenario A for dwelling spaces only

From Figure 11, heating increased from 39% to 47%, and lighting decreased by 11%. This pie chart is closer to common energy consumption end use of residential buildings in North America, however, it would be more accurate if domestic hot water heating can be taken into consideration.

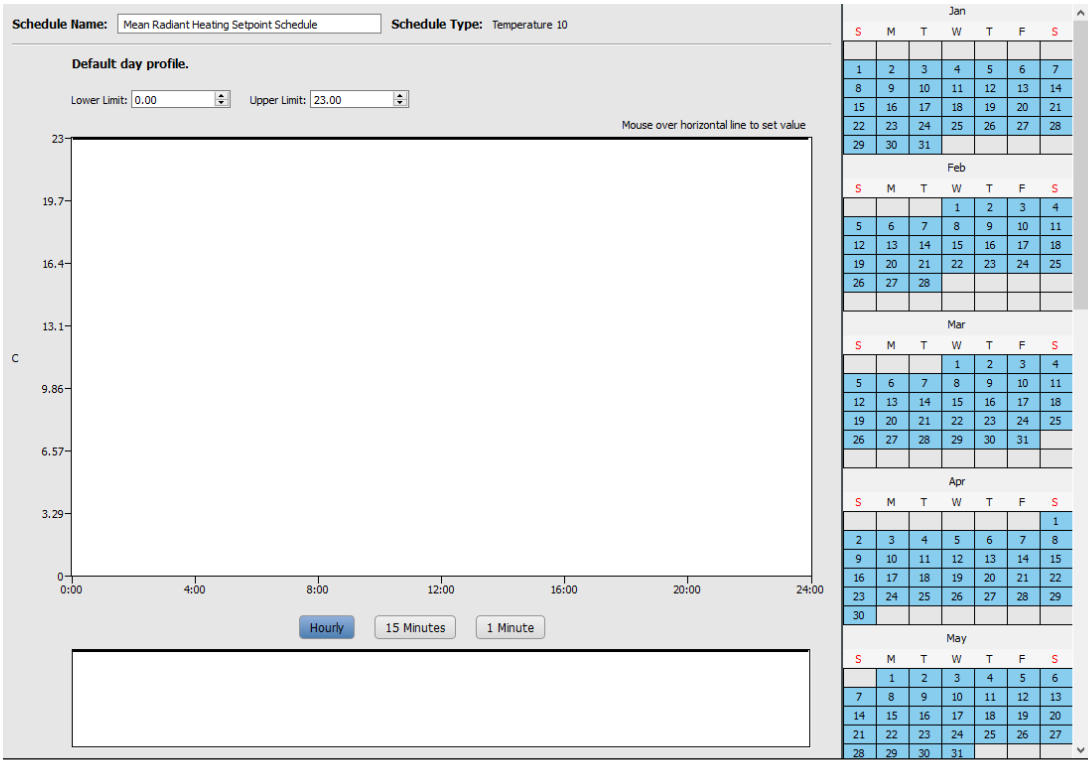
3.2 Scenario B

3.2.1 Inputs

3.2.1.1 Internal Loads

Internal loads of scenario B could refer to that of scenario A. The only difference between scenario B and scenario A was heating setpoint.

3.2.1.2 Schedules



Schedule Name: Mean Radiant Heating Setpoint Schedule **Schedule Type:** Temperature 10

Default day profile.

Lower Limit: 0.00 Upper Limit: 23.00

Mouse over horizontal line to set value

Figure 12 Scenario B heating setpoint schedule

In scenario B, to define the upper bond of energy consumption, 23 °C was assigned 24/7 for the whole year.

3.2.2 Results

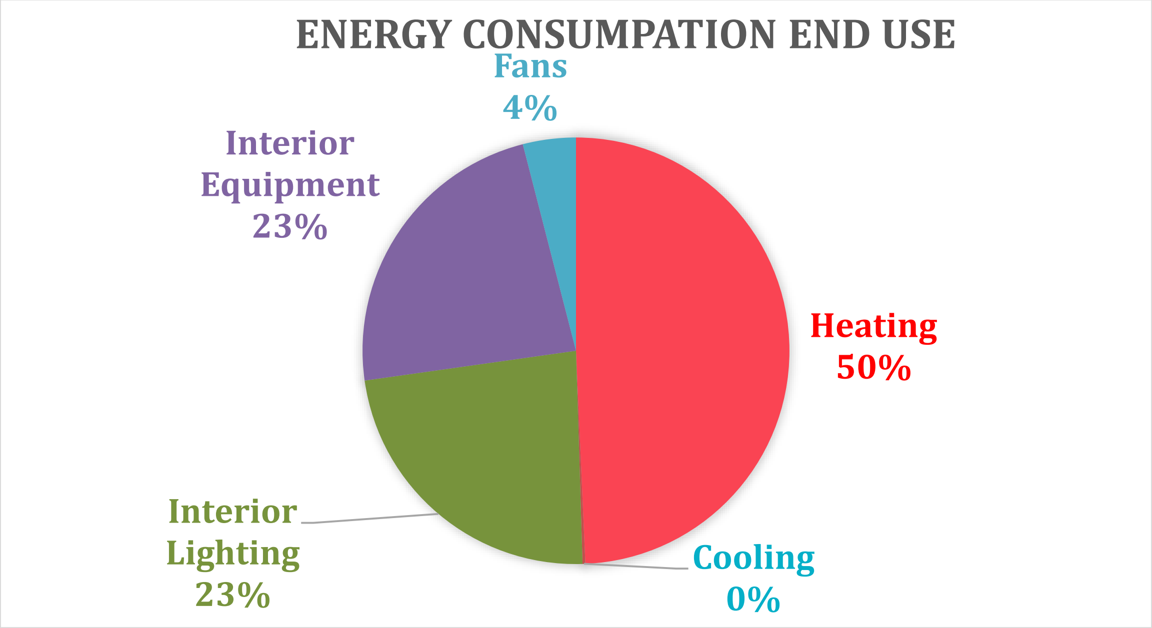


Figure 13 Annual energy consumption end use of scenario B

Table 5 Annual end use and energy use of scenario B

End Use	Annual Consumption (kBtu)	Energy use
Heating	599,864	District heating
Cooling	0	
Interior Lighting	282,990	Electricity
Interior Equipment	282,535	Electricity
Fans	48,794	Electricity
Pumps	66	Electricity
Total	1,214,249	Mixed

It can be noted that from Figure 13 and Table 5 the increase of heating setpoint did have a huge impact on heating consumption. In scenario B, the setpoint went up to

23°C, and there was a growth of 204,283 kBtu for district heating. It was approximately 51% more of heating consumption than that of scenario A.

3.3 Scenario C

3.3.1 Inputs

3.3.1.1 Internal Loads

The aim of scenario C was to use the inputs from Williams Engineering's model to run the simulation in the model established by Energy Plus, and compare the difference between simulation results by Energy Plus and results from WE report using EE4.

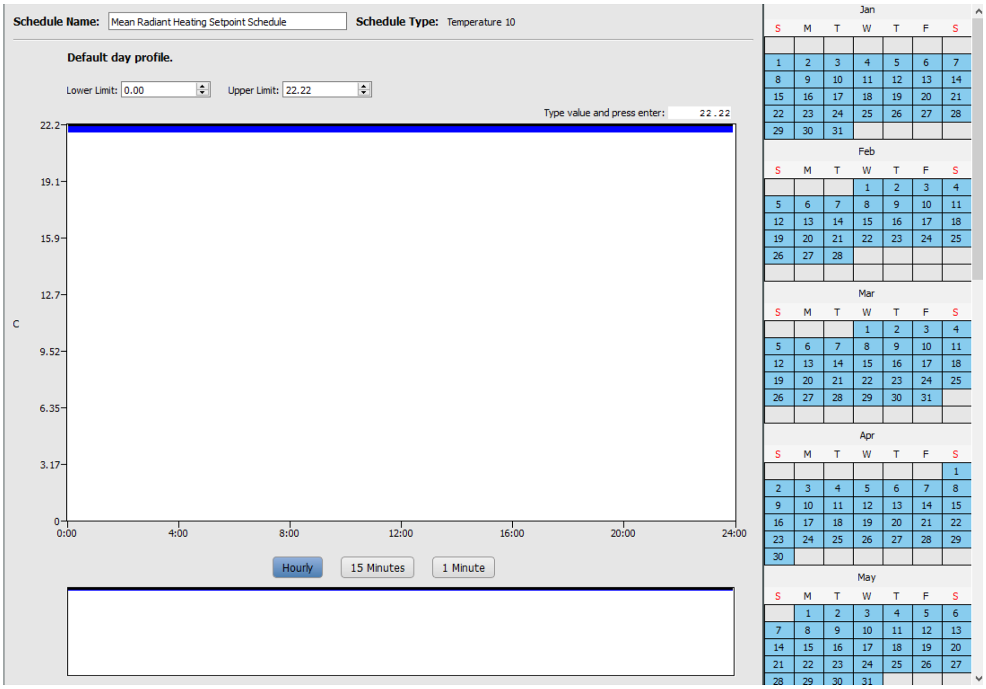
Table 6 Internal loads of Williams Engineering simulation

Internal Loads			
	Occupants (people/m2)	**Interior Lighting Power Density (W/m2)**	**Plug loads (W/m2)**
Apartment	0.028	7	2.5
Corridor	N/A	7	N/A
Stair	N/A	7	N/A
Lobby	0.33	7	N/A
Storage(Parkade)	N/A	N/A	N/A

Williams Engineering's model assumed one space type only, and therefore all spaces were assumed the same number for interior lighting power density of 7 W/m^2. For interior equipment, 2.5 W/m^2 was assigned to apartment spaces.

3.3.1.2 Schedules

The indoor heating setpoint of Williams Engineering's model was 72°F (22.2°C)



Schedule Name: Mean Radiant Heating Setpoint Schedule **Schedule Type:** Temperature 10

Default day profile.

Lower Limit: 0.00 Upper Limit: 22.22

Type value and press enter: 22.22

Figure 14 Scenario C heating setpoint schedule

3.3.2 Results

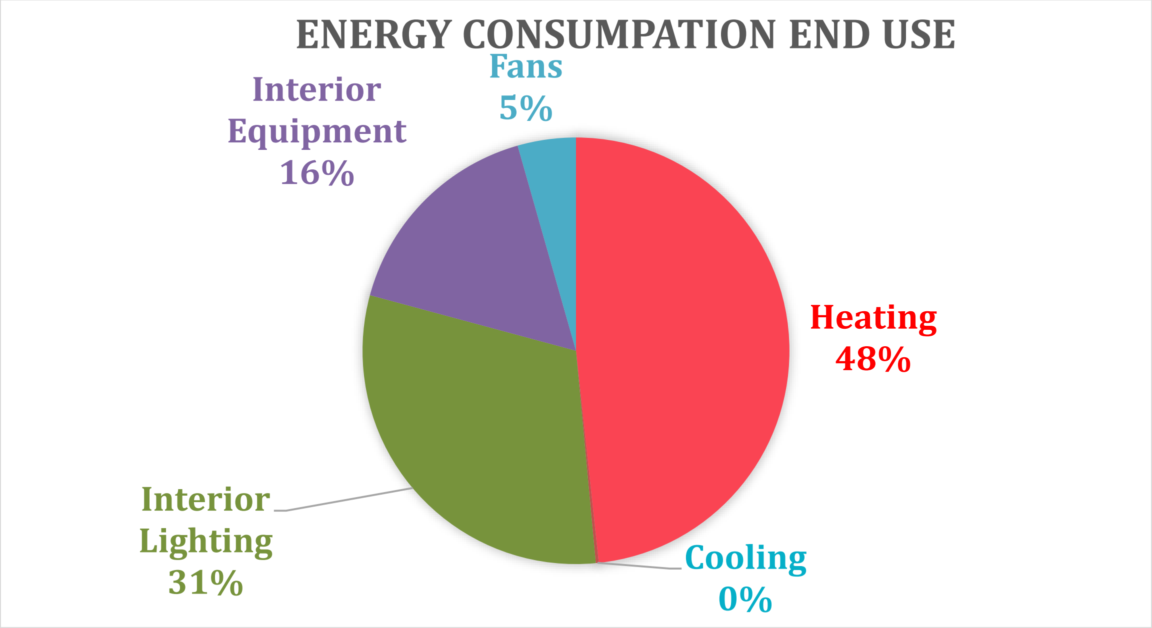


Figure 15 Annual energy consumption end use of scenario C

Table 7 Annual end use and energy use of scenario C

End Use	Annual Consumption (kBtu)	Energy use
Heating	537,062	District heating
Cooling	0	
Interior Lighting	341,157	Electricity
Interior Equipment	182,284	Electricity
Fans	49,040	Electricity
Pumps	47	Electricity
Total	1,109,590	Mixed

Because of a lower heating setpoint and a higher lighting power density than those of scenario B, the results from Figure 15 and Table 7 show that scenario C consumed less energy for heating, but more for lighting. In this case, lighting occupied 31% of total energy consumption end use, being a little high. The reason leading to this result was that in Williams Engineering's model, all spaces were assigned one lighting density of 7 W/m^2, but in ASHRAE standard, for example, 2 W/m^2 is the minimum requirements in parking spaces. The difference of 5 W/m^2 would make the discrepancy of end use.

3.3.3 Scenario C results and WE modelling results comparison

The comparison of two simulation results is shown as Table 8 below.

Table 8 Comparison between scenario C and WE modelling

	Scenario C	**WE Modelling**
Lighting (kWh)	99,983	117,556
Plug Loads(kWh)	53,422	31,902
[Heating(kWh)	157,397	240,142
Fans(kWh)	14,372	9,717
EUI for heating(mj/m2)	154.76	204.23
EUI for heating(kWh/m2)	43	56.7

All results of WE modelling were from the REAP energy modelling report prepared by Williams Engineering. It can be found that even if the same inputs were assigned, the simulation results cannot match each other. EUI (energy use intensity) for heating of WE modelling is much higher than EUI of Scenario C by 31%. Here are some reason that could contribute to this gap.

1. When the geometry was established, the difference had already been induced in the different models. Besides, each setting step would create some differences as well. These slightly differences kept accumulating, leading to the gap.
2. Two energy modelling software (Energy Plus and EE4) have their own calculation methods to run the simulation, which means the key factors in each calculation process would be different.
3. Different simulation processes would cause the result difference. In energy plus, space types, energy standard, thermal zones must be assigned before running simulation, while EE4 works in a different way.

These possibilities would have combined effects, contributing to the significant gap between two simulations.

3.4 Nobel House

Nobel house is also located at Wesbrook Place, having a similar hydronic radiant heating system like Webber House. It is a 6-story residential building and went into operation since 2015.The operation data of Nobel House can be collected. Because of the same location, building function and similar heating system, EUI of Webber house should be close to EUI of Noble. To verify the reliability of Webber House energy model, it is worth comparing EUI among Nobel house, scenario A, scenario B, scenario C and WE modelling results.

3.4.1 Comparison among Nobel House, Scenario A, Scenario B and WE modelling results

Table 9 EUI comparisons

	EUI for heating (mj/m2)	EUI for heating (kWh/m2)
Scenario A	113.86	31.63
Scenario B	172.86	48.01
Scenario C	154.76	43
WE modelling	204.23	56.7
Nobel House	154	42.78

As shown in Table 9, EUI of Noble House is 42.78 kWh/m^2, being calculated from the operation data. Once 42.78 kWh/m^2 is set as a baseline data, it can be noted that the EUI of scenario A and scenario B can cover the baseline data, which means in the future operation, actual EUI of Webber is likely to be in the range between scenario A and B. Moreover, compared with Nobel House, EUI of WE modelling is much higher, while scenario C is close enough.

As a conclusion, scenario A consumed the least energy, and scenario B was a reasonable upper bond. EUI of WE modelling was too high, perhaps because it considered the worst situation, and it established the model for a different purpose, achieving REAP credits.

4. Sensitivity Analysis

To explore how lighting and infiltration rate would affect the heating consumption, a sensitivity analysis is introduced.

4.1 Lighting

To analyze the sensitivity of lighting, three cases were assumed.

1. Scenario A (Base case)
2. No lighting(compared to base case, using 100% less lighting)
3. LED(compared to base case, using 30% less lighting)

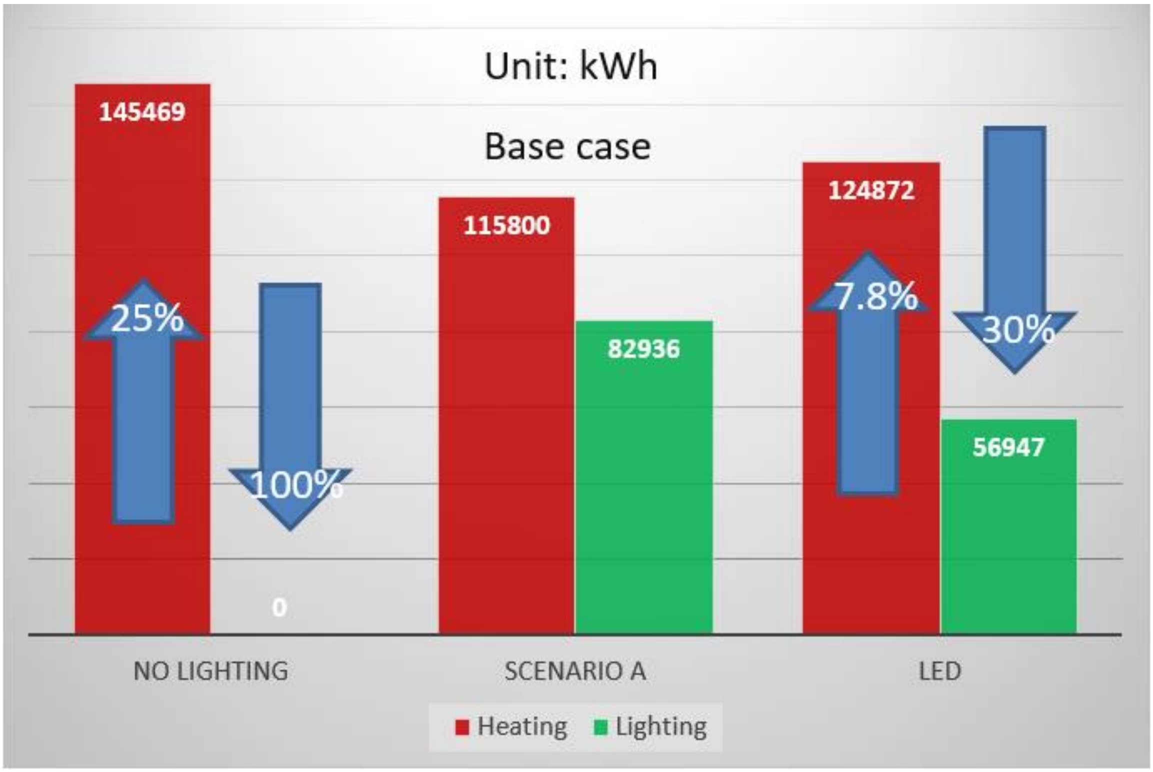


Figure 16 Sensitivity analysis of lighting

It can be seen by Figure 16, lighting dropped by 100%, and heating would increase by 25%. For LED, 30% less lighting led to a 7.8% growth in heating. Using less lighting means there is less internal gain as well, and therefore more heating is needed to offset the heat loss from lighting.

4.2 Infiltration rate

To analyze the sensitivity of infiltration rate, two cases were assumed.

1. Scenario A (Base case)
2. 130% infiltration rate of scenario A

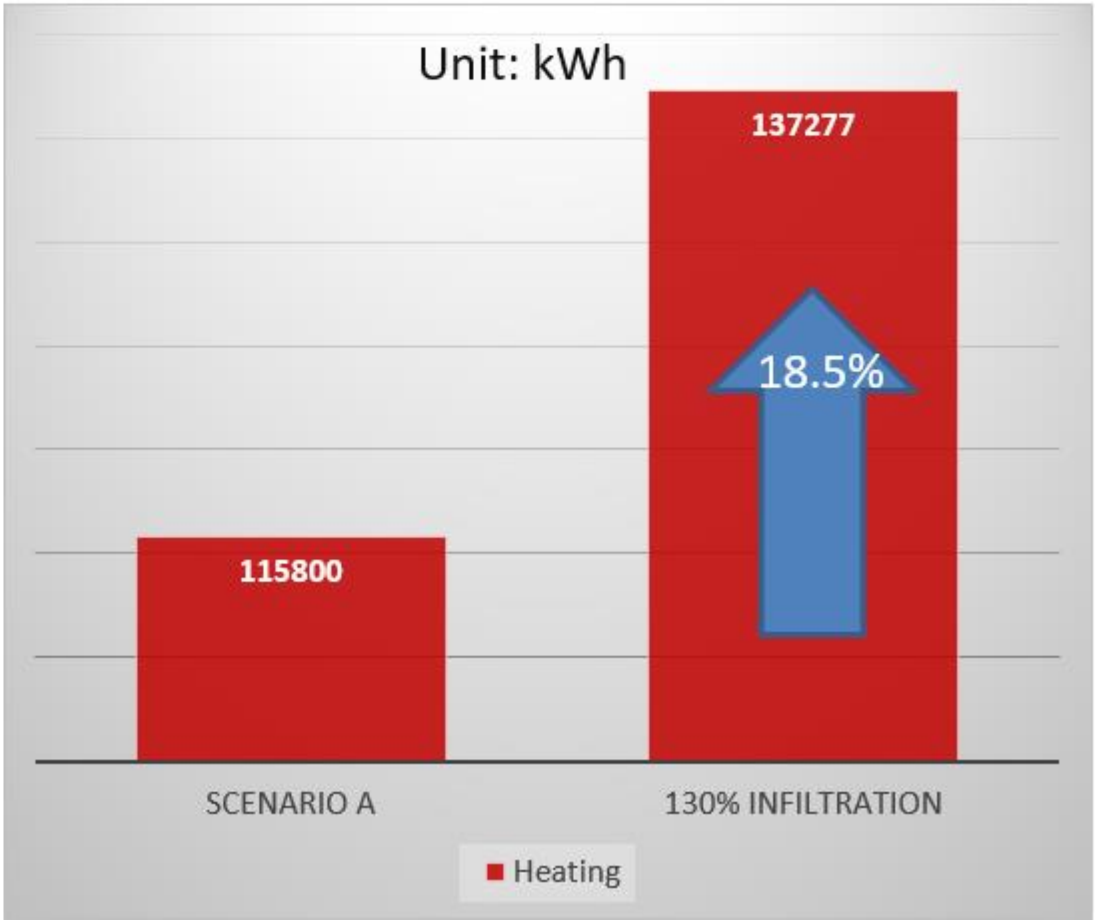


Figure 17 Sensitivity analysis of infiltration rate

It can be seen by Figure 16, 30% increase of infiltration rate caused an 18.5% growth in heating.

Table 10 Sensitivity analysis

	EUI for heating (mj/m²)	**EUI for heating (kWh/m²)**	**Percentage** difference **(%)**	**Ratio**
Scenario A(Base case)	113.86	31.62		
No lighting	143.03	39.73	+25%	0.25
LED	122.78	34.11	+7.8%	0.26
130% Infiltration rate	134.98	37.49	+18.5%	0.61

Ratio in Table 10 was calculated by the following equation:

$$\text{Ratio} = \frac{percentage\ difference\ for\ lighting\ or\ infiltraion\ rate}{percentage\ increase\ of\ heating}$$

Taking 130% infiltration rate as an example, ratio=30%/18.5%=0.61. The ratio reflects the degree of influence. The greater ratio is, the more influence degree will be. Therefore, compared with lighting, infiltration rate has a greater influence on heating consumption. In the other words, infiltration rate should be carefully assumed to make the simulation more accurate.

5. Scenario A feasibility analysis

As analyzed above, Scenario A had the lowest heating consumption. However, it still needs to be verified whether scenario A can provide occupants' thermal comfort and achieve energy saving.

5.1 Thermal comfort analysis

To analyze thermal comfort, operative temperature and relative humidity for conditioned spaces are necessary.

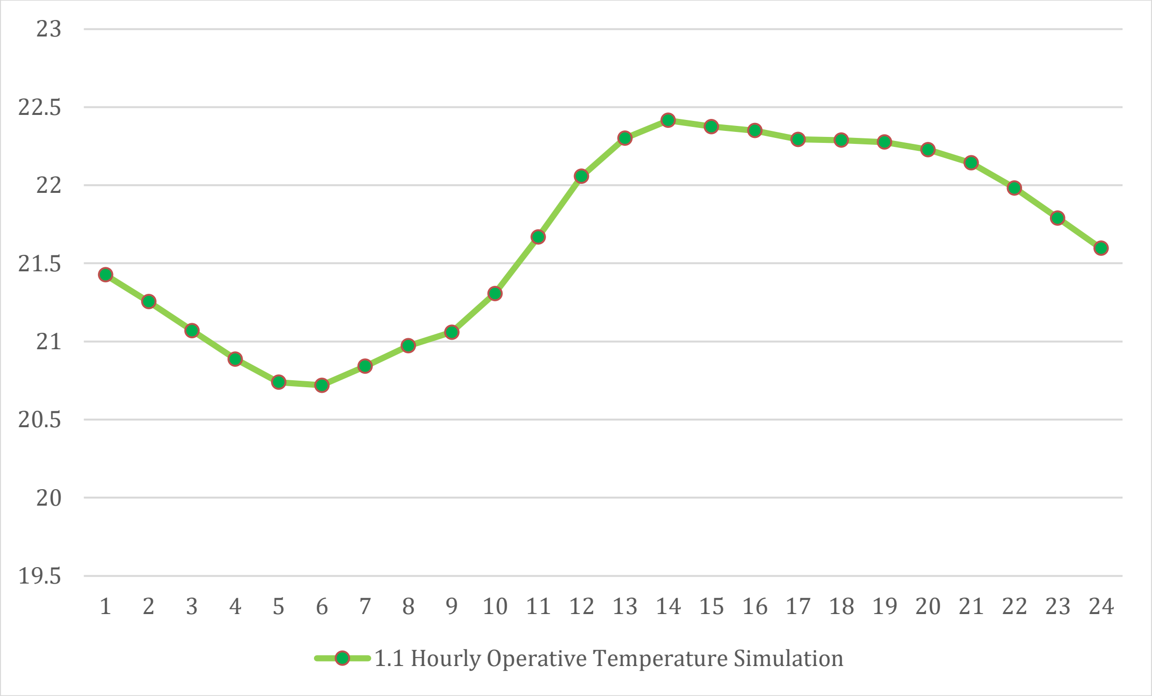
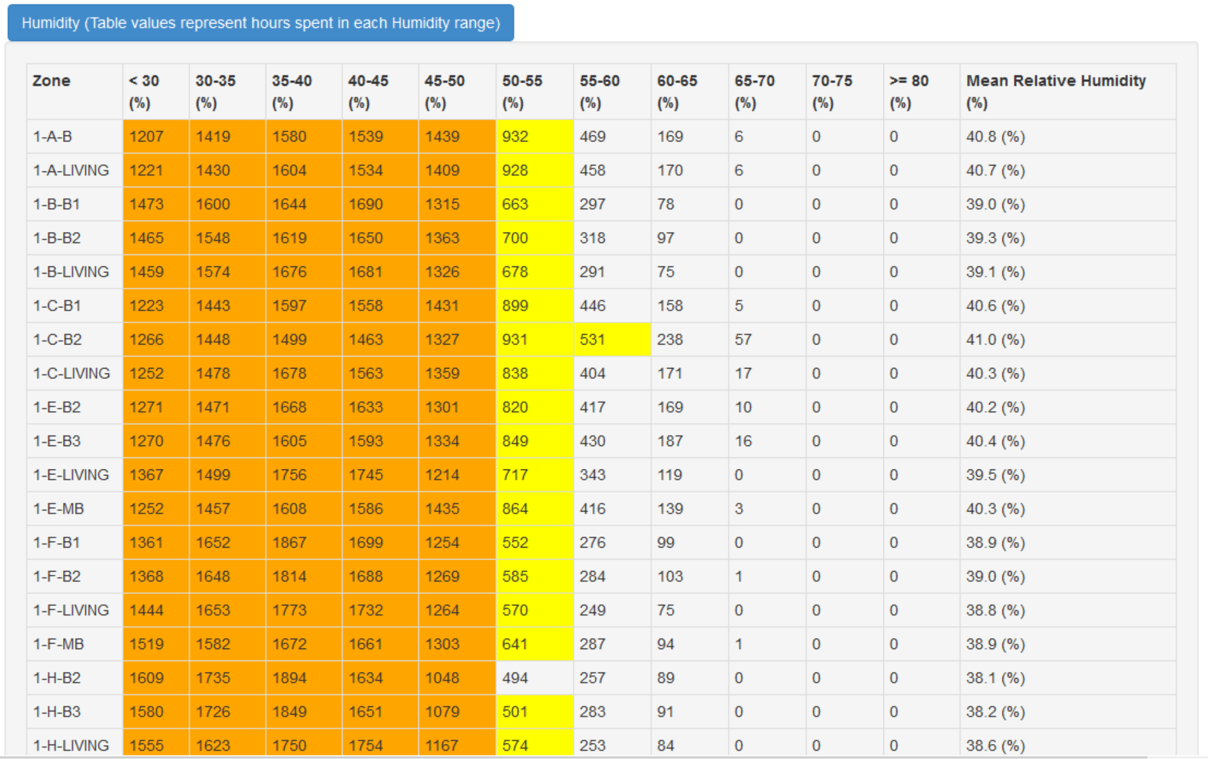


Figure 18 January 1st Hourly Operative Temperature Simulation

Energy plus can run the simulation for hourly operative temperature of each unit. In this case, January 1st was chosen because it was one of the coldest day in the whole year. If thermal comfort can be provided on this date, for other days tenants would feel comfortable as well. The average temperature for the occupied period (17:00-24:00) was approximately 22 °C after calculation.



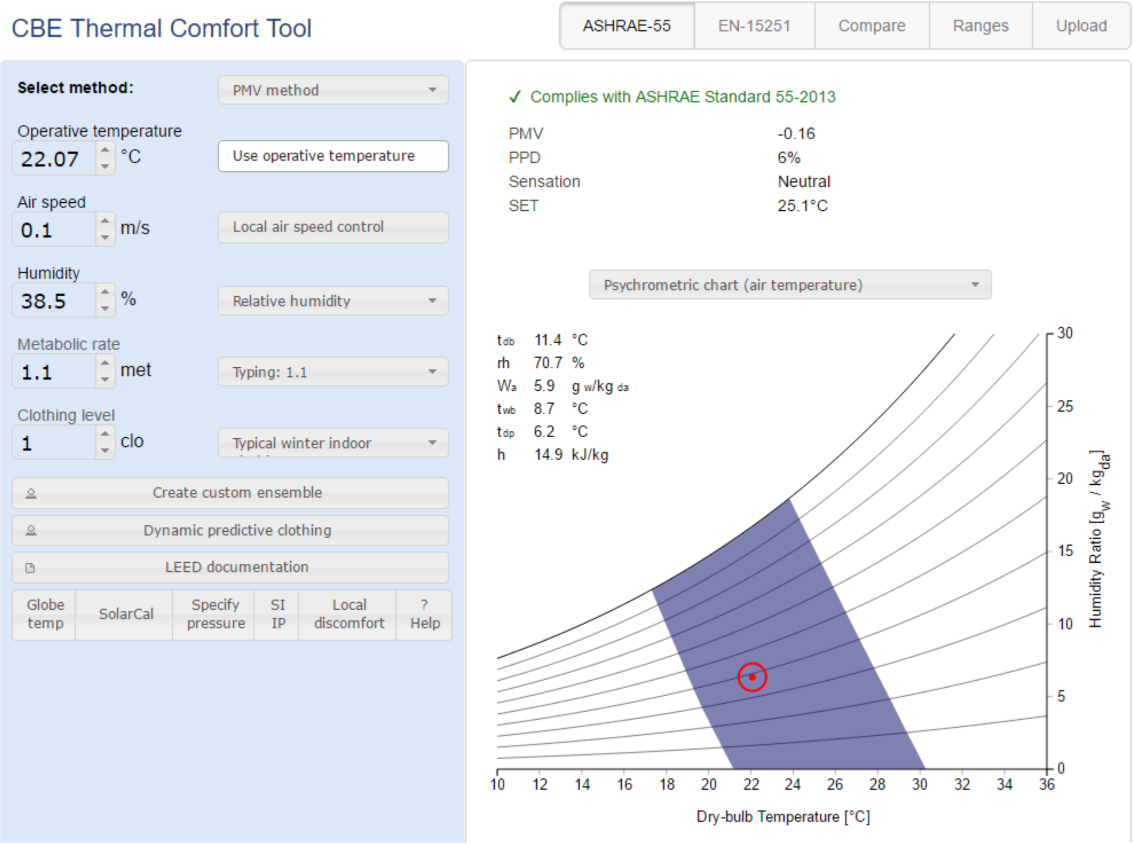
Humidity (Table values represent hours spent in each Humidity range)

Zone	< 30 (%)	30-35 (%)	35-40 (%)	40-45 (%)	45-50 (%)	50-55 (%)	55-60 (%)	60-65 (%)	65-70 (%)	70-75 (%)	>= 80 (%)	Mean Relative Humidity (%)
1-A-B	1207	1419	1580	1539	1439	932	469	169	6	0	0	40.8 (%)
1-A-LIVING	1221	1430	1604	1534	1409	928	458	170	6	0	0	40.7 (%)
1-B-B1	1473	1600	1644	1690	1315	663	297	78	0	0	0	39.0 (%)
1-B-B2	1465	1548	1619	1650	1363	700	318	97	0	0	0	39.3 (%)
1-B-LIVING	1459	1574	1676	1681	1326	678	291	75	0	0	0	39.1 (%)
1-C-B1	1223	1443	1597	1558	1431	899	446	158	5	0	0	40.6 (%)
1-C-B2	1266	1448	1499	1463	1327	931	531	238	57	0	0	41.0 (%)
1-C-LIVING	1252	1478	1678	1563	1359	838	404	171	17	0	0	40.3 (%)
1-E-B2	1271	1471	1668	1633	1301	820	417	169	10	0	0	40.2 (%)
1-E-B3	1270	1476	1605	1593	1334	849	430	187	16	0	0	40.4 (%)
1-E-LIVING	1367	1499	1756	1745	1214	717	343	119	0	0	0	39.5 (%)
1-E-MB	1252	1457	1608	1586	1435	864	416	139	3	0	0	40.3 (%)
1-F-B1	1361	1652	1867	1699	1254	552	276	99	0	0	0	38.9 (%)
1-F-B2	1368	1648	1814	1688	1269	585	284	103	1	0	0	39.0 (%)
1-F-LIVING	1444	1653	1773	1732	1264	570	249	75	0	0	0	38.8 (%)
1-F-MB	1519	1582	1672	1661	1303	641	287	94	1	0	0	38.9 (%)
1-H-B2	1609	1735	1894	1634	1048	494	257	89	0	0	0	38.1 (%)
1-H-B3	1580	1726	1849	1651	1079	501	283	91	0	0	0	38.2 (%)
1-H-LIVING	1555	1623	1750	1754	1167	574	253	84	0	0	0	38.6 (%)

Figure 19 Relative humidity simulation

Not only operative temperature, but also relative humidity can be simulated by Energy Plus. (Figure 19) The average relative humidity of conditioned spaces was 38.5%.

Once average operative temperature and relative humidity were calculated, thermal comfort can be analyzed by online tool.



CBE Thermal Comfort Tool

Select method: PMV method

Operative temperature 22.07 °C — Use operative temperature

Air speed 0.1 m/s — Local air speed control

Humidity 38.5 % — Relative humidity

Metabolic rate 1.1 met — Typing: 1.1

Clothing level 1 clo — Typical winter indoor

✓ Complies with ASHRAE Standard 55-2013

PMV -0.16
PPD 6%
Sensation Neutral
SET 25.1°C

Psychrometric chart (air temperature)

t_{db} 11.4 °C
rh 70.7 %
W_a 5.9 g w/kg da
t_{wb} 8.7 °C
t_{dp} 6.2 °C
h 14.9 kJ/kg

Figure 20 Thermal comfort analysis

As shown on Figure 20, once metabolic rate and clothing level were assigned, the tool generated a comfort zone (blue area) on the psychrometric chart based on ASHRAE 55-2013. After inputting operative temperature and humidity calculated before, the tool showed a red dot on chart as well. From the chart, it can be found that occupants would feel highly comfortable since red dot is in the middle of the comfort zone.

5.2 Energy saving analysis

Table 11 Energy saving analysis

	Annual Energy Consumption For Heating (kWh)
Scenario A	115,933
Scenario B	175,802
Difference	59,869

Compared with the upper bond Scenario B, Scenario A can save 51% energy by simply decreasing the setpoint.

6. Conclusion

Based on the analysis above, it can be found that the heating setpoint had a significant influence on heating consumption. Scenario A consumed the least among all simulations. Meanwhile, it provided high thermal comfort and achieved energy saving. Therefore, it is worth encouraging tenants to go with scenario A for their heating setpoint.

From sensitivity analysis, it should be noticed that infiltration rate does affect the thermal performance to a great extent. Thus, after operation, the actual situation, especially for infiltration rate, should be verified.

7. Future Work

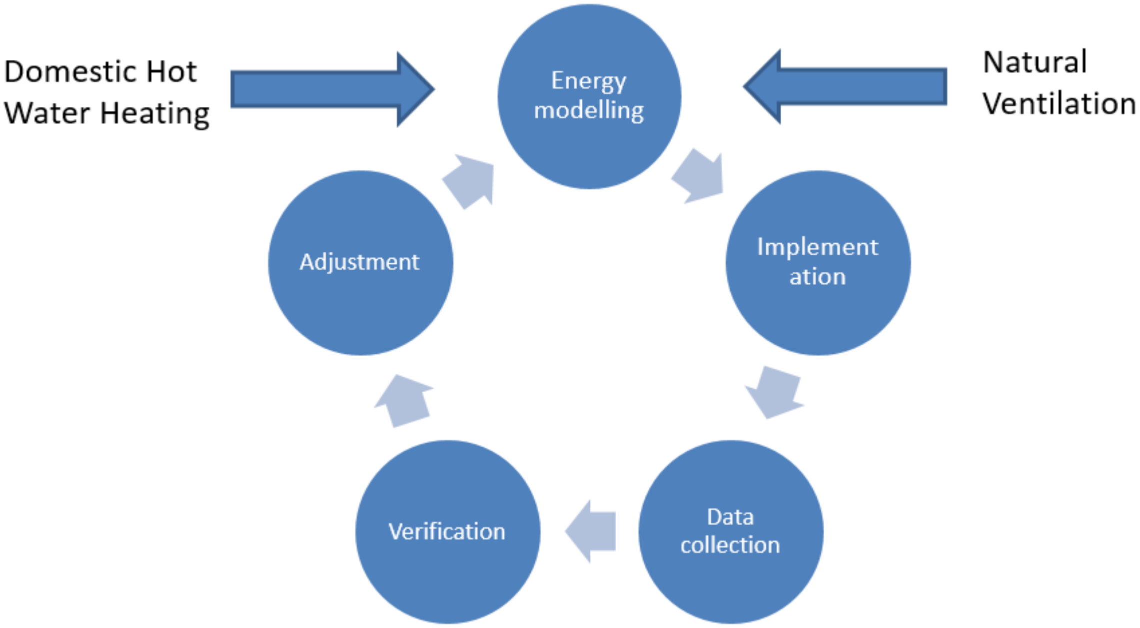


Figure 21 Future work process

Since scenario A is the best option for heating setpoint, next step is to encourage the potential tenants to set their thermostats' setpoint with scenario A. After Webber house being in use, the operation data can be collected from building performance software. It is important to verify the model using actual performance data. If the actual data cannot match the simulation results, the inputs need to be adjusted to match the real situation. The new model after adjustment can try some new scenarios, forming a cycle to improve the building performance.

Apart from that, adding domestic hot water heating and natural ventilation into energy modelling is also valuable to make the simulation more accurate and comprehensive.

Finally, the disadvantage of radiant heating is slow response time. Thus, it would be a progress if the time period reaching the setpoint can be simulated.

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Project Manager	Liska Richer
Green Buildings Manager	Penny Martyn

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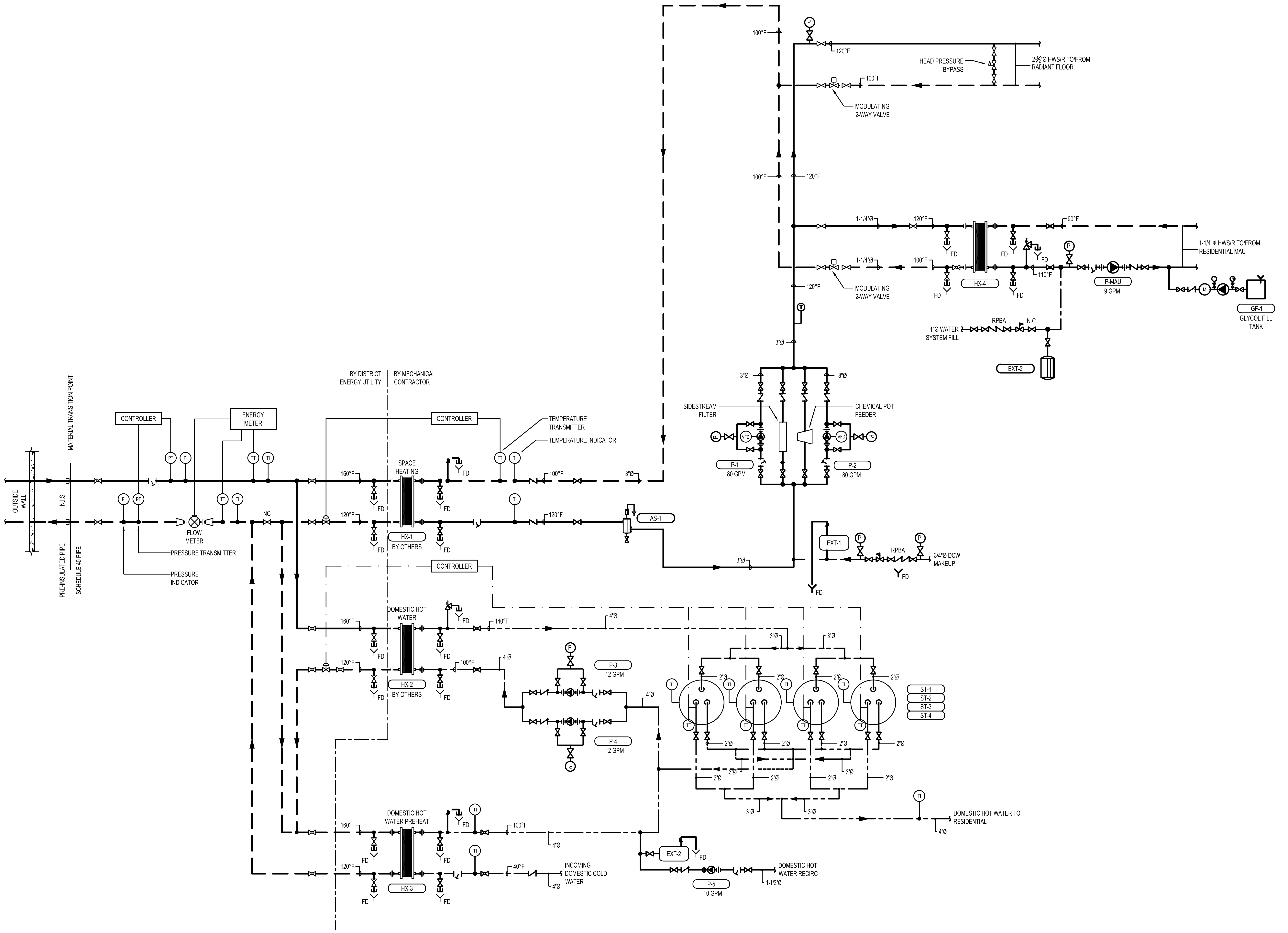
Appendix A



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2	October 1, 2015	Issued For Foundation Permit
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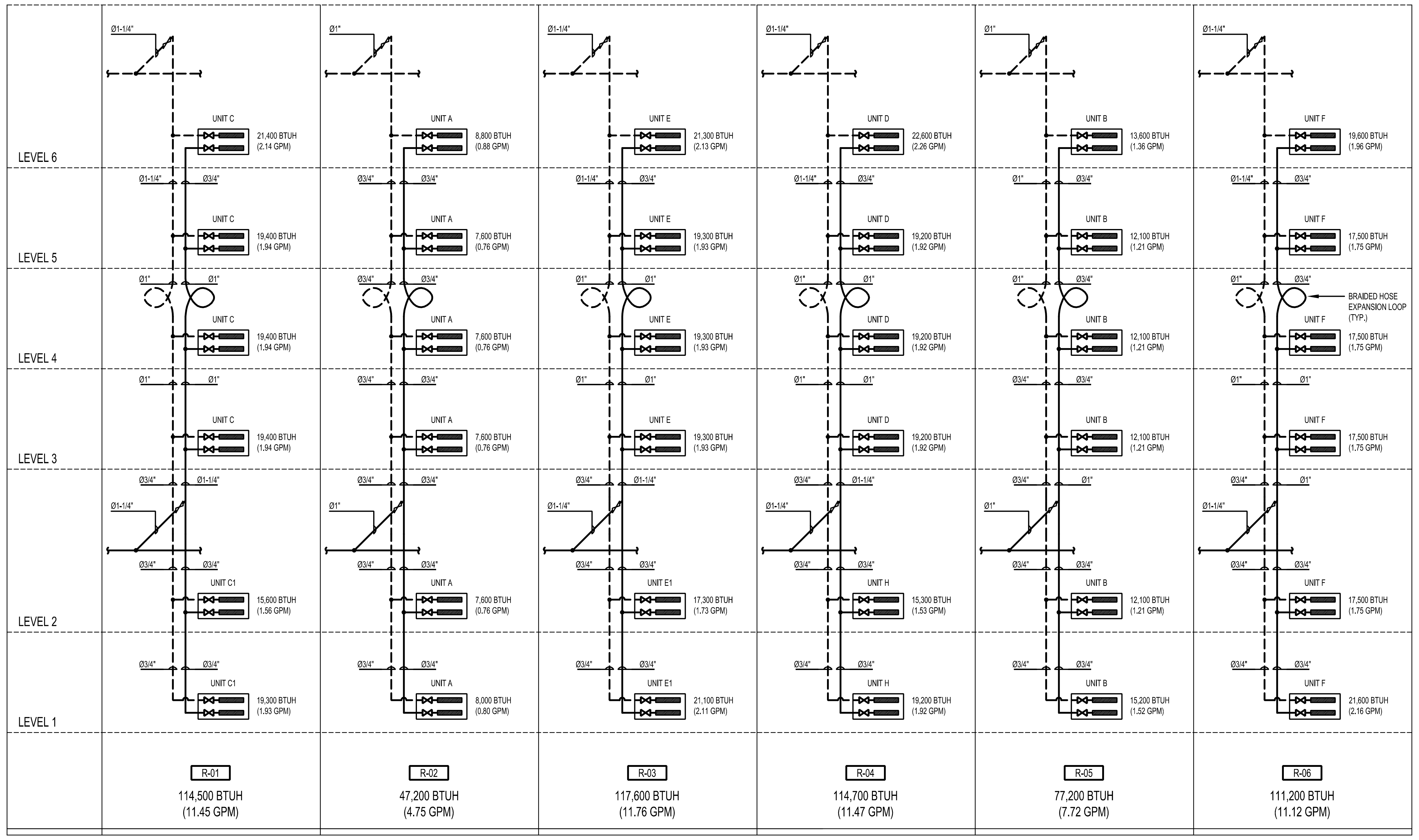
Appendix B



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