ASHRAE STUDENT DESIGN COMPETITION
SYSTEM SELECTION
Beijing,China – Spring 2016

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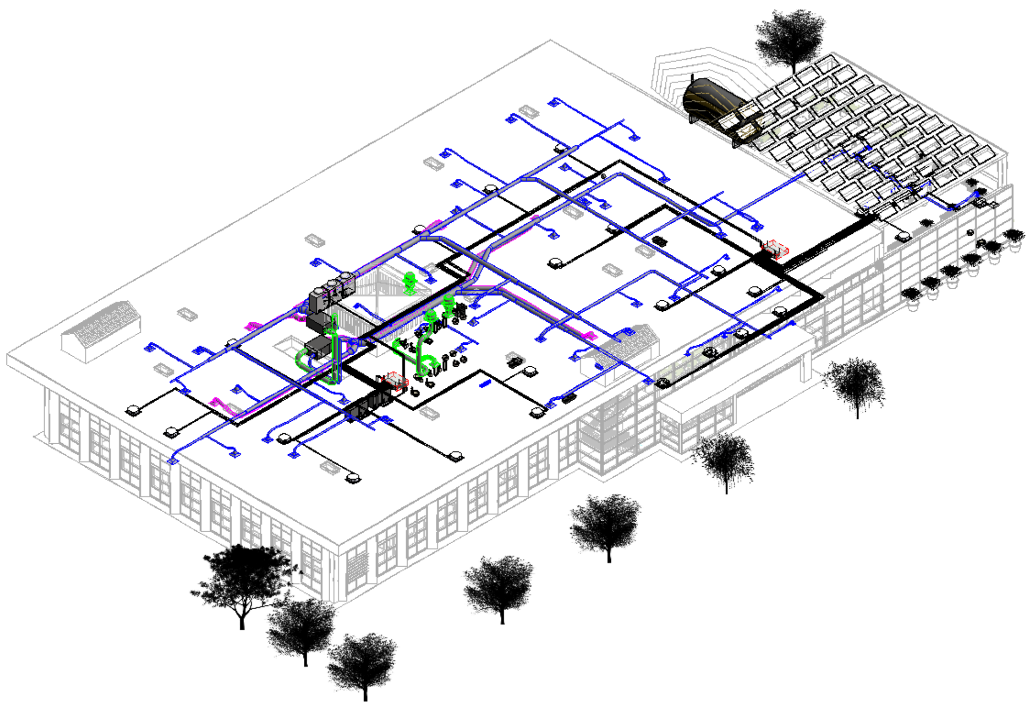
EXECUTIVE SUMMARY

The purpose of this report is to present the system selection process of a heating, ventilation, and air conditioning system for a two story office and administration building located in Beijing, China. The new building of approximately 40,000 square feet, will house individual offices, cubical spaces, meeting rooms, and shared spaces such as reception area, copier, and break areas. In addition, the building houses a non-stop service to dispatch emergency and nonemergency government vehicles.



In order to size the equipment for an HVAC system, a weather analysis was performed on the location. Based on most recent data a load analysis was performed using TRACE 700. The following three systems were considered in this project:

- Variable Refrigerant Flow with Ground Coupled Heat Pump..
- Hybrid Variable Refrigerant Flow with Outdoor Heat Recovery
- Fan Coils with Dedicated Outdoor Air System

A separate system was designed for the server room and an automatic ventilation system was proposed for the ambulance garage. In addition, several energy saving strategies were suggested for architecture design such as a skylight for using the natural light during day, operational air intakes for natural ventilation, and rainwater harvesting tank.

ASHRAE Standard 62.1 was referenced when making determinations for proper ventilation rate, in addition to the air filtration system design. Contrary to the recommendation of MERV 11 filters, the team recommends that MERV 14 filters be used. Their increase in efficiency for small particulate matter, less than 2.5 micron, filtration at a similar cost to MERV 11 filters makes them the optimal choice. With the flexibility granted by each of the three systems considered, the building was divided into 31 zones. It was done in such a way that would increase occupant control and consequently comfort, while maintaining optimal efficiency. ASHRAE Standard 55 was consulted for the determining the necessary parameters for occupant comfort and their acceptable levels in unity. All three systems were designed with the goal of providing an 80% occupant acceptance rate in comfort.

When designing each of the three systems, special considerations were taken to minimize negative impacts on the environment. The group A1 refrigerant, R410-A, was chosen for it's low level of toxicity, flammability, and non-existent release of chlorofluorocarbons. Energy usage, water usage, and carbon emissions were considered. Several measures have been taken to decrease energy usage, such as the inclusion of heat recovery in each of the systems.

Energy analyses were conducted for all four systems, including the baseline, to determine the energy consumption of each system. Moreover, the installation and maintenance cost were calculated and a cost analysis was performed for a 50 year period based on the present value of investment for each system. A decision matrix was developed and each system was scored based on the following categories:

- Energy Efficiency
- Controllability
- Health and Safety
- Initial Cost
- Operating Cost
- Occupant Comfort
- Reliability/Flexibility
- Sustainability
- Environmental Impact
- Maintainability

The team recommends a Hybrid Variable Refrigerant Flow with Outdoor Heat Recovery unit for this office building. The system is safe, reliable and efficient that can maintain the building at optimum conditions at all times.

In addition to the main building a server room split system with DOAS system is designed to meet the cooling loads. The system also generates potable hot water. An automatic ventilation system operates fans and mechanical louvers in the garage to ensure the toxic gases are removed from the building.

2.1 - Building Description

Due to an increasing demand for office spaces, a government official in Beijing, China is funding a two-story building where mostly government specific operations, such as council meetings, medical emergency support and administrative operations will be conducted.

The building will consist of private offices, cubicles and meeting rooms for staff members.

Additionally, a small room will serve as the command/control center for medical emergency vehicles. In order to accommodate the emergency vehicles operation inside the garage, a special exhaust system will be installed. The system is required to meet the ventilation demand for the ambulance exhaust established by ambulance performance tests.

The building will accommodate the command center operators and ambulance workers in special suites. The two ambulance crew members will be able to rest in specially designed sleeping areas. During weekdays, the building is expected to operate from 6:00AM – 6:00PM and the command center along with the ambulance crew will be present 24/7.

2.2 - Owner's Requirements

The following are the main requirements of the owner:

- Comply with and exceed energy conservation requirements as stated in ASHRAE 189.1.
- The building to meet allowable budget of USD $200/ft^2.
- The most efficient building that has the best lifecycle cost, considering the climate and the owner's budget.
- Operational and maintainable building.
  - Easy serviceability, maintainability, and secure.
  - Low utility costs.
  - Low maintenance cost of installed building systems.
- Excellent indoor air quality which meets ASHRAE Standards 62.1 and 55.
- Sustainable design that includes energy efficiency, health and safety, occupant comfort, functionality, flexibility, longevity, serviceability and maintainability.

Other requirements to meet include:

- Vehicle exhaust system for small garage where ambulance is parked and performance test are taken place on regular bases.
- Low noise from HVAC systems.
- Acoustic system that provides minimum sound transmission from general office work areas to adjacent rooms.
- Independant HVAC system for server room.

2.3 - Building Envelope

The building envelope required for the building was assumed based on ASHRAE 90.1 Building Envelope Requirements specified for Zone 4A where building is located. The following table shows the assumed U-factors.

Elements	Construction	Proposed
Roof Construction	R-30 Roof	U-0.032
Skylight	lindal vinyl Low E Argon Window, SHGC=0.37	U-0.310
Wall Construction	8" CMU Wall	U-0.069
Window	Double Thermal Break Tinted, SHGC=0.57	U-0.550
Door Construction	Double Thermal Break Tinted	U-0.550
Spandrel Wall	bronze-tinted R13	U-0.077

Table 2.1 : Building Envelope

2.4 - Lighting

Lighting power density (LPD) assumed was based on ASHRAE Standard 90.1-2013 for a range of space types. Typical office space LPD are as follows:

Enclosed Office: 1.11 W/ft^2

Open Plan Office: 0.98 W/ft^2

2.5 - Utility Costs

The utility cost provided by the owner will be used to calculate the life cycle cost of the building.

Electricity		
Peak Consumption Rate	0.1614	$/kWh
Peak Demand Cost	9.75	$/kWh
All other times	0.085	$/kWh
Inflation Rate	3.50%	
Other		
Natural Gas	7.91	$/Mcf
Annual Increase	3.00	%
Water	0.02	$/cu ft
Sewer	0.003	$/gal
Annual Increase	2.50	%

Table 2.2 : Utility Costs

2.6 - Weather Data

Outdoor design temperatures are from ASHRAE Fundamentals Handbook. The design temperatures used are based on 1% cooling and 99% heating design where exceptionally harsh conditions are not expected.

- Cooling Dry Bulb Temperature: 91.8°F
- Heating Dry Bulb Temperature: 15.6°F

2.7 - Indoor Design Conditions

The following indoor temperatures and relative humidities were assumed based on the owner's requirements :

- Summer Dry Bulb: 73.4°F 55% Relative Humidity
- Winter Dry Bulb: 70.0°F 55% Relative Humidity

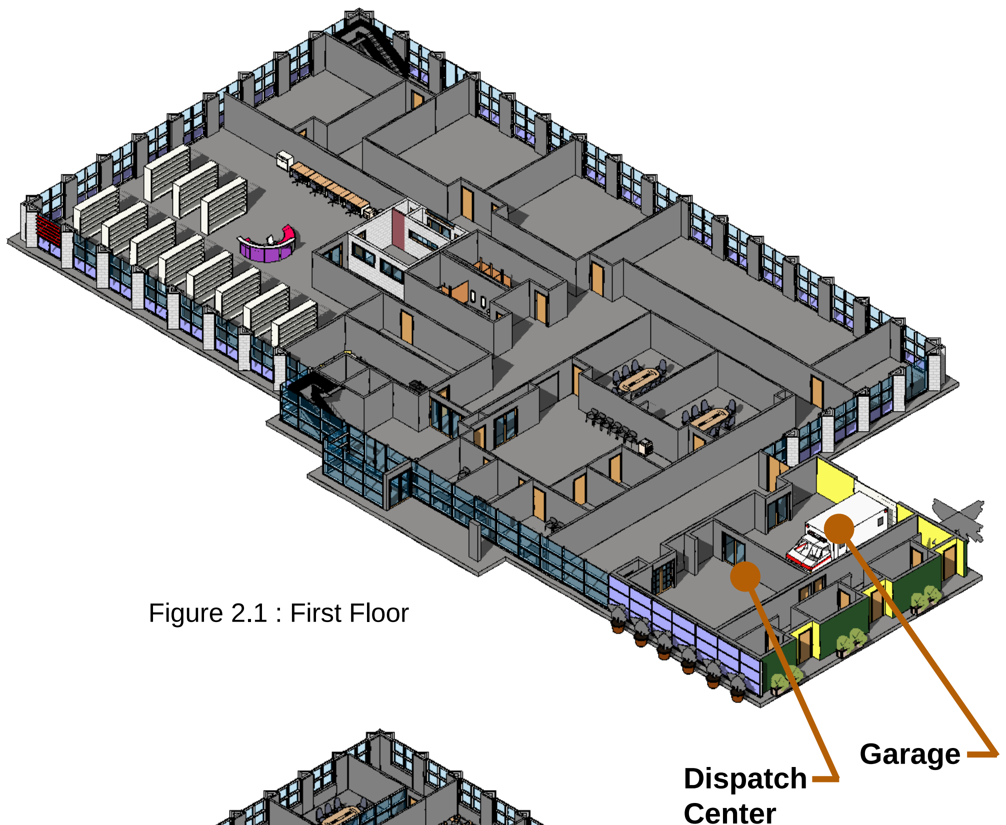


Figure 2.1 : First Floor

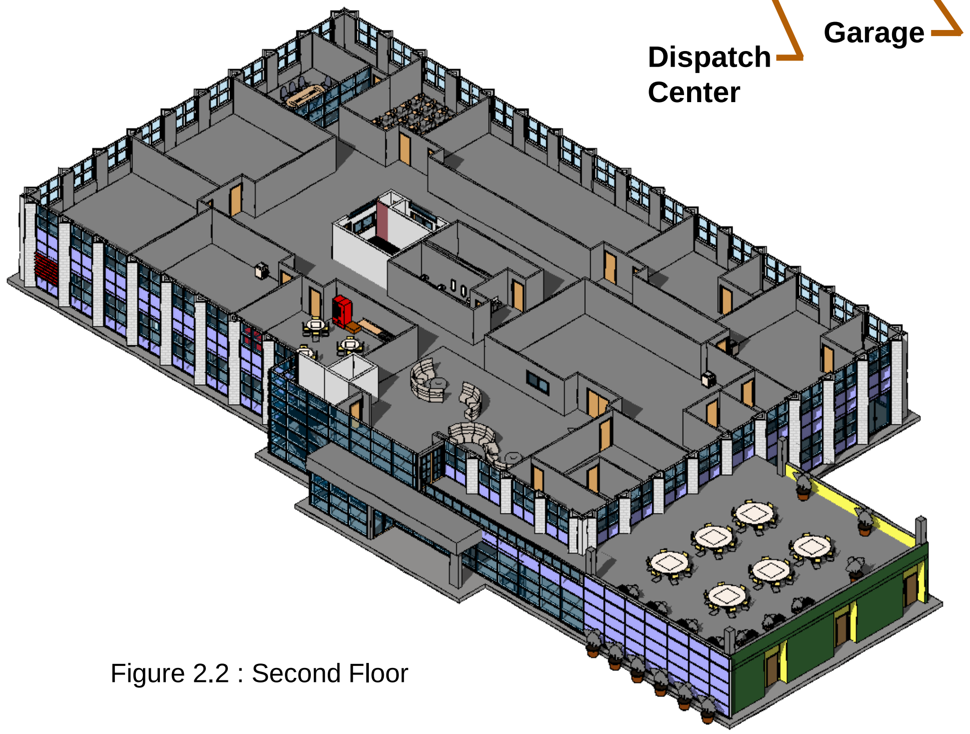


Figure 2.2 : Second Floor

3.1 - Weather Data

The first step in the design process involved obtaining weather data for the region. An analysis of the weather data was required in order to provide a preliminary assessment of possible HVAC systems. Additionally, weather information would provide important insights into systems that would best meet the building's demand at various hours of operation. The most important data for the location provided includes wind speed, dry bulb temperatures, relative humidity, air quality and rain precipitation.

3.2 - Wind Speed

Wind speed data was analyzed to decide if wind turbine technology could be used to save energy. Currently, commercial wind turbines do not generate any electricity when wind speed is below 7 mph. Based on the "csv" file provided, there are only 440 hours or approximately 18 days in a year when the wind speed is above 7 mph. Considering that only 5% of a year wind energy can be used, design team does not recommend using wind turbine for the building since the initial cost of the installation of wind turbine will be higher than its savings.

3.3 - Dry Bulb Temperatures

The IWEC2 (International Weather for Energy Calculations) weather file provided by ASHRAE was used to plot a dry bulb temperature graph. The "csv" file provided important information, including hourly dry bulb temperatures throughout the year. The monthly dry bulb temperature graph indicates the range of temperatures and assisted with the system selection process. In addition, it provided useful information such as maximum, minimum, and median; first quartile in blue and third quartile temperatures in green.The box on the vertical line shows the temperatures that happen more often during a month. Since the building experiences high and extremely low temperatures, it would require an HVAC system that could provide simultaneous heating and cooling.

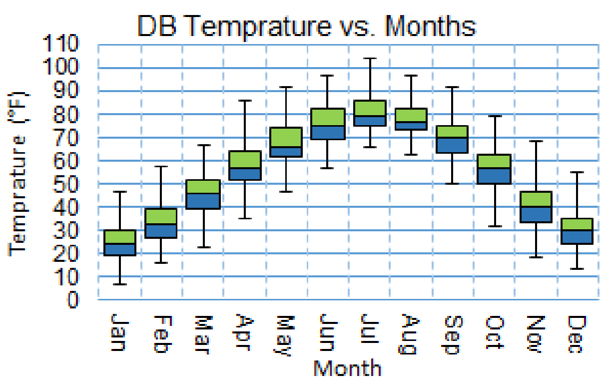


Figure 3.1 : Monthly DB Temperatures

3.4 - Relative Humidity

The frequency of relative humidity graph as shown in Figure 3.2 indicates the range of humidity ratios and how often those ratios occur in a year. The data was derived from the IWEC2 file provided and indicates that for ultimate occupancy comfort, both humidifying and dehumidifying are required for occupied spaces.

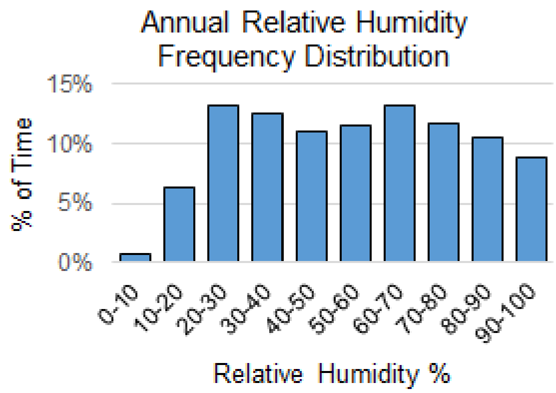


Figure 3.2 : Relative Humidity Frequency Distribution

3.5 - Air Quality

The air quality is an important data in regards to the weather in Beijing. Based on air quality, the air filter type and other air purifying methods were selected. These methods will provide the best occupant comfort and productivity.

As shown in following graph, the air pollution in Beijing is mainly due to PM2.5 and PM10. PM2.5 is particulate matter that is smaller than 2.5 micron. These small particles pose a greater risk to resident's health because these particles can pass through the lungs and can have long term and short term side effects.The short terms effects include eye, nose, throat and lung irritation, coughing, sneezing, worsened asthma, and shortness of breath. The long term health effects include lung cancer and heart disease. Sample data for gases on a certain day is provided below. The figure indicates that PM2.5 and PM10 are of the most concern.

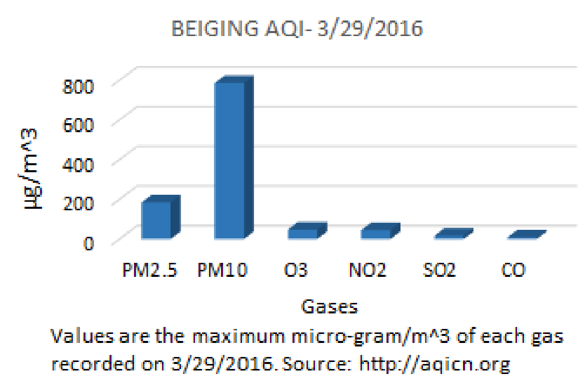


Figure 3.3 : Dangerous gases present on a certain day in Beijing

The graph below shows that approximately half of the year, or 130 days, the air in Beijing is very dangerous to breath.

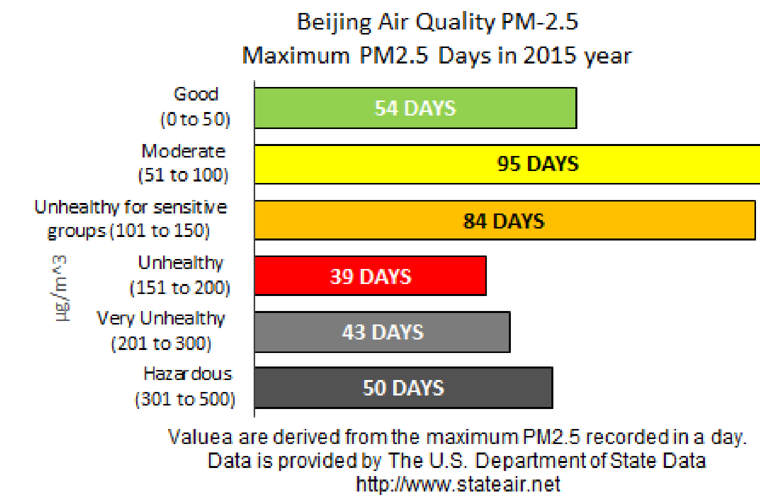


Figure 3.4 : PM2.5 Days in year 2015

3.6 - Rain Precipitation

The following graph shows the amount of rain precipitation in beijing. Based on the data presented, the design team recommends that a water storage tank be used in the building in order to save water.

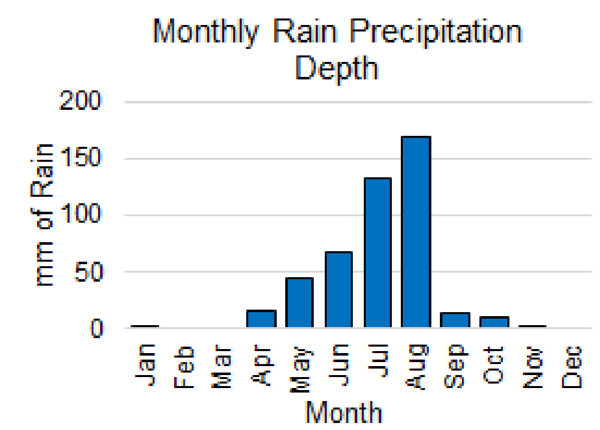


Figure 3.5 : Monthly Rain Precipitation in Beijing

4.0 - Energy Savings
As recommended by ASHRAE Advanced Energy Design Guide for Small Office Buildings, different methods of energy savings were considered. The psychrometric chart in Appendix D was used to guide the design team in the selection of the best energy saving methods.

4.1 - Natural Ventilation
1 The design team recommends implementing a natural ventilation system utilizing the mechanical rooms. When the air quality meets the natural ventilation requirements the air can be used within the building. The ventilation system will have motorized blinds that can adjust the amount of outside air entering the building. Air filters will be located within the ventilation system to stop harmful and undesired contaminants.
The mechanical rooms shall have perforated floors to allow the ventilation air and light to reach both floors of the building. It is expected that the South and East wall of the building will receive the most sunlight.
Additionally, the air in these locations will have a higher temperature and lower density. Consequently, the hot air will rise and exit the building which will complete the natural ventilation process. Additional vertical and horizontal operable windows located on the mechanical room wall will allow for greater light and air penetration.

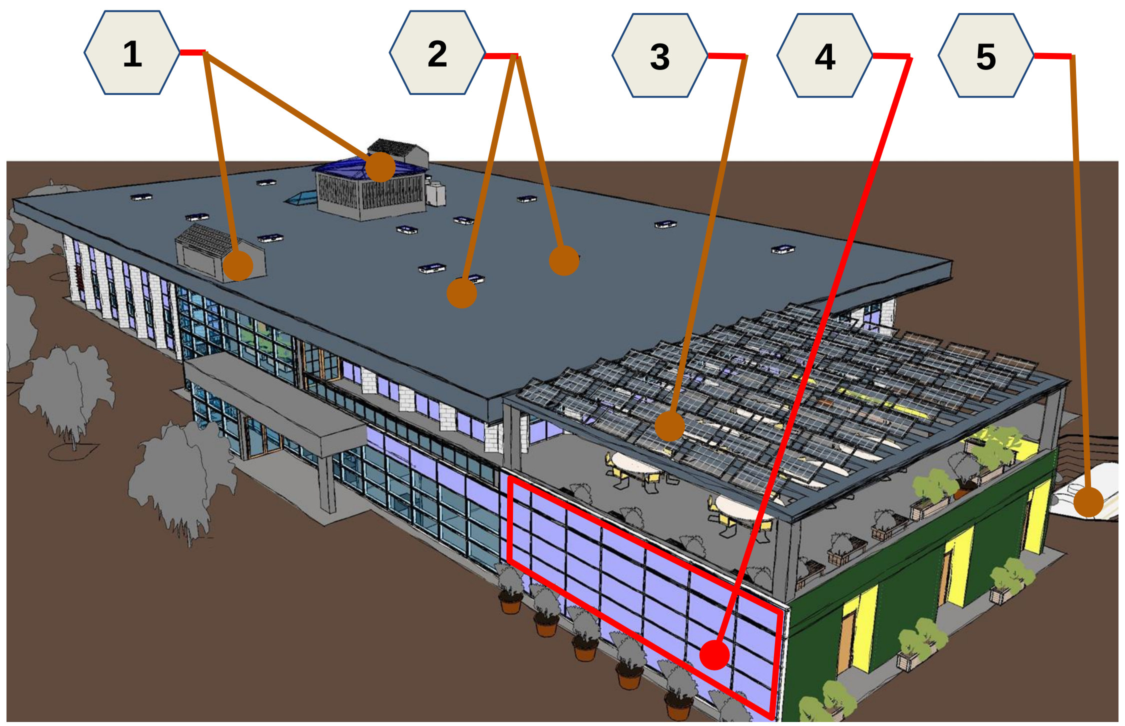


Figure 4.1 : Building Overview

4.2 - Skylights
2 Skylights can be utilized during the day to bring in natural light and reduce the need for artificial lighting. Following the guidelines specified by 90.1 Section 5.2.1, up to 5% of the total roof surface area can be utilized for skylights. Additionally, the skylight shall have a glazing material or diffuser that has a haze value greater than 90%.

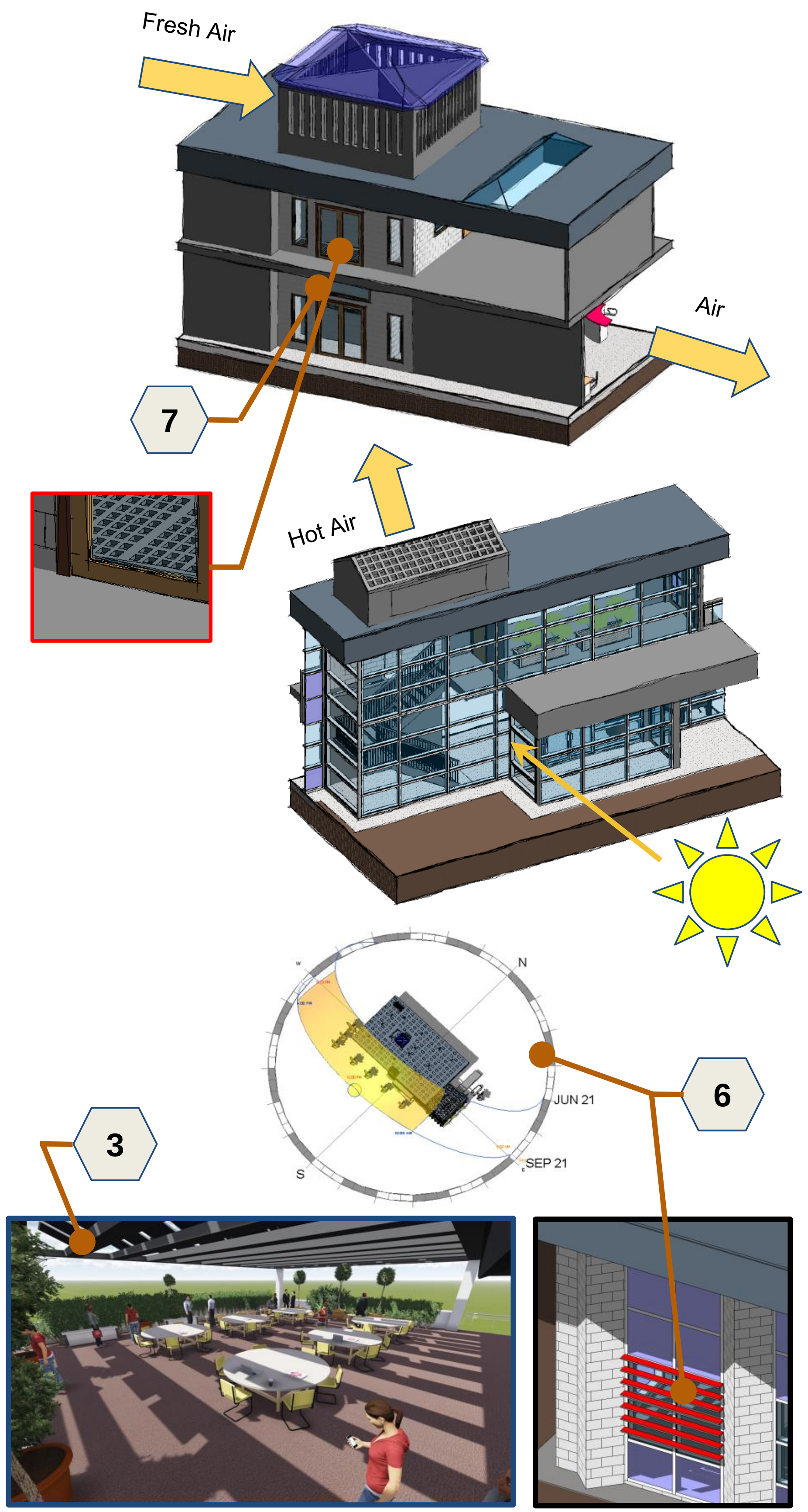
4.3 - Solar Panels
3 Using Solar panels over the garage and dispatch center rooms can reduce solar heat gain through the roof, provide 5% of energy use of the building, and create a nice environment for employees to enjoy the weather for almost half of the year when the outside air is acceptable to breath..
Using System Advisor Model (SAM), a solar panel with a capacity of 11 kW is needed. Using SAM the optimum angle relative to the building is found to be 42 degrees and a total module area of 580 square feet required. The system is able to produce 16,000 kWh of energy per year.

4.4 - Solar Water Heaters
4 In addition to water heating provided in the building, solar water heaters can be used to provide domestic hot water and save energy.

4.5 - Water Storage
5 To take advantage of high rainfall averages in Beijing throughout the year, a rainwater harvest tank will be placed underground. This tank will collect and store rainwater that will be used to water vegetation and assist in the restrooms, where a high water demand is expected. In addition, an infiltration pit will be implemented and utilized to filter rainwater and refill underground aquifers.

4.6 - Operable Horizontal Louvers
6 This passive solar energy technique can be used to heat the building during cold weathers while reducing envelope heat gain during summer. Using a summer sun path analysis, It was observed that south wall of the first floor is the best location to install the louvers.

4.7 - Natural Lighting
7 Perforated floor in the second floor mechanical room, transparent doors, and windows on the walls or above the doors can provide enough natural lighting to meet the required capacity and minimize the lighting load in the building.



ASHRAE MANDATORY REQUIREMENTS AND LOAD CALCULATIONS

5.1 - ASHRAE 90.1 - Section 4.2

Standard 4.2.1.1 requires that all new buildings comply with either the provisions in section 5, 6, 7, 8, 9, 10 or 11. These requirements will be discussed later. Section 4.2 also specifies requirements for construction, documentation and inspection which are beyond the scope of the project.

5.2 - ASHRAE 90.1 - Section 5.4

The mandatory provisions set forth by section 5.4 are as follows:

- All insulation required must comply with section 5.8
- Fenestration and door performance procedures must follow section 5.8.2
- Values for air leakage for fenestration and doors as provided in section 5.4.3.2 must be accounted for
- The entire building must be designed with a continuous air barrier to resist positive or negative pressure from wind, stack effect and mechanical ventilation
- Vestibules that separate the building entrance from the outside air must have a self-closing device

5.3 - ASHRAE 90.1 - Section 6

The mandatory provisions set forth by section 6 are as follows:

- All equipment specified in this section must have minimum performance ratings when tested in specified test conditions.
- Equipment utilized in this project that must comply with these minimum requirements include air conditioners, condensing units, heat pump, water-chilled packages, boilers, and heat transfer equipment.
- Load calculations for heating and cooling systems must comply with ASHRAE Standard 183.
- The operation of the heating and cooling system for each zone must be controlled by a thermostatic control system with a deadband of at least 5 degrees F.
  - This project will utilize a smart thermostat that will use algorithms to determine the comfort level required by the occupants of the room.
- Requirements for ventilation controls
- Enclosed parking garage ventilation must automatically detect contamination levels and modulate fan to 50% of design capacity if contamination levels are low
- Section 6.5.1.1 specifies that air economizers must be able to modulate dampers to provide 100% outdoor air for cooling when air quality is acceptable.
- Simultaneous heating and cooling systems shall prevent reheating or recooling

5.4 - ASHRAE 90.1 - Section 7.4

The mandatory provisions set forth by section 7.4 are as follows:

- Service hot water system shall comply with manufacturer's published data and accepted engineering practices
- Minimum equipment efficiencies for hot water systems is provided

5.5 - ASHRAE 90.1 - Section 8.4

The mandatory provisions set forth by section 8.4 are as follows:

- Minimum requirements for the electrical power of the building is provided in this section. These must be followed to ensure proper power to the building and mechanical systems

5.6 - ASHRAE 90.1 - Section 9.4

The mandatory provisions set forth by section 9.4 are as follows:

- Lighting controls for a building shall comply with requirements in this section
- Automatic control devices shall be installed within the rooms to automatically lower or turn off the lights when a room is not occupied for more than 30 minutes with the exception of restrooms, hallways and entrances
- Table 9.4.3B specifies power allowances for building exteriors in each zone

5.7 - ASHRAE 90.1 - Section 10.4

The mandatory provisions set forth by section 10.4 are as follows:

- Minimum requirements for other equipment such as electric motors, service water pressure booster and elevators.

5.8 - ASHRAE 55- Section 5

- ASHRAE Standard 55 details the factors that contribute to an acceptable thermal comfort of an occupied space. The factors discussed include, metabolic rate, clothing insulation, air temperature, radiant temperature, speed, and humidity.
- An acceptable range for environmental thermal conditions is provided to ensure that an 80% acceptance rate of the occupants is achieved.

5.9 - ASHRAE 62.1

Standard 62.1 specifies the requirements for the ventilation equipment and systems. This includes requirements for duct location and controls, resistance to mold growth and erosion and buildings with attached garages. Classification of air and filtration devices required for PM2.5 are specified. Table 6.2.2.1 specifies the minimum ventilation rates required in different zones. The load calculation software utilizes the requirements to determine the ventilation rate in each zone. Exhaust ventilation from each air class must also be handled properly as specified by 6.5.

5.10 - ASHRAE 15

ASHRAE Standard 15 outlines the requirements for safe operation and handling of refrigerant within the system. In order to ensure occupant safety, the inclusion of refrigerant leak detectors is needed. Additionally, special measures must be taken when maintenance is being performed and and individuals are being exposed to the refrigerant.

5.11 - Load Calculations

Trane Trace 700 is utilized to determine the heating and cooling loads of the system. In addition the energy consumption of the building and HVAC system is also determined utilizing Trace. Each room is modeled according to the standards discussed in this section and in section 2.0. Each room is given a type and within each type a typical loading caused by the occupants as well as equipment is selected. Trace provides the loads and concentration for the occupants whereas the equipment loads had to be entered manually. These loads were determined by following industry standard practices or by calculations depending on the amount of electrical energy consumed. The heating and cooling load as well as ventilation requirements was determined by selecting the respective air-side system and performing the load calculation. Once the equipment was selected an energy analysis was also conducted using Trace. Some manufacturers had Trace file libraries that contained equipment efficiencies and performance characteristics. A heating and cooling plant was created for each system and an energy analysis was conducted. The energy analysis provided the energy consumption during peak and off peak hours as well as the energy demand. For certain systems the water and natural gas consumption was also provided. The heating and cooling loads provided are for the main coil loads. The results of the calculations is summarized below.

System	Heating	Cooling	Energy Usage (kW/year)	Energy Demand (kW)	Water Usage	Gas Usage (Mcf)
Baseline	-750	110 ton				
VRF with	-400	60 ton	753,582	104	0	0
Fan Coil Units	-650	70 ton	1,669,223	113	0	8738
HVRF	-400	60 ton	1,926,956	129	0	0

Table 5.1 : Calculated Load Data

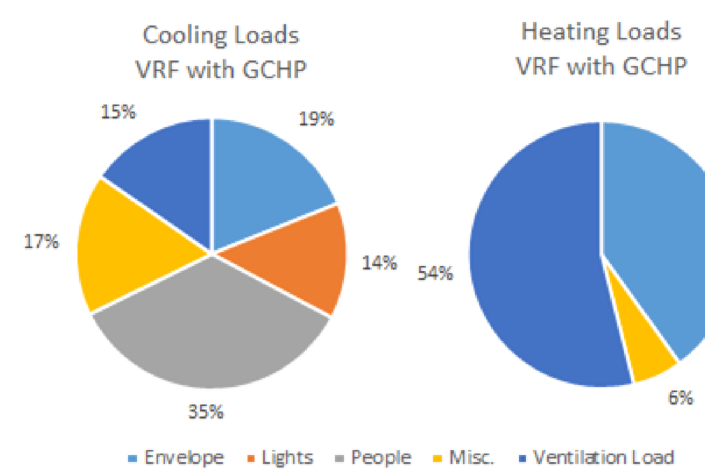


Figure 5.2 : Load Pie Chart

HVAC SYSTEMS

The following HVAC systems were considered as possible options for the system selection process. Each system was considered keeping in mind the requirements set by the owner and the team as well as ASHRAE recommendations.

System 1

VARIABLE REFRIGERANT FLOW (VRF) with Ground Coupled Heat Pump (GCHP)

A Variable Refrigerant Flow (VRF) with Ground Coupled Heat Pump (GCHP) system is considered as a possible HVAC system due to its high efficiency, flexibility and high comfort level. This 2-pipe system relies on the reverse Rankine vapor compression cycle to accomplish the desired outcome. A heat recovery ventilator is also utilized to supply the rooms with new air.

Advantages:

- High year-round COP of heat pumps
- Refrigerant and water side heat recovery
- Flexible design
- Minimize outside air with small ducting required
- Water not required for operation
- No defrost cycle required
- Minimize energy requirement
- High comfort level by increasing temperature control
- Very low indoor unit noise
- Simple mechanical installation of indoor units (2 pipe system)
- Disadvantages
- High initial cost
- Large quantity of fans indoor
- Refrigerant in occupied spaces
- More complex controls required
- Requires refrigerant leak detectors in all zones

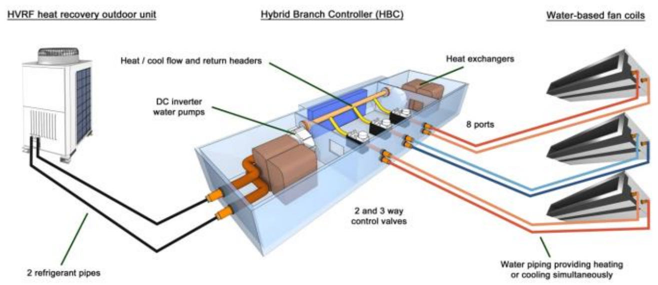
System 2

HYBRID VARIABLE REFRIGERANT FLOW (HVRF) WITH Outdoor Air Cooled Heat Recovery Unit

A relatively new HVAC system known as Hybrid Variable Refrigerant Flow (HVRF) system is also selected as a possible option. HVRF combines the best elements of VRF technology and chiller system. The HVRF utilizes an outdoor heat recovery air-cooled unit and uses refrigerant between the outdoor unit and branch controller, and water between the branch controller and indoor units. The same heat recovery ventilator as system 1 will be utilized in this design.

Advantages:

- Water side heat recovery
- Only water in occupied spaces
- Flexible design
- Minimize outside air with small ducting required
- Closed loop water system (minimize water required)
- Minimize energy requirement
- High comfort level by increasing temperature control
- Very low indoor unit noise
- Simple mechanical installation of indoor units (2 pipe system)
- Can use plastic water pipes
- More stable water temperatures within indoor units requiring no insulation
- Disadvantages
- High initial cost
- Large quantity of fans indoor
- More complex controls required
- Heat recovery not as efficient as a standard VRF units



System 3

HYDRONIC FOUR PIPE FAN COIL SYSTEM WITH A DEDICATED OUTDOOR AIR SYSTEM

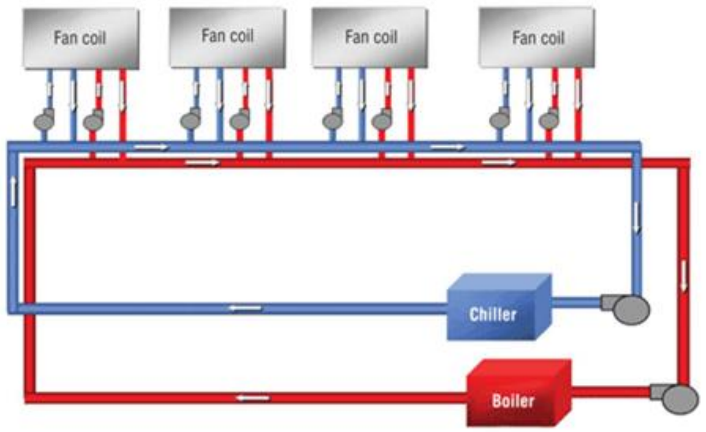
A hydronic fan coil system where each zone has separate fan coil and all fan coil units are equipped with bouh heating and cooling coils. This system employs a air cooled oil free chiller and a modular condensing boiler for heating and cooling and a dedicated outdoor air system to provide the ventilation the DOAS is equipped with a cooling coil to pre cool and dehumidify the outdoor air it also has a enthalpy wheel and enthalpy sensor to provide some energy recovery and free cooling.

Advantages:

- Simultaneous heating and cooling
- Each zone can operate independently
- Only water in occupied spaces
- Design simplicity
- Minimize outside air
- Small ducting for outside air
- Good Maintainability

Disadvantages

- Large quantity of piping
- Limited heat recovery
- Large number of fans
- More difficult noise control



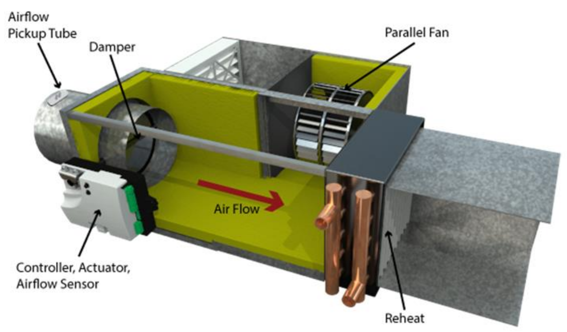
Baseline

BASELINE- PACKAGED RTU VAV WITH REHEATING COIL, DX AND HOT WATER

A Variable Air volume system that controls the quality of the air in each zone by regulating the flow of supply air. This system has a rooftop package unit that provides the cold air and it equipped with a direct expansion cooling coil and each VAV unit has a heating coil that uses hot water provided by a boiler

Advantages:

- Simple design.
- One Air Handling Unit can serve multiple zones.
- Deccent noise control.
- Large central plant equipments is not needed.
- Lower capital cost
- Disadvantages
- Limited control of air quality.
- Not efficient to provide simultaneous heating and cooling.
- Large space needed for ductwork.



7.1 System Description

This system operates by utilizing the Earth as a heat source or heat sink depending on the demands of the building. The main components of this system are as follows: vertical ground pipe network, water source heat pump, branch controller, indoor units, and a ventilation system.

The ground pipe network is designed to either dissipate energy into the ground during cooling or extract energy during heating. Coils of High Density Polyethylene (HDPE) pipes are placed vertically in the ground to accomplish this task. The WSHP utilizes a water-to-refrigerant heat exchanger to create a mixture of liquid and gas refrigerant. This mixture is sent through a single pipe to the branch controller (BC), which is the key behind the 2-pipe VRF system. The BC contains a liquid and gas separator and linear expansion valves (LEV). The LEVs are used to send either the liquid or gas to the indoor units depending on if cooling or heating is needed. The BC can also send refrigerant from one indoor unit to another.There are several varieties of indoor units, but they all contain a fan, coil, and filter. The fan recirculates the air within the room through the filter and coil. The refrigerant within the coil either cools or heats the air. For cooling, the condensation is also collected and pumped out of the indoor units with a small DC pump. The refrigerant is then sent back to the branch controller. In order to comply with ASHRAE 62.1 requirements a ventilation system is included. An energy recovery ventilator (ERV) along with an auxiliary filter box and UV light are used to supply the required ventilation air.

7.1.1 Ground Pipe Network

The ground pipe network (GPN) must be designed in such a way such that energy can be dissipated to the ground during the cooling cycle and absorbed from the ground during the heating cycle. The calculations below are based off of 2015 ASHRAE Handbook - HVAC Applications Chapter 34 Section 3.2. The GPN bores used for this system is a 5” bore diameter, ¾” HDPE pipe diameter. From the HVAC Applications handbook, the HDPE pipe location within the bore is chosen to be B as it gives a conservative answer, with this information and Table 6 from the handbook, the grout conductivity ,R_b =0.45 Btu/h-ft-F. The loop length for cooling is calculated from equation 4 found in Section 3.2 of Chapter 34 from the handbook.

The building block cooling, q_{lc} , and heating, q_{lh} , loads were determined using Trace 700. The energy efficiency ratio (EER) and coefficient of performance (COP) were determined based on the selected heat pump system which will be discussed in Section 7.1.2

All other variables were determined using 2015 ASHRAE Handbook - HVAC Applications Chapter 34 Figure 16, Table 8, and corresponding equations. Table 15 of the handbook recommends a 200 ft/ton for a vertical bore. The calculated value of 260 ft/ton can be considered relatively accurate.

Another issue to consider in the design of a GPN is the water freezing within the HDPE pipes. ASHRAE recommends that water be mixed with Antifreeze in regions where significant heating is needed.

Since Beijing has very cold winter seasons, an antifreeze solution must be selected. Table 22 provides possible options. Glycol is chosen as the solution since the health, environmental, and fire risk is minimal or not a potential problem. Glycol does have a high installation and energy cost, but these costs must be undertaken to ensure the safety and reliability of the HVAC system.

In Chapter 34, Table 10 of the handbook, ASHRAE provides the total price of installing vertical GPN in a four-story, 40,000 sq ft office building. A suggestion of $10.57 per foot or $2114 per ton is made. The cost of the GPN will be calculated utilizing the $10.57 per foot method as it results in a more conservative answer by providing a higher initial cost. For life cycle analysis, the cost of the GPN will be set to $178,000. To ensure that the pipe network will last the desired 50 years, ASHRAE recommends spacing the ground bores a minimum of 20 feet. This will ensure that adjacent bores will not cause any interference.

A water pump is also necessary for the operation of the GCHP. The HVAC Applications handbook provides a grading system for the pump based off the head of the pump required. A survey by Caneta Research found that the range of pumping power was from 0.04 to 0.21 hp/ton. Assuming the worst case scenario, this means a 15 HP pump will also need to be purchased for this system. To ensure the reliability of the pumping system, two pumps will be operated in parallel at half capacity using variable frequency drive (VFD) controls. Two pumps with VFD controls will cost $9000 total.

Table 22 Suitability of Selected GCHP Antifreeze Solutions

Category	Methanol	Ethanol	Propylene Glycol	Potassium Acetate	CMA	Urea
Life-cycle cost	***	***	**1	**1	**1	***
Corrosion	**2	**3	***	**	**4	*5
Leakage	***	**6	**6	*7	*8	*9
Health risk	*10,11	**10,12	***10	***10	***10	***10
Fire risk	*13	*13	***14	***	***	***
Environment risk	**15	**15	***	**15	**15	***
Future-use risk	*16	**17	***	**18	**19	**19

Key: * Potential problems, caution in use required
** Minor potential for problems
*** Little or no potential for problems

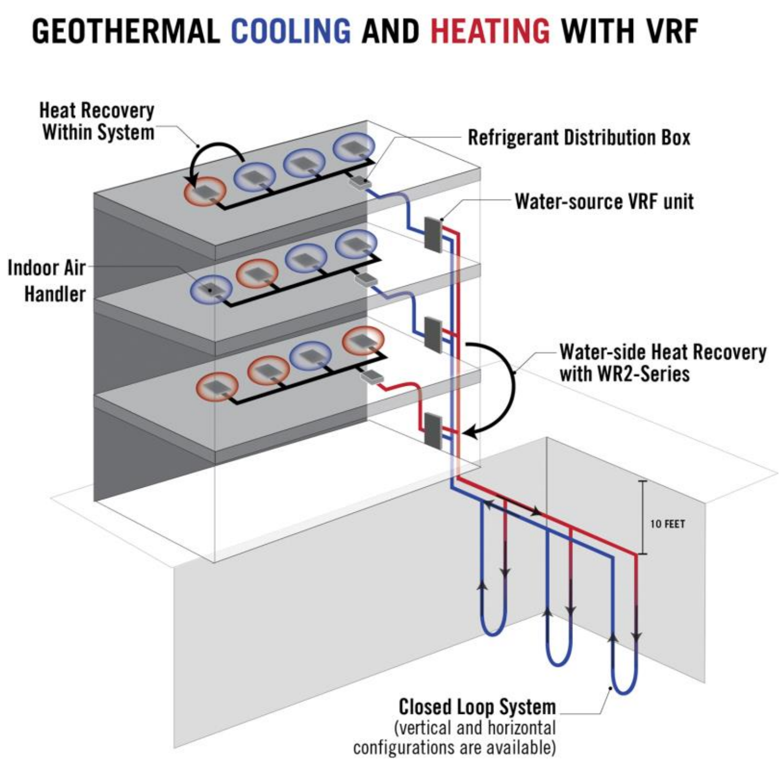


Figure 7.1 : Vertical GPN
Source: Encyclopedia of Alternative Energy

7.1.2 Water Source Heat Pump (WSHP)

A total of four 2-pipe water source heat pumps are selected for this system; two for each floor of the building. Doing so will make each unit smaller and the additional costs will be balanced by the higher system efficiency and energy recovery as discussed in Section 10.1.

The water from the GPN enters the water-to-refrigerant heat exchanger where the transfer of energy between the water and refrigerant occurs. A mixture of liquid and vapor refrigerant is sent to the branch controller where it can be distributed to the indoor units.

Table 7.1 : WSHP (Source: Mitsubishi Engineering Catalog)	
Cooling/Heating Capacity	192600 / 216000 (Btu/hr)
EER/COP	15.51/5.01
Refrigerant	R410A
Operating Inlet Water Range /Flowrate	50F - 113 F / 25.4 GPM
Cost/Lifespan	$48,000 / 20 years

Figure 7.2 : 2 -Pipe WSHP Unit
Source: Mitsubishi Application Guide

7.1.3 Branch Controller (BC)

Each WSHP will be connected to a single branch controller. The BC unit has a mechanism that separates the liquid and vapor refrigerant sent from the WSHP.

Table 7.2 : Branch Controller (Source: Mitsubishi Engineering Catalog)	
Capacity: Per Branch/Total	125,000 / 360,000 (Btu/hr)
Number of Branches	13
Cost/Lifespan	$3,500 / 15 years

Once the liquid and vapor are separated, a series of valves can send either the liquid or vapor to each of the up to 13 connected indoor units. The system can also send the refrigerant from one indoor unit to another. This allows for heat recovery and will be discussed in Section 10.1.

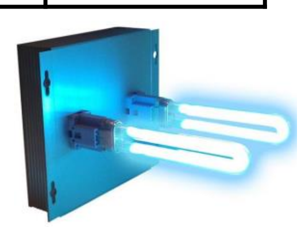


Figure 7.4 : Ultraviolet Filter
Source: Ultravation Catalog

7.1.4 Ultraviolet Filtration

An ultraviolet (UV) light source will be incorporated in the incoming and exiting air streams. The light will utilize wavelength of 265 nm, which is ideal for degrading organic material and inactivating microorganisms. This will ensure that any bacteria entering the airstream will be incapacitated before going through the filters. The light will also help reduce mold growth in the filters and Lossnay Core.

7.1.5 Indoor Units

Each zone must have a minimum of one indoor unit. For small offices a ceiling-recessed 4 way cassette style indoor unit is utilized. For larger offices and meeting areas a ceiling-concealed ducted unit is better suited for the application. Each zone is assigned an indoor unit based off the cooling and heating load, whichever is greater. Two sample indoor units as shown below. The indoor units have the allowable static head for the installation of a high efficiency MERV 10 filter.

Figure 7.5 : Ceiling-Recessed Cassette
Source: Mitsubishi Application Guide

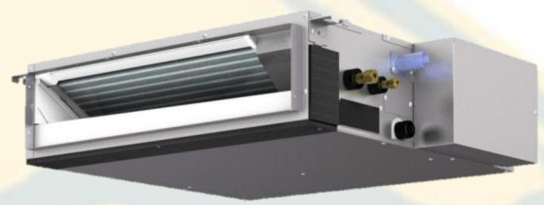


Figure 7.6 : Ceiling-Concealed Ducted
Source: Mitsubishi Application Guide

Table 7.3 : Indoor Unit (Source: Mitsubishi Engineering Catalog)		
Criteria	4-Way Cassette	Ceiling-Concealed Ducted
Cooling/Heating (Btu/hr)	12,000 / 13,500	30,000 / 34,000
Max Airflow	390 CFM	883 CFM
Max Sound Level	39 dB	39 dB
Cost / Lifespan	$1,800 / 15 years	$3,200 / 15 years

7.1.6 Ventilation

In order to meet the requirements set by ASHRAE 62.1, a ventilation system must be included. A Mitsubishi Lossnay system is utilized because it can provide the necessary ventilation as well as transfer sensible and latent heat in order to reduce the load caused by ventilation. This system utilizes fans to draw outside air and return air from the zones.

The two airstreams are passed through a the Lossnay cores where water molecules can pass through and energy can be transferred. The cores are made from a specially treated paper as shown and arranged in an alternating pattern. The Lossnay core can be cleaned but current ongoing test have shown a lifespan of 7 years without any loss in efficiency.

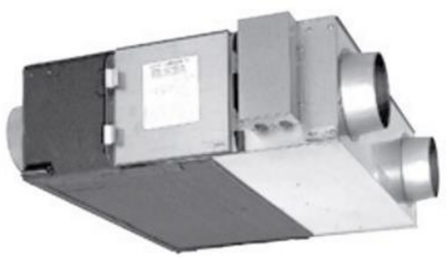


Figure 7.7 : Lossnay Ventilator
Source: Mitsubishi Application Guide

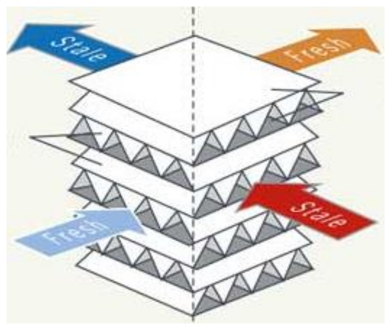


Figure 7.8 : Lossnay Core
Source: The Heat Pump Shop

Table 7.4: Lossnay Ventilator (Source: Mitsubishi Engineering Catalog)	
Max Airflow	1200 cfm
Enthalpy Recovery Efficiency	Heating- 62% Cooling - 44%
Temperature Recovery	69%
Cost / Lifespan	$5,000 / 7 years

7.1.7 Prefiltering

To maximize the health of the occupants inside, a prefilter box will be utilized along with the Lossnay system. A MERV 14 filter will be used in the filter box to remove smoke and other contaminants. The Lossnay fans cannot develop the needed static head to overcome the filter box 1 in WG. Therefore a variable speed fan with a flow capacity of 1200 cfm will be used to provide the necessary static head. This prefiltering will remove majority of the contaminants. The filters will need to be cleaned or replaced every 3 months due to the high concentration of pollutants in the outside air. The filters must comply with ASHRAE 52.1 specifications to ensure the filter has the proper dust arrest and holding capacity.

Figure 7.9 : Filter Box and Fan
Source: Johnstone Supply Catalog

8.1 System Description

A HVRF system operates in a similar manner to a standard VRF unit, but with several key differences. Water is used within the indoor units rather than R410 refrigerant. This makes the system very safe while still providing all the benefits of a VRF system. Leak detection equipment is also not required with a HVRF system. The manufacturer suggests that this type of system utilize air-cooled outdoor heat recovery units. The outdoor units utilize pressurized refrigerant which helps the system operate at very low temperatures.. The condenser is also very efficient since its task is to compress and reject heat during cooling mode and collect heat and compress during heating mode. The units will be connected in series to provide the total cooling required for the system. The outdoor units provide the cool refrigerant liquid or hot refrigerant gas to the hybrid branch controllers (HBC). The HBC uses the refrigerant to heat or cool water. The water is diverted to different zones depending on if heating or cooling is required. Plastic water pipes are used to transport the water from the indoor units to the HBC. The pipes are more affordable than copper pipes and are better insulators. This means the water released from the HBC will relatively be the same temperature when it reaches the indoor units. The indoor units contain coils, fans, filters, and they operate in a similar manner to a standard VRF. Water can be transferred between systems in heating and cooling zones via the HBC. A ventilation system with prefiltering and UV light filtering is also added to ensure the required minimum ventilation is achieved. The ventilation is independent of the main air conditioning system and can be operated at full capacity, around the clock if required.

8.1.2 Outdoor Heat Recovery Unit

A total of four Mitsubishi R2-Series outdoor heat recovery units will be utilized. They will be connected in series to provide the total cooling and heating capacity required by the calculations. Air sourced units are utilized due to the requirement by the manufacturer. The system will provide simultaneous heating and cooling similar to system 1, but HVRF has advantages over traditional VRF with condenser units including shorter defrost times and milder off coil temperatures.

Figure 8.1 : Outdoor Unit
Source: Mitsubishi Application Guide

Table 8.1 : Outdoor Unit (Source: Mitsubishi Engineering Catalog)	
Cooling/Heating Capacity	192000 / 215000 (Btu/hr)
Refrigerant	R410A
Temperature Range (Cooling / Heating)	23 F - 115 F / -13 - 60 F
Cost/Lifespan	$48,000 / 25 years

The system can operate at full capacity at the temperature ranges shown in Table 8.1. In cases where the temperature is below the listed values, the system can perform automatic defrosting to prevent the refrigerant from freezing. The condensers can also supply 50% to 150% of the nominal rated capacity depending on the need of the indoor units. These systems are also very efficient and are compact enough to be placed on the roof of the building.

Water in heating mode or cold water in cooling mode. When operating in mixed mode, one set provides hot water while the other provides cold water. Each set of plate heat exchangers has a DC inverter driven water pump which circulates the closed loop water system between the HBC and indoor units. The discharge flow rate from the pump is controlled by the valve block.

8.1.3 Hybrid Branch Controller (HBC)

HBC transfers energy from the refrigerant circuit to the sealed water system, it contains two sets of plate heat exchangers placed at the opposite ends of HBC box. Both sets provide hot

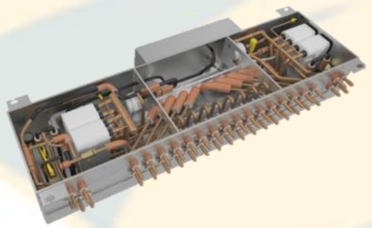


Figure 8.2 : Branch Controller

Table 8.2 : Branch Controller (Source: Mitsubishi Engineering Catalog)	
Capacity: Per Branch/Total	360,000/125,000 (Btu/hr)
Number of Branches	16
Cost/Lifespan	$5,500 / 15 years

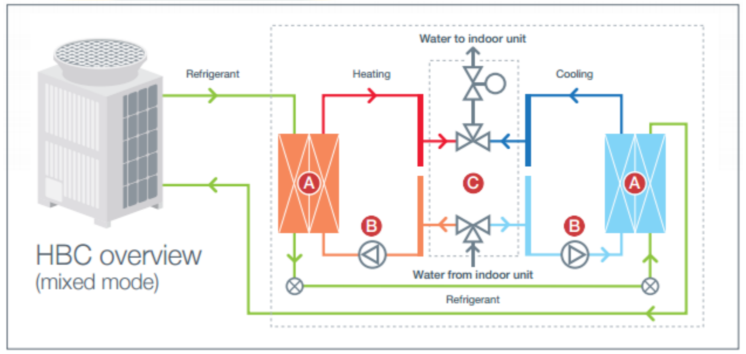


Figure 8.3 : HBC diagram

8.1.4 Hybrid Indoor Units

Similar to system 1 each zone must have a minimum of one indoor unit. Depending on the size, loading and air distribution requirements either a 4 way cassette or a ceiling-concealed ducted unit will be used. Each unit has coils that will circulate hot or cold water depending on the demand of the zone. The system offers the same energy savings as a standard VRF system but the energy recovery is not as efficient as system 1.

Figure 8.3 : Ceiling-Recessed Cassette
Source: Mitsubishi Application Guide

Figure 8.4 : Ceiling-Concealed Ducted
Source: Mitsubishi Application Guide

Since water is used as the refrigerant within the indoor units the temperature of the water within the system can be kept very stable year round. The defrosting cycle can utilize the hot water within the pipes of the system. This means shorter defrost cycles while having minimal influence in the room temperatures, according to the manufacturer. Plastic pipes will be used to connect the HBC to the indoor units.

Table 8.3 : Indoor Unit (Source: Mitsubishi Engineering Catalog)		
Criteria	4-Way Cassette	Ceiling-Concealed Ducted
Cooling/Heating (Btu/hr)	19,000 / 21,500	19,000 / 21,500
Max Airflow	556 CFM	742 CFM
Max Sound Level	39 dB	42 dB
Cost / Lifespan	$1,800 / 15 years	$3,200 / 15 years

8.1.5 Ventilation and Prefiltration

The same energy recovery ventilator and prefilter system used in system 1 will be used. Section 7.1.5 specifies the details of the ventilator. Section 7.1.6. details the prefiltering system.

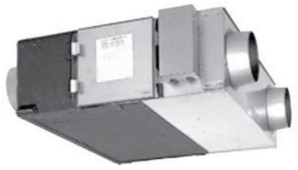


Figure 8.5 : Lossnay Ventilator
Source: Mitsubishi Application Guide

Figure 8.6 : Filter Box and Fan
Source: Johnstone Supply Catalog

FAN COILS WITH DEDICATED OUTDOOR AIR SYSTEM (DOAS)

9.1 System Description

Hydronic four pipe fan coil system with a chiller, boiler, and dedicated outdoor air system. Each zone has its own fan coil unit equipped with cooling and heating coil.the schematic of this system is shown in appendix C (Figure 21.3).

9.1.1 Chiller

An air-cooled chiller with oil-free centrifugal compressor was selected to increase efficiency and reduce operating costs. The compressor uses magnetic bearings to eliminate high friction losses and mechanical wear. Since there is no need for a oil management system, the maintenance costs can be dropped significantly. The oil-free chiller eliminates the accumulation of lubricants on heat transfer surfaces which could block normal thermodynamic heat transfer processes, and as a result increases the efficiency of the chiller**.**

- **0.33 KW /1 ton**

Figure 9.1 : Chiller

Figure 9.2 : Condenser

9.1.2 Boiler

A forced draft condensing boiler with premixed modular air/fuel ratio burner is selected for this system. Since the system is sized based on the highest load and only two or three days in a year may reach that condition to run the the boiler in full capacity it is not efficient to cycle the entire boiler on and off, so it is prefered to use a multi unit modular boiler that can be regulated according to heating demand. Condensing boilers have much less NOx and CO emissions and they are relatively very efficient with levels above 90% .

- 95% Efficiency
- 70% less NOx emission

Figure 9.3 : Boiler

9.1.3 Four pipe fan coil

Each zone has at least one fan coil unit sized in accordance to the zone's heating and cooling demand. Fan coils are equipped with two separate heating and cooling coils and a fan. Each fan coil unit has two automatic control valves, one for hot water and one for cold, that can be controlled by the thermostat or controller to regulate the flow rate and consequently provide the right amount of cooling or heating. In addition, occupants can control the supply airflow rate by manipulating the fan speed through the controller.

Figure 9.7 : Fan Coil Unit

Figure 9.5 : Fan Coil Cassette

Figure 9.6 : Fan Coil Unit

9.1.4 Dedicated Outdoor Air System (DOAS)

Fan coils recirculate the air inside the room and are unable to bring outside fresh air into the building. For this reason, a DOAS was utilized to take care of ventilation needs. The DOAS contains cooling and heating coils which precondition the outside air before entering the room, and as a result reducing the load on indoor fan coil units. The DOAS also utilizes an enthalpy wheel which is an energy recovery heat exchanger positioned within supply and exhaust air streams. The enthalpy wheel brings the temperature of supply air close to the desired indoor temperature by recovering the wasted energy of the exhaust air. The DOAS also utilizes an economizer and a series of damper to control the amount of supplied fresh air based on building's specific needs. During mild weather conditions, when outside temperature is close to desired indoor temperature, the economizer can eliminate the need for mechanical cooling.

Figure 9.7 : Dedicated Outdoor Air System

9.1.5 Pumps

Since our system has a 4 pipe reverse return configuration we used two pumps for hot water and two pumps for cold water. Pumps are sized to overcome the total pressure loss in the system including all coils and control valves. However they are operating under variable frequency drive and the flow is modulated according to needed flow rate.

9.1.6 Expansion Tank

The expansion tanks are diaphragm type where there is a flexible membrane in the water and air interface to prevent any stress caused by expansion or contraction of water while at the same time isolating the hydronic system from outside air.

9.1.7 Control System

Fan Coil units are equipped with 2 control valves that can regulate the flow of hot and cold water. Automatic control valves can be controlled by means of thermostat in each zone. Additionally, all pumps and fans can be integrated with a central control system.

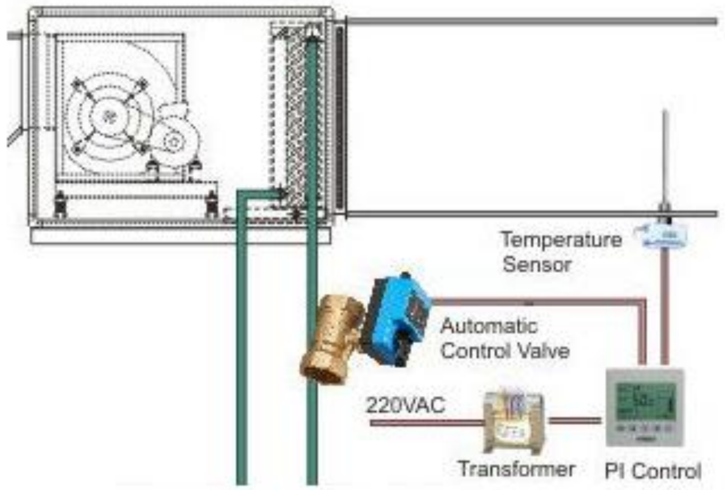


Figure 9.8 : Control System

10.1 VRF WITH GCHP

10.1.1 Heat Recovery - Refrigerant Side

As described in 2012 ASHRAE Handbook-HVAC systems and Equipment, Chapter 18 a water-source VRF systems has the advantage of high annual COP, consistent performance, no defrost cycles, and multilayer heat recovery. It is a combinations of these factors that make this system very efficient. The system is the most efficient when different zones require heating and cooling at the same time, this occurs during shoulder seasons. As described in Chapter 18, if the total heating and cooling demand of the connected zones is equal then the system is in total balance. In this state high pressure, hot vapor is sent from the WSHP to the branch controller where it is diverted to zones that require heating. What exits the coils of these zones is subcooled liquid. The branch controller diverts the subcooled liquid to zones that require cooling, in these zones the subcooled liquid becomes low-pressure vapor. The branch controller sends the low-pressure vapor to the WSHP where it is only compressed to a high-pressure vapor without any heat energy being added or removed. In this state, the system is the most efficient and requires the minimal amount of energy input. If the cooling and heating loads are not exactly in balance, the WSHP must either add or remove heat energy depending which load is higher. The capacity of the indoor units can also be adjusted based on the demand in a specific zone; this also helps with energy savings.

10.1.2 Heat Recovery - Water Side

Since each floor of the building will have two WSHP, the system will have greater flexibility when it comes to the capability of transferring energy. The WSHP will have the option to utilize the water from the ground pipe network but also from the other WSHP in the system. This means that the water that exits the WSHP heat exchanger can be sent to the other WSHPs if the conditions are correct. For example if the first floor requires heating while the second floor requires heating then the following heat exchange process is possible. The water that will exit the WSHP of the first floor will be hotter than the ground pipe network water. This hot water can be sent to the second floor WSHP where it can be used to create hot vapor refrigerant. In this manner, the energy from the first floor is utilized in the second floor. The two layer heat recovery can offer great energy savings, electricity and monetary savings.

10.1.3 Heat Recovery - Air Side

The Lossnay system is an energy recovery ventilator (ERV) and is an important part of the energy efficiency of the system. This system can be either incorporated or decoupled for the air conditioning system. Having a decoupled system has several advantages. As stated in Chapter 18 a decoupled system is one in which the ventilation air is sent directly to the zone rather than being incorporated with the cooling or heating system. Since each indoor unit has a built in fan the airflow needed for heating and cooling is independent of the ventilation flow rate. Trace 700 provides the required ventilation rate for each room based off ASHRAE 62.1, The decoupled nature of the system means the air handler, ducting, diffusers are all smaller and thus easier to install and less expensive. The ventilation system can operate at all times if needed regardless of the heating or cooling needs of the system. Since Beijing has very cold winters and hot summers it is important the the outside air be treated prior to entering the room. This is done to reduce the ventilation load placed upon the air conditioning system. The Lossnay system does this by taking return air from the zones and passing it over the Lossnay core. The core allows water vapor as well as heat energy to transfer from the outside air and the return air. This dramatically decreases the ventilation load by as much as 70% according to the manufacturer.

Table 10.1 : Resource Usage per System

	VRF	HVRF	FCU	Baseline
Energy Consumption (kBtu / year)	753,582	1,086,109	1,669,223	1,926,956
On-Peak Electricity Consumption (kWh)	203,985	278,679	428,442	492,474
On-Peak Demand (kW)	104	129	113	175
Off Peak Consumption (kWh)	12,548	22,476	48,848	49,521
Water Consumption (Gal / year)	0	0	0	24,000
Gas Consumption (Mcf / year)	0	0	8738	6346

10.2 HVRF with Rooftop Heat Recovery Unit

10.2.1 Heat Recovery - Water Side

A hybrid VRF system enjoys many of the same energy saving benefits as a standard VRF system. The HBC can divert water between the indoor units that are operating in opposite heating and cooling modes. This is most likely to occur during shoulder seasons. The heat recovery is not as efficient as a standard VRF due to the fact that the water remains in liquid form during the whole process. In a standard VRF the refrigerant can transfer more energy between the rooms because it can change phases in addition to increasing its temperature.

10.2.2 Heat Recovery - Air Side

System 2 utilizes the same ventilation system as detailed in 7.1.6 and has all the energy recovery advantages as described in Section 10.1.3.

10.3 Hydronic Four Pipe Fan Coil System with DOAS

10.3.1 Natural Gas consumption

The only component that consumes natural gas in this system is the boiler. The team tried to use the most efficient boiler to minimize the gas consumption. Therefore, A forced draft condensing boiler with premixed modular air/fuel ratio burner was employed to provide the hot water. According to 2012 ASHRAE Handbook-HVAC systems and Equipment chapter 32, condensing boilers are generally more efficient than non condensing boilers at any return water temperature. Moreover, they can achieve an efficiency above 90% when using with lower returning water temperature. Also the boiler can operate at different capacities that minimizes the wasted energy and resources

10.3.3 Heat Recovery - Air Side

The dedicated outdoor air system in this design utilizes a enthalpy wheel and Enthalpy sensor that enable it to recover some of energy from exhaust air, also it can operate in economizer mode when the outdoor air condition has the desired condition for comfort and health.

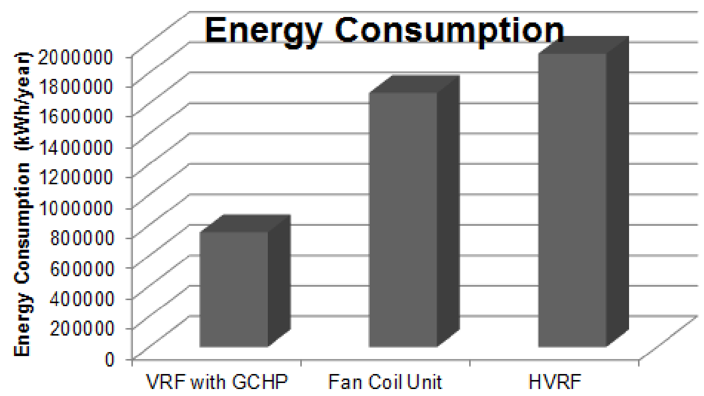


Figure 10.1 : Systems Energy Consumption

11.1 Maintainability

Indoor units are much smaller than conventional boilers or chillers and occupy less space. They can be housed in floor-level utility closet or mechanical rooms for minimum disruption to occupied space and convenient access. The ground loops are made of very durable plastic tubings and have an estimated life of 50+ years, and once buried they can generally be forgotten. The antifreeze that circulates around the ground loops doesn't need any maintenance, as long as it is correct with the right biocides in it, as the system is sealed. Although it's very rare for a ground loop of the geothermal system to spring a leak, it can occasionally occur; especially when they are near to the end of their life expectancy.

The inclusion of refrigeration in all three systems, means that special precautions will need to be taken to ensure safe handling of the refrigerant fluid. In accordance with ASHRAE Standard 15, only certified technicians should be allowed to service any component of an HVAC system where refrigerant is used. In order to avoid occupant exposure, only manufacturer specified valves and fittings should be used. When maintenance is performed, special ventilation is required for those partaking in the task.

The use of Variable Refrigerant Flow in Systems 1 and 2 will require that any system components replaced, be replaced with components from the same manufacturer. Interchangeability of parts within vrf systems is not suggested. A longer life cycle, higher efficiency, and most importantly, proper system operation can be expected if the proper maintenance strategies are utilized. Luckily, the popularity of VRF technology in the region, will make it much easier for the correct parts/components to be obtained when required.

The filtration system utilized with merv 14 filters will require yearly maintenance. It is recommended that the filters be replaced once a year. Replacing them once a year will ensure optimum efficiency at a relatively low cost.

11.2 Sustainability

According to ASHRAE GreenGuide, sustainability is defined as "providing for the needs of the present without detracting from the ability to fulfill the needs of the future." In other words, buildings should provide a safe and healthy indoor environment while at the same time minimizing the impact on natural resources. Based on this definition, a sustainable building can also be defined as a "Green" building. Energy conservation is also another important aspect in a sustainable design.

Using ground-source heat pump eliminates the need for a boiler, chiller and cooling tower which means no CO_2 emission and minimum water consumption. Ground-source heat pumps use the sustainable and renewable energy stored in the earth to heat and cool the building. Since the ground-source heat pump uses earth's constant temperature as the exchange medium instead of outside air, the efficiency of the system is much higher than the air-cooled VRF systems specially in extreme cold or hot weather conditions. By combining VRF technology with the geothermal system we can achieve very high energy efficiencies since the flow of the refrigerant to each indoor unit can be varied based on the amount of heating or cooling needed for each room. The VRF system also utilizes a heat recovery system when the system is operating on both heating and cooling modes simultaneously, which reduces the power consumption of the compressors. The energy efficiency of the system is later increased by utilizing energy recovery units in the ventilation system. Energy recovery units transfer energy between supply and exhaust air and heat or cool the incoming fresh air to a temperature close to the existing indoor air temperature which decrease the ventilation load significantly.

All Considered systems can operate on widely different operating conditions and can provide heating and cooling independently to each space regarding the zone expectation. Spaces with relatively constant or weather-independent load such as the ambulance garage and the server room have separate systems and the building's primary air conditioning system only acts as an auxiliary or backup system for them. Minimum outside air is used only to meet the ASHRAE 62.1 standard and conditioned air is recirculated after being filtered and cleaned. In addition, all systems provide controls that enable them to operate in occupied and unoccupied modes.

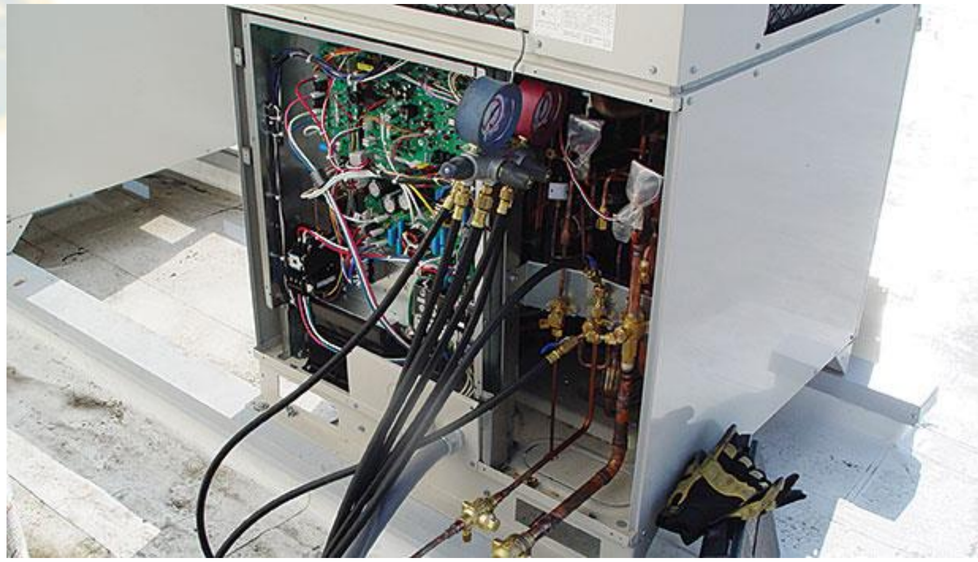


Figure 11.1 : Maintenance of VRF Condenser

COST ANALYSIS

12.1 Initial Cost of VRF WITH GCHP

VRF with GSHP				
Initial Cost				
Item	Description	QTY	Price	Total
HVAC Equipment Cost				
1	4-Way Ceiling Cassette - 1 TON	9	$2,200.00	$19,800.00
2	4-Way Ceiling Cassette - 1.5 TON	15	$2,300.00	$34,500.00
3	4-Way Ceiling Cassette - 2 TON	5	$2,700.00	$13,500.00
4	Cieling-Concieled Ducted - 3 TON	3	$2,800.00	$8,400.00
5	Ducting for Item 4 (80 ft each)	3	$400.00	$1,200.00
6	Pump for indoor units	31	$115.00	$3,565.00
7	Water Source Heat Pump	4	$30,000.00	$120,000.00
8	Energy Recovery Ventilators	4	$5,000.00	$20,000.00
9	Ducting for item 4 (800 ft)	4	$4,000.00	$16,000.00
10	UV Filter	8	$650.00	$5,200.00
11	AUXILIARY FILTER BOX	4	$400.00	$1,600.00
12	FILTER MERV 13 (2 PER BOX)	8	$23.00	$184.00
13	Booster Fan (1200 CFM, 5 in WG) 2 per box	8	$450.00	$3,600.00
14	Main Refrigerant Line (200 ft)	200	$17.00	$3,400.00
15	Indoor Refrigerant Line (7000 ft)	7000	$1.20	$8,400.00
16	Ground Pipe Network	1	$650,000.00	$650,000.00
17	Smart Thermostat	45	$250.00	$11,250.00
18	Leak Detector	45	$750.00	$33,750.00
		Total		$954,349
Labor Cost				
1	Ducting Installation	1	$45,000.00	$45,000.00
2	Piping Installation	1	$75,000.00	$75,000.00
3	Indoor Unit Installation	31	$1,000.00	$31,000.00
4	Thermometer Installation	45	$60.00	$2,700.00
5	Leak Detector Installation	45	$100.00	$4,500.00
6	Commisioning	1	$6,000.00	$6,000.00
7				
		Labor Total		$164,200.00
		Sub-Total		$1,118,549.00
Taxes and Fees				
1	Sales Tax	1	7%	$78,298.43
2	Subtotal	1		$1,196,847.43
3	Safety Factor	1	10%	$119,684.74
Total Initial Cost				$1,316,532.17

12.2 Initial Cost of Hybrid VRF

HVRF				
Initial Cost				
Item	Description	QTY	Price	Total
HVAC Equipment Cost				
1	4-Way Ceiling Cassette - 1 TON	9	$2,200.00	$19,800.00
2	4-Way Ceiling Cassette - 1.5 TON	15	$2,300.00	$34,500.00
3	4-Way Ceiling Cassette - 2 TON	5	$2,700.00	$13,500.00
4	Cieling-Concieled Ducted - 3 TON	3	$2,800.00	$8,400.00
5	Ducting for Item 4 (80 ft each)	3	$400.00	$1,200.00
6	Pump for indoor units	31	$115.00	$3,565.00
7	Air Source Heat Pump	4	$30,000.00	$120,000.00
8	Energy Recovery Ventilators	4	$5,000.00	$20,000.00
9	Ducting for item 4 (800 ft)	4	$4,000.00	$16,000.00
10	UV Filter	8	$650.00	$5,200.00
11	AUXILIARY FILTER BOX	4	$400.00	$1,600.00
12	FILTER MERV 13 (2 PER BOX)	8	$23.00	$184.00
13	Booster Fan (1200 CFM, 5 in WG) 2 per box	8	$450.00	$3,600.00
14	Main Refrigerant Line (200 ft)	200	$17.00	$3,400.00
15	Indoor water Line (7000 ft)	7000	$1.20	$8,400.00
16	Smart Thermostat	45	$250.00	$11,250.00
			Total	$270,599
Labor Cost				
1	Ducting Installation	1	$75,000.00	$75,000.00
2	Piping Installation	1	$75,000.00	$75,000.00
3	Indoor Unit Installation	31	$1,000.00	$31,000.00
4	Thermometer Installation	45	$60.00	$2,700.00
5	Leak Detector Installation	45	$100.00	$4,500.00
6	Commisioning	1	$6,000.00	$6,000.00
7	Outoor Unit Installation	4	$8,500.00	$34,000.00
			Labor Total	$228,200.00
			Sub-Total	$498,799.00
Taxes and Fees				
1	Sales Tax	1	7%	$34,915.93
2	Subtotal	1		$533,714.93
3	Safety Factor	1	10%	$53,371.49
Total Initial Cost				$587,086.42

12.1.Initial Cost of Hydronic 4 Pipe Fan-Coil

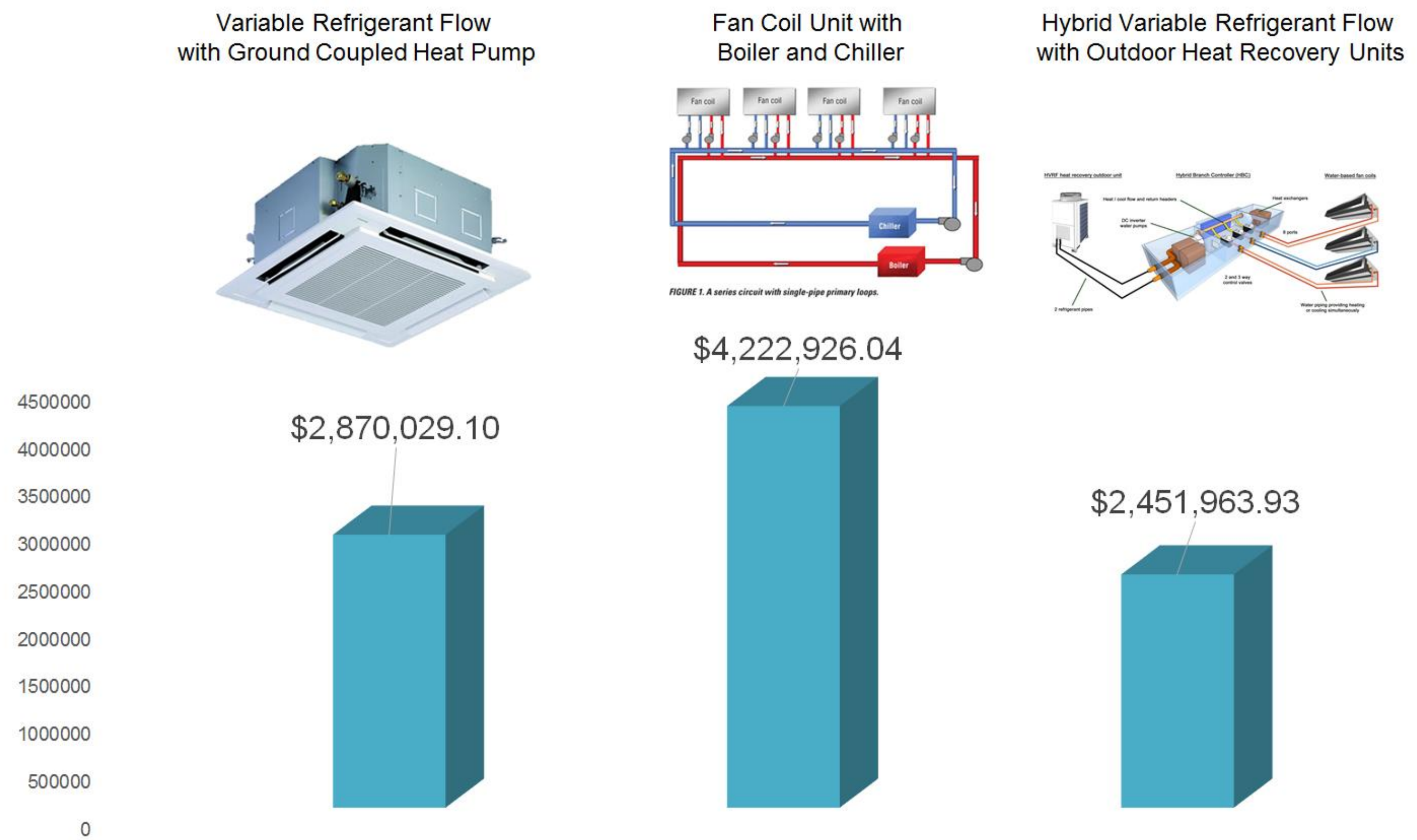
Fan Coils with DOAS				
Initial Cost				
Item	Description	QTY	Price	Total
HVAC Equipment Cost				
1	Chiller & Cooling Tower	1	$66,000.00	$66,000.00
2	Boiler	1	$16,500.00	$16,500.00
3	VFD pump	4	$1,200.00	$4,800.00
4	fan coil i	5	$900.00	$4,500.00
5	fan coil ii	20	$1,100.00	$22,000.00
6	fan coil iii	9	$1,600.00	$14,400.00
7	DOAS	1	$40,000.00	$40,000.00
8	Heat Recovery System	1	$1,000.00	$1,000.00
9	Pipe	1	$11,700.00	$11,700.00
10	Fittings	1	$1,400.00	$1,400.00
11	Controls unit	1	$12,750.00	$12,750.00
			Total	$195,050
Labor Cost				
1	Ducting Installation	1	$75,000.00	$75,000.00
2	Piping Installation	1	$150,000.00	$150,000.00
3	Indoor Unit Installation	31	$1,000.00	$31,000.00
4	Thermometer Installation	45	$60.00	$2,700.00
5	Control unit Installation	1	$85,000.00	$85,000.00
6	Commisioning	1	$6,000.00	$6,000.00
			Labor Total	$349,700.00
			Sub-Total	$544,750.00
Taxes and Fees				
1	Sales Tax	1	7%	$38,132.50
2	Subtotal	1		$582,882.50
3	Safety Factor	1	10%	$58,288.25
Total Initial Cost				$641,170.75

13.1 Life cycle cost

The ongoing annual costs for the systems include scheduled filter replacements, system inspections, refrigerant recharging, cooling tower maintenance. With proper installation and maintenance the indoor and outdoor units can last for 15-30 years depending on the equipment. The replacement cost is incorporated within the cost analysis. Energy and utility rates provided by the owner are also used to calculate the annual energy and utility costs with a 3% inflation rate and a 7% interest rate is used to calculate the present value of a 50 year life cycle cost for the three systems. Only the even years are shown in the sample calculation due to space restrictions.

VRF with GSHP										
Year	Electricty - Peak Consuption	Electricty - Peak Demand	Electricty - Off Peak	Water	Gas	Equipment Replacement	Maintinance	Initial	Total	Present Worth
0								$1,316,532.17	$1,316,532.17	$1,316,532.17
2	$35,268.13	$1,086.22	$1,142.55	$ -	$ -	$ -	$23,727.63		$61,224.54	$53,475.88
4	$37,780.11	$1,163.59	$1,223.93	$ -	$ -	$ -	$25,417.63		$65,585.25	$50,034.68
6	$40,470.99	$1,246.46	$1,311.10	$ -	$ -	$ -	$27,228.01		$70,256.56	$46,814.91
8	$43,353.54	$1,335.24	$1,404.48	$ -	$ -	$ -	$29,167.32		$75,260.59	$43,802.35
10	$46,441.40	$1,430.35	$1,504.52	$ -	$ -	$ -	$31,244.76		$80,621.02	$40,983.64
12	$49,749.18	$1,532.22	$1,611.68	$ -	$ -	$ -	$33,470.17		$86,363.25	$38,346.32
14	$53,292.57	$1,641.36	$1,726.47	$ -	$ -	$ -	$35,854.08		$92,514.48	$35,878.71
16	$57,088.33	$1,758.26	$1,849.43	$ -	$ -	$ -	$38,407.79		$99,103.82	$33,569.89
18	$61,154.45	$1,883.49	$1,981.16	$ -	$ -	$ -	$41,143.39		$106,162.49	$31,409.65
20	$65,510.17	$2,017.65	$2,122.27	$ -	$ -	$ -	$44,073.82		$113,723.91	$29,388.42
22	$70,176.14	$2,161.35	$2,273.43	$ -	$ -	$ -	$47,212.98		$121,823.90	$27,497.26
24	$75,174.43	$2,315.30	$2,435.35	$ -	$ -	$ -	$50,575.73		$130,500.81	$25,727.79
26	$80,528.73	$2,480.20	$2,608.81	$ -	$ -	$36,689.38	$54,177.98		$176,485.10	$30,389.94
28	$86,264.39	$2,656.85	$2,794.62	$ -	$ -	$39,302.58	$58,036.81		$189,055.26	$28,434.33
30	$92,408.57	$2,846.09	$2,993.67	$ -	$ -	$435,053.02	$62,170.48		$595,471.84	$78,225.42
32	$98,990.37	$3,048.80	$3,206.89	$ -	$ -	$45,100.61	$66,598.57		$216,945.25	$24,892.54
34	$106,040.96	$3,265.95	$3,435.31	$ -	$ -	$48,312.91	$71,342.06		$232,397.18	$23,290.69
36	$113,593.73	$3,498.57	$3,679.98	$ -	$ -	$51,753.99	$76,423.39		$248,949.67	$21,791.92
38	$121,684.44	$3,747.76	$3,942.09	$ -	$ -	$55,440.17	$81,866.65		$266,681.11	$20,389.60
40	$130,351.42	$4,014.69	$4,222.87	$ -	$ -	$59,388.90	$87,697.60		$285,675.47	$19,077.52
42	$139,635.70	$4,300.64	$4,523.64	$ -	$ -	$63,618.87	$93,943.86		$306,022.71	$17,849.87
44	$149,581.25	$4,606.95	$4,845.84	$ -	$ -	$68,150.12	$100,635.02		$327,819.17	$16,701.22
46	$160,235.17	$4,935.08	$5,190.98	$ -	$ -	$73,004.12	$107,802.75		$351,168.10	$15,626.48
48	$171,647.92	$5,286.58	$5,560.71	$ -	$ -	$78,203.83	$115,481.00		$376,180.04	$14,620.91
50	$183,873.55	$5,663.12	$5,956.77	$ -	$ -	$83,773.90	$123,706.13		$402,973.47	$13,680.05
									Total	$2,870,029.10

Table 13.1 : VRF with GSHP Life Cycle Cost



LEADERSHIP IN ENERGY AND ENVIRONMENTAL DESIGN (LEED)

LEED as a third party certification program is a comprehensive system for designing, constructing, operating, and certifying green buildings. The system has been established to define "green" buildings by creating measurable benchmarks, increasing positive results for the environment, occupant health, and financial return. Some of LEED certification benefits include: reduced operating costs, occupant comfort/employee retention, risk management, etc.

Although LEED certification is not part of the building's owner requirements, the team decided to evaluate each of the selected systems based on the number of possible LEED points they could earn. This evaluation can further help the team compare the three HVAC systems based on energy performance and environmental quality.

Based on available credits specified in "LEED v4 for BD+C'', each system has the potential to earn credits in the areas specified in the table 14.1. Points were assigned to each system using LEED v4 for Building Design and Construction. The following are the guidelines to obtain some of the credits showed in table 14.1:

- Optimize Energy Performance credit is evaluated based on the percentage improvement in energy performance of the building compared with the baseline. There are maximum of 18 points available for this credit. To earn the maximum points, the building must achieve 50% improvement in energy performance.

- Renewable Energy Production credit can be earned by offsetting building energy costs by using renewable energy systems. The percentage of renewable energy can be calculated using the following formula:

$$\%\ \text{renewable energy} = \frac{\text{Equivalent cost of usable energy produced by the renewable energy system}}{\text{Total building annual energy cost}}$$

  Maximum of 3 points can be earned if 10% renewable energy is achieved.

- The thermal comfort credit can be earned by designing the HVAC system and the building envelope to meet the requirements of ASHRAE standard 55-2010, Thermal Comfort Conditions for Human Occupancy.

- ASHRAE standard 62.1-2010, sections 4-7, Ventilation for Acceptable Indoor Air Quality, compliance is a LEED prerequisite for Indoor Environmental Quality. Some of the options to obtain credit in "Enhanced Indoor Air Quality Strategies" section include:

  - Increasing outdoor air ventilation rates to all occupied spaces by 30% above the minimum rates specified in the prerequisites
  - Monitoring CO2 concentration within all densely occupied spaces
  - Filtration of supplied outside air in accordance with ASHRAE standard 52.2 (minimum efficiency reporting value (MERV) of 13 or higher)
  - Sufficiently exhausting each space where hazardous gases may be present, such as garage, using the exhaust rates determine in EQ Prerequisite Minimum Indoor Air Quality Performance or a minimum of 0.5 cfm per square foot to create negative pressure with respect to adjacent spaces.

	Applicable Credits	Possible Points	GSVRF	Fan Coil	HVRF
Energy and Atmosphere	Optimize Energy Performance	18	17	9	15
	Advanced Energy Metering	1	1	1	1
	Renewable Energy Production	3	3	3	3
	Enhanced Refrigerant Management	1	1	1	1
	Enhanced Commissioning	6	6	6	6
Indoor Environmental Quality	Enhanced Indoor Air Quality Strategies	2	2	2	2
	Construction Indoor Air Quality Management Plan	1	1	1	1
	Indoor Air Quality Assessment	2	2	2	2
	Thermal Comfort	1	1	1	1
	Daylight	3	2	2	2
	Acoustic Performance	1	1	-	1
	Total Points		37	28	35

Figure 14.1 : LEED Points Matrix

15.1 Ventilation

Air ventilation requirements are outlined in ASHRAE Standard 62.1. Occupancy size, space type, floor area, and floor level are considered when determining ventilation rates. Trace 700 was used in conjunction with Standard 62.1 to determine the needed ventilation rates for the different occupied spaces within the building. Each of the systems considered can provide proper ventilation rates for peak occupancy, as required, at the minimum. In order to meet the necessary ventilation rates, Lossnay ventilation systems with heat recovery will be used in systems 1 and 2. It has been determined that two Lossnay systems per floor will be sufficient to meet the ventilation rate requirements. In addition, booster fans will be used to overcome the static pressure of the filtration system. The heat recovery aspect of the Lossnay ventilation systems will meet recirculation requirements, based on on air class, as outlined in section 5.16.3 of Standard 62.1. System 3 would use a more common DOAS system to meet the required ventilation rates. An enthalpy wheel will be utilized in system 3 for the tasks of recirculation and heat recovery. Exiting air will be mixed with incoming fresh air within the rotating wheel to create an air stream of optimum condition for delivery to the occupied space. Special considerations were made for the attached garage where the ambulance would be stored and partially operated. It is required that the space be kept at a pressure equivalent to its surroundings or lower to keep contaminated air from entering the surrounding spaces.

15.2 Occupant Comfort

ASHRAE Standard 55 details the factors that contribute to an acceptable thermal comfort of an occupied space. The factors discussed include, metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. Unfortunately, metabolic rate and clothing insulation are two factors which the design team has no control over, but they were considered in accordance to the expected expected workplace activity. An acceptable range for environmental thermal conditions is provided by ASHRAE Standard 55 and shown below in Figure 15.1 to ensure that an 80% acceptance rate of the occupants is achieved. Temperature and humidity ranges will be kept within the specified ranges with the help of various components within each of the systems. In systems 1 and 2, the Lossnay ventilation systems will assist with humidification/dehumidification as deemed necessary. Additionally, indoor units will remove the excess humidity added to the air after the cooling process. Similarly, system 3 will maintain adequate temperature and humidity levels with the help of an enthalpy wheel. The three systems can maintain winter indoor conditions between 68 and 75 F with relative humidity between 20 and 60%. Similarly, the three systems can maintain summer indoor conditions between 74F and 81F with relative humidity between 25 and 55%.

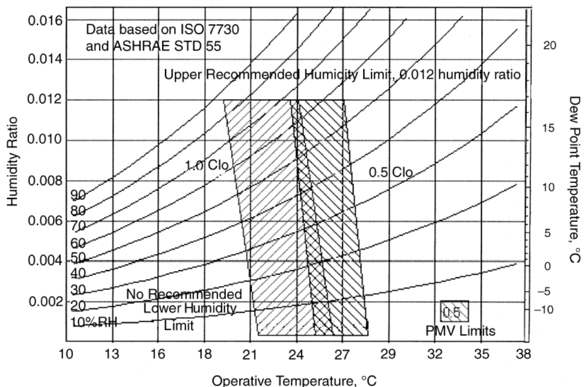


Figure 15.1 : Psychometric "Thermal Comfort" Chart

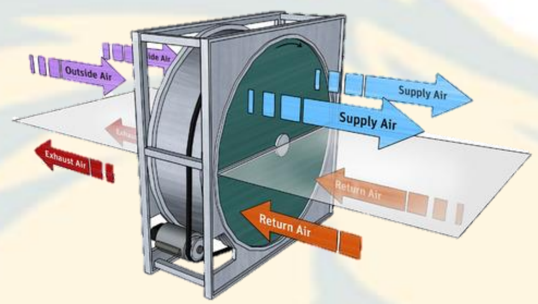


Figure 15.2 : Enthalpy Wheel

15.3 Zoning and Temperature Control

Vrf technology provides a higher level of flexibility with regards to temperature control. As a result, greater freedom exists for the zoning of the building. In an effort to provide greater control for the end user, the building was zoned in such a way that created the highest number of zones in conjunction with maximizing efficiency. When zoning, multiple factors including occupancy of the space and the potential necessity for tighter temperature control were considered. The result was the creation of 31 zones. The possibility of maintaining different rooms at different temperatures will significantly increase comfort levels.

15.4 Air Filtration

ASHRAE Standard 62.1 categorizes the type of filtration required based on the size of particulate matter. Pollution studies conducted in the city of Beijing, indicate that fine particulate matter, PM2.5, is present. In order to account for the possible presence of particulate matter smaller than PM2.5, the guidelines for air with a particulate matter smaller than 2.5 micrometers will be used. This means that any outdoor air being brought into building will need to be filtered with filters that have at the least a Minimum Efficiency Rating Value of 11.

If greater control of air quality is desired, filters with a higher MERV rating can be substituted. For this application, it has been determined that a filter with a higher MERV rating will be best suited. It will ensure that the occupants have air with higher quality than what is recommended by Standard 62.1. To achieve this, MERV 14 filters will be utilized in all three systems. They are more efficient at removing small particulate when compared with MERV 11 filters for a relatively similar cost. A two stage filtration system, with MERV 14 filters, will filter the air in Systems 1 and 2 before it reaches the Lossnay Core and within the DOAS for System 3. To overcome the head loss from the filtration system, booster fans will be included and placed at the inlets.

15.5 Optimizing Working Environment

Special focus has been placed on the air filtration systems to ensure that high quality air will be circulated throughout the building.. Additionally, special measures have been taken to reduce acoustic levels of the utilized systems and the means for increasing air movement when desired will exist. Additionally, the team recommends that additional measures be taken to optimize the working space. A study done by NASA on clean air has found that certain plants can assist in removing harmful chemicals from the air. These chemicals include benzene, ammonia, and formaldehyde to name a few. Each of these chemicals when present in the air, have been linked to headaches, sore throats, and irritation of the eyes. All of these factors considered in unity will result in a highly comfortable work environment from a physiological point of view.

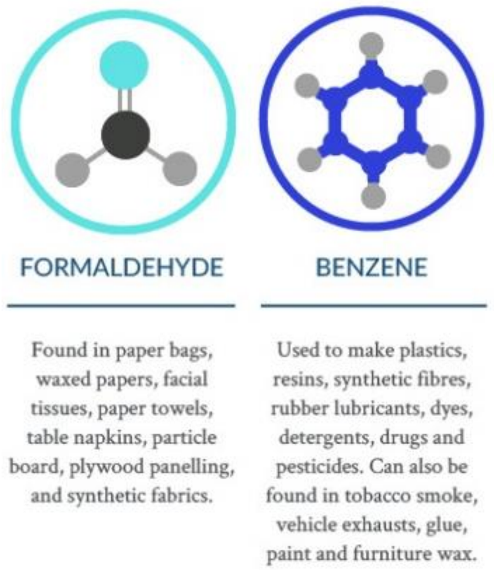


Figure 15.3 : Chemicals Present in Air

Source: LifeHacker

Figure 15.4 : Air Filtering Plants

Source: LifeHacker

16.1 Overview

When considering environmental impacts, a substantial emphasis was placed on the energy consumption of each of the three systems considered. Additionally, the consideration of systems using refrigerant, warranted the consideration of refrigeration on the environment. ASHRAE Standards 15 and 34 together provide guidelines for the safe use of refrigerants.For the most part both emphasize on human safety, but they indirectly influence environmental impacts.

ASHRAE Standard 34 classifies the safety of refrigerants in terms of toxicity and flammability. Based on this classification, six groups refrigerants have been established where each varies in the level of toxicity and flammability. Group A1 is on the low end for both spectrums and thus refrigerants that fall into this subgroup are the safest and most environmentally friendly. The refrigerant chosen by the design team for each of the three systems considered is R410-A. This refrigerant is categorized into group A1. Because the refrigerant is fluorine based, there are no chlorofluorocarbon by-products, making the refrigerant more environmentally friendly. Unfortunately, the carbon dioxide levels emitted by the refrigerant are rather high, but this can be circumvented by limiting the power consumption of the system. Thus, limiting the carbon dioxide emissions serves as an incentive to minimize power consumption, which is already a top priority.

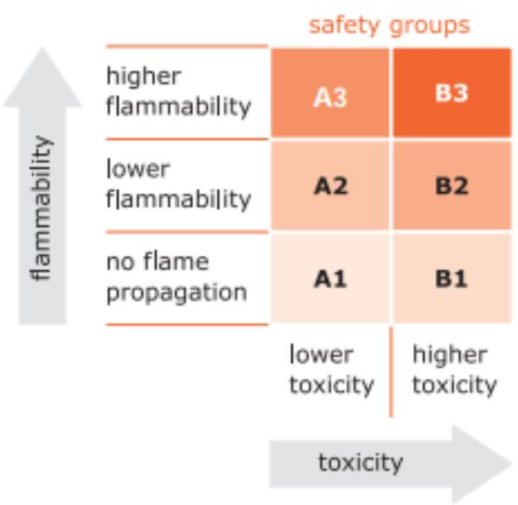
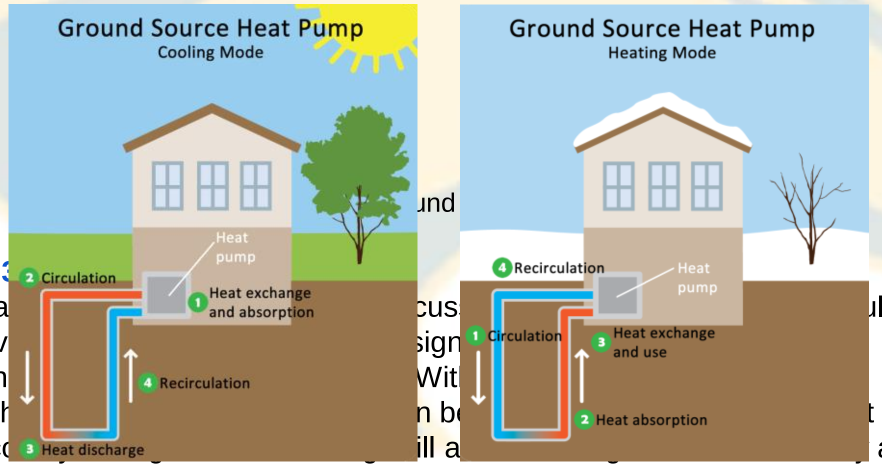


Figure 16 ... ation

16.2 System 1

A significant benefit of using Vrf technology is its ability to decrease energy consumption by limiting the usage of the system because unlike other HVAC systems, VRF does not require operation at full cooling/heating capacity. The flexibility of the system translates to lower energy consumption levels. The geothermal heat pump coupled with the VRF system provides many benefits. For the most part, underground temperatures keep consistent throughout the year. During the hot days of the summer season, it can be expected that underground soil temperatures will be cooler and vise versa for cold days of winter season.

Additionally, the inclusion of the geothermal heat pump in system, serves to significantly reduce the carbon footprint of the system. Utilizing the difference in temperature in soil and incoming water/antifreeze mixture, heat exchange via natural conduction reduces the need for burning of fossil fuels.



...und

16.3 ...

In a ... cus ... ll adv ... sign ... con ... Wit ... tech ... n be ... t rec ... ill a ... and further minimize energy consumption One advantage that System 2 will have over the others is the lower amount of water usage. Unlike System1, large amounts of water will not be needed. The condensing units placed on the roof will strictly use refrigerant to achieve the desired level of heating and/or cooling.

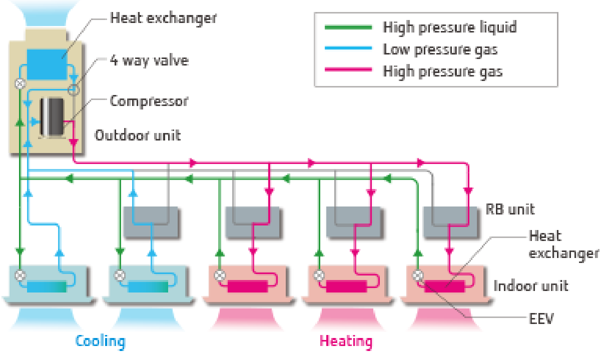


Figure 16.3 : VRF system with Condenser

16.4 System 3

The enthalpy wheel planned for System 3 will be great in helping to reduce energy usage of the system. Water usage will be of concern, but special focus will be placed on making sure that only the necessary amounts are used. When outside air temperatures are within the desired indoor temperature levels, the DOAS can be used to circumvent the necessity of mechanical cooling via the economizer. Additionally, preconditioning of air before entering the system will significantly reduce energy usage. Like the other two systems, R410-A refrigerant will be used. Significantly reducing the potential of causing negative impacts on the environment.

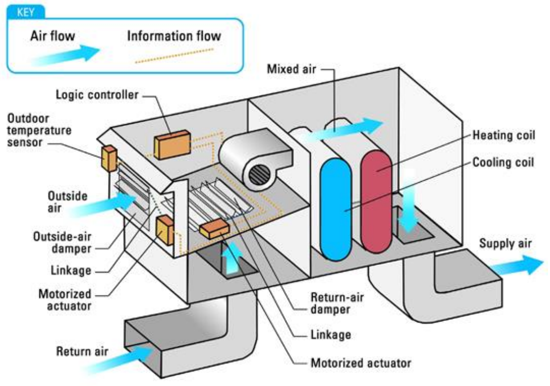


Figure 16.4 : Economizer

17.0 DECISION MATRIX

The decision matrix was created in order to help the groups decide which of the three systems selected would be the most appropriate for the building.

Each category of grading and category points was given a weight from (1) to (5). (1) indicating the least important and (5) indicating the most important. Then the points given to a system was multiplied by the weight to reflect the importance of that category in the final decision. The multiplied values were then summed to indicate the total points given to a system.

Health and safety was given the largest weight, since everyone who leaves work is expected to make a return and the lives of the occupants is the most important issue. In addition, injuries in an unsafe environment can damage the business and can cause potential lawsuits for the owner or the engineer. Therefore Safety was given the largest weight.

Initial cost and Operating cost were given 4 points, since it is required by the owner to be calculated and at very high operational cost, owner's budget would exceed. If the budget exceeds, the owner would no longer be willing to use the system selected.

Table 17.1 : Decision Matrix

Grading Category	Category Weight	Ground Source VRF		Hybrid VRF		Fan Coil	
		Points	C.W. x P.	Points	C.W. x P.	Points	C.W. x P.
Energy Efficiency	3	5	15	4	12	2	6
Controllability	2	2	4	2	4	1	2
Health and Safety	5	3	15	4	20	3	15
Initial Cost	4	2	8	4	20	3	15
Operating Cost	4	4	16	4	20	3	15
Occupant Comfort	4	4	20	4	20	3	15
Reliability/Flexibility	3	3	9	2	6	3	9
Sustainability	4	3	12	4	16	2	8
Environmental Impact	4	3	12	4	16	2	8
Maintainability	3	1	3	3	9	2	6
	Total		114		143		99

18.1 Server Room

As specified by the owner, the government building will contain a server room. The servers may contain important information and therefore it is critical that they be maintained at optimal temperatures. Based on the owner's requirements and general industry practices the cooling load of the server room is calculated to be 2.9 tons using Trace 700. To ensure the system has more capacity for future expansion HVAC system designed has a cooling capacity of 5 tons. As a general guideline the system is designed to be as simple as possible, while maintaining high levels of cooling performance and energy efficiency.

18.1.1 ASHRAE Class 1

ASHRAE Thermal Guidelines for Data Processing Environments defines a Class 1 environment as one that is tightly controlled parameters and contains enterprise servers and storage products. Since the building is a government building the design shall follow the guidelines set forth for a Class 1 environment to ensure the maximum reliability. This classification means the temperature and humidity must have tight controls which will result in a higher total cost of ownership (TCO). The 2011 guidelines allow for a greater flexibility in the temperate/humidity when compared to 2008 guidelines, however the system performance is not compromised. A Class 2 or class 3 classification has a larger range of acceptable temperatures and humidity but the servers will not be at the optimal temperature for safety and reliability. Since the elevation of Beijing is 145 feet then derating factors do not apply as suggested by the Thermal Guidelines. For this design a dry bulb room temperature range of 64.4 to 80.6 degrees Fahrenheit is recommended to maximize reliability and energy efficiency of the server units. For the load calculations a desired room temperature of 68 degrees is chosen.

18.1.2 HVAC System Layout

As requested by the owner an air handler system must provide the ventilation, air filtration, cooling and dehumidification, and heating. To accomplish this goal an air handling unit will be utilized with a outdoor condenser unit. The air handler unit (AHU) has space and capacity of up to a MERV 15 filters to remove contaminants as small as 1 micron with up to 90% efficiency. These filters will need to be replaced every 3 months to ensure the airflow is not restricted. It is important to achieve a high level of filtration in order to remove the contaminants from the air as to not damage the server unit. The 5 ton condenser unit will provide the liquid refrigerant to the coils of the AHU where the outdoor air can be conditioned. The servers will be arranged to create hot and cold aisles as shown in Figure 18.3. The cold air will be supplied from the ground via ground registers, this means the server units will be raised to allow for ducting for the cold supply air. The cold air supplied to the cold aisle will be sent through the server units where the temperature of the air will increase while the temperature of the server unit will decrease. A typical temperature increase of 20 degrees Fahrenheit can be expected as detailed by the Thermal Guidelines. The server racks will have partitions that will separate the cold and hot aisle. This will ensure that the hot air will not mix with the entering cold and and cause thermal contamination. If the hot and cold air were allowed to mix then this would decrease the efficiency of the HVAC system as well as decrease the performance of the servers. As recommended by the Thermal Guidelines as well as the United States Department of Energy, some air-side economizer should also be utilized to save energy by utilizing the outside air when appropriate.

The AHU will be equipped with temperature and humidity sensors of the entering air which can be used to determine if the entering air is appropriate for the server room. If the control system determines that the air has the correct properties then the outdoor unit will not be operated and the outdoor air will simply be filtered and released into the room. The air that is extracted from the hot aisle will be utilized to create hot domestic water. This is done by having a air-to-refrigerant coil at the exit of the server room. The coils will be used to vaporize R410-A refrigerant, the refrigerant is sent through a 3 ton capacity hydronic heat exchanger which acts as a water-to-refrigerant heat exchanger. The water is heated but cannot be used directly, instead it must be sent through a water-to-water heat exchanger located within the hot water tanks. At the operating conditions of the server room domestic hot water at 115 degrees Fahrenheit can be created at a rate of 2 gallons per minute. Along with the economizer and the hot water generation the system can also mix the room exhaust air with the outside air. This can be done in cases when the outdoor air is not right for the economizer but hotter than the exhaust of the server room. This will typically occur during the summer seasons. Having the ability to mix the airstreams will help reduce the load on the outdoor condensing unit, which will reduce electricity costs. Pressurizing the room will ensure that contaminants from the environment or adjacent rooms will not enter the server room. This can be achieved by supplying 10% more cold air then the exhaust air.

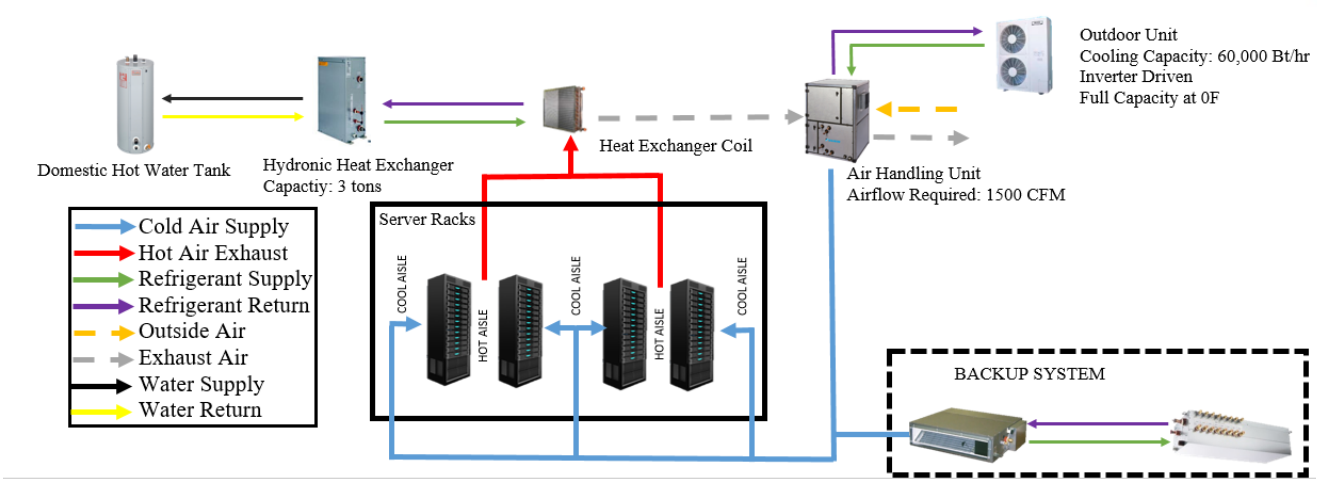


Figure 18.2 : Server room HVAC system line diagram
Source- Authors

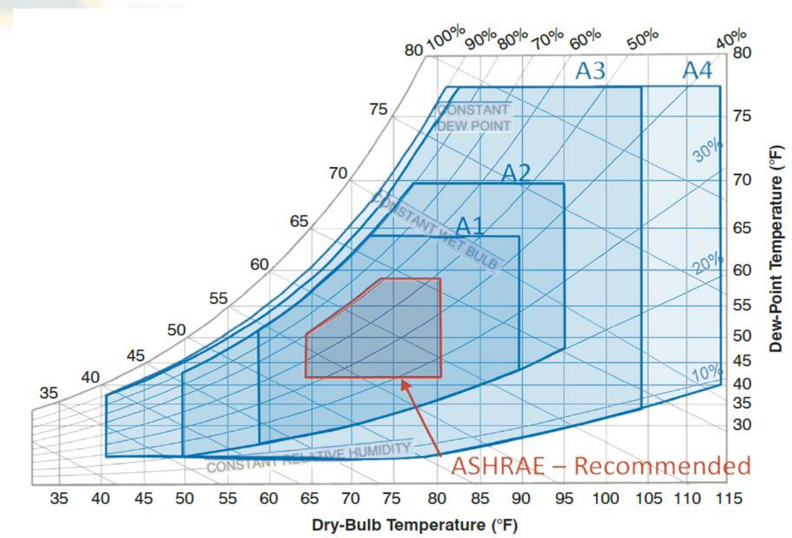


Figure 18.1 : Psychrometric Chart for Data Processing Environments
Source: ASHRAE Thermal Guidelines for Data Processing

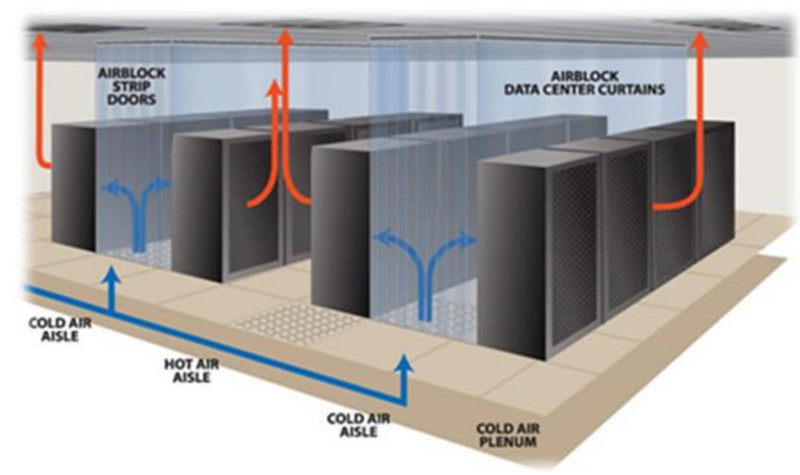


Figure 18.3 : Server room hot/cold aisle design with partitions
Source: Airblock Data Center Systems Catalog

18.1.3 System Advantages and Backup System

This system is relatively straightforward when it comes to the HVAC components. Air handling units have been used in HVAC systems for decades and have proven to be robust and reliable. The outdoor unit is oversizing which will allow the system to run at lower capacity which will reduce the strain on the system. Since this is a air cooled condenser evaporation of water is not a concern. Filters also ensure that the air entering the room is adequately clean for telecommunication applications. The system also offers the advantage of heat recovery, the heat generated by the servers is a positive byproduct rather than an issue that must be dealt with. A computer room air conditioning (CRAC) system was also considered as a possible option but was not utilized . The CRAC system must be located within the server room which will use space that could be used for additional server racks. In addition the use of an economizer or heat recovery would have been more difficult with a CRAC system. As a backup system a ducted indoor unit will also be connected to the server room. During normal operation this indoor unit will not be utilized. In an emergency if the server room HVAC system breaks down then the branch controller of the primary VRF system can provide the cooling needed until the server room system can be repaired.

18.2. Garage

The OPR specifies that the garage will be utilized as a parking area for the ambulance. The vehicle will be operated for 45 minutes twice a week with a standard V-8 diesel engine. The garage is not going to be air conditioned, rather a ventilation system needs to be installed to ensure that the harmful exhaust gases are removed from the area. To automate the process and to conserve energy ASHRAE recommends using a CO sensor to automatically operate the ventilation system when needed. The exhaust system can either remove air from the tailpipe of the ambulance directly or remove air from the room. For this design the air will be removed from the room to ensure that all contaminants from the vehicle entering or exiting the garage will be removed from the room.

18.2.1 Engine Exhaust

As specified the exhaust gases from a V8 engine must be removed from the garage. The engine is assumed to be a 6.7 L Cummings engine that produces around 300 Horsepower. Donaldson Engine Horsepower and Exhaust Flow Rate guide was utilized to determine the exhaust rate of the engine. The following equation is used to determine the flowrate. This calculations includes a room volume of 10,291 cubic feet, this is assuming the garage has a 13 foot ceiling. The exhaust flow rate is oversized to 2000 CFM since the calculated value is for the engine at idle. During testing when the fans are at full speed the system should be able to handle 11.67 air changes an hour or 2000 cubic foot per minute. For garages Greenheck Product Applications Guide suggests 2-10 minutes per air changes for proper ventilation, since the calculated value is 5.14 this can be considered a good design. The exhaust of the engine contains carbon in the form of soot, carbon monoxide, carbon dioxide,, oxides of nitrogen and sulphur to name a few compounds. These compounds can cause irritation, breathlessness and other health problems if they are not removed from the garage. Carbon monoxide and nitrogen dioxide must be monitored closely as they are major contaminants of the diesel vehicles.

$$\left(\frac{(Exhaust\ Temp\ (F)) + 460}{540}\right) * Intake\ Airflow\ (CFM) = Exhaust\ Flow$$

$$\left(\frac{956+460}{540}\right) * 620\ CFM = 1625\ CFM\ oversize\ to\ 2000\ CFM$$

$$\frac{10,291\ ft^3}{2000\ CFM} = 5.14\frac{min}{air\ change} = \frac{60\frac{min}{hr}}{5.14\frac{min}{air\ change}} = 11.67\frac{air\ changes}{hr}$$

18.2.2 Standards

ASHRAE 62.1 Section 5.15 specifies that buildings with attached parking garages must maintain neutral or negative pressure within the garage and use a vestibule system in order to prevent the air from entering the adjacent spaces. The exhaust gases from the engine are classified as Air Class 4. 62.1 Section 5.16.1 defines Class 4 as air that contains highly objectionable fumes or gases, potentially dangerous particles or gasses. Section 5.16.3.4 specifies that class 4 air shall not be recirculated or transferred to any space within the space of origin, this means the air must be directly exhausted from the room. 90.1 Table B-1 specifies the maximum allowable concentration of carbon monoxide of 9 ppm and 5 ppm for nitrogen dioxide for a short period of time. Any concentration above this could cause health issues. To maintain the room at negative pressure the exhaust rate must be greater than the supply rate. ASHRAE recommends using a carbon monoxide sensor to control the meter, however the system utilizes a system that detects both carbon monoxide and nitrogen dioxide to control the fans.

18.2.3 Ventilation System

The system will utilize two variable speed fans with a capacity of 2000 cfm each. By the affinity laws, the power consumption is a cubic function of the fan speed. This means that having two fans operating at half capacity will reduce the energy consumption by one eighth when compared to a single fan system. In addition the noise pollution caused by the system will also be decreased as the fans will be operating at half speed. Two fans also provides redundancy, should one fan fail the other fan can be operated at 100% until repairs are made. The fans are also located in the ceiling of the garage and will be easily serviceable. The E point sensors can detect levels of carbon monoxide and nitrogen dioxide and send a signal to the 301C controller unit when the concentrations of the gases reaches the critical levels discussed in Section 18.2.2. Mechanical Louvers located at the entrance of the garage will be automatically controlled to ensure the room is properly pressurized. This can be accomplished by placing additional E point sensors in rooms adjacent to the garage. If the sensors in the adjacent rooms detect any carbon monoxide or nitrogen dioxide, which is an indication of inadequate negative pressure, then the mechanical louvers will automatically be adjusted and the fan speed increased. This will ensure the proper negative pressure is achieved. Ducts will be connected to the fans to exhaust the air into the outside environment. The exhaust location must be located far from any entrances, walkways, air intakes or other sensitive areas. The team recommends having an exhaust on the roof of the building main building.

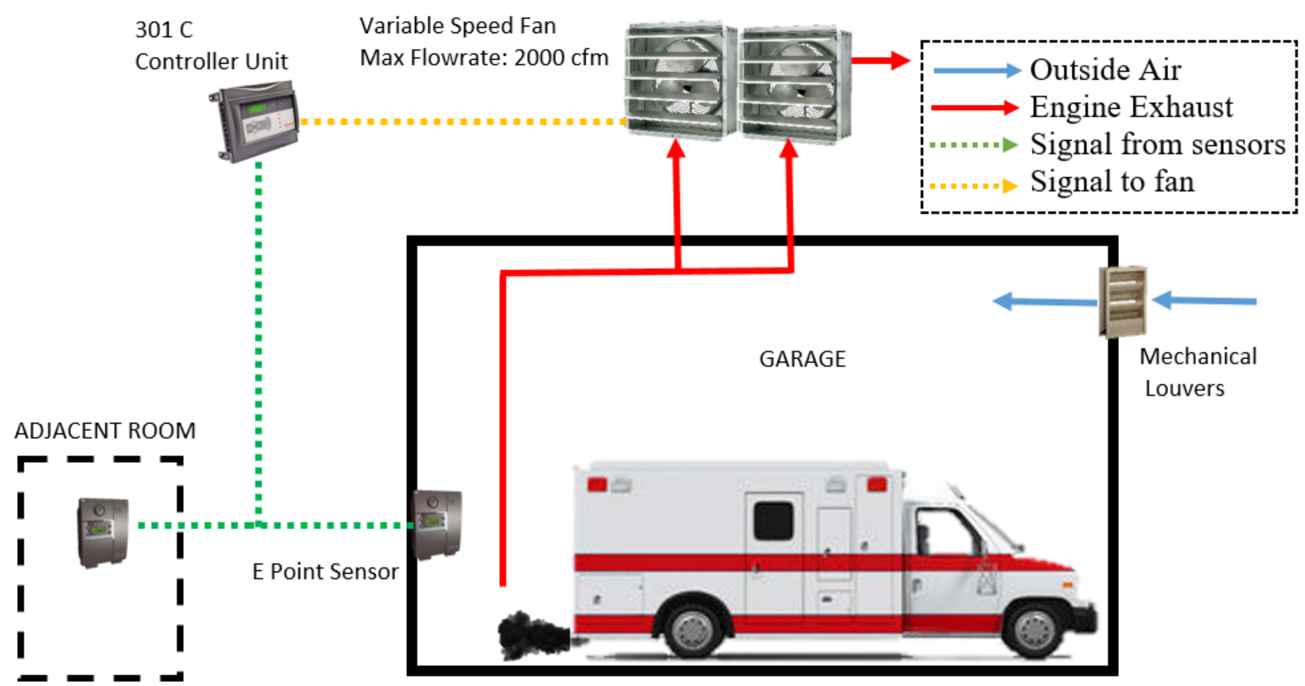


Figure 18.4 : Garage Ventilation System Line Diagram
Source: Authors

Ground Pipe Network

$$q_{cond} = q_{lc} * \frac{EER+3.412}{EER} = -720{,}000\,\frac{Btu}{hr} * \frac{15.51+3.412}{15.51} = -878{,}390\,\frac{\text{Btu}}{\text{hr}}$$

$$q_{evap} = q_{lh} * \frac{COP-1}{COP} = 400{,}000\frac{Btu}{hr} * \frac{5.01-1}{5.01} = 320{,}159\frac{\text{Btu}}{\text{hr}}$$

$$q_a = \frac{q_{cond} * EFLH_C + q_{evap} * EFLH_h}{8760\ hr} = \frac{-878{,}390\frac{\text{Btu}}{\text{hr}} * 760\ hr + 320{,}159\frac{\text{Btu}}{\text{hr}} * 245\ hr}{8760\ hr} = -67253\frac{Btu}{hr}$$

$$Fo_f = \frac{\left(4\ x\ 1.0\frac{ft^2}{day} * 3680.167\ days\right)}{\frac{5}{12}^2 ft} = 84{,}800 \rightarrow Figure\ 16\ of\ HVAC\ Applications \rightarrow G_f = 0.96$$

$$Fo_1 = \frac{\left(4\ x\ 1.0\frac{ft^2}{day} * 3680.167\ days - 3650\ days\right)}{\frac{5}{12}^2 ft} = 695 \rightarrow Figure\ 16\ of\ HVAC\ Applications\ Chapter\ 34 \rightarrow G_1 = 0.58$$

$$Fo_2 = \frac{\left(4\ x\ 1.0\frac{ft^2}{day} * 3680.167\ days - 3680\ days\right)}{\frac{5}{12}^2 ft} = 3.85 \rightarrow Figure\ 16\ of\ HVAC\ Applications\ Chapter\ 34 \rightarrow G_2 = 0.21$$

$$R_{ga} = \frac{(G_f - G_1)}{k_g} = \left(\frac{0.96 - 0.58)}{1.4\frac{Btu}{hr - ft - F}}\right) = 0.271\frac{hr - ft - F}{Btu}$$

$$R_{gm} = \frac{(G_1 - G_2)}{k_g} = \left(\frac{0.58 - 0.21)}{1.4\frac{Btu}{hr - ft - F}}\right) = 0.264\frac{hr - ft - F}{Btu}$$

$$R_{gst} = \frac{(G_2)}{k_g} = \left(\frac{0.21)}{1.4\frac{Btu}{hr - ft - F}}\right) = 0.15\frac{hr - ft - F}{Btu}$$

$$L_C = \frac{q_a R_{ga} + q_{cond}(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} =$$

$$= \frac{-67253\frac{Btu}{hr} * 0.271\frac{hr - ft - F}{Btu} + -878{,}390\frac{\text{Btu}}{\text{hr}} * \left(0.45\frac{Btu}{hr - ft - F} + 0.25 * 0.264\frac{hr - ft - F}{Btu} + 1.04 * 0.15\frac{hr - ft - F}{Btu}\right)}{65F - 95F} = 16772ft$$

$$Number\ of\ Vertical\ Bores = \frac{(16772ft)}{260\ ft/bore} = 65\ bores\ (approx.\ 1\ ton\ per\ bore)$$

ZONING AND DUCTING LAYOUT

Figure 20.1 : First Floor Zoning Plan

Figure 20.2 : Second Floor Zoning Plan

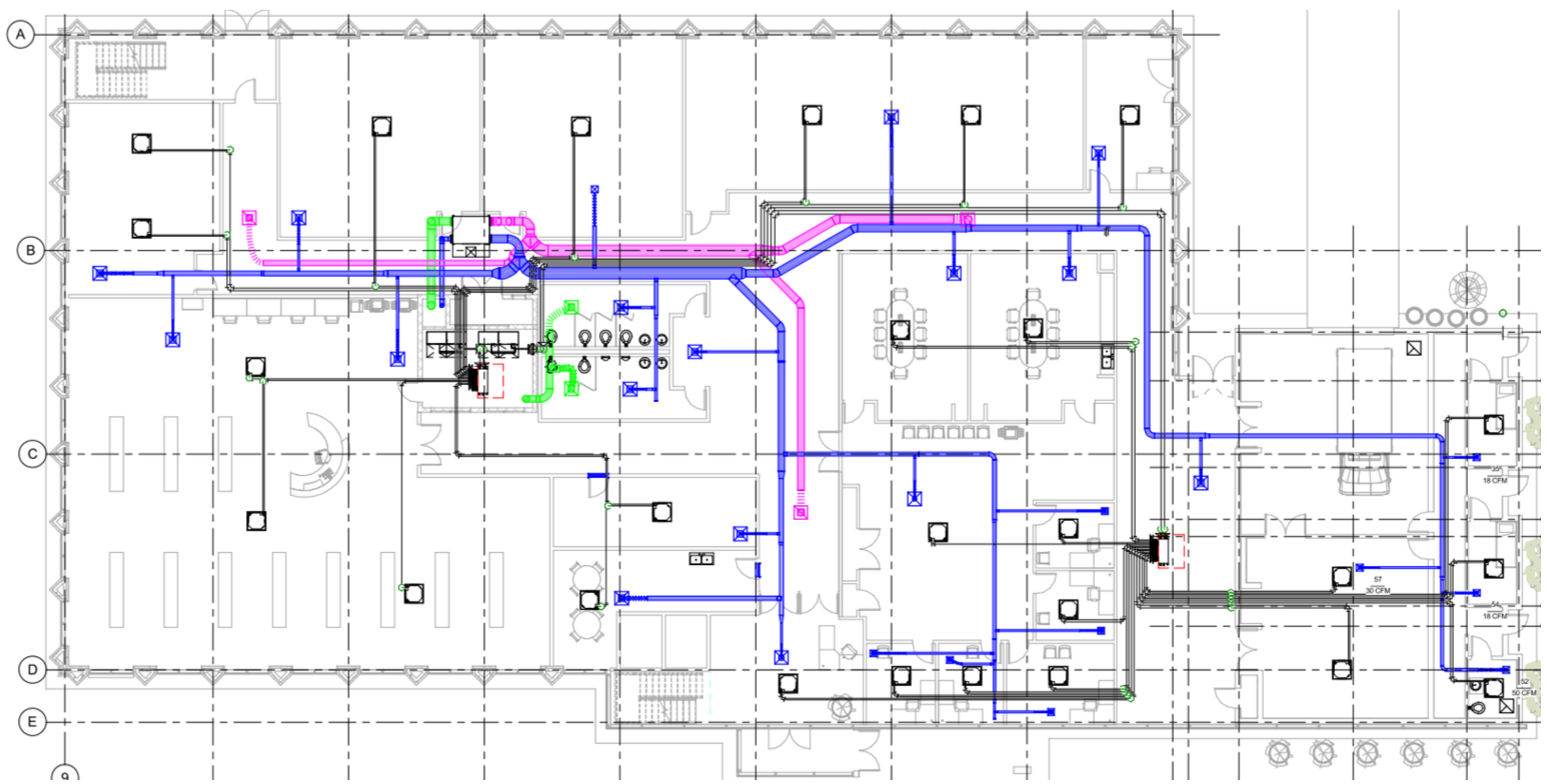


Figure 20.1 : First Floor Ducting and Refrigerant Piping Plan

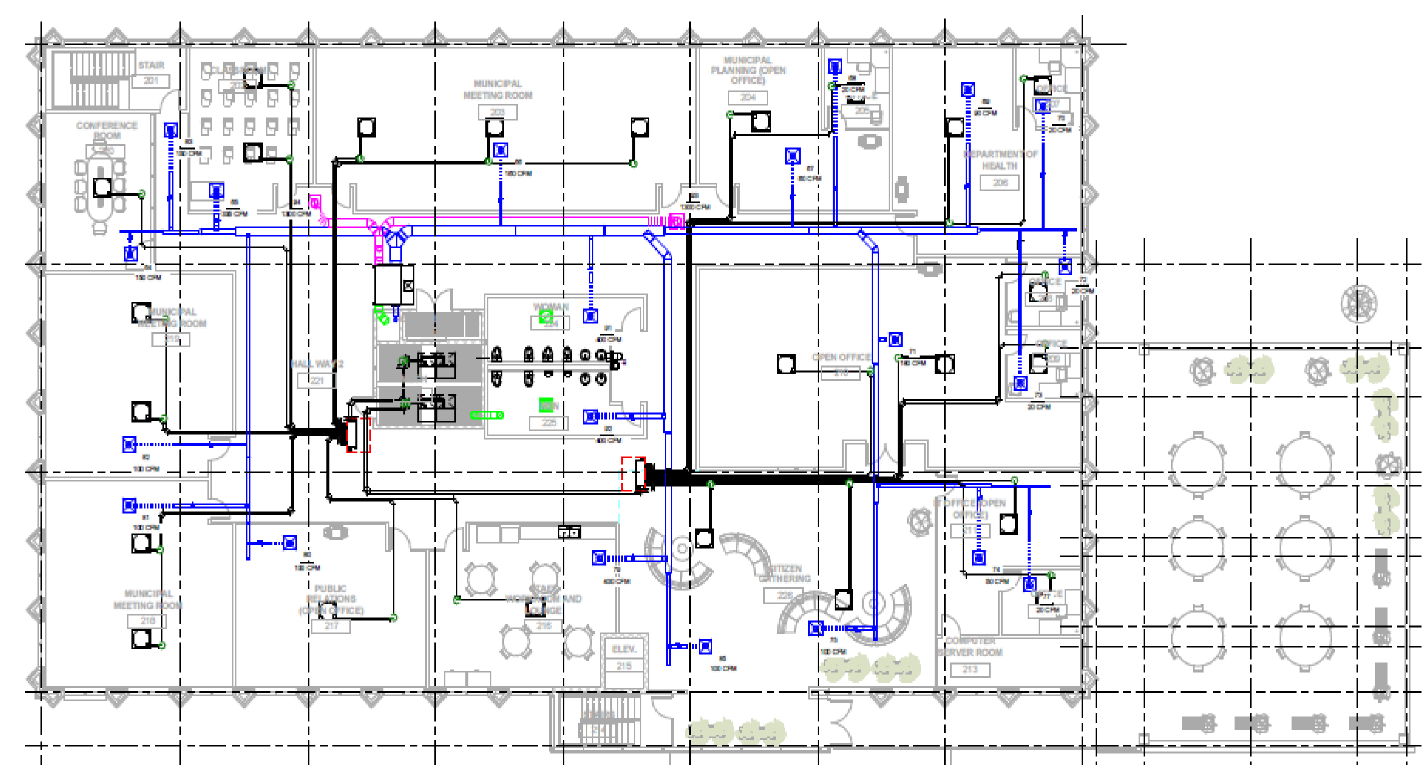


Figure 20.2 : Second Floor Ducting Plan

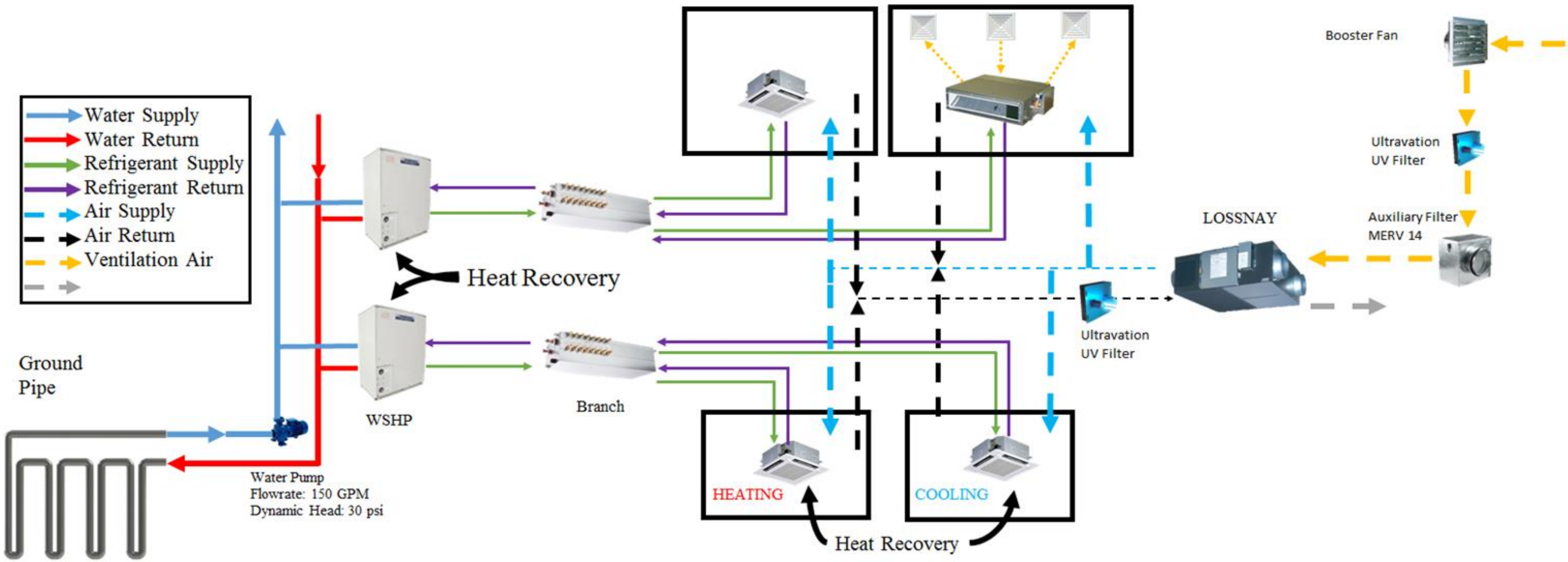


Figure 21.1 : Schematic Diagram of VRF system with Ground Coupled Heat Pump

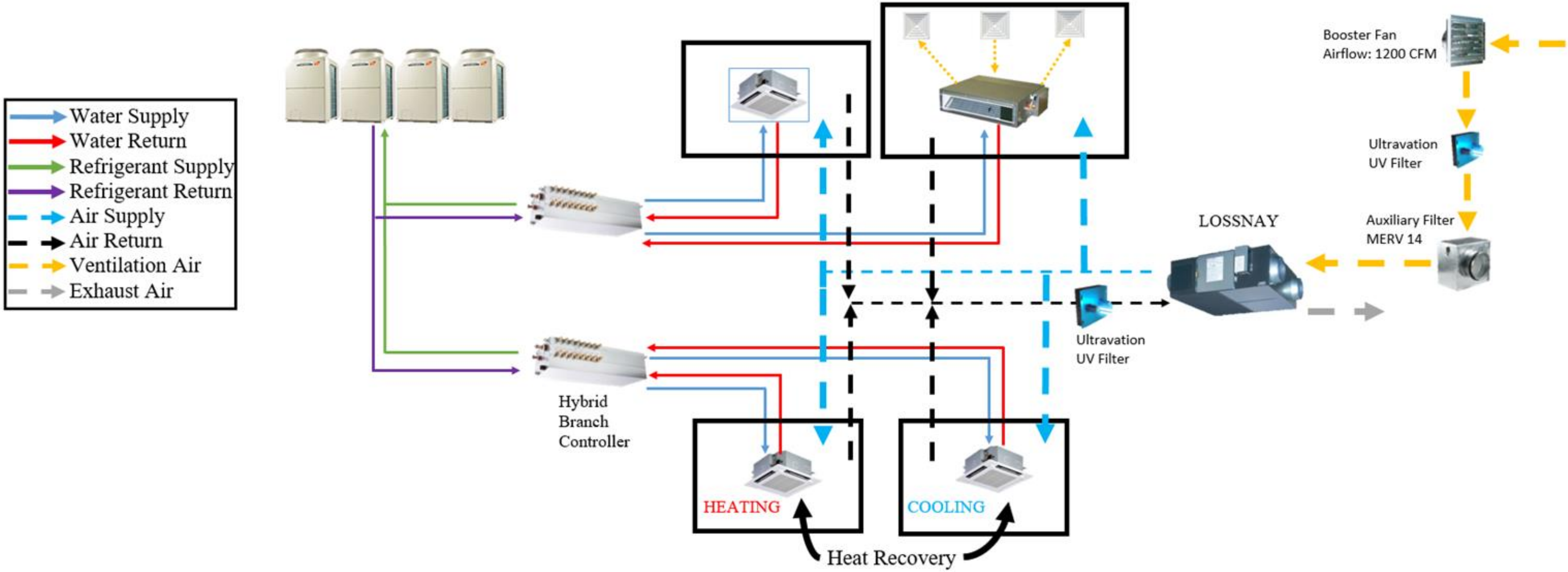


Figure 22.1 : Schematic Diagram of Hybrid VRF System

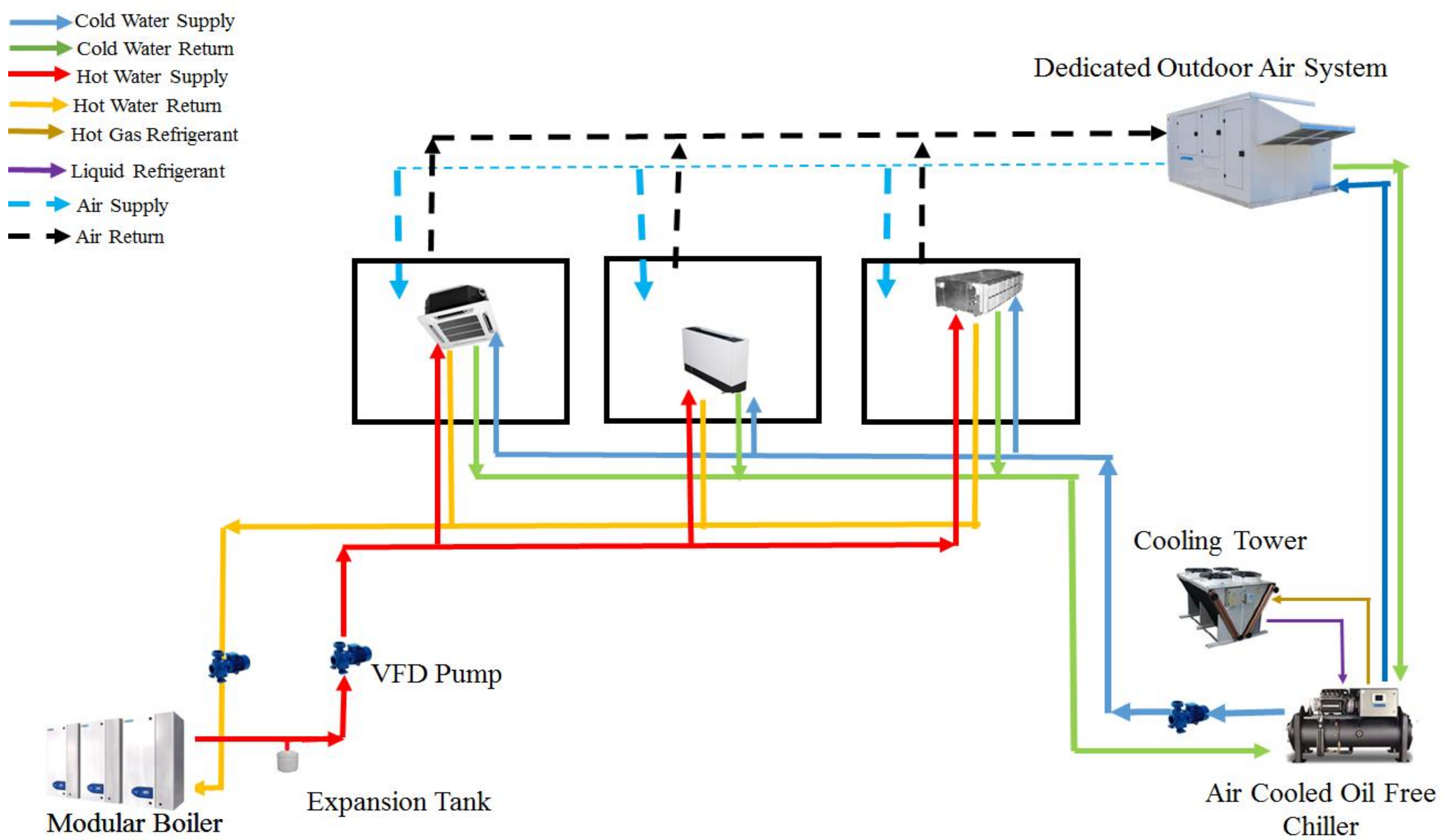


Figure 23.1 : Schematic Diagram of Hydronic Fan Coil System

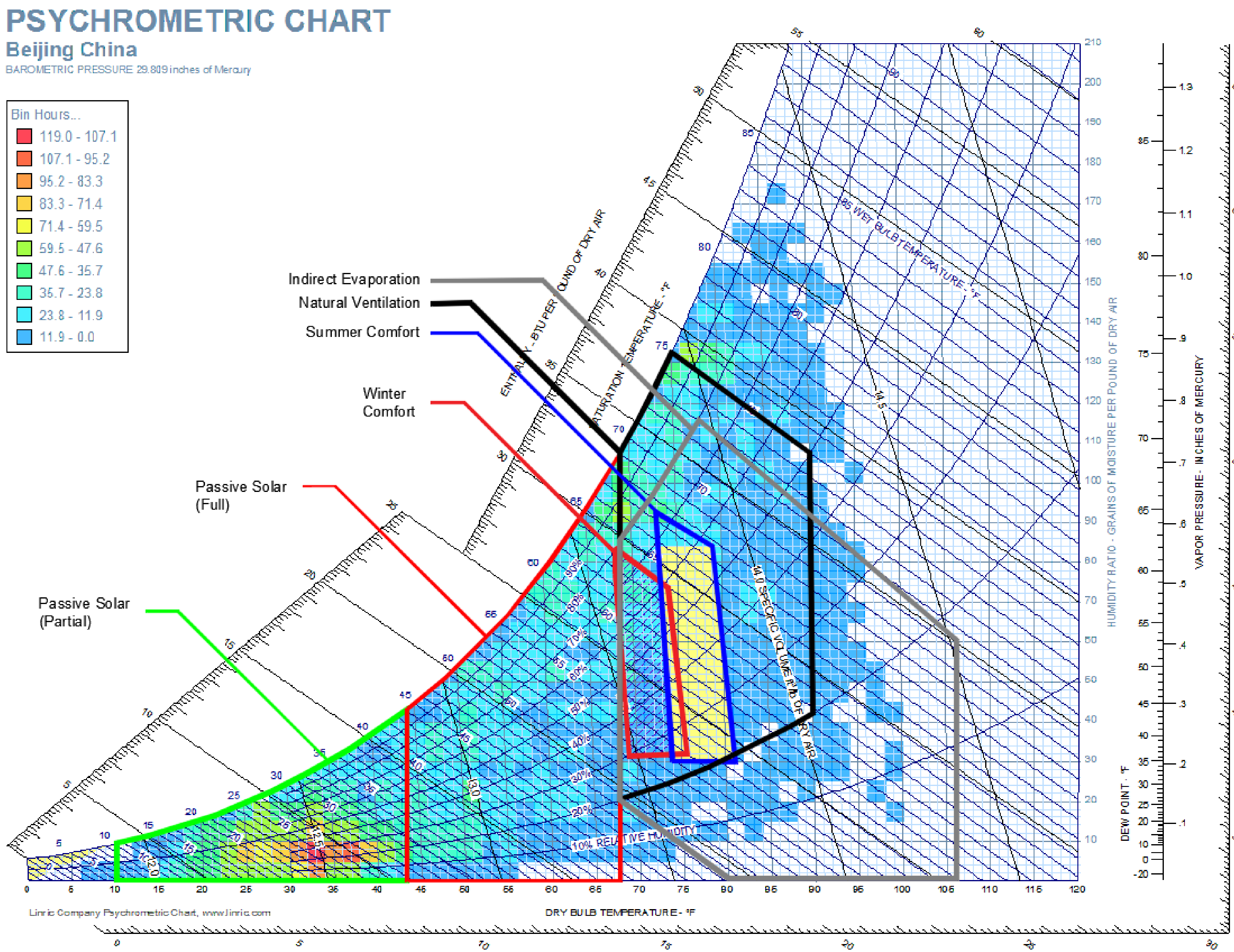


Figure 24.1 : Psychrometric Chart, Source: PsycPro Software. Areas indicated are from ASHRAE Energy Design Guide for Small to Medium Office Buildings

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