1. Project description

1.1 Introduction

The project consisted of a new building to expand the offices of an architectural firm, both owner of the building and designer architect on the project. This building, located on [redacted] in [redacted], has a mixed use: it allows for the expansion of the firm's offices on the first floor and the mezzanine, as well as the development of residential spaces on both higher levels. The building has an area of approximately 14,000 ft^2 spread over 5 levels, including the basement and the mezzanine (on the ground floor). In the basement, the building houses changing rooms, showers, and toilets. Offices are located on the ground floor and on the mezzanine. This part of the building has a maximum capacity of 40 occupants. The normal expected occupancy is 25 employees currently. Levels 2 and 3 house dwelling units, i.e. 8 housing units in total, with an average capacity of 1 to 2 occupants per unit. The building obtained Zero Carbon Building certification from the CaGBC ([redacted]). In addition, the project obtained LEED V4 (BD+C: Multifamily Midrise) Platinum level certification. Due to the use of wood mainly for its structure, the project won the Sustainable Development prize at the [redacted] Excellence Awards gala, thus rewarding its low embodied carbon footprint.

1.2 Design conditions

Outdoor conditions: The outdoor conditions for the design of HVAC systems are determined in the [redacted] Construction Code, which has force of law for new construction projects on the territory of the province. For comparison, the table presents the ASHRAE conditions for [redacted] airport station.

	[redacted] CODE	ASHRAE
Winter – Heating	T_2.5% DB = -9.4°F HDD65 = 7560	T_99% DB = -4.3°F HDD65 = 7662
Summer - Cooling	T_2.5% DB = 86°F T_2.5% WB = 73.4°F	T_1% DB = 83.7°F T_1% WB = 70°F

Thermal comfort: The interior design conditions comply with the ASHRAE 55 standard with the PMV method. During mid-season periods, natural ventilation is allowed in the offices through opening windows. The acceptable comfort temperature range is then extended based on the ASHRAE 55 adaptive comfort method with an acceptability of 80%. Office hours are from 8 a.m. to 6 p.m. Monday to Friday.

	SETPOINTS
Heating	DB min = 69.8°F RH min 20%
Cooling	DB max = 78.8°F RH max 50%

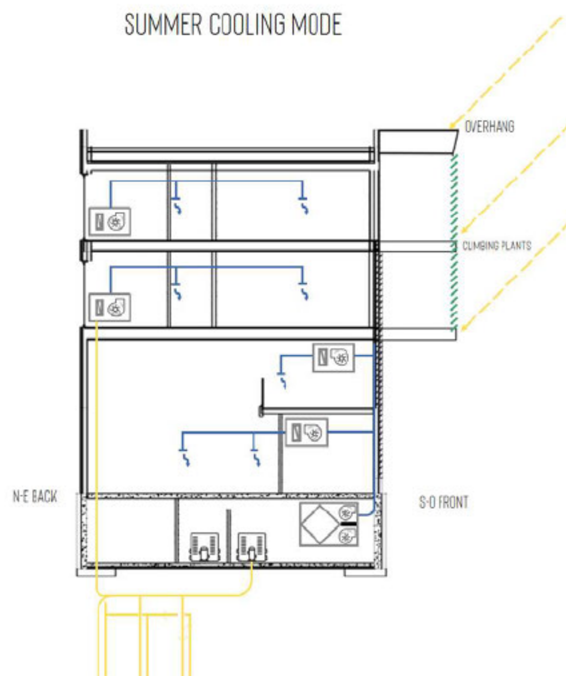
2. Design and system description

The desire to achieve Zero Carbon Building (ZCB) certification from the CAGBC immediately laid the foundations for an effective project. Indeed, this certification requires achieving an TEDI as low as 34 kWh/m^2 (thermal energy demand intensity for heating the envelope and ventilation, excluding the efficiency of mechanical systems). This ambitious goal forced the entire team to adopt a design approach in which reducing loads at source is prioritized before treating residual loads with renewable and efficient energy. Loads reduction strategies include efficient envelope, natural ventilation, efficient lighting, energy recovery from exhaust air, radiant floor heating. Residual treatment strategies include geothermal heat pumps, on-site energy production with photovoltaic solar panels.

2.1 Building envelope and passive systems

The performance of the envelope is mainly based on the use of triple glazed for all windows and patio doors, which greatly reduces heating loads compared to reference. The insulation of the walls and roof is also superior to the ASHRAE 90.1-2010 standard, which is the reference standard for the energy performance of the building within the framework of LEED V4 certification. In addition, the envelope is designed to respect the principles of bioclimatic design. On the one hand, the balconies on the upper floors cut off direct solar gain in summer, while allowing winter solar rays to penetrate the areas in order to benefit from passive heating in winter. This strategy is particularly important for offices in which the cooling load is quite large given the density of workstations. The south-east facade has a fence with climbing plants which reduces solar gain and cooling loads in summer for upper levels. In winter, leaves fall, and solar energy passes through windows to provide a passive heating source. The green roof reduces solar gain through the roof for the upper floor and contributes to the reduction of heat islands, which is particularly a problem in urban neighborhoods of [redacted]. Finally, the fenestration of the offices allows natural cross-ventilation providing sufficient passive cooling to avoid the heat pumps starting up mid-season. Ceiling low-velocity fans allow to extend the use of natural ventilation: the air movement contributes to comfort, allowing to delay the start of mechanical cooling with compressors.

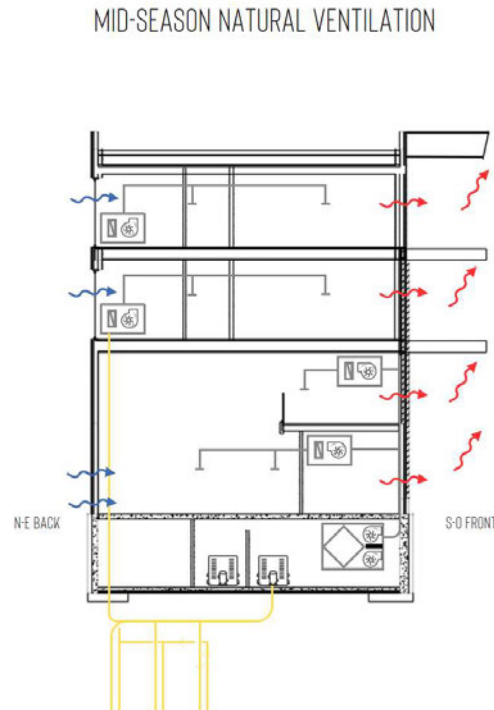
ASHRAE 90.1-2010 ZONE 6A			PROPOSED BUILDING	
Wall (h.pi2.F/Btu)	R 15.6	Wall above grade (steel frame)	R 21.6 R 19.2	M1A – Brick M2A – Metal
Roof (h.pi2.F/Btu)	R 20.8	Roof (entirely above deck)	R 46.3 R 35.2	T1 – Main roof T3 – Staircase roof
Windows (Btu/h.pi^2.F)	U 0.556	Vertical windows (metal framing)	U 0.190 U 0.220 U 0.230	Fixed windows Window doors Patio doors



2.2 Lighting

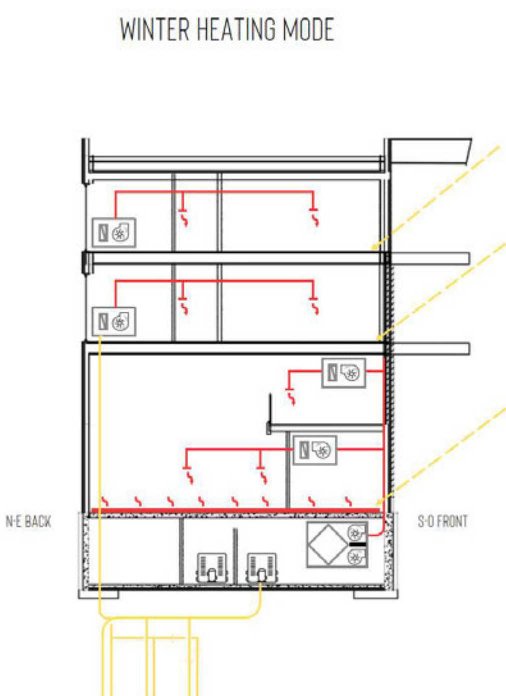
In order to reduce loads, an effort was made to reduce lighting density. All premises are lit by LED luminaires. The installed lighting density varies from 0.4 to 0.8 W/ft^2 for the offices.

2.3 Ventilation



Outdoor air: For offices, the required quantity of outdoor air was determined using the ASHRAE 62.1 standard, using the Ventilation Rate Procedure. A total nominal flow rate of 900 CFM is required for offices ($E_z = 1$). The outdoor air is supplied via a DOAS with heat recovery on the exhaust. Given the low flow rate required, the type of system chosen is an ERV with enthalpy recovery (sensible efficiency 67%, latent efficiency 45%). The DOAS supplies fresh air to the return of the zone fan-coils. Ventilation operates on schedule.

For dwelling units, the outdoor air flow was calculated using the regulatory method requested by local authorities: National Building Code section 9 (method based on the CSA F326 standard). Each unit has its own dedicated ERV (nominal flow 100 CFM, sensible efficiency 66%, latent efficiency 46%). Each air exchanger feeds its flow into the return of the geothermal heat pumps of the dwelling units.



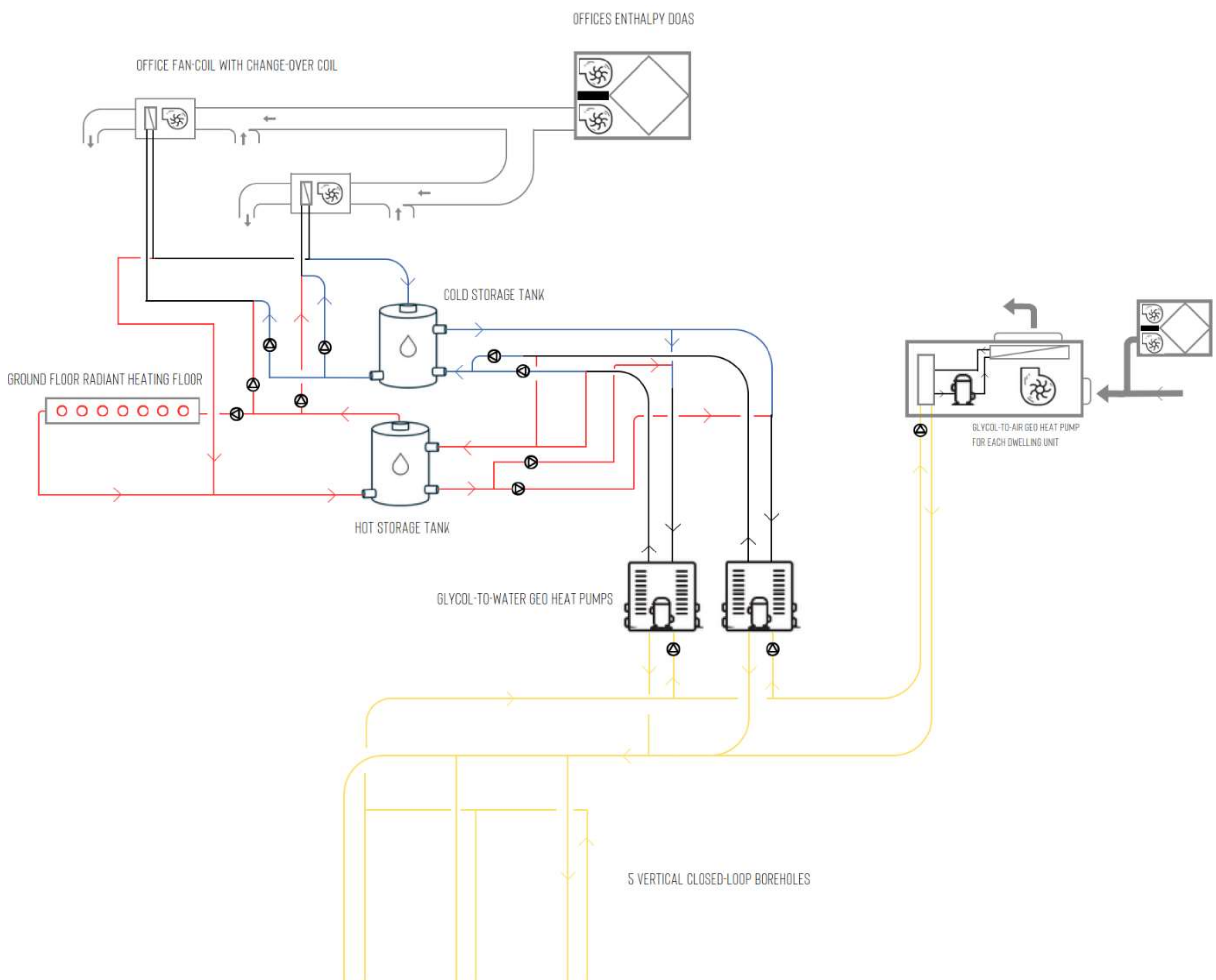
Indoor air quality: The office ventilation system has a MERV 8 filter, as do the office zone fan-coils which operate in recirculation. Geothermal heat pumps in dwelling units are equipped with a MERV 8 filter. The outdoor air supplied by the ERVs is connected upstream of this filter in the return of the heat pumps, although the air is already filtered in the ERVs directly.

2.4 Heating and cooling

Geothermal heat pumps are used to handle 100% of heating and cooling loads in offices and dwelling units. The geothermal loop is made up of 5 closed-loop vertical boreholes in which propylene glycol circulates. The boreholes are 425 ft deep. A pump is dedicated to geothermal wells.

Offices: The offices are equipped with two glycol-to-water geothermal heat pumps. The heat pumps supply two hydronic loops: a chilled water loop and a low temperature hot water loop. Heat pumps can operate in heating mode or in cooling mode. Each heat pump has its primary pump on the source and load sides.

- Heating capacity: 61 500 Btu/h each at 32°F on source, COP 2.9
- Cooling capacity: 68 400 Btu/h each at 77°F on source, EER 14



In terms of heating, the ground floor offices and the conference room are heated using a water-loop radiant floor heated by the geothermal heat pumps. The use of the radiant floor makes it possible to reduce the air temperature without compromising the comfort of the occupants. The other zones are heated with zone fan-coils. The fan-coils have a hydronic change-over coil. Coil capacity is sufficient to handle 100% of the heating load. An electric coil is installed in the supply duct, but it only starts in the event of a breakdown in the heat pumps. When cooling is needed, zone fan-coils supply air conditioning. Each fan-coil is supplied with water by its own secondary pump.

Dwelling units: Each dwelling unit is equipped with its own glycol-to-air geothermal heat pump.

- Heating capacity: 11 500 Btu/h each, COP 3.5
- Cooling capacity: 14 700 Btu/h, EER 17.2

Since dwelling units are rental units, an electric coil is installed in the heat pump supply duct in redundancy with the compressor. The capacity of the heat pump is sufficient to handle 100% of the heating load. The electric coil only starts in the event of a breakdown in the heat pump.

2.5 Domestic hot water

Domestic hot water for the offices is supplied by an electric water heater (3.8 kW, 85 us gal). Each dwelling unit is served by its dedicated electric water heater (4.5 kW, 48 us gal each). Note that in [redacted], electricity rates are fairly low and electricity is produced by hydro-electricity with a GHG emission rate of 2.04 gCO_2/kWh.

2.6 On-site renewable energy

A photovoltaic solar system made up of 36 bifacial PV panels is installed on the roof, for a total power of

	PV panels production	On-site renewable energy
	kWh	%
Predicted	18 380	12
Actual	17 935	18

14.5 kW. Initial modeling predicted production of 18.4 MWh annually. Actual consumption measured from September 2022 to August 2023 is 17.9 MWh, very close to predictions. This production represents 12% of total annual electrical energy required (offices and dwelling units).

3. Energy performance results

The following table presents annual energy consumption, simulation predictions and actual results based on energy bills (excluding PV panels contribution). The energy cost comparison with ASHRAE 90.1 baseline is shown in the next pages in section *6. Cost effectiveness*.

	Energy consumption and peaks for whole building (offices and dwelling units)		
	kWh	**kW**	**GJ/m²**
Simulation ASHRAE 90.1	257 246	135	0.71
Simulation proposed	153 966	49	0.45
Actual	100 291	68	0.29

TEDI: For Zero Carbon Building (ZCB) certification, the targeted TEDI was 34 kWh/m². The energy simulation demonstrated a predicted **TEDI of 23,9 kWh/m²**, which was accepted by [redacted] (CaGBC).

4. Innovation

Beyond the energy performance of the HVAC systems described above, several innovations were put forward in the project.

Solar panels are bifacial. In an area with a snowy winter, this innovation makes it possible to maximize panel production. In winter, when the panels are covered with snow, the underside still allows the radiation reflected by the snow from the roof to be captured. The panels therefore continue to produce electricity. Heat losses from panels in production accelerate the melting of snow on the top of the panels, which increases winter production.

Achieving **Zero Carbon Building (ZCB) certification** is in itself an innovation since this certification was relatively new when the project was designed. It certifies a neutral carbon footprint considering the whole balance: embodied carbon, operational carbon, fugitive emissions, and residual carbon offset.

On the load side of glycol-to-water geothermal heat pumps for offices, there are **two storage tanks**: one for hot water and one for chilled water. These tanks make it possible to absorb sudden load variations on the hydronic loops, avoiding compressor cycling, limiting electrical peaks, and allowing tighter sizing of heat pumps. Also, the tanks allow a certain volume of chilled water to be available even when the heat pumps operate in heating mode, vice-versa. This helps meet hybrid mid-season loads if required.

As geothermal boreholes are sized to meet full heating load, heating his provided with great COP even during peak periods. Combine to storage tank, **this strategy allows to reduce electric winter peak demand** which is a major problem in [redacted]. The building contributes to the province peak management effort.

In terms of **water conservation measures**, office toilets include hybrid waterless urinals (a flush of 3.8 L every 72 hours).

5. Operation and maintenance

Periodic maintenance of the systems is carried out by an external subcontractor. However, the building is operated by employees of the architectural firm. It was therefore important that the control and operation of the HVAC systems was simple. A low-tech approach was therefore chosen for the design of the control system.

Offices: A centralized controller integrates the programming of the fan-coils. Each zone is equipped with a room thermostat whose demand controls the fan-coil hydronic coil valve and the radiant floor valve. The DOAS operates according to a schedule consistent with office occupancy hours. The chilled water storage tank is maintained at 45°F and the hot water storage tank is maintained at 97°F (low temperature). The glycol-to-water geothermal heat pumps start to maintain the set point of the tanks and according to the demand of the fan-coils. For example, the cold tank is not maintained in winter when no zone is in cooling.

Room set points and operating schedules are accessible and editable by office employees via a minimalist, easy-to-interpret web graphical interface. During unoccupied periods, the office temperature setpoint is allowed to drift from 3.6 to 5.4°F depending on the season. Prioritizing the reduction of thermal loads at the source made it possible to reduce the sizing of equipment and reduce the quantity of equipment, reducing therefore maintenance cost.

Dwelling unit: Each geothermal glycol-to-air heat pump has its own control panel directly integrated into the equipment allowing the compressor stages to be activated according to the request of the room thermostat. ERVs have their own residential-style wall controller.

6. Cost effectiveness

Energy cost: In terms of annual energy cost, the proposed building presents an annual saving **of 52.3% compared to ASHRAE 90.1-2010** reference building (excluding contribution of PV panels), which has been approved and recognized by LEED.

Construction cost: The total cost of the project was approximately \$4.5 million (CAN). Out of the total, the mechanical-electrical costs are detailed in the table beside. The pandemic has affected the construction site in terms of schedule delays and cost. A cost reduction effort was made. In particular, the hydronic coils for outdoor air treatment have been removed from the project. The residual thermal load at the DOAS outlet is treated by the zone fan-coils. The fresh air loads are relatively low and the recovery efficiencies relatively good. As explained above, a low-tech approach was

SUB-TRADES	COST $ (CAN)	UNITARY $/SQ.FT.
Plumbing	200,000	14.29
HVAC	350,000	25.00
Electrical	305,000	21.79
PV system	58,000	4.14

recommended in terms of controls to reduce costs and complexity. The selected heat pumps have their own integrated circulator, which made it possible to reduce the costs of pumps installation and connection to the site. The quantity of zone fan-coils was minimized by combining zones with the same thermal demand profile on the same unit. Noted that the roof, windows, geothermal heat pumps and ventilation systems, due to their energy performance, benefited from a subsidy from [redacted] (electricity energy supplier), via their program called [redacted].