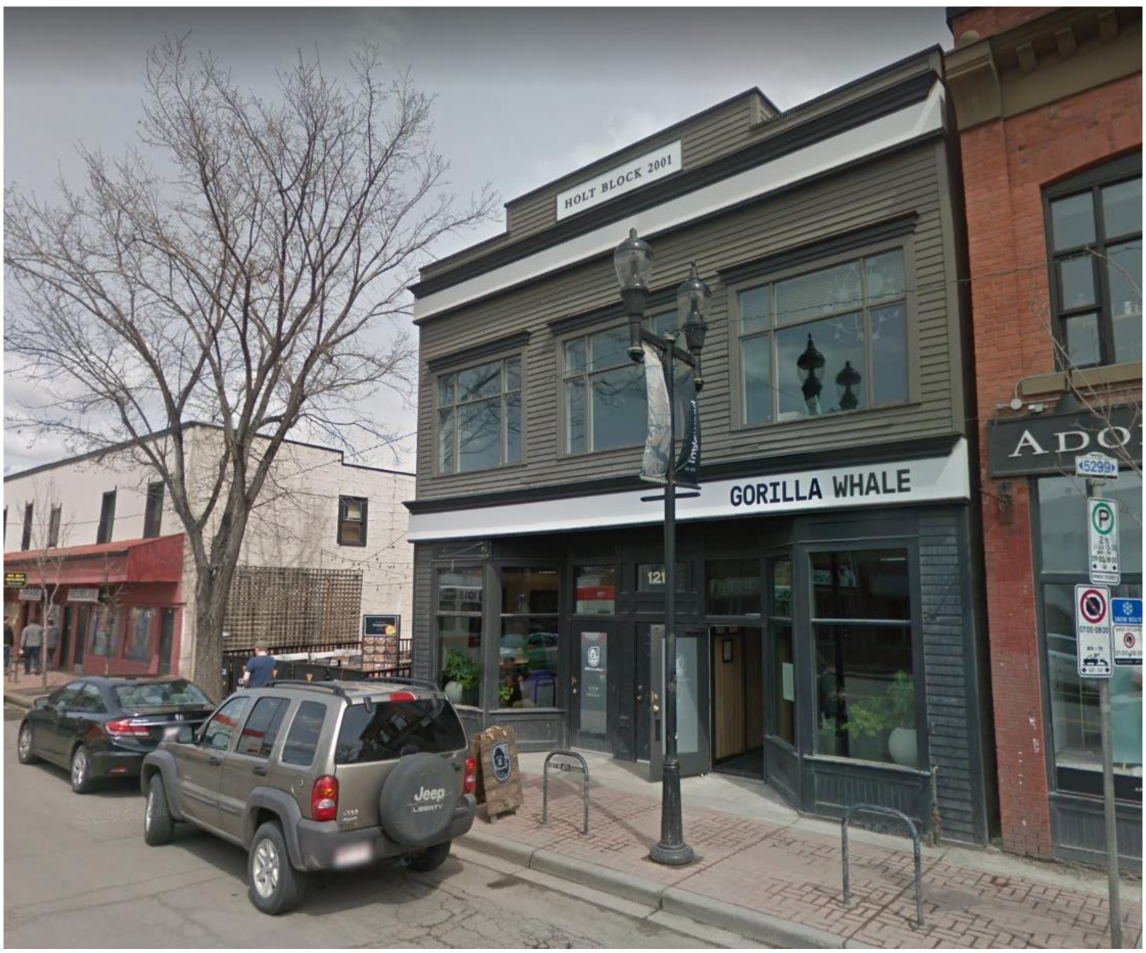
ENME 583: Mechanical Systems in Buildings – Term Project Report
Prepared for Dr. Simon Li

Designing HVAC System for a Two-Story Multiuse Building in Calgary



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Executive summary:

Presented is a Heating, Ventilation, and Air-Conditioning project with the objective to design and investigate the HVAC systems. The primary modeling steps are inputting design conditions; modeling the building envelope; developing occupancy, lighting, and cooking schedules; inputting internal loads; and configuring a HVAC system. The modeling and simulation are performed with eQuest. eQuest is a DOE sponsored building energy simulation software. The building modelled is in Calgary, Alberta – as shown on the cover letter. The site is a 532m^2 mixed-use building with two floors: the ground floor is an office, and the top floor is a restaurant.

The HVAC system modeled is a Packaged Single Zone DX with Furnace; one for each floor. The cooling system is a DX Cooling Coil which is energized by electricity and the heating system is a natural gas furnace operates on combustion. The results are as follows: peak cooling load for the entire building is 30 kW and the peak heating load is -73.40 kW. Annual energy consumption for the building is 1,052 GJ. The office (ground floor) has a peak cooling load of 12.32 kW and the peak heating load of -32.36 kW. The restaurant (top floor) has a peak cooling load of 15.65 kW and the peak heating load is -41.17 kW. Temperature data for monthly and hourly calculations were extraction from Calgary weather station 718770 (CWEC).

Section 1: Description of building

The building is a two-story mixed used building on 19th Avenue SE, Calgary, Alberta. The lower floor is an office, and the upper floor is restaurant. The building is 27.9 m long and 9.5 m wide, furthermore it is 8m high (until roof deck). Each floor has is 266m^2 of floor space – 532 m^2 in total. The walls are constructed with the following materials: 200 mm concrete block, 25.4 mm air space, 75 mm ridged insulation, and 12.7 mm gypsum board. The roof is constructed of the following materials: 12.5 mm fiberboard, 100 mm rigid insulation and, 12.7 mm gypsum board, 38 mm metal deck. All windows are double glazed sealed units. The orientation of the building is such that true north and building north are congruent. There are assumed to be no adjacent buildings. This information is extracted from the Integral Group – Coordination Set.

Section 2: Design conditions

The design conditions include two days: winter design day for heating and summer design day for cooling. The winter design day falls on January 21st and has a dry bulb and wet bulb temperature of -29.1°C and a dry bulb range of 0°C. Summer design day falls on July 21st and has a dry bulb temperature of 28.6°C and a wet bulb temperature of 15.7°C, where the dry bulb is ranging between 12.3°C. A 3D heat map of the Calgary temperature is created, the data extracted from Station 718770 (CWEC). The graph is as attached in Appendix A. It is important to note the variation in daily as well as annual temperatures. It also helps us contextualise the general climate of the location.

Figure 1 represents a sun path diagram of Calgary. As the location is in the northern hemisphere, the sun shines predominantly from the south, which is an azimuth of 180° according to the diagram. The elevation angle is at a maximum of 60° in summer noon and 15° at the winter noon. This elevation angle means that the sun will not be directly above (elevation = 90°) us during the noon time. Elevation angle of 60° (summer) to 15° (winter) indicates to an architect or an HVAC engineer that the sun will most likely be beaming into the windows when the sun is the brightest (during noon). If the building has a lot of south facing windows, incoming solar irradiation increases the summer cooling loads and reduces the winter heating loads and thus is an important design consideration.

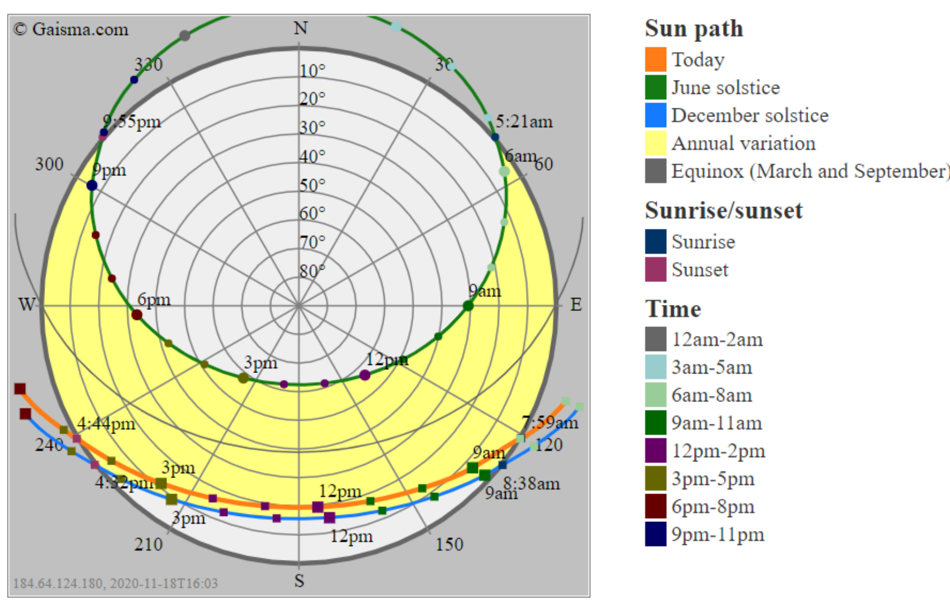


Figure 1. Sun path diagram of Calgary.

Section 3: Description of the building model

Zones and surfaces:

The model is divided into two zones. One for each floor; the ground floor, which is the office is Zone 1, the top floor which is the restaurant is Zone 2. Zone 2 can be further divided into two spaces, one for the kitchen and one for the dining space, but this was not implemented to reduce complexity. As the kitchen needs additional ventilation, exhaust, and cooling it would be recommended model upgrade in the next revision. As described in Section 1, the building has two primary surfaces: walls and roof. The floor is modelled like the wall with more concrete and insulation. Table 1 describes the wall and roof material construction in real life and the model. Window model is included too. Information for the wall and roof materials were derived from the Integral Group – Coordination Set.

Table 1. Construction (material assembly) of the surfaces as compared to real life.

Construction	Real Life	Model
Wall	200 mm concrete block	Conc HW 140lb 8in (CC05)
	25.4 mm air space	Air Lay <3/4in Vert (AL11)
	75 mm ridged insulation	Insul Bd 3in (HF-B4)
	152mm steek studs @ 400mm O.C	None
	12.7 mm gypsum board	GypBd 1/2in (GP01)
Roof	12.5 mm fiberboard	Plywd 1/2in (PW03)
	50 mm rigid insulation	Roof Insul 2in (IN74)
	50 mm rigid insulation	Roof Insul 2in (IN74)
	12.7mm gypsum sheathing	GypBd 1/2in (GP01)
	38 mm metal deck	Steel Siding (AS01)
	44x356mm plywood web joists	None
Window	Double Glazed Sealed Units	Double Visteon Versalux RC/Air/Clear 6mm
Door	Opaque Door Unknown	Wood, Solid Core Flush, 3.47cm

The heat transfer coefficients (U-value) were calculated for the modelled walls and roof. The U-value is a measure of the effectiveness of a material (or layers of materials) at reducing the heat transfer between inside and outside. The lower the U-value the better insulation ability. Appendix B describes the heat transfer parameters and the resulting U-value. The wall reveals a U-value of 0.440 W/m^2-°K and, coincidently, the roof also reveals a similar U-value of 0.443 W/m^2-°K. To contextualize these values, we can compare them with typical U-values of other building constructions. The U-value of a solid brick wall is 2 W/m^2-°K, a cavity wall will no insulation is 1.5 W/m^2-°K and a insulated wall is 0.18 W/m^2-°K. Recommended values for walls is below 0.18 W/m^2-°K and for roofs is 0.13 W/m^2-°K [1]. Our construction design does not meet the minimum required values, thus excessive heat loss will exist.

The door descriptions could be summarized with two facts: one door is 2.0m in height and 0.8m in width and that there are five doors at the north facing wall and one door at the South facing wall. The window descriptions can be summarized by stating the percent of window each wall is: 4% of the north facing wall is window and 32% of the south facing wall is window. The precent values were calculated from actual window dimensions to make the building design simpler. An image of the final constructed building is at attached in Appendix C. In the model, true north and project are assumed to be the same.

Internal gains and schedules:

As pointed out earlier the building has a multifunction use: it doubles as a restaurant and an office. The office has typical work hours and the restaurant only operates 10 hours a day. Both zones have setpoint temperatures for occupied and unoccupied hours. The values for each are outlined in table 2. There are three types of internal loads inputted in the model: lights, cooking, people. The lighting internal loads and occupancy are as described in table 2. The lighting and office schedules are visualized in Appendix D and E. Cooking load is assumed to be 50 W/m^2, where 25 W/m^2 is due to the electrical equipment and 25 W/m^2 is due to the natural gas equipment [2].

Table 2. Internal Gains and schedule summary.

	Working hours	***Winter setpoints** (°C)	***Summer Setpoints** (°C)	**Max Occupancy** (m^2/person)	**Lighting Internal Loads** (W/m^2)
Office	8am to 5pm Weekdays	21 (15)	24 (30)	20	11.9
Dinning	10am to 8pm Monday off	21 (15)	24 (30)	10	10.7
Kitchen	10am to 8pm Monday off	21 (15)	24 (30)	20	9.6

* Brackets represent unoccupied temperature.

Section 4: Description of the HVAC system

Peak load conditions:

The peak load conditions are calculated using Design Day conditions. As mentioned before: The winter design day falls on January 21st and has a dry bulb and wet bulb temperature of -29.1°C and a dry bulb range of 0°C. Summer design day falls on July 21st and has a dry bulb temperature of 28.6°C and a wet bulb temperature of 15.7°C, where the dry bulb is ranging between 12.3°C. **Peak cooling load for the entire building is 30 kW and the peak heating load is -73.40 kW.** For Zone 1 (Ground Floor), which is conditioned by System 1, the peak cooling load is 12.32 kW and the peak heating load is -32.36 kW. For Zone 2 (top floor), which is conditioned by System 2, the peak cooling load is 15.65 kW and the peak heating load is -41.17 kW. Figure 2 is a representation of the heat flows on peak heating and cooling days. It is created with the assumption that internal space temperature is constant, and ventilation is neglected. The 9 parameters used in the analysis show the magnitude of heat flows. As evident, for heating loads: wall conduction, roof conduction and infiltration, make a large impact on the loads. Whereas, for cooling loads, light to space, occupants and solar radiation window make a large impact on the loads. This will be further discussed in the Section 5 – improvements to reduce energy use.

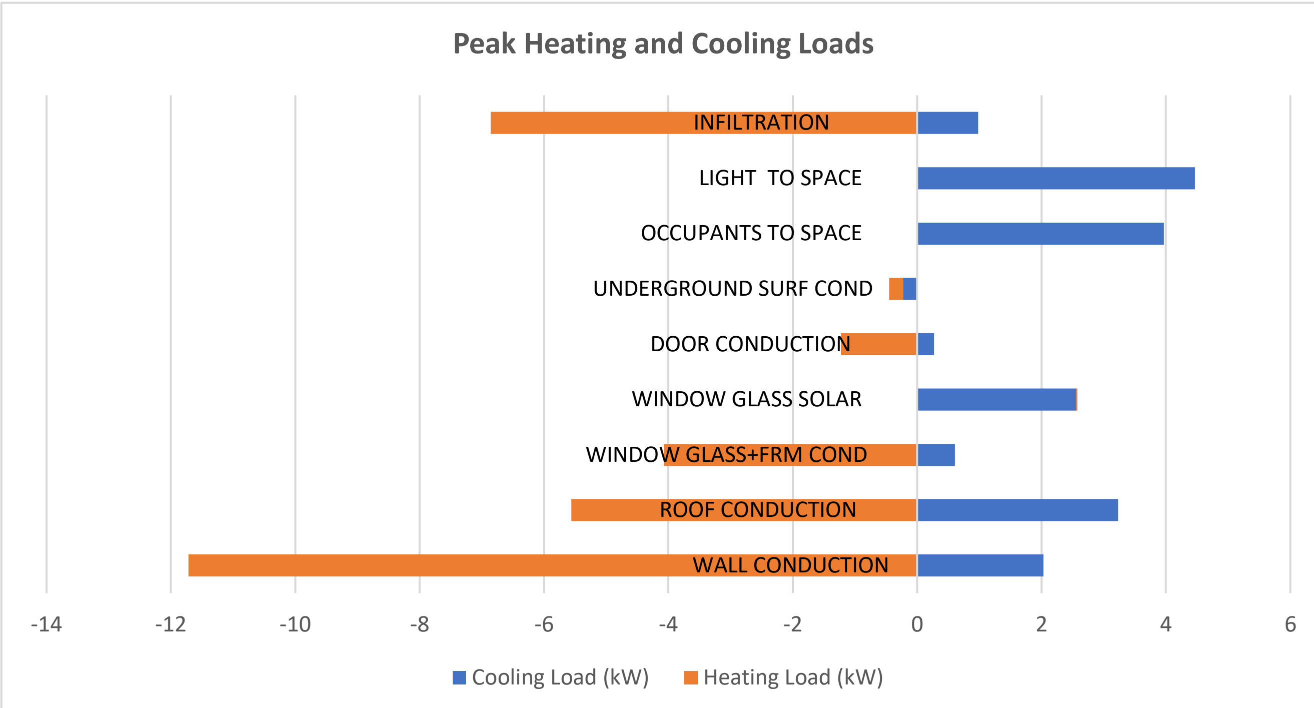


Figure 2. Heat flows on Design Days

HVAC system overview

Description of the resulting system:

The system is a “Packaged Single Zone DX with Furnace.” This system is a central packaged single zone air conditioner with combustion furnace. DX refers to Direct Expansion which utilizes the refrigeration effect to cool or remove heat from a space. The refrigeration employs a compressor which is energized with electricity. The furnace refers to a natural gas furnace which combusts natural gas to add heat to the space. The system is a single zone system which indicates that it handles only one floor. There are two systems in place for the building, one for the office and the other for the restaurant. Independent systems were chosen as the restaurant air might disperse unwanted aromas in the office space through the recycled air for a central system. Also, since, both spaces might be leased by different companies, individual tracking, billing and maintenance of the utilities may be desired. To avoid this, two independent systems were selected.

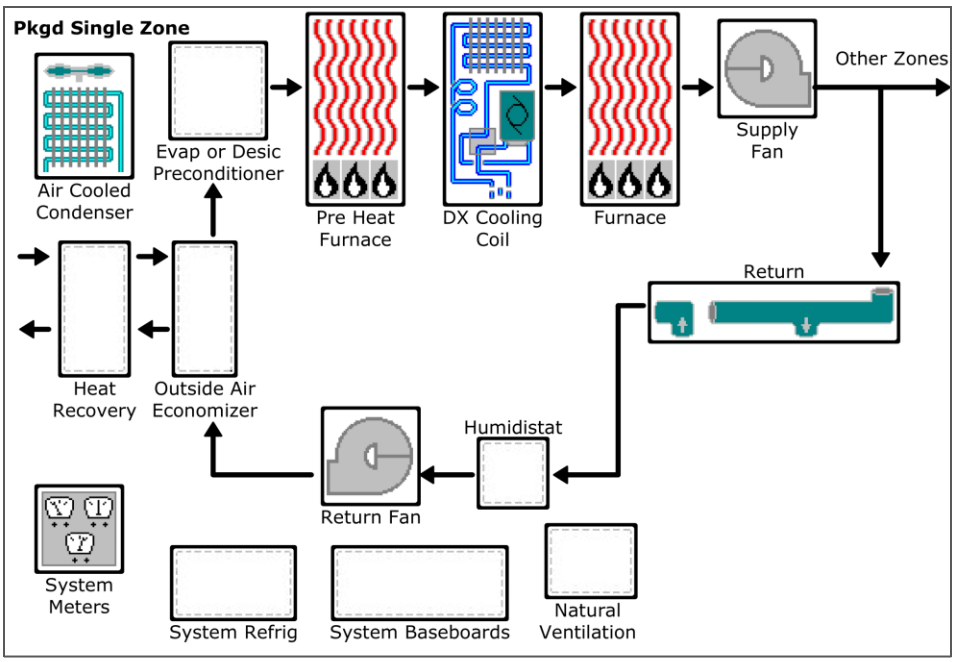


Figure 3. Packaged Single Zone DX with Furnace Schematic

The schematic above in figure 3 shows the active and inactive components of a Packaged Single Zone DX with Furnace system. Outside air enters from the left into the system and is received by the pre-heat furnace. Since the location is in Calgary, it is necessary to have a pre-heat furnace to protect the equipment from freezing. The air is then conditioned with either DX cooling coils or a natural gas furnace depending on the conditioning requirement. The air is then pushed by the supply fan into the zones. The air is then returned and a fraction of it is exhausted out of the system. The return fan then pushes the air back into a loop while fresh air is added to the system. The air cold condenser is positioned on the outside of the build which rejects the heat collected from the space out of the building. Components such as heat recovery, outside air economizer, preconditioner among others were not installed. Although this increases the efficiency of the system, it adds to the complexity of the model. The system is the same for Zone 2 (Restaurant).

Description of the specifications of major components:

There are three major components that which will be discussed in this section: DX Cooling coils, Furnace, and Supply fan. As mentioned before, both floors, the office and the restaurant utilize the same system type called a Packaged Single Zone (PSZ) with DX and Furnace. Therefore, both floors have the same components. The office utilizes a 4-ton DX cooling equipment, with a capacity of 12.32 kW and a Coefficient of Performance of 2.89. The restaurant employs the same grade of cooling equipment, at 4 tons, but with slightly higher cooling capacity at 15.65 kW. The COP is the same, at 2.89. The natural gas furnace is a has a capacity of -32.36 kW for the office and -41.17 kW for the restaurant. The efficiency for both components is the same at 81%. The last notable component discussed it the supply fan. The supply fan for the office has a flowrate capacity of 777 L/s with a power demand of 0.455 kW. The restaurant requires a slightly higher capacity at 790 L/s and has a power demand of 0.463 kW. Both fans have a static pressure of 1.2 in-H2O (or 298 Pa) and efficiencies of 0.53. The increased capacities for the components in the restaurant (upper floor) can be explained by higher loads in the restaurant floor (as demonstrated by figure 2). The restaurant has a kitchen which is has a heating load of 50 W/m^2, a higher occupancy heat load, larger window to wall ratio, roof conduction loss and larger ventilation requirements because of higher occupancy . Therefore, the restaurant requires larger capacities. The summary of the information presented above can be found in table 3.

Table 3. Summary of the specification for major components.

		System 1 (Office)	System 2 (Restaurant)
DX Cooling Coils	*tons*	4	4
	kW/m2	166.9	212.3
	Capacity (kW)	**12.32**	**15.65**
	COP	2.89	2.89
Furnace	*kW/m2*	-776.8	-900.6
	Capacity (kW)	**-32.36**	**-41.17**
	Efficiency	0.806	0.806
Supply Fan	*Capacity (L/s)*	776.8	789.6
	Power Demand (kW)	0.455	0.463
	Static Pressure (in-H2O)	1.2	1.2
	Efficiency	0.53	0.53

Section 5: Building energy use

Discussion of the building energy consumption:

The building has two sources of energy: electrical and natural gas. The DX Cooling coils use electrical energy, and the furnace uses natural gas. In Calgary, natural gas is used instead of electricity for heating because it is cheaper to directly burn the gas than to convert it into electricity and then use it. Furthermore, natural gas consumption is very high as Calgary has a very cold climate. As evident from the temperature graph (Appendix A) even in mid-summer the temperatures generally remain comfortable (at around 24°C). Although winters can get very cold at -24°C (the temperature values are averaged over a 14-day rolling average). The fuel input ranges from 128.5 GJ in December to 1.06 GJ in July. As illustrated in figure 4 (right graph), the natural gas consumption is like a valley where the dip is during the summer and the tip is during the winters. The total annual natural gas consumption is 672 GJ. There is a tiny fraction of gas used for the kitchen equipment.

As illustrating in figure 4 (left graph), the consumption of electricity is dominated by area lighting, yellow bar, at a monthly consumption of roughly 1700 kWh. The green bar represents the electrical cooking equipment averaging 500 kWh of monthly energy. The pink is the fans in the system ranging from 600 kWh in the winters and 300 kWh in the winters. The most relevant component is the DX cooling coil energy consumption. The system consumes 46 kWh of electricity in May, 209 kWh in June, 465 kWh in July, 431 kWh in august 148 kWh in September. The remaining months have no electrical consumption for cooling. **The total building annual energy consumption is 1,052 GJ.** Temperature data for annual energy consumption calculations are extracted from Calgary weather station 718770 (CWEC) [3].

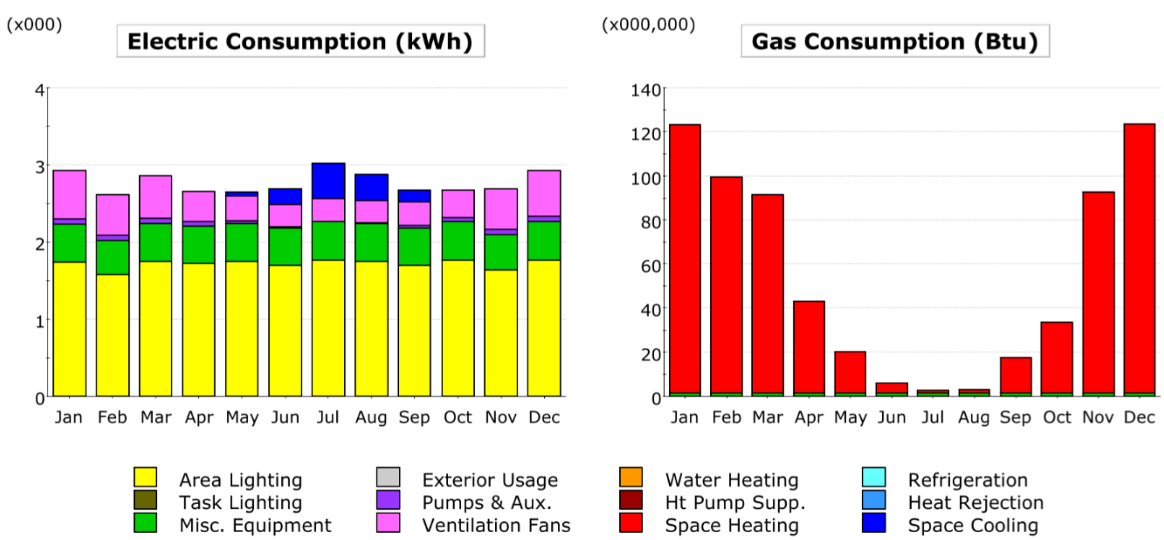


Figure 4. Monthly Electricity and Natural Gas consumption of the building.

Recommended engineering improvements for reduction in energy use:

Figure 2 is particularly helpful in advising improvements to save energy for the building. To start off, focus should remain on reducing the heating loads as the site's predominant energy consumption is due to heating. As evident from figure 2, wall and roof conduction create the largest heating load. The walls and the roof have a U-value of 0.44 W/m2-K. This must be reduced to down to 0.18 W/m2-K as it is the recommended value [1]. A cost benefit analysis can further demonstrate the savings from natural gas consumption due to high insulation walls. Although this is not possible since the building is already constructed. Another improvement is to increase the tightness of the envelope. Currently the ACH is set at 0.2. Weather stripping doors and caulking may be effective. Heat loss from windows is also significant. The windows are already a decent "Double Visteon Versalux RC/Air/Clear 6mm" in the model. Perhaps insulative drapes could be installed. Lastly, little can be done to reduce to cooling load other than constructing higher insulative walls and roofs, which is not be possible since the building is already built. The only two other possible suggestions are to install blinds for the windows to reduce the cooling load from the solar radiation. The second is to install LED bulbs as they are more efficient at converting electricity to light and therefore have a lower heat output.

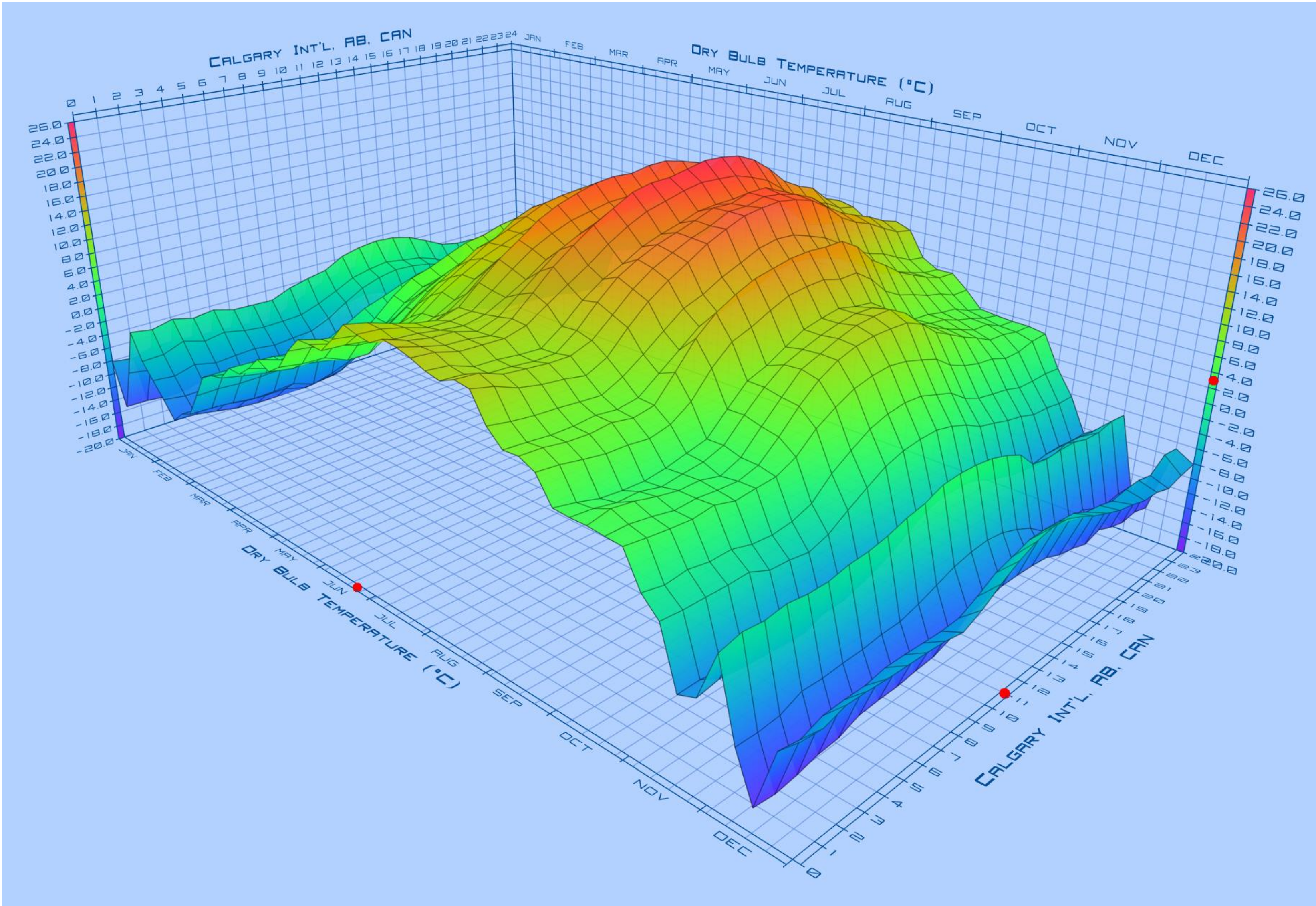
References:

[1] Designing Buildings|U-Values. (n.d.). Retrieved November 26, 2020, from https://www.designingbuildings.co.uk/wiki/U-values

[2] Heat gain from restaurant equipment. (n.d.). Retrieved November 26, 2020, from https://www.iklimnet.com/expert_hvac/cooling_load_restaurant_equipment.html

[3] Weather Data - North And Central America WMO Region 4 - Canada - Alberta. (n.d.). Retrieved November 26, 2020, from https://energyplus.net/weather-Location/north_and_central_america_wmo_region_4/CAN/AB/CAN_AB_Calgary.718770_CWEC

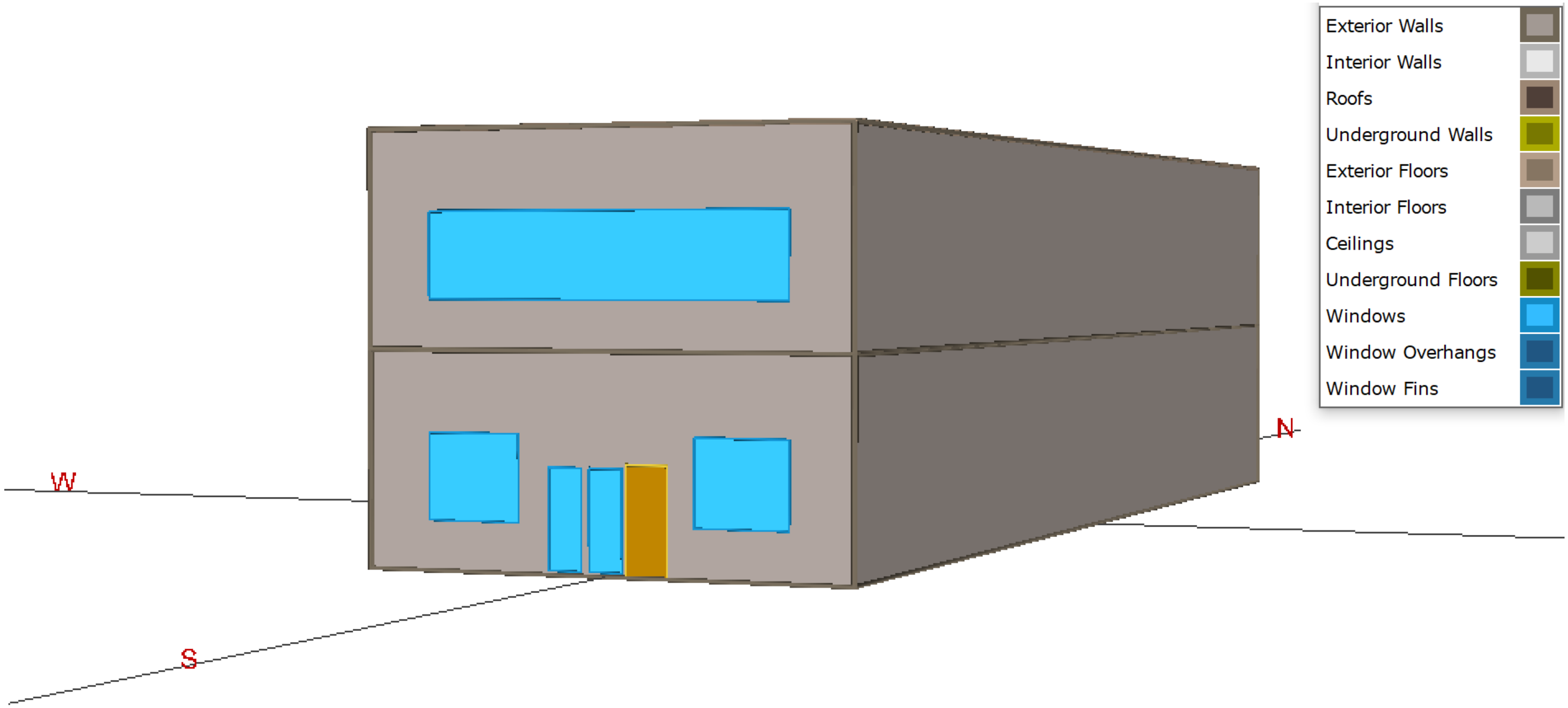
APPENDIX A - Calgary weather (14-day rolling average) – Data visualised from: CAN_AB_Calgary.718770_CWEC.ewp [3]



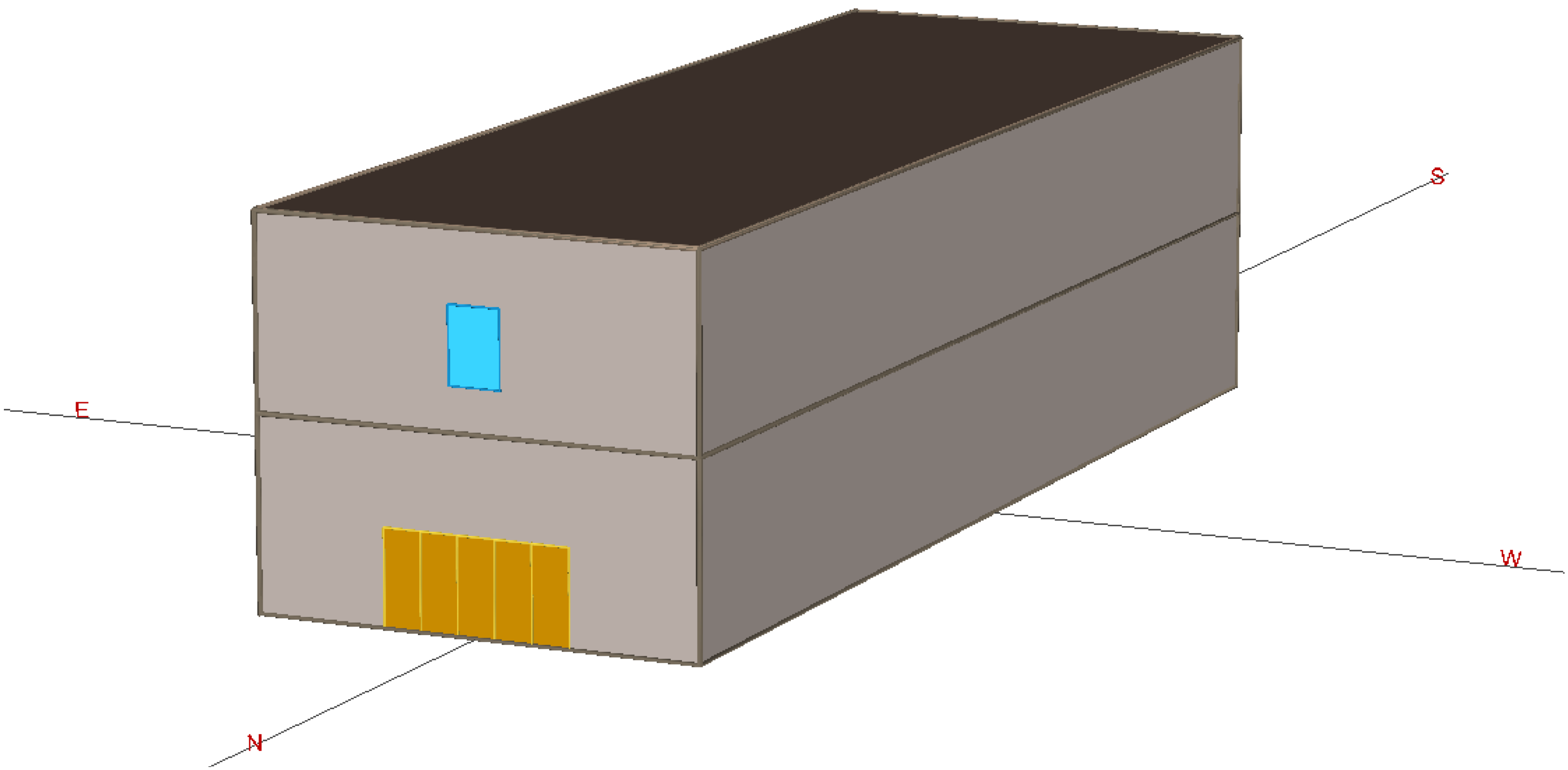
APPENDIX B - Heat transfer parameters of the wall and roof and the resulting U-value of the modeled version.

Construction	Material Name	Thickness (m)	Conductivity (W/m-°K)	Density (kg/m3)	Spec. Heat (J/kg-°K)	R-Value (m2-°K/W)	U-value (W/m2-°K)
Wall	*Conc HW 140lb 8in (CC05)*	0.203	1.3103	2,242.6	837	n/a	0.440
	Air Lay <3/4in Vert (AL11)	n/a	n/a	n/a	n/a	0.159	
	Insul Bd 3in (HF-B4)	0.076	0.0432	32	837	n/a	
	GypBd 1/2in (GP01)	0.013	0.1602	800.9	837	n/a	
Roof	*Plywd 1/2in (PW03)*	0.013	0.1154	544.6	1,213	n/a	0.443
	Roof Insul 2in (IN74)	0.051	0.0519	256.3	837	n/a	
	Roof Insul 2in (IN74)	0.051	0.0519	256.3	837	n/a	
	GypBd 1/2in (GP01)	0.013	0.1602	800.9	837	n/a	
	Steel Siding (AS01)	0.002	44.9696	7,688.9	418	n/a	

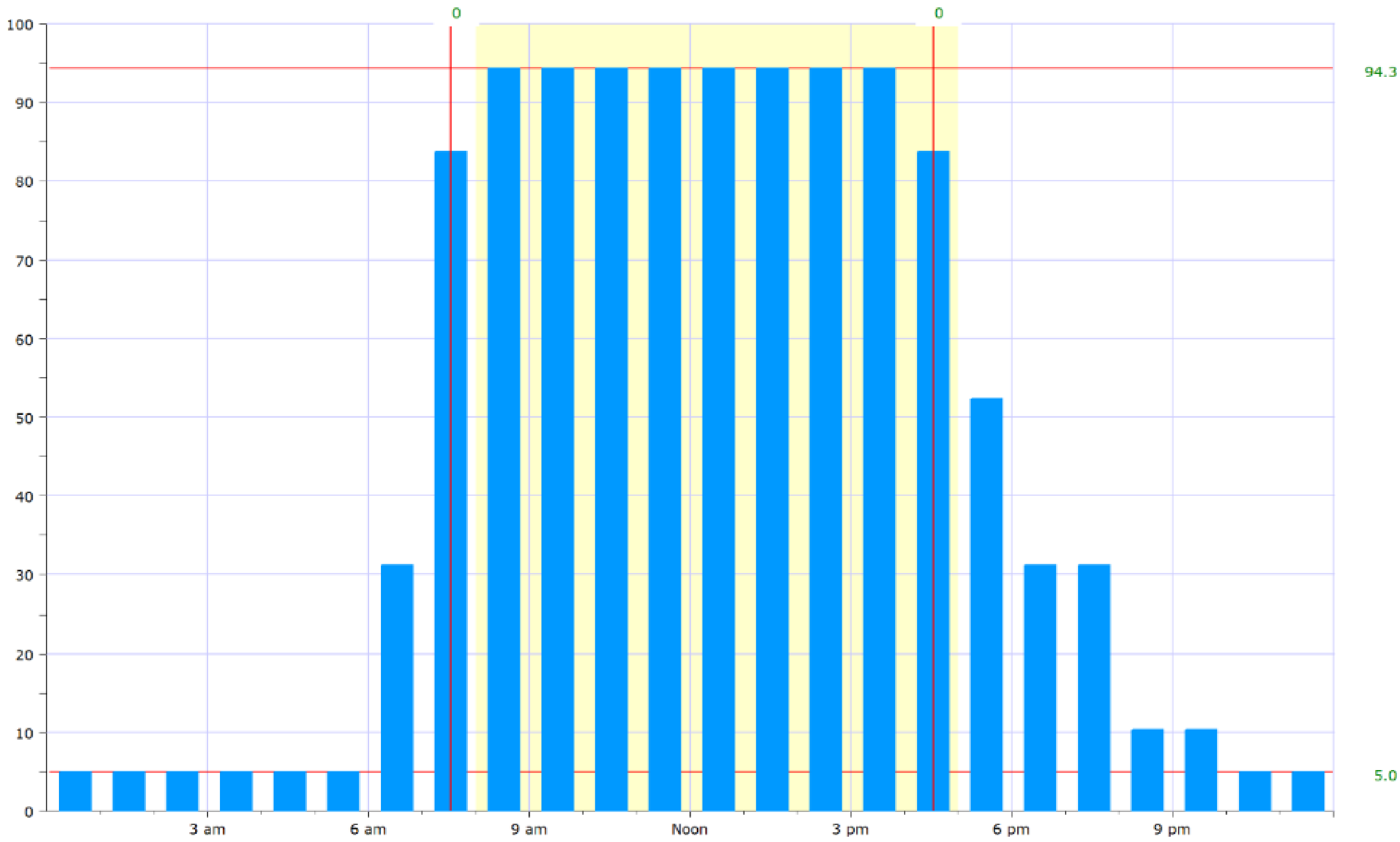
APPENDIX C - Part 1 – South facing side of the modeled building. The image was developed with eQuest.



APPENDIX C - Part 2 - North facing side (and roof) of the modeled building. The image was developed with eQuest.



APPENDIX D - Lights schedule for entire building



APPENDIX E - Office occupancy schedule for ground floor