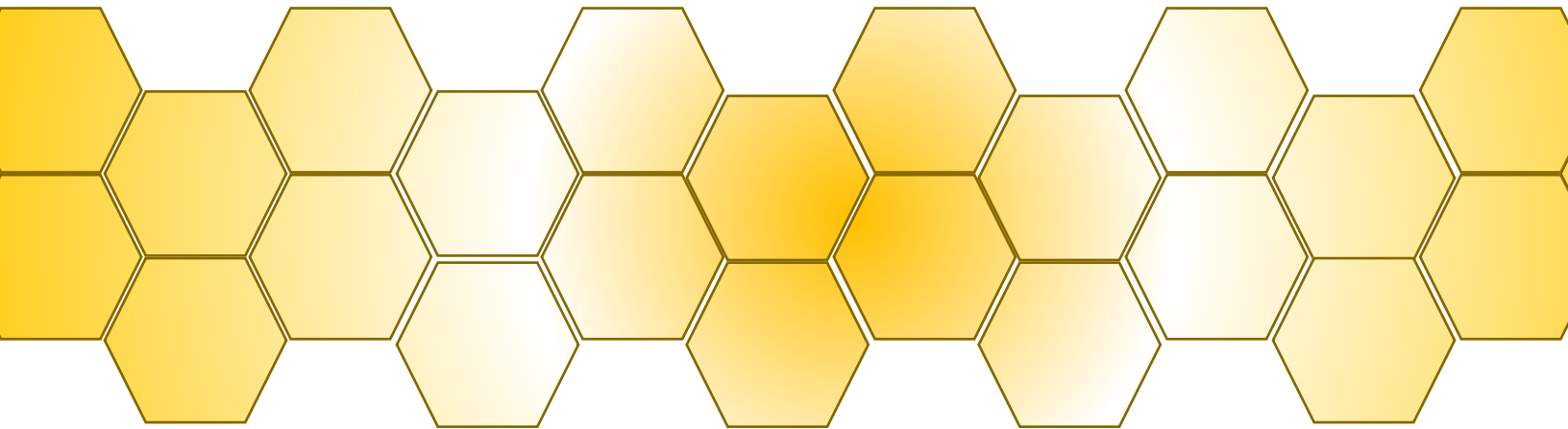


# PHASE III REPORT

**Overwintering Honeybees: Detailed Design**

APRIL 10<sup>TH</sup>, 2019



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## EXECUTIVE SUMMARY

sWarm Solutions was tasked by the Alberta Beekeepers Commission (ABC) to design a smart overwintering building for the storage of 6000 honeybee colonies. The key objectives of the project were to design a building that could overcome current honeybee overwintering challenges in order to improve the survival rates of honey bees in the winter and allow Alberta to continue to thrive as Canada's largest honey producing province.

Out of the three concept designs generated in Phase II, based on the specifications stated in Phase I, the "Return Air" design was chosen by sWarm Solutions to be transformed into the final product. This design was further refined and analyzed in Phase III. These refinements include reconfiguring the honeybee stacking scheme to reduce the storage dimensions and building costs, optimizing the amount of air recirculation to keep the CO<sub>2</sub> concentration at a safe level for the honeybees, and remapping building sensors to provide more emphasis on the coverage of the stacks. The analyses performed in this phase include recalculations of the building's heat loss, HVAC parameters, and simulations of the air flow and ambient temperature of the storage area. Additionally, a study of the hourly outdoor weather in several locations across Alberta was performed to determine the most cost-efficient operating schedule for overwintering. Building and equipment costs were estimated to be \$493,700, and the annual operating cost was estimated to be \$8,500 per winter, dependent on location.

The final product will consist of a building that can store 6000 colonies in 300 stacks, in complete darkness, that could be loaded with any conventional forklift. It features an HVAC system that is able to maintain an interior temperature of 4 degrees Celsius with low humidity and an acceptable CO<sub>2</sub> concentration level. This is the optimal environment to keep the honeybees in a state of "pseudo-hibernation" which allows them to conserve their energy and live through the winter. The HVAC system will be operated under three different modes, designed to handle all climate scenarios to a good degree.

Activities done in Phase III included detailed design and analysis, poster design, presentation delivery, and report preparation. They combined to a total of 254 engineering hours expended, a 13.2% reduction from the estimate from Phase II. Overall, a total of 629 engineering hours were expended for this project, incurring a cost of \$57,330. This is a 5% reduction from the estimated value.

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## 1.0 INTRODUCTION

“Overwintering” honeybees is a method that is practiced by beekeepers in colder climates. It consists of a set of measures that help preserve the population of honeybees. This is done by forcing the honeybees in a state of pseudo-hibernation by keeping the hives cool and in complete darkness. These measures can be accomplished by a range of methods, from insulating the beehives with plastic to storing them indoors in buildings. The current accepted practice is to wrap the hives in insulation, however this can be dangerous. If the winter goes longer than expected, the honeybees’ initial serving of food can run out. The insulating wrap prevents any further food from being added, and the lack of sensors prevent a beekeeper from noticing. Storage buildings aim to tackle this issues, in addition to better controlling the environment the bees are in.

sWarm Solutions, an Edmonton based start-up, was tasked by the Alberta Beekeepers Commission to design an overwintering storage building concept for use in Alberta. The final design must house 6000 colonies, maintain cool temperatures, and have a proper ventilation system. Furthermore, the beekeepers must have a reliable, yet mostly hands-off method, of monitoring the honeybees’ health and building environment. The objective of sWarm Solutions is to improve honeybees’ survival rate and help Alberta continue to prosper as Canada’s largest honey producing province.

## 2.0 DESIGN REFINEMENT

After further analysis of the chosen conceptual design from Phase II, three major improvements were conducted.

### 2.1 Building Size

Based on a recommendation from the client, the beehive column configuration was changed. Each column will now contain two rows of beehive stacks instead of one. This has allowed for the reduction of the size of the building which was deemed as beneficial to the design as it would lead to lower heating costs. Furthermore, it was found that the hive stacks interfere with both the internal frame of the building and the ducts, which led to a height increase of the building. The size of the mechanical room also increased from initial design after determining exact HVAC equipment needed, requiring more space than previously anticipated. Finally, the vestibule size was changed to better comply with the new building dimensions. A summary of changes is laid out in Table 1.

**Table 1:** Building size refinements

Area	Initial Dimensions (ft x ft)	Final Dimensions (ft x ft)
Main Storage Area	136 x 110	110 x 100
Mechanical Room	20 x 10	40 x 20
Vestibule	10 x 8	12 x 6

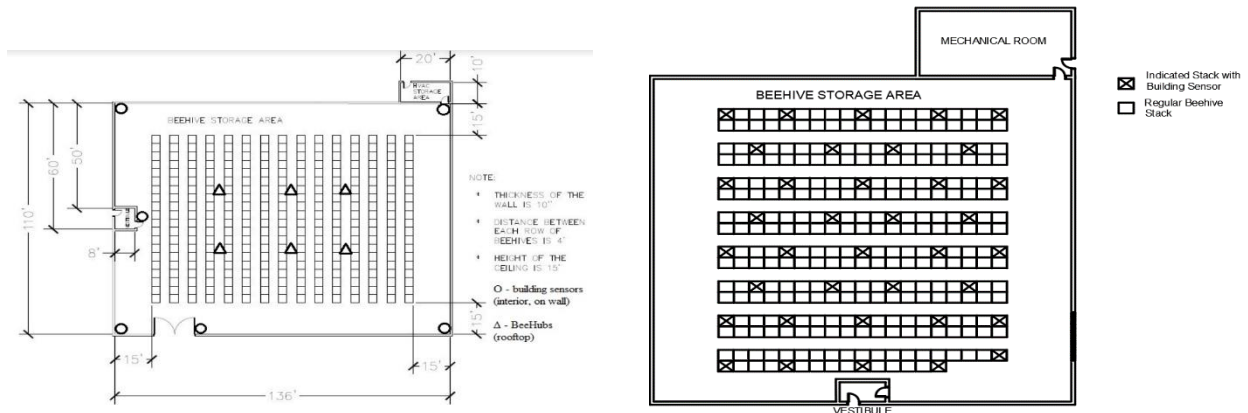
### 2.2 HVAC Adjustments

Detailed biological data regarding honeybee respiration was provided by the client early in Phase III, sourced from a recent presentation by the University of Manitoba. This new data provided sWarm Solutions new design limitations that had to be adjusted for. One key detail was the mass of CO<sub>2</sub> released per honeybee hive, said to be 3 – 11 g/hr [1]. It was found that with the Phase II proportion of recycled air (90%), the CO<sub>2</sub> levels within the building could not be controlled and the honeybees would soon run out of oxygen. To keep the CO<sub>2</sub> levels under control, the air exchange rate was doubled from 4 air changes per hour to 8 air changes per hour, and the return air proportion reduced to 30%. With these new parameters the steady-state CO<sub>2</sub> levels in the building remain at an acceptable level of ~800 ppm under standard operating procedure. Refer to Appendix C for calculations.

Doubling the air exchange rate caused the required power of the supply fans to greatly increase, exponentially increasing the cost of the required supply fan. It was found that in order to save cost, two separate smaller supply fans in parallel were more cost effective than a single large fan. Thus, the intake branch was split in two. Refer to HVAC layouts shown in Section 3.2 and Appendix C for more details of this split.

## 2.3 Building Sensor Locations

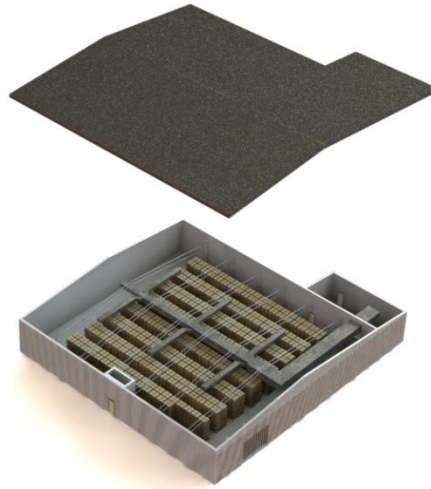
The building sensors were initially placed at locations where there was less air flow and thus considered worst case conditions, for example the corners of the building. The reasoning behind this was that if proper readings were measure at these locations, one can assume that the locations of interest (beehive stacks) are being properly regulated. After feedback from Phase II was received, it was clarified that it is more beneficial to place the sensors at the beehive colonies to directly monitor areas of interest. Figure 1 shows the contrast between Phase II and Phase III building sensor layouts.



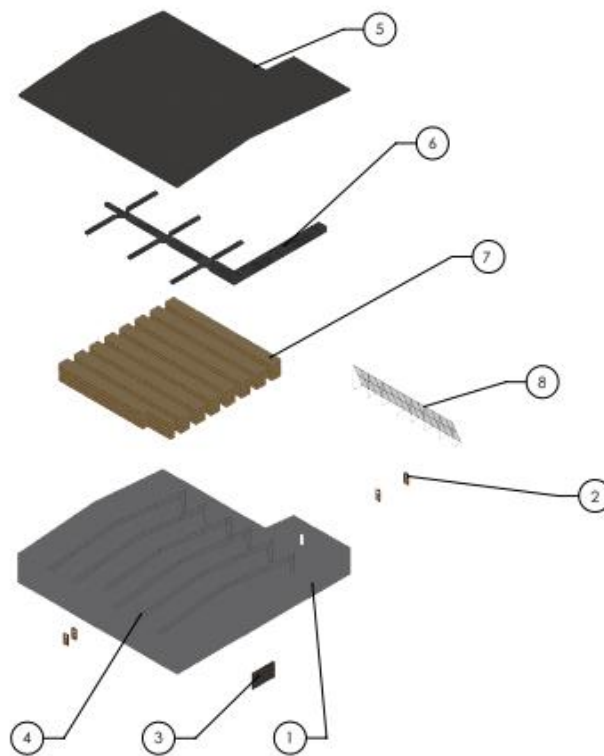
**Figure 1:** Phase II (left) and refined Phase III (right) sensor layouts. Circles indicate building sensor locations in Phase II on left while X's indicate hive stacks with building sensors near them in Phase III.

### 3.0 DESIGN OVERVIEW

Refer to Figure 2, Figure 3, and Table 2 for a high level overview of the honeybee overwintering building. Figure 4 shows the design process of Phase III.



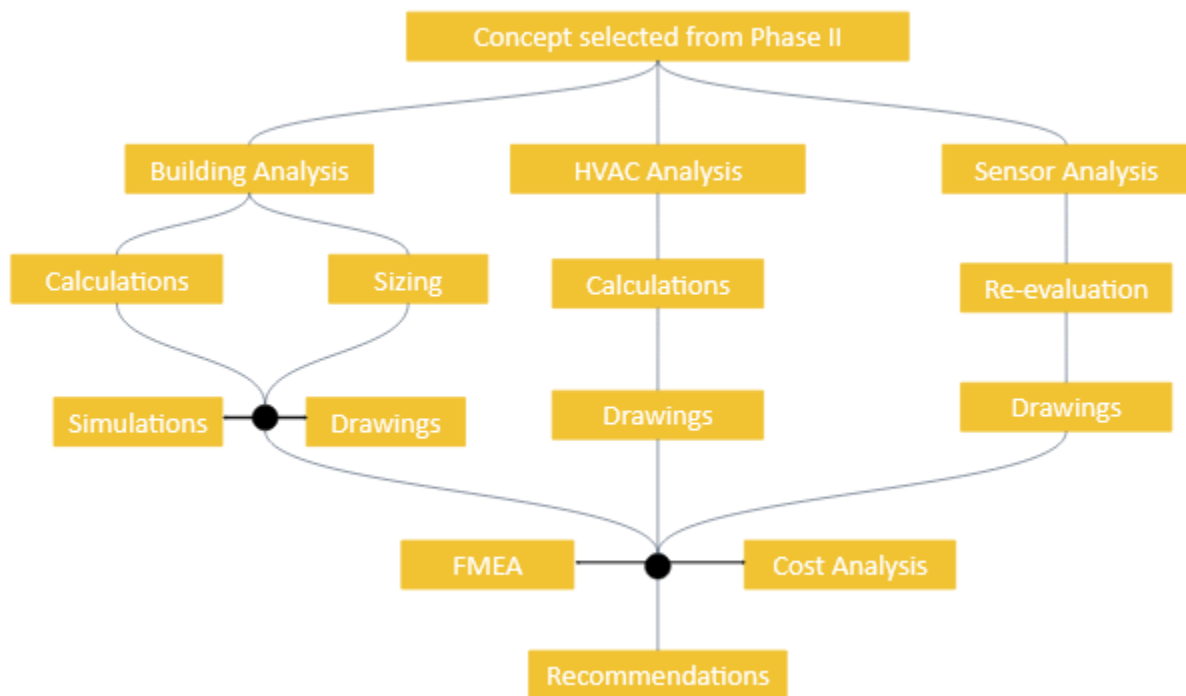
**Figure 2:** Final honeybee overwintering building - external view



**Figure 3:** Final honeybee overwintering building - exploded view of primary parts

**Table 2:** Legend for Figure 3

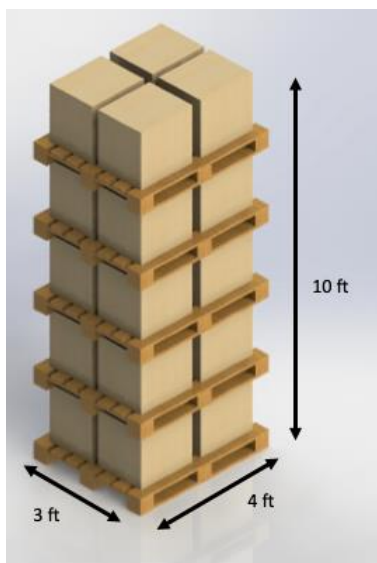
Item Number	Part	Quantity
1	Building structure	1
2	Standard door	4
3	Forklift door	1
4	Internal building frames	8
5	Roof	1
6	Main building HVAC equipment	1
7	Beehive stack	300
8	Solar Heater	1


**Figure 4:** Phase III detailed design flow chart

## 3.1 Building Design

### 3.1.1 STACK CONFIGURATION

The six thousand colonies stored inside the building are organized in three hundred stacks, where each stack holds twenty colonies in five layers. Each layer consists of a standard 48" x 40" pallet with four 19 $\frac{7}{8}$ " x 16" x 19 $\frac{1}{4}$ " Langstroth hives. A factor of safety (FOS) calculation was performed to check the feasibility of this stacking configuration, and returned a FOS in an order of over a hundred for the bottom stack. Thus, it was concluded that the chance of failure in directly stacking hive pallets is slim, and that shelving to store the hives was not necessary. Refer to Figure 5 which shows the overall dimensions of an individual stack, and Appendix A for the stacking calculations.



**Figure 5:** Layout and dimensions of a single hive stack

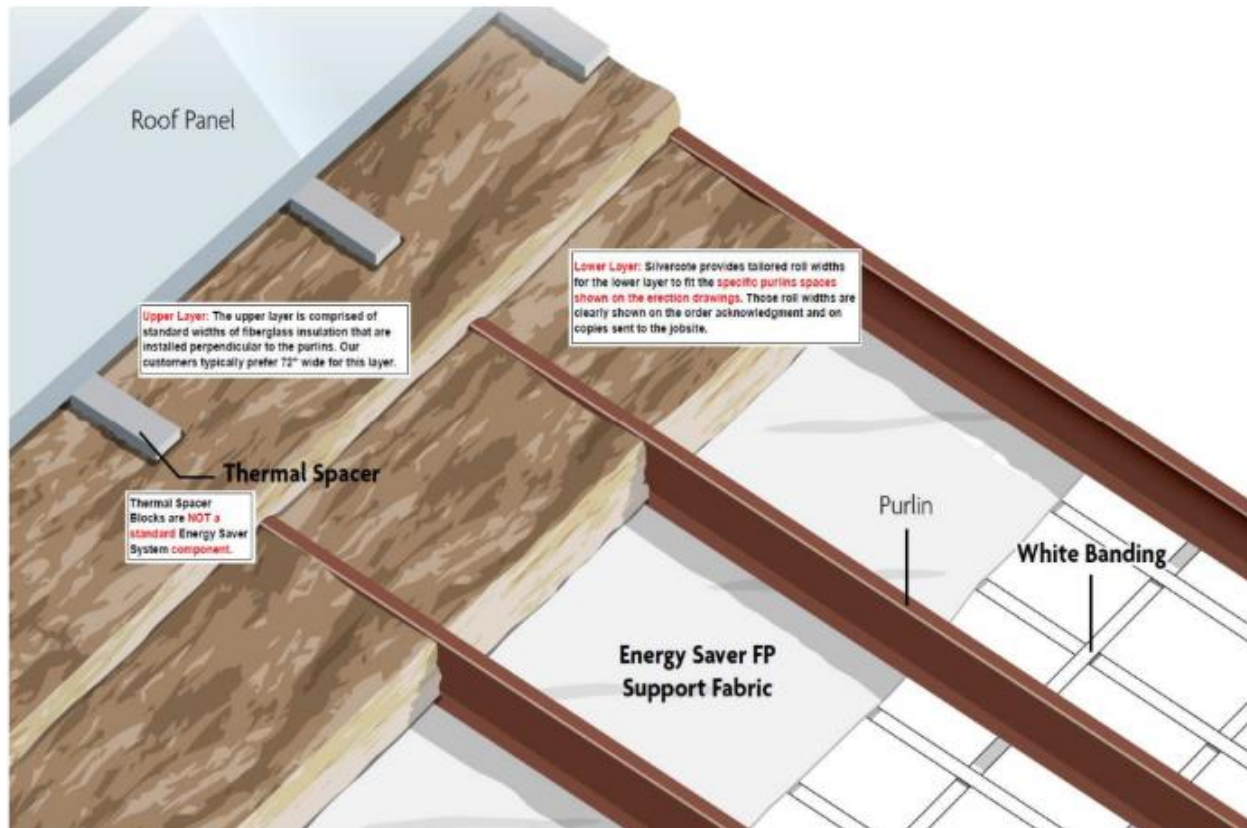
### 3.1.2 BUILDING LAYOUT

The building contains a main storage area, a vestibule, and a mechanical room. The purpose of the vestibule is to ensure complete darkness remains inside the building when individuals wish to enter, and can also be used to store bee suits and any sanitization process required. The mechanical room stores HVAC equipment while the main storage area houses the 6000 beehive colonies. A separate, larger sliding door is located on the building for a forklift to enter, but is not meant for regular usage as it will allow light in. Refer to [F] for the final layout.

### 3.1.3 INSULATION

The insulation package of the building is a combination of fiberglass and purlins that are encased by steel wall panels. The insulative materials are held together using banding, thermal spacers, and thermal tape. The building walls will be insulated with a thermal resistance value (R-value) of 30, and the roof will be insulated with an R-value of 40 by containing an extra layer of R10 insulation. The building's overall heat loss was estimated to be 106,000 BTU/hour, which can be found in Appendix B. An example of the roof insulation guide is shown in Figure 6.





**Figure 6:** Building roof insulation detail [2]

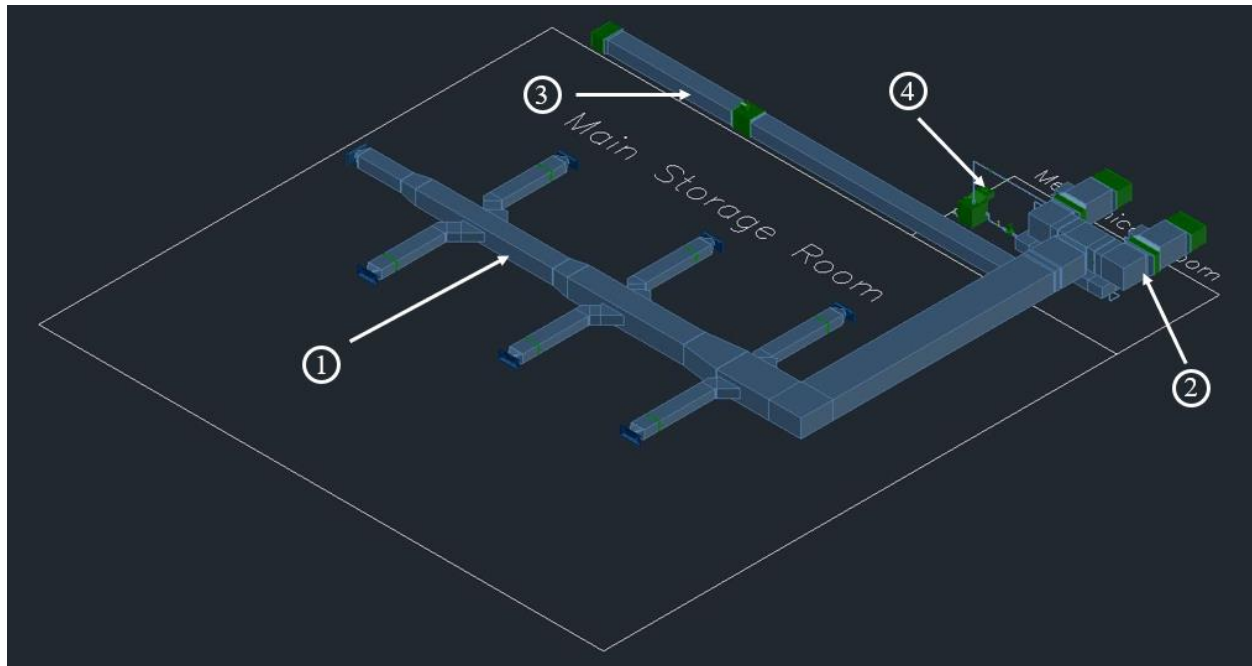
### 3.1.4 BUILDING LOADING METHODS

The rows between the beehives do not directly contain enough space for an average forklift (~4 ft) [3]. The forklift will only be used to add the beehives during the early winter season and remove them during the spring. This was specified by the client, as beekeepers have no requirement to pick individual hives or pallets out of the building during the overwintering process. During loading, the hive pallets will be stacked row by row starting from the furthest corner, moving towards the forklift door. During unloading, the opposite process will be utilized. Thus, space for a forklift between rows was not required.

## 3.2 HVAC Design

Refer to Figure 7 for the overall layout of the HVAC system to be installed in the honeybee overwintering building.

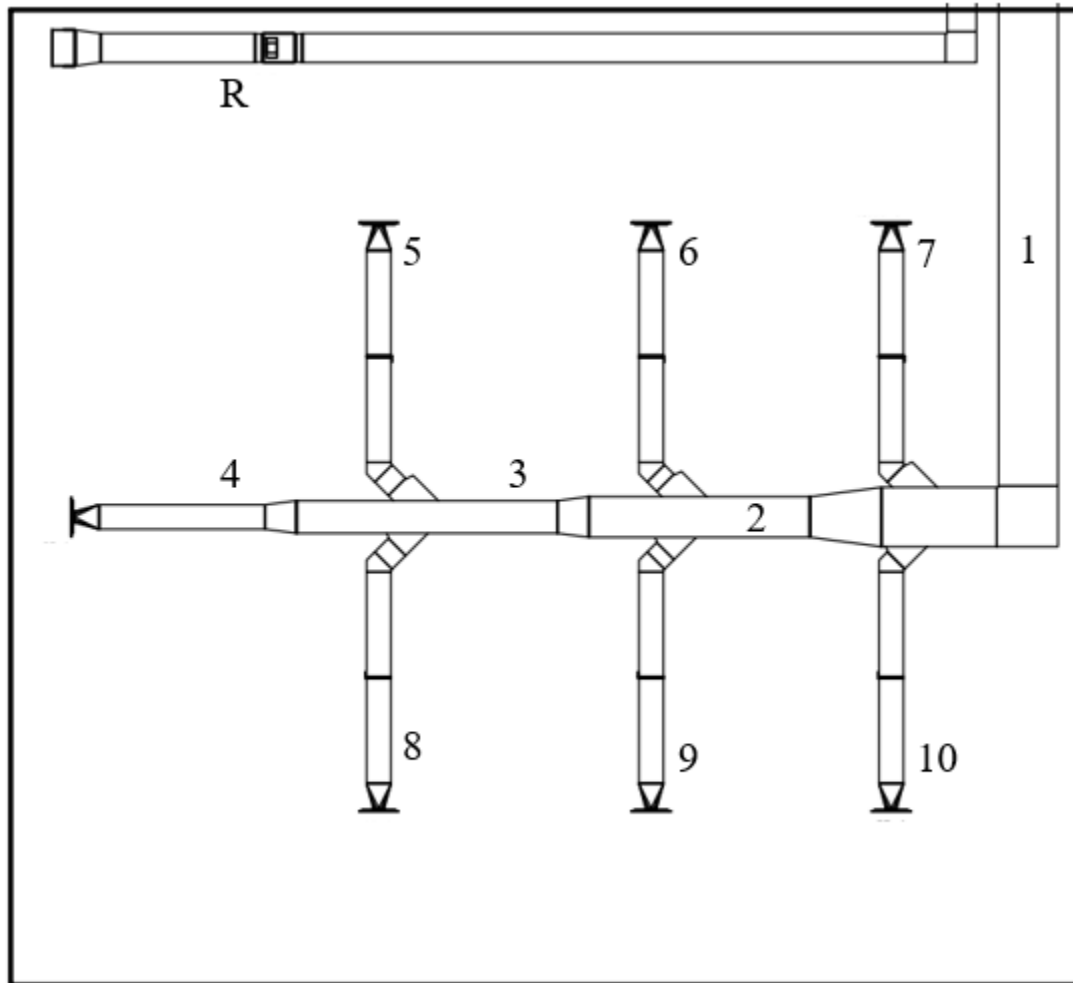




**Figure 7:** Overall HVAC layout - isometric view. 1 = storage room duct network, 2 = intake duct detail, 3 = return air line, 4 = heating water loop

### 3.2.1 AIR SYSTEM

Refer to Figure 8 for the final storage room ducting layout of the honeybee overwintering system. The system consists of 2 supply fans supplying air at 26,400 CFM, 4 exhaust fans exhausting a total of 18,480 CFM, and a return fan recycling air at a rate of 7,920 CFM (30%). The 30% recycled air is returned to the supply air intakes and serves to raise the temperature of incoming outside air, reducing heating costs. This air is mixed and then heated to 0°C. The remaining temperature difference is made up by the heat generated by the honeybees. In each diffuser branch, manual butterfly dampers are installed to balance the flow to all areas of the building. In addition, filters are installed in supply and return intakes to reduce the potential risk of damage to equipment such as fans and heating coils. Per SMACNA duct guidelines, hangers supporting the ducts will consist of paired  $\frac{3}{8}$ " threaded rods, spaced at 8-foot intervals [4]. Refer to Table 3 for the duct sizes in each section. Refer to HVAC calculations in Appendix C and Equipment Schedule in Appendix I for more details.

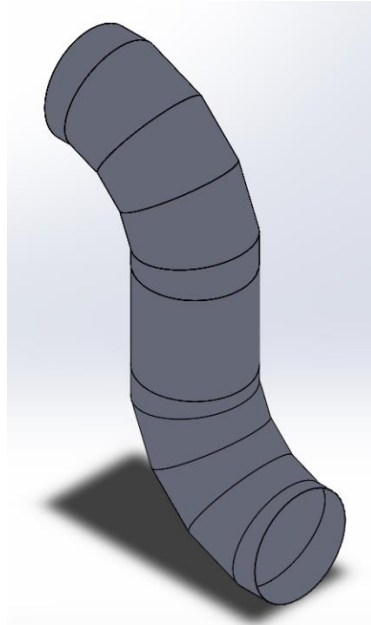


**Figure 8:** Main storage area duct layout

**Table 3:** Legend of Figure 8 and relevant design parameters of duct branches in main honeybee storage area

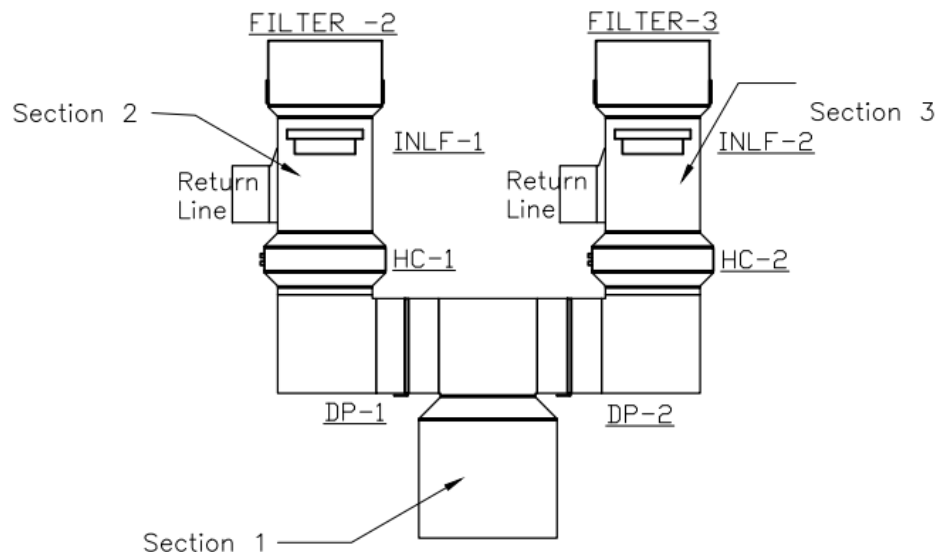
Section	Size [in x in]	Airflow Rate [cfm]	Velocity [fpm]	Pressure loss [inWg/100 ft]	Length [ft]
1	75 x 45	26400	1200	0.0255	67
2	55 x 45	19200	1200	0.0293	30
3	45 x 35	12000	1174	0.0374	30
4	30 x 25	4800	984	0.0421	15
5 -10	30 x 20	3600	930	0.0435	15
R	38 x 28	7920	1149	0.0457	85

Each wall-mounted exhaust fan has a small section of duct on the outside of the building. This is to prevent light from getting into the honeybee storage area, and it is further recommended the interior of these ducts be painted or otherwise made in a dark colour that absorbs light to prevent light from reflecting through. Refer to Figure 9 for a visual description.



**Figure 9:** Double-bend exhaust duct for light prevention

Within the mechanical room, the air intake is split in two sections, each with its own fan, heating coil, and return air mixing. Refer to Figure 10 and Table 4 for further clarity.



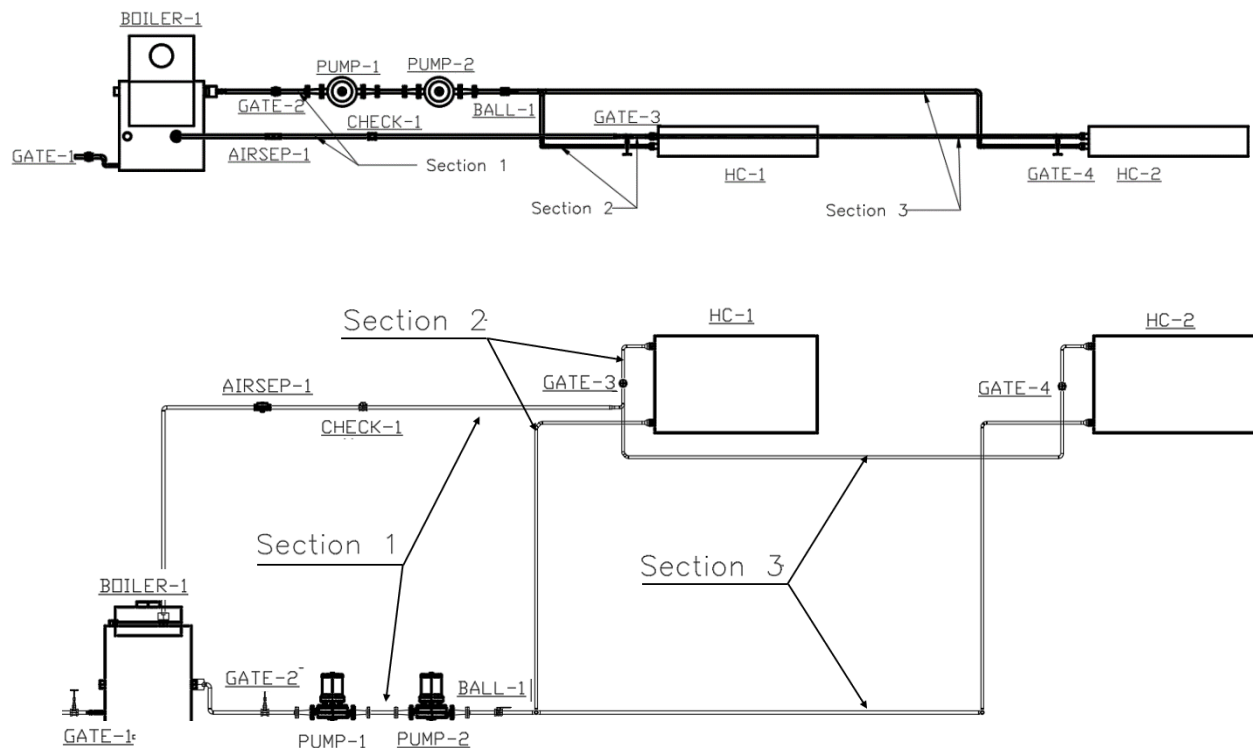
**Figure 10:** Split air intake detail

**Table 4:** Legend of Figure 10 and relevant design parameters of air intake system in mechanical room

Section	Size [in x in]	Length [ft]	Airflow rate [cfm]	Velocity [fpm]	Friction loss [inWg/100ft]
1	75 x 45	5	26400	1160	0.0255
2, 3	50 x 45	15	13200	773	0.0136
Return Line Connections	30 x 22	16	3960	926	0.0406

### 3.2.2 HEATING WATER SYSTEM

The heating water system in this building was designed to be a simple recirculating hot water loop, consisting of a boiler and two pumps in series in order to feed two terminal units: the heating coils raising the temperature of the incoming air. Figure 11 presents the layout of the heating water system, and Table 5 the pipe sizing details. The boiler is powered by natural gas and provides 845,000 BTU/hr, while the pumps are 1/6 HP each, providing 14 GPM flow through the system.



**Figure 11:** Top view (top) and side view (bottom) of heating water system

**Table 5:** Legend for Figure 11 showing relevant pipe design parameters

Section	Diameter [in]	Length [ft]	Flow rate [GPM]	Friction loss [inWg/100ft]
1	1	34	14	1.8
2	3/4	12.6	7	1.2
3	3/4	41	7	2.0

### 3.2.3 MODES OF OPERATION

Table 6 describes the three modes of operation and the conditions upon which they occur. The method of switching between modes will be hardwired in-duct sensors connected to actuated dampers in the duct lines and the fan motors. However, the exact control design must be finalized at a later date as per Section 8.2 – Future Design Considerations.

**Table 6:** Building modes of operation

Mode	Condition of Occurrence	Description
Standard Operation	Intake air temperature is below 0°C	<ul style="list-style-type: none"> <li>System operates as usual, with all fans, boilers, and pumps on.</li> </ul>
Cooling Mode	Intake air temperature is above 0°C	<ul style="list-style-type: none"> <li>Supply and exhaust fans shut off, conserving the temperature inside. Boiler shuts off <ul style="list-style-type: none"> <li>CO<sub>2</sub>, humidity, and temperature slowly build due to honeybee respiration</li> </ul> </li> </ul>
Emergency Exhaust Mode	CO <sub>2</sub> above 2500 ppm (barring failure, this mode will only engage while in cooling mode)	<ul style="list-style-type: none"> <li>Return fan turns off, supply and exhaust fans turn on for one full cycled air exchange (7.5 minutes). Boiler remains off.</li> </ul>

## 3.3 Sensor Design

### 3.3.1 HIVE SENSORS

The selected sensors for monitoring the in-hive environment are built by Nectar Technologies Inc., a Canadian start-up based in Montreal. These sensors are known as BeeCons and are placed inside a hive to measure real-time data on parameters relevant to the health of hives such as internal temperature, humidity, sound frequency, and activity. Data from multiple BeeCons are received through Bluetooth by BeeHubs located on the roof. The data gathered by the BeeHubs is transmitted through a cellular network to the analyzing platform which allows beekeepers to monitor their hives [5]. A 10% distribution of hive sensors over the six thousand colonies was recommended to obtain sample data that represents the entire population, meaning that six hundred BeeCons exist in the building, two per hive stack.

### 3.3.2 BUILDING SENSORS

In contrast, the selected building sensor SHTC3 is a commercially-available product that measures both the temperature and humidity inside the building. Its compactness (2 mm x 2 mm x 0.75 mm), low power

consumption, and compatibility with mobile or wireless applications make it an ideal choice for the design. In addition, while strict control over the ambient temperature and humidity is not necessary, building sensors were mapped as shown in [F] to provide accurate monitoring of the storage area. It should be noted that these sensors are external to the HVAC equipment and do not control any system; just monitor.

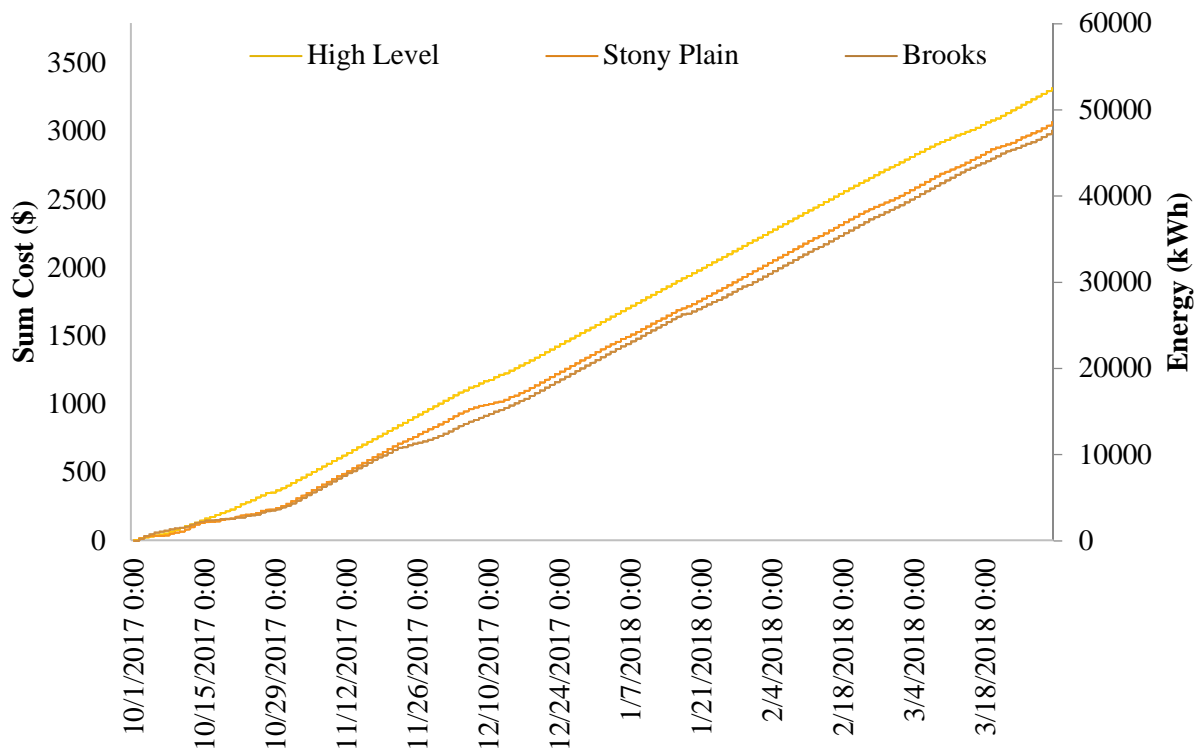
## 4.0 COST ANALYSIS

### 4.1 Construction Cost

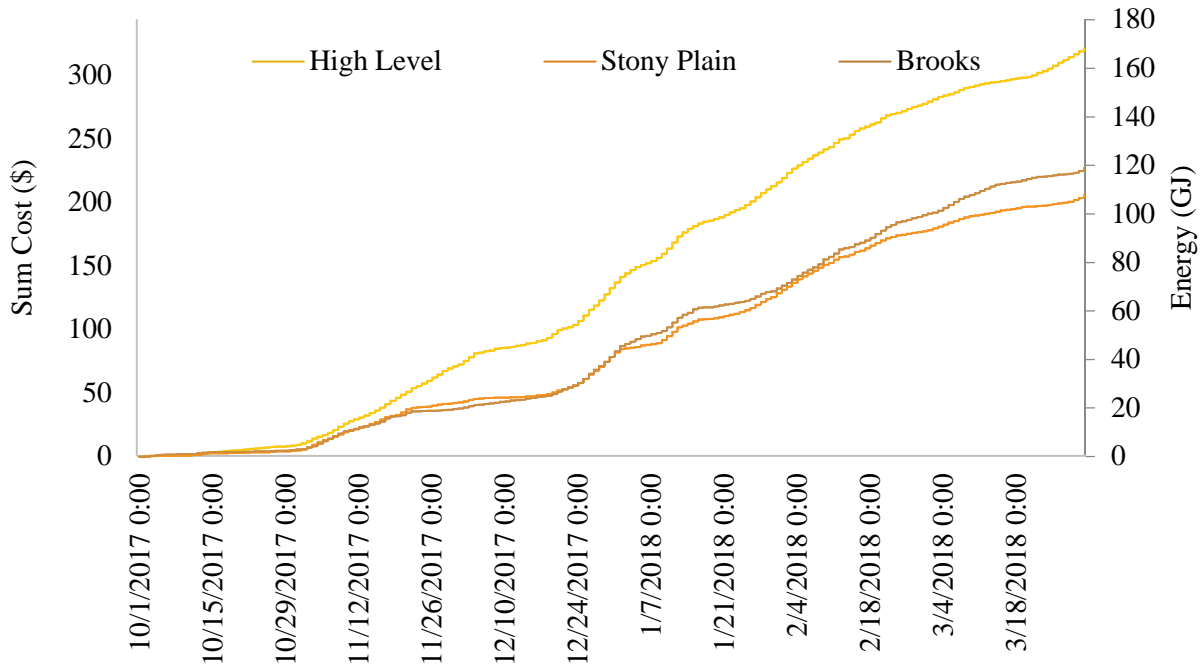
Refer to Appendix E for a cost breakdown of the building. In addition, refer to Appendix G for the quote provided by Olympia Steel Buildings of Canada. The final construction cost was found to be \$493,700. ABC did not provide a budget, however sWarm Solutions worked to produce a final cost that was as affordable as possible.

### 4.2 Operation Cost

In Phase II, the operational cost was compared by using energy requirements during the coldest weather in winter. For Phase III, a more accurate estimation was created by running hourly weather data through the calculations in question, for every hour in winter. As a specific location was not provided by the Alberta Beekeepers Commission, three locations representative of North, Central, and Southern Alberta were checked: High Level, Stony Plain, and Brooks. These specific locations were primarily driven by the availability of data. Refer to Figure 12 and Figure 13 for plots of the electrical and natural gas power consumed over the course of a winter. Refer to Appendix D for the MATLAB script. The cost of electricity on a farm was found to be 6.32 cents per kWh [6], while the cost of natural gas was found to be \$1.91 per GJ [7].



**Figure 12:** Sum cost and consumption of electricity over the course of winter, using 2017/18 data



**Figure 13:** Sum cost and consumption of natural gas over the course of winter, using 2017/18 data

Refer to Appendix E for a calculation of long term cost when compared to the primary alternative overwintering technique, the insulating wrap. From this analysis, it was found that the payback period of this building is only 4.02 years, at which the cumulative cost would have been \$604,000, or \$25 per hive per winter. Assuming a 10 year minimum lifetime of the HVAC equipment, savings in this period total \$732,000 when compared to the insulating wrap alternative.



## 5.0 DESIGN CONSIDERATIONS

### 5.1 Sustainability and Environmental Impact

A solar air heater is introduced to this building to use solar energy to raise the intake temperature of the air system. This reduces heating costs and makes the building more sustainable due to the renewable energy source. In addition, the steel structure allows the support of solar panels should ABC desire them.

These methods help reduce the environmental impact of the overwintering building. In Alberta, a large proportion of electricity generation comes from fossil fuels. As such, it is vital that grid electricity usage in addition to natural gas usage be minimized where possible. There should be no major environmental impact of the building on the land, as the building will likely be on farmland and not require any atypical chemicals or pollutants to construct or operate.

### 5.2 Adaptivity

The overwintering building is designed for use in winter (4-6 months). As such, it was important to ABC and sWarm Solutions that this large building be available for alternate use in the summer period. Per Section 3.1.1, it was found that no shelving is needed to store pallets of honeybees, minimizing clutter that would need to be removed. In addition, the concrete slab floor, steel frame building, ventilation system, and forklift door allows for alternate uses involving hanging or securing heavy equipment; leaving the opportunity for the building to be used in some part of the summer honey production.

### 5.3 Winter Optimization

A major source of savings for the overwintering building is the lack of cooling system. Instead of installing an expensive cooling system capable of keeping a warehouse at 4 degrees Celsius, a second mode was defined (see Section 3.2.3). While this has the advantage of savings, it leaves the honeybee storage area at risk of high CO<sub>2</sub>, humidity, and temperatures if a winter experiences warm temperature for long consecutive periods of time. Thus, it is recommended this building be used in extreme cold environments only, preferably in areas with minimal chinooks. To compensate for this expected usage, the building is designed to consistently maintain 4 degrees at temperatures as low as -40 degrees Celsius by containing a strong boiler and heavy insulation in the walls and roof.

### 5.4 Failure Modes Analysis

Refer to Table 7 for a failure modes analysis of the overwintering building. The highest risk priority number (RPN, Equation 1) was found in the case of a power outage. This is due to its high severity of shutting off all fans, in addition to its potential frequent occurrence assuming the location of the building is rural. As such, this drives a recommendation to have a generator on hand. Note that sensors are battery powered and will not be affected. Severity and occurrence rankings are assigned according to tables provided by Dr. Lipsett [8].

$$RPN = Severity \times Occurrence$$

**Equation 1**

**Table 7:** Failure modes and effects analysis (FMEA)

Component	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/ Mechanism(s) of Failure	Occurrence	Rank	Recommended Action(s)
Electrical system	Loss of power	All electric equipment fails	8	Local city electrical system down, panel fails, main power feed to building fails	7	56	Recommend generator be available on hand
Supply Filters #1 and #2	Partial blockage	Reduces air flow to main storage room	5	Fouling of filter	7	35	Replace filters on a regular basis
Supply Filters #1 and #2	Complete blockage	No fresh air is provided	8	Severe fouling	2	16	Replace filters on a regular basis
Return Line Filter	Partial blockage	Reduces rate of air flow through return line	2	Fouling	7	14	Replace filters on a regular basis
Heating Coils #1 & #2	Air is not heated to 0 degrees	Storage room may not maintain warmth.	4	Fouling in tubes, partial blockage in tubes for water and/or supply air, water/air leakage [9]	3	12	Reduce fan speeds or temporarily turn off supply and exhaust fan. The honeybees heat will raise the temperature as it is larger than the building's heat loss.
Pump #1 & #2 (Heating water Loop)	No Flow in pump	Heating of air is halted	4	Broken coupling and/or pipe, loss of power in motor, broken motor [10]	2	8	Reduce fan speeds or temporarily turn off supply and exhaust fan. The honeybees heat will raise the temperature as it is larger than the building's heat loss.
Boiler	No Supply Gas Flow	Heating of air is halted	4	Broken duct, overheating, no gas from supply tank [11]	2	8	Reduce fan speeds or temporarily turn off supply and exhaust fan. The honeybees heat will raise the temperature as it is larger than the building's heat loss.

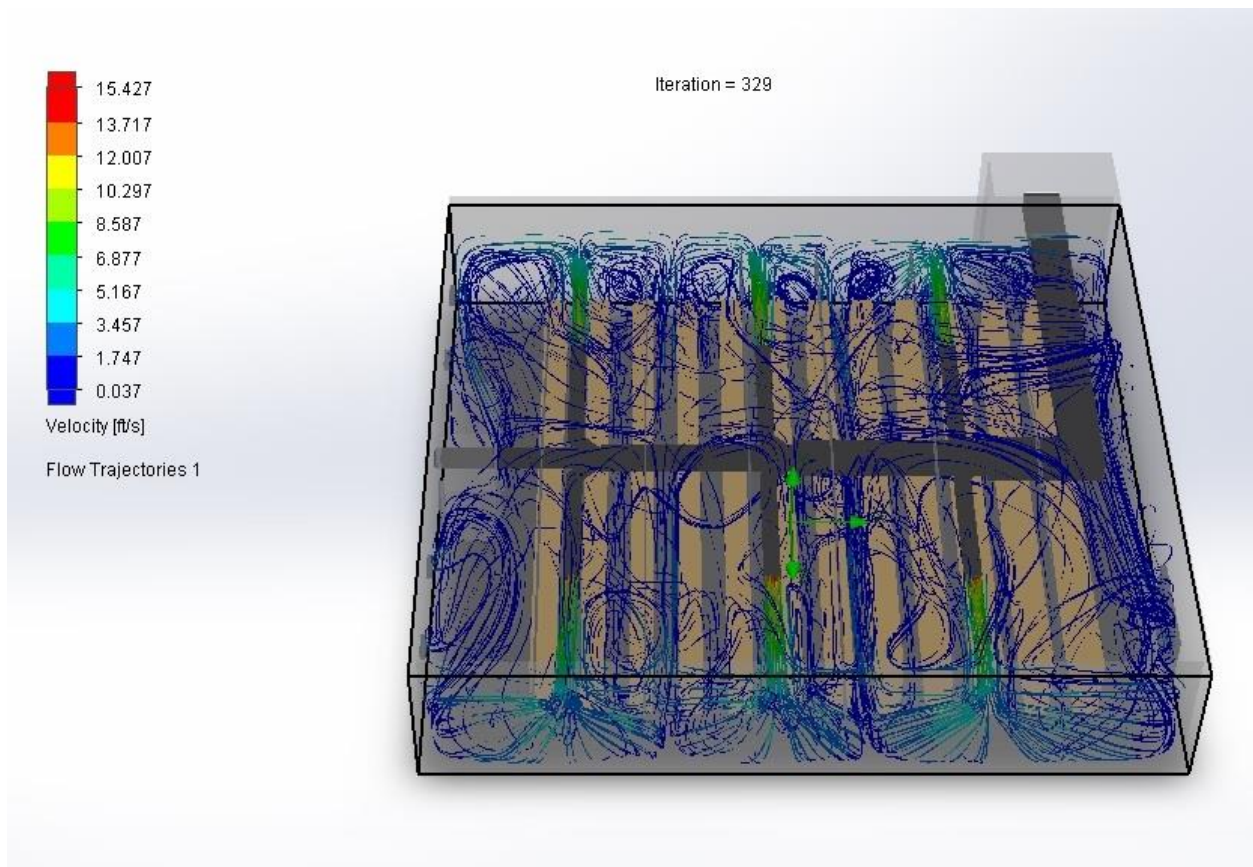
Component	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s)/ Mechanism(s) of Failure	Occurrence	Repair	Recommended Action(s)
Heating Coils #1 & #3	Air is not being heated	Storage room may not maintain warmth.	4	Broken tubes, complete blockage in tubes for water and/or supply air, no water from boiler and/or no supply air [9]	2	8	Reduce fan speeds or temporarily turn off supply and exhaust fan. The honeybees heat will raise the temperature as it is larger than the building's heat loss.
Supply Fan #1 and #2	1 fan stops working	Not enough ventilation is provided.	4	Damage to electrical circuit powering fan, motor damaged [12]	2	8	Turn off return fan to prevent buildup of CO2 and humidity
Supply Fan #1 and #2	Both fans stop working	No fresh air is provided	8	See above, if both occur at same time	1	8	No recommended action.
Natural Gas System	Loss of natural gas	Boiler stops heating	4	City natural gas system down, gas leak	2	8	No recommended action
Building Wall or Roof	Wall breaks	Air escapes, light gets into honeybee storage	7	Natural disaster	1	7	No recommended action
Pump #1 & #2 (Heating water Loop)	Flow is below 14 GPM	Longer time to heat air through heating coils.	2	Degraded impeller and/or motor, loose gasket and/or coupling, leak in pipe line [10]	3	6	No recommended action provided fix occurs relatively quick. Honeybees can tolerate temporarily cold weather.
Boiler	Feedwater flow is lower than required or non-existent	System cannot maintain water levels and will stop heating air if levels too low	3	Degraded pipes, leak [11]	2	6	No recommended action provided fix occurs relatively quick. Honeybees can tolerate temporarily cold weather.
Forklift Door	Door jams open	Light gets into honeybee storage	6	Forklift collides with door, door otherwise damaged	1	6	No recommended action
Boiler	Supply Gas flow is lower than required	Longer time to heat air through heating coils.	2	Degraded duct, leak, corrosion [11]	2	4	No recommended action provided fix occurs relatively quick. Honeybees can tolerate temporarily cold weather.

Component	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	O c c	R P N	Recommended Action(s)
Exhaust fans	1 fan stops working	More air is supplied than exhausted	2	Damage to electrical circuit powering fan, motor damaged	2	4	Turn off return fan
Exhaust fans	All fans stop working	No air is exhausted out of building	4	See above, if all occur at same time	1	4	Relieve pressure build-up by opening a door
Exhaust fans	3 fans stop working	Much more air is supplied than exhausted	3	See above, if all occur at same time	1	3	Turn off 1 supply fan and return fan to prevent overpressuring building
Return Line Fan	Fan stops working	No air is recycled	1	Damage to electrical circuit powering fan, motor damaged	2	2	No recommended action.
Exhaust fans	2 fans stop working	More air is supplied than exhausted	2	See above, if both occur at same time	1	2	Turn off 1 supply fan to prevent overpressuring building
Return Line Filter	Complete blockage	Halts recycling of air	1	Severe fouling	2	2	Replace filters on a regular basis
Solar Air Heater	Glass panel breaks	Air bypasses solar air heater	1	Item falls on solar air heater	2	2	No recommended action

## 5.5 Building Simulations

### 5.5.1 AIR CIRCULATION

To check if the current design has sufficient air circulation around the hives, a simplified model of the storage building was created to perform a 3D Computational Fluid Dynamics (CFD) analysis. This was done in SolidWorks to visualize the flow of air inside the building. Figure 14 shows the resultant flow trajectories, in which flows are represented by coloured lines, the colours indicating the flow velocity.



**Figure 14:** Air circulation simulation, flow trajectory and velocity

It can be seen that the airflow covers most of spaces inside the building, indicating that most of the stacks are receiving sufficient air flow except for those toward the middle, which is acceptable considering the fact that this simulation is describing a worst-case scenario where the effects of ceiling fans were not taken into account.

## 6.0 DESIGN COMPLIANCE

Refer to Table 9 for the design compliance matrix of this project. Refer to Table 8 for a description of the 1-5 scale of importance. Only one change was made to the specifications in Phase III, with regards to the allowable CO<sub>2</sub> levels in the building. In discussions with Dr. Martin Currie, head of entomology at the University of Manitoba, it was found that honeybees can tolerate much higher levels of CO<sub>2</sub> than previously thought [13] [1]. This change is reflected in item A.4 of Table 9.

**Table 8:** Design compliance matrix importance rating explanation

<b>Importance Rating</b>	<b>Description</b>
5	Required; must have
4	Important
3	Should have
2	Optional
1	Unimportant; nice to have

**Table 9:** Design compliance matrix

Item	Description	Specification	Design Authority	Importance	Design Compliance		Improvements
					(Y/N)	Notes	
A	Functionality						
A.1	Smart Monitoring	The system must allow beekeepers to monitor the honeybee’s environment without entering the building. Monitoring will be assisted via sensors and software.	Client	5	Y	Hive sensors allow for direct monitoring of bees, and building sensors track building temperature and humidity	No changes from Phase II.
A.2	Heating	The system must be able to maintain a maximum temperature of 4 degrees Celsius in order to keep the bees from leaving their hives.	Client	5	Y	Under cold conditions the system will maintain the internal temperature at 4 degrees C. As long as winter temperatures do not stay warm for long the temperature will remain reasonably low. Refer to Section 8.1.	Intake air lines were split in 2, requiring a second heating coil. The heating capacity as a whole did not change.
A.4	Ventilation	The system must ensure proper ventilation to prevent the accumulation of excess carbon dioxide that could potentially suffocate the honeybees. <del>500 ppm is an acceptable level of CO<sub>2</sub>.</del> Building should maintain CO <sub>2</sub> under 1000 ppm under normal conditions and not permit any higher than 3000 ppm. [1]	Client	5	Y	System maintains a CO2 level of ~800 ppm under standard conditions.	The air changes per hour (ACH) rate was doubled from 4 to 8 to increase ventilation and reduce build up of CO2 and humidity. In addition, the percentage of return air was reduced to 30% due to high build-up of CO2.

Item	Description	Specification	Design Authority	Importance	Design Compliance		Improvements
					(Y/N)	Notes	
A.5	Humidity	The system must maintain a dry environment (30%-40% humidity) in order to prevent the spread of disease. Additionally, if the humidity is below 30%-40%, the honeybee's food source will become too dry and inedible.	Client	4	Y	Average humidity throughout winter is between 30 and 40%.	No changes from Phase II.
A.6	Darkness	To ensure honeybees remain in their hives, total darkness must be achieved for the entirety of overwintering.	Client	5	Y	Building is subjected to total darkness. A vestibule is used for beekeepers to enter to prevent light and the exhaust ducts have two elbows to prevent light from entering.	No changes from Phase II.
A.9	Flexibility	Equipment or features of the building should be removable to enable alternate uses in non-winter months.	sWarm Solutions	2	Y	There are no equipment or fixtures permanently affixed to the floor of the main storage space.	No changes from Phase II.
A.11	Feeding	The system allows bees to be fed more than once	sWarm Solutions	1	Y	The hives will not be insulated or covered, allowing beekeepers to add food if needed (i.e in the case of a long winter)	No changes from Phase II.
<b>B</b>	<b>Building</b>						



Item	Description	Specification	Design Authority	Importance	Design Compliance		Improvements
					(Y/N)	Notes	
B.1	Entrances	The main doors must be large enough to allow access for forklifts to move hive pallets in and out. Entrances for forklifts should be at least 4 m wide and 3 m high.	Client	5	Y	Forklift door is 4.6 m, large enough for a standard forklift or larger.	No changes from Phase II.
B.2	Building Size	The building should be at least 15 feet tall and must be able to overwinter 6,000 or more honeybee hives. Each hive consists of 2 stacked Langstroth boxes. Langstroth boxes are transported on pallets which can hold 4 hives.	Client	5	Y	Building is capable of fitting 6000 colonies	The height of the building was increased from 15 ft to 18 ft to provide more room for the HVAC equipment and the beehive stacks.
B.3	Flooring	A concrete floor and foundation should be implemented to prevent pests from entering the building via burrowing.	Client	4	Y	Building will include concrete floor and foundation.	No changes from Phase II.
B.4	Protection Against Wildlife	The building should provide adequate protection against any animals that could possibly get attracted by the honey (rodents, bears, etc).	Client	3	Y	Building has a concrete base to prevent burrowing animals and walls prevent animals getting in.	No changes from Phase II.

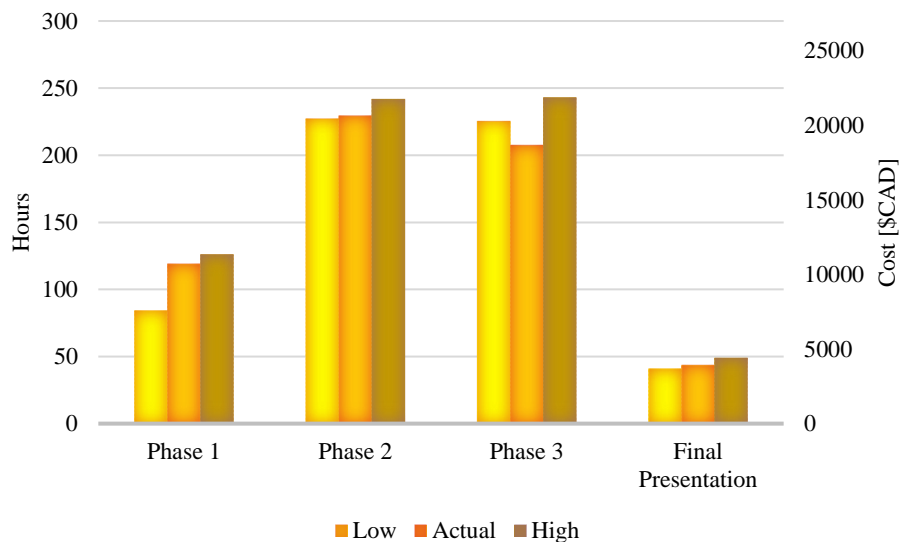
Item	Description	Specification	Design Authority	Importance	Design Compliance		Improvements
					(Y/N)	Notes	
B.7	Insulation	Building should be insulated from outside by means of insulation with an R-value no less than 20.	sWarm Solutions	4	Y	The insulation will be R30 for the wall and R40 for the roof	No changes from Phase II.
C	Others						
C.1	Cleanability	The system and building must be cleanable, with surfaces that are resistant to chemicals when sanitization takes place during the summer.	Client	3	Y	The surface of the building will be concrete which is resistant to standard cleaning chemicals. Ducts are standard and can be cleaned using standard duct cleaners.	No changes from Phase II.
C.2	Maintenance	The system must require minimal maintenance and be easily maintained by an individual.	Client	4	Y	Equipment is standard	Specification removed individual portion. It is unrealistic an HVAC system can be easily maintained by an individual with no training.
C.3	Construction Cost	The current bee overwintering approach of wrapping the hives with improvised insulation, although not efficient, is relatively inexpensive (\$100 for 4 hives); as such, the system must not cost significantly more than existing methods when considered over a long-term period.	Client	5	Y	Payback period is under 5 years, at which point the building becomes cheaper than the wraps on a per-hive basis	No specific improvements to cost – improvements to other systems affected this.

Item	Description	Specification	Design Authority	Importance	Design Compliance		Improvements
					(Y/N)	Notes	
C.3A	Operation costs	Cheap operation costs associated with heating the building and the electronics	Client	5	Y	Operation costs of the building are low when compared to warehouse operation costs.	No specific improvements to cost – improvements to other systems affected this.
C.4	Viability	The system must be feasible and reliable; system errors must be prevented or minimized.	Client	5	Y	System is viable.	An FMEA was conducted that shows all failure modes and how they are prevented and detected.
C.5	Codes and Standards	The building and system must be designed to meet all applicable standards as per Table 6.	Authority Having Jurisdiction	5	N/A	Alberta farm buildings with low human occupancy are exempt from building codes [14].	No changes from Phase II.
C.6	Simplicity	System must be simple to be operated and monitored by an individual.	sWarm Solutions	3	Y	The building and hives will be monitored by the beekeepers from their cellular devices. Operation of building systems is automatic.	No changes from Phase II.

Item	Description	Specification	Design Authority	Importance	Design Compliance		Improvements
					(Y/N)	Notes	
C.7	Sustainability	System can be environmentally friendly and sustainable.	sWarm Solutions	2	Y	Solar heater are used in the design which is a renewable method that can help reduce heating costs. Furthermore, solar panels are available to be implemented on the building due to it's relatively flat roof.	Solar heater was adapted to the return air concept to make the design more sustainable and reduce heating costs.

## 7.0 PROJECT MANAGEMENT

Refer to Figure 15 for the estimated and actual time spent on each phase, in addition to the final presentations. Table 10 summarizes the hours spent and finalized engineering costs. Maintaining the same rate in Phase III as others, Junior engineers are charged out at \$90 per hour, while Intermediate Engineers are charged out at \$150 per hour.



**Figure 15:** Final hours spent when compared to initial estimates of engineering time

**Table 10:** Final engineering hours broken down by Phase

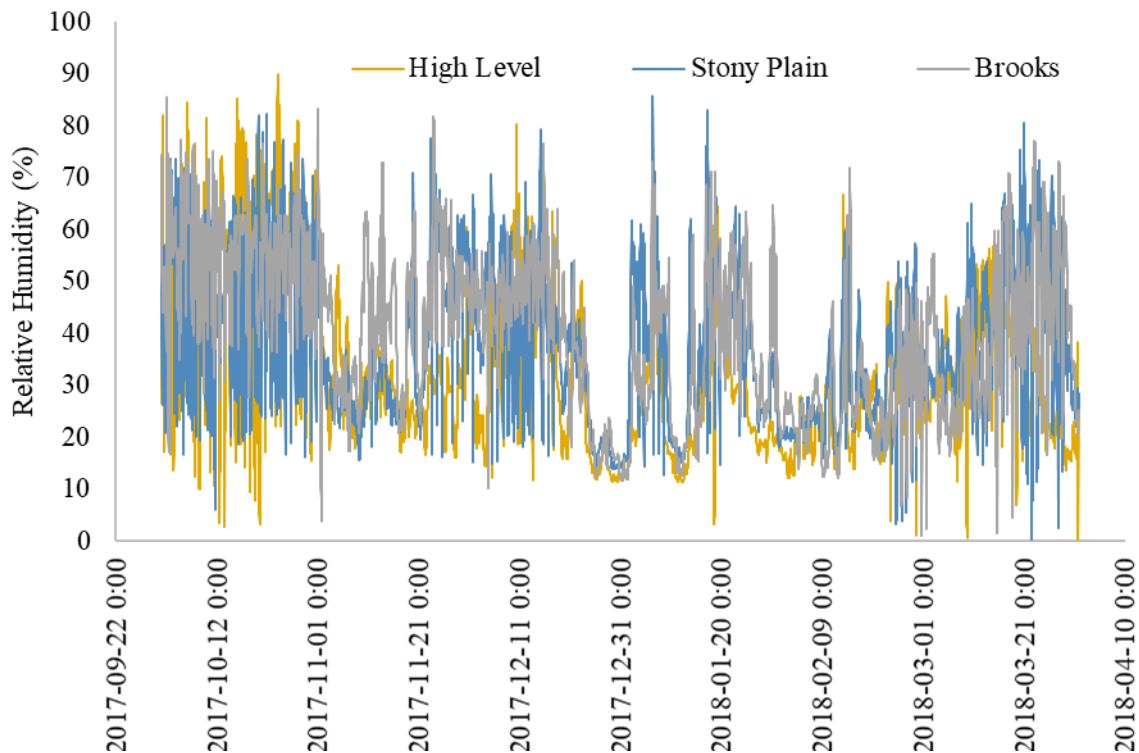
Phase	Junior Engineer Hours	Intermediate Engineer Hours	Cost
Letter of Intent	23.5 (actual)	0	\$2,115
Phase I	119 (actual)	2	\$11,010
Phase II	229 (actual)	3	\$21,060
Phase III	207 (actual)	4	\$19,230
Final Presentation	43.5 (actual)	0	\$3,915
<b>Total</b>	<b>622</b>	<b>9</b>	<b>\$57,330.00</b>

Compared to the initial estimated cost of \$60,390 in Phase I, sWarm Solutions saved 5%, or 34 hours. This savings occurred largely in Phase III, as the time taken to perform design refinements was lower than originally expected. Automatic calculation programs such as SMATH Studio and MathCAD help greatly with this, as parameter changes are easily accommodated in short periods of time.

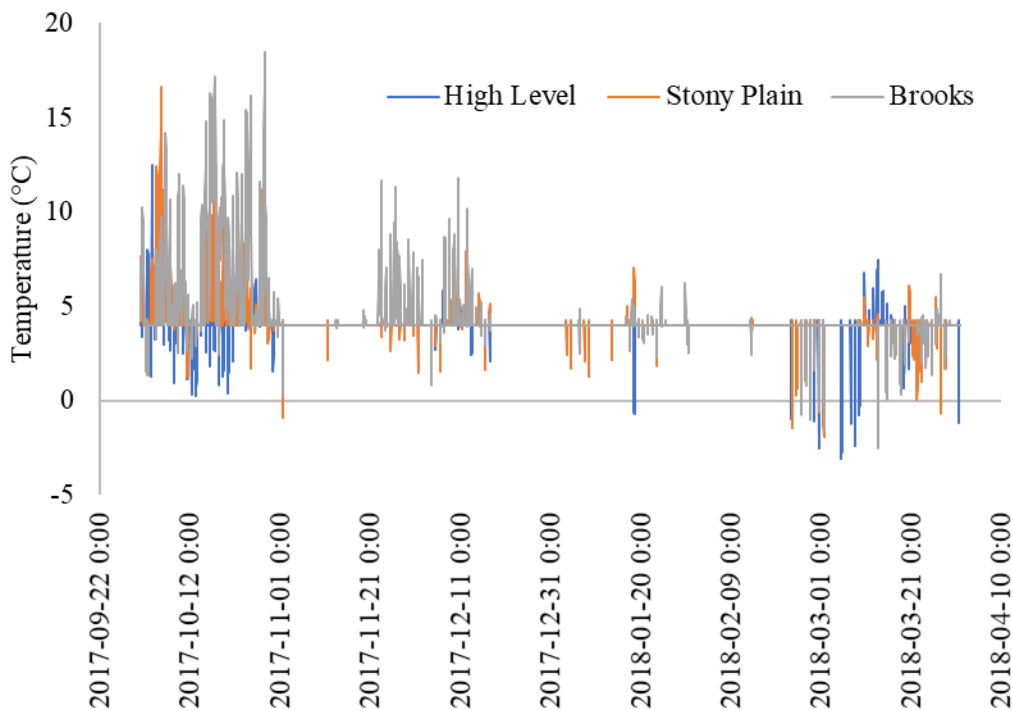
## 8.0 FUTURE WORKS AND RECOMMENDATIONS

### 8.1 Recommendations for Building Use

Using the same MATLAB script described in Section 4.2, certain parameters were tracked throughout an entire winter using hourly weather data. These parameters are shown in Figure 16 and Figure 17, and drove some of sWarm Solutions' recommendations. Refer to Table 11 for recommendations of the future overwintering storage building's uses.



**Figure 16:** Internal building humidity over the course of winter, using 2017/18 data



**Figure 17:** Internal building temperature throughout winter, using 2017/18 data

**Table 11:** Building use recommendations as a result of hourly performance analysis

Problem	Recommendation
CO <sub>2</sub> and temperature are too high too often in the month of October	Overwintering building should not be used until the winter is sufficiently cold (regularly below freezing). This was confirmed with ABC as beekeepers do not set a strict date on overwintering; it depends on the climate.
Relative humidity varies often	Average humidity is maintained between 30 and 40% per specification and acceptable for standard use. If further control is required recommend humidity control be installed in the form of in-duct nozzles and/or evaporator coils.
Chinooks cause warm temperatures in the middle of winter	The overwintering building maintains environment best in climates that do not generally get chinooks. If installed in a region with chinooks, sWarm Solutions recommends a full cooling system or other method of temporary cooling be on hand for the case of an extended period of warm temperature.

## 8.2 Future Design Considerations

While the building's system is fairly simple, further design work regarding the controls system is required. The equipment used in the building is required to be integrated in order for the building to switch between the three modes defined in Section 3.2.3. In addition, an integrated controls system can be further connected to a central computer to potentially allow for further external monitoring of the equipment or even control. Refer to Table 12 for other future design considerations.

**Table 12:** Future design considerations

Future Design Consideration	Details
Summer Usage	The overwintering building was designed and optimized for winter. As such, more time could be spent on analyzing and improving the design to allow for better summer requirements
Location Optimization	A specific location was not provided by ABC as part of this project. Once this is determined, more accurate cost estimates and calculations can be created, in addition to further optimization based on the physical site.
Electrical Systems	While not in scope due to skillset, co-operation with electrical engineers could allow for the electrical systems to be included in the costs and calculations of this building. These systems would include lighting, power, and communications.
Fire Suppression	If desired by client, a commercial fire suppression system could be further looked into.
Nectar Performance Testing	Currently, the Nectar hive monitoring system is a new product. More work needs to be done to show proof of concept to confirm all technology works as advertised.
Solar Air Heater – Manufacturing Analysis	Due to time constraints, a full manufacturing analysis was unable to be completed and should be done to confirm viability and true cost before moving forward with this component.



## 9.0 CONCLUSION

Over the last four months, sWarm Solutions developed a honeybee overwintering building with the purpose of lowering honeybee losses currently experienced by beekeepers across the province. The goal of Phase III was to refine the return air concept chosen in Phase II, and to present the Alberta Beekeepers Commission with a solution that met all requirements. Phase III analysis included refinement of building size, HVAC systems, and sensor mapping. The final design was visually communicated to the client via detailed drawings. Simulations were provided that confirmed operation of the overwintering building and checked the hourly operation of the building. Additionally, a customized solar air heater was added to improve the heating cost by up to 10%, and also increases the sustainability of the project. With the finalized design proposed to the client as a solution to overwintering of the honeybees, sWarm Solutions is confident that the building will improve the survival rates of honeybees through the harsh winter in Alberta.

## 10.0 ACKNOWLEDGMENTS

- Dr. Michael Lipsett (Course Professor) - for providing instructions and support for this course.
- Connie Phillips (Executive Director at Alberta Beekeepers Commission), for providing feedback and information on honey bee biology.
- Dr. Lexuan Zhong (Academic Advisor), for providing engineering support and approvals for heat loss and HVAC calculations.
- Maximilian Cherney (Manager, Marketing and Business Development at Nectar Technologies Inc.), for liaising, facilitating communication between sWarm Solutions and Nectar Technologies Inc, and providing relevant cost documentation.
- Evan Henry (Lead Apicultural Scientist at Nectar Technologies Inc.), for contribution information on the workings of the BeeCon sensors and BeeHub sensor hubs.
- George W Zakhem (Chief Estimator at Olympia Steel Buildings of Canada), for providing estimates on the total building cost of the initial design.
- Dr. Robert Currie (Professor and Head of Entomology Department at the University of Manitoba), for providing valuable honey bee data required for the proper design of this project
- Jeremy Olthof (Local Beekeeper), for providing information of current storage solutions for overwintering honey bees in Alberta.
- Dr. Mark Ackerman (Professor), for for providing engineering support for heat loss calculations.

## 11.0 REFERENCES

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## **APPENDIX A: HIVE STACKING CALCULATIONS**

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## Calculation #1: Mass of a Honeybee Hive

Author : Manel Ajbouni

Checked by: Son Le

Revision Number: 1

Revision Details: Formatting

Revision Checked by: Patrick Leung

### Objective

To determine the average mass of a single beehive.

### Known Data

$$M_{bee} := 0.1 \text{ g}$$

$$N_c := 20000$$

$$M_{Bee} := 54.4 \text{ kg}$$

$$M_F := 3 \text{ kg}$$

### Assumptions

1. Number of colonies was determined based on a 2015 study
2. Langstroth beehive is a standard and the mass of the hive is assumed to be same as the clients
3. Each beehive contains two langstroth boxes

### Variable Definition

M.bee = Mass of a single honeybee

N.c = Number of bees in a colony

M.Bee = Mass of two Langstroth

M.F = Mass of the food in a single beehive

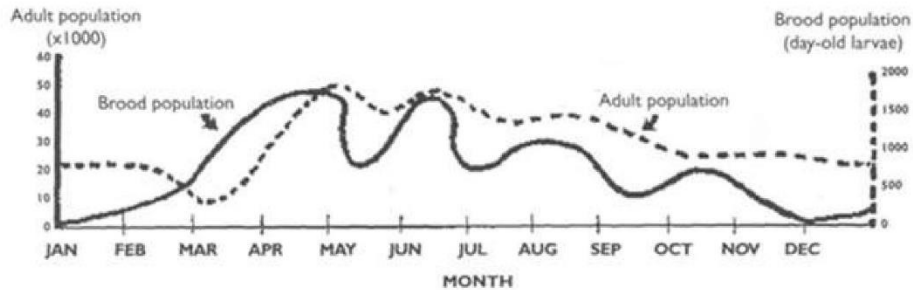
### Sketch

Not applicable- Sketch is not needed to determine the mass of one beehive

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## Analysis

Population of beehives through out the year from a 2015 study by Extension:



Population in the month of October was taken as it approximates the period of when beehives are expected to be stored.

Total mass of bees in the beehive

$$M_{Total\_Bee} := M_{bee} \cdot N_c = 2 \text{ kg}$$

Total mass of the beehive

$$M_T := M_{Total\_Bee} + M_{Bee} + M_F = 59.4 \text{ kg}$$

## Conclusion

Total mass of each beehive before storage is approximately 59.4 kg.

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## Calculation #2: Safety Factor of Beehive Lid

Author : Manel Ajbouni

Checked by: Son Le

Revision Number: 1

Revision Details: Clarification on the properties of wood

Revision Checked by: Alex Madsen

### Objective

Determine the safety factor of the beehive lids

### Known Data

$$M_T = 59.4 \text{ kg}$$

$$m := 18 \text{ kg}$$

$$a := 0.5302 \text{ m}$$

$$b := 0.4064 \text{ m}$$

$$t := 0.0508 \text{ m}$$

$$S := 41.4 \text{ MPa}$$

$$g := 9.81 \frac{\text{m}}{\text{s}^2}$$

### Assumptions

1. Yield tensile strength,  $S$ , is for pine wood (standard)
2. Thickness of the plate was estimated based on observations
3. Stress equation assumes that thickness of the plate is less than 10% of the length

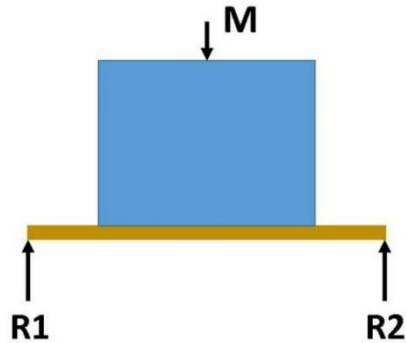
### Variable Definition

 $T$  = Total mass of beehive $m$  = Mass of pallet $a$  = Length of lid $b$  = Width of lid $t$  = Thickness of lid $S$  = Yield strength of american eastern white pine wood $g$  = acceleration due to gravity $M_H$  = Mass applied on each beehive $p$  = Distributed load on each beehive

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## Sketch

Stacking of the beehives:



## Analysis

### Safety factor with 1 layer of beehives and pallet

1. Mass applied on each hive

$$M_H := \frac{(M_T \cdot 4 + m)}{4} = 63.9 \text{ kg}$$

2. Determine the distributed load on each beehive lid

$$p := \frac{(M_H) \cdot g}{a \cdot b} = 2909.2192 \text{ Pa}$$

3. Stress acting on the lid

$$\sigma_m := \frac{(0.75 \cdot p \cdot b^2)}{t^2 \cdot \left(1.61 \cdot \left(\frac{b}{a}\right)^3 + 1\right)} = 80949.8516 \text{ Pa}$$

4. Factor of safety

$$n := \frac{S}{\sigma_m} = 511.4277$$

\*Very high safety factor, Iterate by adding another layer of beehives and pallet

### Iteration 1: Safety factor with 2 layers of beehives and pallets

1. Mass applied on each hive

$$M_{H2} := \frac{(M_T \cdot 8 + 2 \cdot m)}{4} = 127.8 \text{ kg}$$



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2. Determine the distributed load on each beehive lid

$$p := \frac{(M_{H2}) \cdot g}{a \cdot b} = 5818.4384 \text{ Pa}$$

3. Stress acting on the lid

$$\sigma_m := \frac{(0.75 \cdot p \cdot b^2)}{t^2 \cdot \left(1.61 \cdot \left(\frac{b}{a}\right)^3 + 1\right)} = 1.619 \cdot 10^5 \text{ Pa}$$

4. Factor of safety

$$n := \frac{S}{\sigma_m} = 255.7139$$

\*Very high safety factor, Iterate by adding another layer of beehives and pallet

**Iteration 2: Safety factor with 3 layers of beehives and pallets**

$$M_{H3} := \frac{(M_p \cdot 12 + 3 \cdot m)}{4} = 191.7 \text{ kg}$$

2. Determine the distributed load on each beehive lid

$$p := \frac{(M_{H3}) \cdot g}{a \cdot b} = 8727.6576 \text{ Pa}$$

3. Stress acting on the lid

$$\sigma_m := \frac{(0.75 \cdot p \cdot b^2)}{t^2 \cdot \left(1.61 \cdot \left(\frac{b}{a}\right)^3 + 1\right)} = 2.4285 \cdot 10^5 \text{ Pa}$$

4. Factor of safety

$$n := \frac{S}{\sigma_m} = 170.4759$$

\*Very high safety factor, Iterate by adding another layer of beehives and pallet

**Iteration 3: Safety factor with 4 layers of beehives and pallets**

$$M_{H4} := \frac{(M_p \cdot 16 + 4 \cdot m)}{4} = 255.6 \text{ kg}$$

2. Determine the distributed load on each beehive lid

$$p := \frac{(M_{H4}) \cdot g}{a \cdot b} = 11636.8767 \text{ Pa}$$

3. Stress acting on the lid

5 / 6

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$$\sigma_m := \frac{(0.75 \cdot p \cdot b^2)}{t^2 \cdot \left(1.61 \cdot \left(\frac{b}{a}\right)^3 + 1\right)} = 3.238 \cdot 10^5 \text{ Pa}$$

4. Factor of safety

$$n := \frac{S}{\sigma_m} = 127.8569$$

\*Very high safety factor, Iterate by adding another layer of beehives and pallet

**Iteration 4: Safety factor with 5 layers of beehives and pallets**

$$M_{H5} := \frac{(M_T \cdot 20 + 5 \cdot m)}{4} = 319.5 \text{ kg}$$

2. Determine the distributed load on each beehive lid

$$p := \frac{(M_{H5}) \cdot g}{a \cdot b} = 14546.0959 \text{ Pa}$$

3. Stress acting on the lid

$$\sigma_m := \frac{(0.75 \cdot p \cdot b^2)}{t^2 \cdot \left(1.61 \cdot \left(\frac{b}{a}\right)^3 + 1\right)} = 4.0475 \cdot 10^5 \text{ Pa}$$

4. Factor of safety

$$n := \frac{S}{\sigma_m} = 102.2855$$

Maximum height is reached

## Conclusion

Each layer will include 4 beehives (8 langstroth boxes) and one pallet. Calculations were conducted on the lid of the bottom beehive to determine if having 5 layers will result in low safety factor and ultimately cause the beehive to collapse. Safety factor of the lid with five layers of beehives and pallets stacked was found to be in the order of hundreds which therefore eliminates the need for shelves. Only a maximum of five layers can be stacked due to height restrictions that a standard forklift can reach (10 ft).

## **APPENDIX B: HEAT TRANSFER CALCULATIONS**

10 Apr 2019 11:04:23 - Heat Transfer (revised).sm

## Calculation: Building Heat Loss

Author: Son Le

Checked By: Alex Madsen

Revision Number: 0

Revision Details: No issues after calculation was revised per Phase II mistakes

Revision Checked By:

### Objective:

To determine the heat loss of the Return Air concept using heat transfer calculations calculations.

### Assumptions:

- 1) Steady operating conditions for heat Conduction and Convection
- 2) Negligible Radiation
- 3) Outside and inside ambient temperatures are constant
- 4) All doors have the same insulation as the wall
- 5) Local atmospheric pressure is 1 atm (100-101 kPa)
- 6) The building wall is oriented vertically at an angle of exactly 90 degrees
- 7) The concrete floor is uninsulated.
- 8) The building enclosures are tight fitted.

### Variable Definitions:

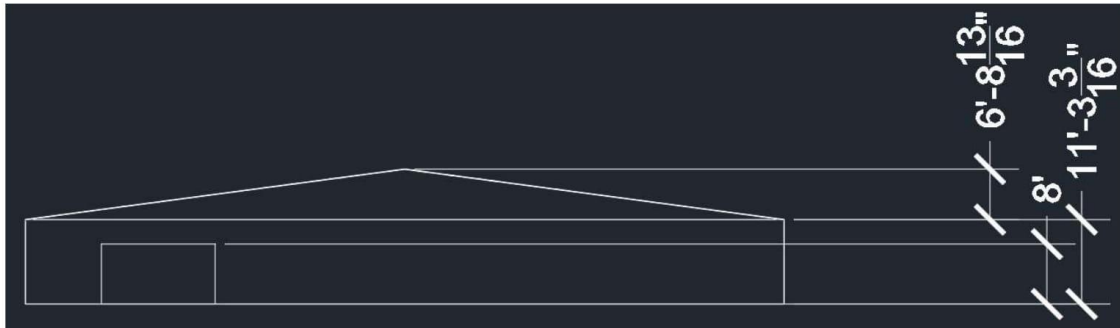
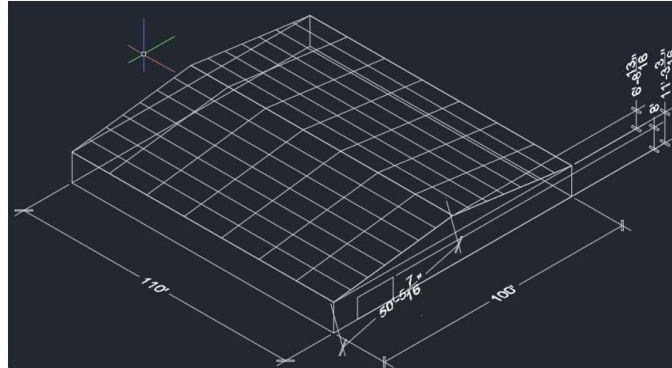
A1 : Cross-sectional area of the side walls  
A2 : Cross-sectional area of the front and back walls  
A3 : Cross-sectional area of the roof  
A4 : Cross-sectional area of the wall between the ceiling and roof  
ACH : Air changes per hour constant  
Arf : The area of the roof panel  
Cs : Air sensible heat factor  
Cl : Air latent heat factor  
Fp : Heat loss coefficient of the floor's perimeter  
HR\_in : Humidity ratio of the interior air  
HR\_out: Humidity ratio of the outside air  
Ht : Height of the building wall  
Htrf : Height of the roof  
L : Length of the building wall  
Peri : The perimeter of the concrete floor  
Q : Heat transfer between the building and the surrounding environment  
Ql : The building's latent heat loss  
Qs : The building's sensible heat loss  
Q\_dot\_infil: The infiltration rate of the outside air  
Q\_fb : Heat loss from the front and back walls  
Q\_fl : Heat loss from the floor  
Q\_rf : Heat loss from the roof  
Q\_side : Heat loss from the side walls  
Q\_total : Total heat loss  
R\_finr: Surface film resistance of the interior roof  
R\_finw: Surface film resistance of the interior wall  
R\_foutr: Surface film resistance of the exterior roof  
R\_foutw: Surface film resistance of the exterior wall  
R\_ins : R-value of the insulation within the walls  
R\_ins\_roof: R-value of the roof insulation  
Rw\_tot : Total thermal resistance of the walls  
Rr\_tot : Total thermal resistance of the roof  
Slrf : Length of the roof's slope

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$T_{\infty in}$  : Interior wall ambient temperature  
 $T_{\infty out}$  : Exterior wall ambient temperature  
 $Wid$  : Width of the wall  
 $\Delta T$  : The temperature difference between the inside and outside air

## Sketches:



## Known Data:

$$\begin{aligned}
 Ht &:= 11.266 \text{ ft} & T_{\infty in} &:= 498.87 \text{ }^{\circ}\text{Ra} & ACH &:= 0.59 \cdot \frac{1}{\text{hr}} & R_{ins} &:= 30 \frac{\text{ft}^2 \cdot ^{\circ}\text{Ra hr}}{\text{BTU}} \\
 L &:= 100 \text{ ft} & T_{\infty out} &:= 419.67 \text{ }^{\circ}\text{Ra} & & & R_{ins\_roof} &:= 40 \frac{\text{ft}^2 \cdot ^{\circ}\text{Ra hr}}{\text{BTU}} \\
 Ht_{bld} &:= 18 \text{ ft} & HR_{out} &:= 0.00008 & Fp &:= 2.12 \frac{\text{BTU}}{\text{hr ft}^2 \cdot ^{\circ}\text{Ra}} & R_{foutw} &:= 0.17 \frac{\text{ft}^2 \cdot ^{\circ}\text{Ra hr}}{\text{BTU}} \\
 Wid &:= 110 \text{ ft} & HR_{in} &:= 0.005 & & & R_{finw} &:= 0.68 \frac{\text{ft}^2 \cdot ^{\circ}\text{Ra hr}}{\text{BTU}} \\
 & & Cs &:= 1.10 \frac{\text{BTU min}}{\text{hr } ^{\circ}\text{Ra ft}^3} & & & R_{foutr} &:= 0.17 \frac{\text{ft}^2 \cdot ^{\circ}\text{Ra hr}}{\text{BTU}} \\
 Htrf &:= Ht_{bld} - Ht = 6.734 \text{ ft} & Cl &:= 4840 \frac{\text{BTU min}}{\text{hr ft}^3} & & & R_{finr} &:= 0.92 \frac{\text{ft}^2 \cdot ^{\circ}\text{Ra hr}}{\text{BTU}} \\
 Slrf &:= \sqrt{\left(\frac{L}{2}\right)^2 + (Htrf)^2} = 50.4514 \text{ ft} & & & & & & 
 \end{aligned}$$

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## Analysis:

First, the cross-section areas of the side, front, back walls, and roof are calculated. The perimeter of the floor is also calculated.

$$\begin{aligned} A1 &:= \text{Wid} \cdot \text{Ht} = 1239.26 \text{ ft}^2 & A_{rf} &:= S_{lrf} \cdot L = 5045.143 \text{ ft}^2 \\ A2 &:= L \cdot \text{Ht} = 1126.6 \text{ ft}^2 & \text{Peri} &:= (L + \text{Wid}) \cdot 2 = 420 \text{ ft} \\ A3 &:= L \cdot \text{Wid} = 11000 \text{ ft}^2 & A4 &:= \frac{L \cdot \text{Htrf}}{2} = 336.7 \text{ ft}^2 \end{aligned}$$

The temperature difference is then calculated

$$\Delta T := T_{\infty \text{in}} - T_{\infty \text{out}} = 79.2 \text{ }^{\circ}\text{Ra}$$

The air infiltration rate is:

$$Q_{\text{dot\_infil}} := \frac{\text{ACH} \cdot \left( L \cdot \text{Wid} \cdot \text{Ht} + \frac{\text{Htrf} \cdot \text{Wid}}{2} \cdot \text{Ht} \right)}{60} = 20.9939 \frac{\text{ft}^3}{\text{min}}$$

The total thermal resistances of the walls and roof are then determined

$$R_{w\_tot} := R_{\text{ins}} + R_{\text{finw}} + R_{\text{foutw}} = 30.85 \frac{^{\circ}\text{Ra ft}^2 \text{ hr}}{\text{BTU}}$$

$$R_{r\_tot} := R_{\text{ins\_roof}} + R_{\text{finr}} + R_{\text{foutr}} = 41.09 \frac{^{\circ}\text{Ra ft}^2 \text{ hr}}{\text{BTU}}$$

From here, the heat losses due to infiltration of cold air into the building is:

$$Q_s := C_s \cdot Q_{\text{dot\_infil}} \cdot \Delta T = 1828.9916 \frac{\text{BTU}}{\text{hr}}$$

$$Q_l := C_l \cdot Q_{\text{dot\_infil}} \cdot (\text{HR}_{\text{in}} - \text{HR}_{\text{out}}) = 499.9244 \frac{\text{BTU}}{\text{hr}}$$

The heat losses from conduction and convection of the side walls, front and back walls, floor, and roof are:

$$Q_{\text{side}} := 2 \cdot \frac{A1 \cdot \Delta T}{R_{w\_tot}} = 6363.0076 \frac{\text{BTU}}{\text{hr}} \quad Q_{\text{rm}} := 2 \cdot \frac{A4 \cdot \Delta T}{R_{w\_tot}} = 1728.7935 \frac{\text{BTU}}{\text{hr}}$$

$$Q_{\text{fb}} := 2 \cdot \frac{A2 \cdot \Delta T}{R_{w\_tot}} = 5784.5524 \frac{\text{BTU}}{\text{hr}}$$

$$Q_{\text{rf}} := 2 \cdot \frac{A_{rf} \cdot \Delta T}{R_{r\_tot}} = 19448.7867 \frac{\text{BTU}}{\text{hr}}$$

$$Q_{\text{fl}} := F_p \cdot \text{Peri} \cdot \Delta T = 70519.68 \frac{\text{BTU}}{\text{hr}}$$

The total heating load on the building is:

$$Q_{\text{total}} := Q_s + Q_l + Q_{\text{side}} + Q_{\text{fb}} + Q_{\text{rf}} + Q_{\text{fl}} + Q_{\text{rm}} = 1.0617 \cdot 10^5 \frac{\text{BTU}}{\text{hr}}$$

## Conclusion:

By performing a convective and conductive heat transfer analysis on the walls, given the set insulation R values, it was found that the heat loss out of the Return Air style building is a maximum of ~106,000 BTU/hr. This value may be used to calculate the heat that is required for the building.

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## Tables:

**Table 5-12 Surface Film Coefficients/Resistances<sup>1</sup>**  
(Table 10, Chapter 26, 2017 ASHRAE Handbook—Fundamentals)

Position of Surface	Direction of Heat Flow	Surface Emittance, $\epsilon$					
		Non-reflective $\epsilon = 0.90$			Reflective $\epsilon = 0.05$		
		$h_f$	$R$	$h_f$	$R$	$h_f$	$R$
		<b>STILL AIR</b>					
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32
Sloping—45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70
Sloping—45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55
<b>MOVING AIR (Any position)</b>							
		$h_o$		$R$			
15 mph Wind (for winter)	Any	6.00		0.17		—	
7.5 mph Wind (for summer)	Any	4.00		0.25		—	

Notes: (References are to Chapter 26 in the 2017 ASHRAE Handbook—Fundamentals)  
 1. Surface conductance  $h_f$  and  $h_o$  measured in Btu/h·ft<sup>2</sup>·°F; resistance  $R$  in °F·ft<sup>2</sup>/Btu.  
 2. No surface has both an air space resistance value and a surface resistance value.  
 3. Conductances are for surfaces of the stated emittance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10°F and for surface temperatures of 70°F.  
 4. See Chapter 4 in the 2017 ASHRAE Handbook—Fundamentals for more detailed information.  
 5. Condensate can have a significant impact on surface emittance.

**Table 5-1 Change Rates as a Function of Airtightness**

Class	Outdoor Design Temperature, °F								
	50	40	30	20	10	0	-10	-20	-30 -40
Tight	0.41	0.43	0.45	0.47	0.49	0.51	0.53	0.55	0.57 0.59
Medium	0.69	0.73	0.77	0.81	0.85	0.89	0.93	0.97	1.00 1.05
Loose	1.11	1.15	1.20	1.23	1.27	1.30	1.35	1.40	1.43 1.47

Note: Values are for 15 mph wind and indoor temperature of 65°F.

**Table 6-20 Heat Loss Coefficient  $F_p$  of Slab Floor Construction**

Construction	Insulation	$F_p$ , Btu/h·ft <sup>2</sup> ·°F
8 in. block wall, brick facing	Uninsulated floor	0.68
	R-5.4 from edge to footer	0.50
4 in. block wall, brick facing	Uninsulated floor	0.84
	R-5.4 from edge to footer	0.49
Studded wall, stucco	Uninsulated floor	1.20
	R-5.4 from edge to footer	0.53
Poured concrete wall with duct near perimeter*	Uninsulated floor	2.12
	R-5.4 from edge to footer	0.72

\*Weighted average temperature of the heating duct was assumed at 110°F during heating season (outdoor air temperature less than 65°F).

## APPENDIX C: HVAC CALCULATIONS



10 Apr 2019 10:38:59 - 01 - Duct Layout.sm

## Calculation #1: Duct Sizing and Fan

Author: Shengnan Chen

Checked By: Alex Madsen

Revision Number: 0  
Revision Details: No issues

Revision Checked By:

## Objective:

To select the duct sizes and supply fan required to meet or exceed the requirements of the honeybee environment.

## Custom Units:

$$\text{cfm} := 1 \frac{\text{ft}^3}{\text{min}} \quad \text{inWg} := 248.84 \text{ Pa} \quad \text{inWg}_{100} := 1 \frac{\text{inWg}}{100 \text{ ft}} \quad \text{fpm} := 1 \frac{\text{ft}}{\text{min}}$$

## Preliminary:

- 1) The working fluid will be air
- 2) The length of the duct is constrained by dimensions of the room.

## Assumptions:

- 1) Air is moving slow enough to be assumed incompressible ( $< 0.3 \times \text{Speed of Sound}$ )
- 2) Honeybee heat generation is negligible (honeybee hive thermoregulation is quite efficient resulting in the generated heat staying contained within the hive)
- 3) Motor inefficiencies get converted entirely into heat
- 4) Low velocity system desired, as honeybee comfort requires little wind.  
with the low-velocity system requirement, assume the velocity in main duct is 1100 fpm  
the velocity in branch duct is 800 fpm (According to table below)
- 5) Galvanized steel used as duct material.
- 6) Entrance to system is assumed to be a bellmouth entrance to minimize pressure drop
- 7) Elbows will be pleated as this is the industry standard and cheaper.
- 8) Air will be delivered from diffuser connected to the duct, and equivalent length of diffuser are 20 ft
- 9) Filters used in this system, and have a pressure drop about  $0.2 \text{ inWg}$ .

Low-Velocity Systems			
Designation	Private Residences	Schools, Theaters, Public Buildings	Industrial Buildings
Maximum Velocities (fpm)			
Main ducts	800–1200	1100–1600	1300–2200
Branch ducts	700–1000	800–1300	1000–1800
Branch risers	650–800	800–1200	1000–1600
Typical Velocities (fpm) <sup>a</sup>			
Throwaway filter	200–800		
Heating coil	400–500 (200 min, 1500 max)		
Cooling coil	500–600		

Source: Howell, Sauer, and Coad [9].

<sup>a</sup>Ductulator, Trane US Inc., La Crosse, Wisconsin.

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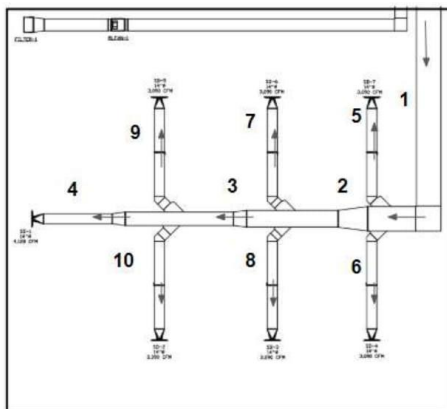
## Data known:

Length of building:  $L_{bldg} := 110 \text{ ft}$   
 Height of building:  $H_{bldg} := 18 \text{ ft}$   
 Width of building:  $W_{bldg} := 100 \text{ ft}$   
 Air pressure drop from tube bank:  $\Delta P_{bank} := 0.5 \text{ inWg}$

## Variable Definition:

D: diameter  
 H: Height  
 L: Length  
 Q: Volumetric Flow Rate  
 V: Volume  
 W: Width  
 $\Delta P$ : Pressure Drop

## Sketch:



## Analysis:

Total Air flow Rate:

$$V_{bldg} := L_{bldg} \cdot H_{bldg} \cdot W_{bldg} = 1.98 \cdot 10^5 \text{ ft}^3$$

$$Q := 8 \cdot V_{bldg} \cdot \frac{1}{60 \text{ min}} = 26400 \text{ cfm}$$

According to the duct layout, the airflow rate for each branches are:

Section 1: 26400cfm  
 Section 2: 19200cfm  
 Section 3: 12000cfm  
 Section 4: 4800cfm  
 Section 5,6,7,8,9,10: 3600cfm

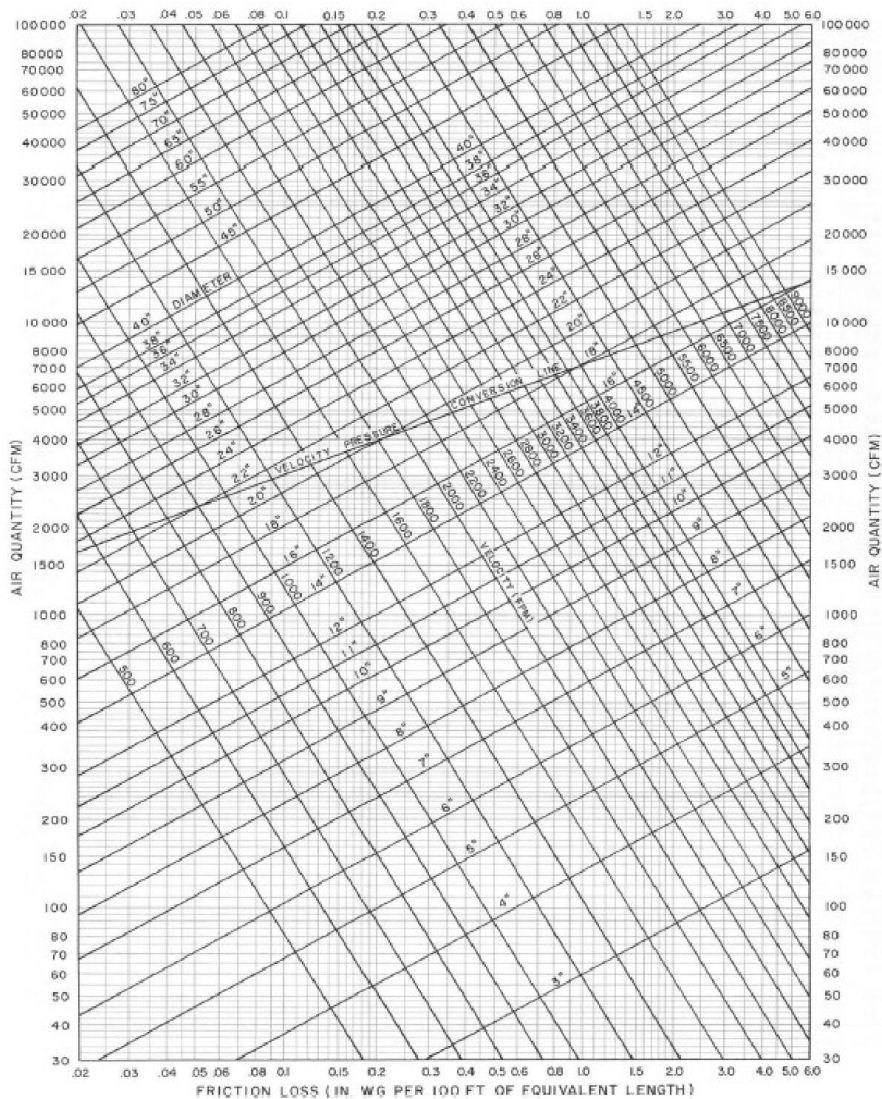
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Duct sizing by chart below:

Section	Diameter(inches)	Velocity(fpm)	Pressure Drop(inWg./100ft
1	60	1200	0.027
2	55	1180	0.028
3	45	1100	0.03
4	30	980	0.04
5,6,7,8,9,10	24	900	0.04

All flow velocity satisfied with low-velocity system.



To reduce the duct size we use rectangular duct, the equivalent rectangular duct size for each section will be:

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Section	x	y	circular	Ratio	Velocity (fpm)	Pressure Drop (inWg./100)
1	75	45	$D_1 := 63 \text{ in}$	1.67	1200	0.0255
2	55	45	$D_2 := 54.3 \text{ in}$	1.22	1200	0.0293
3	45	35	$D_3 := 43.3 \text{ in}$	1.29	1174	0.0374
4	30	25	$D_4 := 30 \text{ in}$	1.2	984	0.0421
5-10	30	20	$D_5 := 26.6 \text{ in}$	1.5	930	0.0435

The ratio for each sections all less than 4  
All flow velocity satisfied with low-velocity system.

Dimension for each section:

$$\begin{aligned}
 L_1 &:= 65 \text{ ft} & L_5 &:= 15 \text{ ft} & L_9 &:= 15 \text{ ft} \\
 L_2 &:= 30 \text{ ft} & L_6 &:= 15 \text{ ft} & L_{10} &:= 15 \text{ ft} \\
 L_3 &:= 30 \text{ ft} & L_7 &:= 15 \text{ ft} & & \\
 L_4 &:= 15 \text{ ft} & L_8 &:= 15 \text{ ft} & L_{diffuser} &:= 20 \text{ ft}
 \end{aligned}$$

Pressure drop for each section:

Equivalent lengths for selected fittings in circular duct are selected from table below

Equivalent Length (ft)					
Fitting	Diameter (in.)	6	8	10	12
Elbows					1
Pleated, 90°	8	10	13	15	
Pleated, 45°	5	6	8	9	
Mitered, 90°	30	40	50	60	
Mitered with vanes	5	7	8	10	
Transitions					
Converging, 20°	2	3	3	4	
Diverging, 120°	20	27	33	40	
Abrupt expansion	30	40	50	60	
Round to rectangular boot, 90°	25	33	40	50	
Round to rectangular boot, straight	5	7	8	10	
Entrances					
Abrupt, 90°	15	20	25	30	
Bellmouth	6	8	10	12	
Branch fittings, diverging					
Wye, 45°, branch	10	13	17	20	
Wye, 45°, through	4	5	7	8	
Tee, branch	20	27	33	40	
Tee, through	4	5	7	8	
Branch fittings, converging					
Wye, 45°, branch	10	13	17	20	
Wye, 45°, through	5	7	8	10	
Tee, branch	20	27	33	40	
Tee, through	6	8	10	12	

Source: McQuiston, F., Parker, J., and Spitler, J. (2000) *Heating, Ventilating, and Air Conditioning: Analysis and Design*. 5th edn. John Wiley & Sons, Inc., New York. p. 433.

Section 1

$$L_{bellmouth} := 12 \cdot D_1 = 63 \text{ ft}$$

$$L_{elbow.90} := 15 \cdot D_1 = 78.75 \text{ ft}$$

$$\Delta P_1 := \frac{0.0255 \text{ inWg}}{100 \text{ ft}} \cdot (L_1 + L_{bellmouth} + L_{elbow.90}) = 0.053 \text{ inWg}$$

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Section 2

$$L_{2.wye.through} := 10 \cdot D_2 = 45.25 \text{ ft}$$

$$L_{2.conv50_45} := 4 \cdot D_1 = 21 \text{ ft}$$

$$\Delta P_2 := \frac{0.0293 \text{ inWg}}{100 \text{ ft}} \cdot (L_2 + 2 \cdot L_{2.wye.through} + L_{2.conv50_45}) = 0.041 \text{ inWg}$$

Section 3:

$$L_{3.wye.through} := 10 \cdot D_3 = 36.083 \text{ ft}$$

$$L_{3.conv45_32} := 4 \cdot D_2 = 18.1 \text{ ft}$$

$$\Delta P_3 := \frac{0.0374 \text{ inWg}}{100 \text{ ft}} \cdot (L_3 + 2 \cdot L_{3.wye.through} + L_{3.conv45_32}) = 0.045 \text{ inWg}$$

Section 4:

$$L_{4.wye.through} := 10 \cdot D_4 = 25 \text{ ft}$$

$$L_{4.conv.32_22} := 4 \cdot D_4 = 10 \text{ ft}$$

$$\Delta P_4 := \frac{0.0421 \text{ inWg}}{100 \text{ ft}} \cdot (L_4 + 2 \cdot L_{4.wye.through} + L_{4.conv.32_22} + L_{diffuser}) = 0.04 \text{ inWg}$$

Section 5:

$$L_{5.wye.branch} := 20 \cdot D_5 = 44.333 \text{ ft}$$

$$\Delta P_5 := \frac{0.0435 \text{ inWg}}{100 \text{ ft}} \cdot (L_5 + L_{5.wye.branch} + L_{diffuser}) = 0.035 \text{ inWg}$$

Section 6:

$$\Delta P_6 := \Delta P_5 = 0.035 \text{ inWg}$$

Section 7:

$$\Delta P_7 := \Delta P_5 = 0.035 \text{ inWg}$$

Section 8:

$$\Delta P_8 := \Delta P_5 = 0.035 \text{ inWg}$$

Section 9:

$$\Delta P_9 := \Delta P_5 = 0.035 \text{ inWg}$$

Section 10:

$$\Delta P_{10} := \Delta P_5 = 0.035 \text{ inWg}$$

Therefore branch 1-2-3-4 is the longest branch:

$$\Delta P_{1_2_3_4} := \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4 = 0.179 \text{ inWg}$$

To balance each branch and for better maintainness, damper is installed on each branch. The position of damper for balancing each branche can determined as:

Branch 1-5:

$$\Delta P_{1_5} := \Delta P_1 + \Delta P_5 = 0.087 \text{ inWg}$$

$$\Delta P_{5,damper} := \Delta P_{1_2_3_4} - \Delta P_{1_5} = 0.092 \text{ inWg}$$

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Branch 1-6:

$$\Delta P_{6.damper} := \Delta P_{5.damper} = 0.092 \text{ inWg}$$

Branch 1-2-7:

$$\Delta P_{1\_2\_7} := \Delta P_1 + \Delta P_2 + \Delta P_7 = 0.129 \text{ inWg}$$

$$\Delta P_{7.damper} := \Delta P_{1\_2\_3\_4} - \Delta P_{1\_2\_7} = 0.05 \text{ inWg}$$

Branch 1-2-8:

$$\Delta P_{8.damper} := \Delta P_{7.damper} = 0.05 \text{ inWg}$$

Branch 1-2-3-9:

$$\Delta P_{1\_2\_3\_9} := \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_9 = 0.174 \text{ inWg}$$

$$\Delta P_{9.damper} := \Delta P_{1\_2\_3\_4} - \Delta P_{1\_2\_3\_9} = 0.005 \text{ inWg}$$

Branch 1-2-3-10:

$$\Delta P_{10.damper} := \Delta P_{9.damper} = 0.005 \text{ inWg}$$

With the pressure drop in tube bank, the total pressure drop will be:

$$\Delta P_{tot} := \Delta P_{bank} + \Delta P_{1\_2\_3\_9} = 0.674 \text{ inWg}$$

For branches in the mechanical room:

Section	x	y	circular	Ratio	Velocity (fpm)	Pressure Drop (inWg)
1	75	45	$D_{1.room} := 63 \text{ in}$	1.67	1200	0.0255
2	50	45	$D_{2.room} := 51.8 \text{ in}$	1.1	901	0.0182

Section	Air flow rate (cfm)	Length (ft)
1	26400	$L_{1.room} := 5 \text{ ft}$
2	13200	$L_{2.room} := 15 \text{ ft}$

$$\Delta P_{1.room} := \frac{0.0255 \text{ inWg}}{100 \text{ ft}} \cdot L_{1.room} = 0.0013 \text{ inWg}$$

$$L_{tee.branch} := 40 \cdot D_{2.room} = 172.67 \text{ ft}$$

$$L_{elbow} := 15 \cdot D_{2.room} = 64.75 \text{ ft}$$

Return air line connect with inlet line

$$L_{tee.through} := 8 \cdot D_{2.room} = 34.53 \text{ ft}$$



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$$\Delta P_{2.room} := \frac{0.0182 \text{ inWg}}{100 \text{ ft}} \cdot (L_{2.room} + L_{tee.branch} + L_{tee.through} + L_{elbow}) = 0.05 \text{ inWg}$$

$$\Delta P_{filter} := 0.2 \text{ inWg}$$

$$\Delta P_{room} := \Delta P_{1.room} + \Delta P_{2.room} + \Delta P_{filter} = 0.25 \text{ inWg}$$

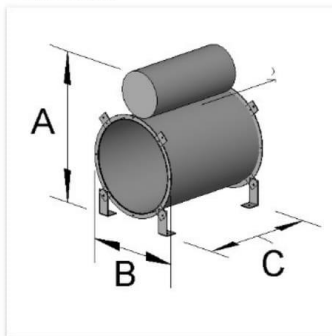
The total pressure required from the fan in inlet line is:

$$\Delta P_{fan} := \Delta P_{bank} + \Delta P_{1\_2\_3\_4} + \Delta P_{room} = 0.93 \text{ inWg}$$

Therefore, the selected fan should able to lift air 0.93inWg, According to the informat Provided by GreenHeck, an inline fan was selected based on the system airflow rate of 92. (with return air system, only 70% fresh air is introduce to the system).

Two Inline fan TBI-CA-3H30 are used and the average altitude of Alberta is 2000ft:

#### Dimensions



Label	Value (in.)	Description
A	47.578	Overall Height
B	33.625	Overall Width
C	24	Overall Length

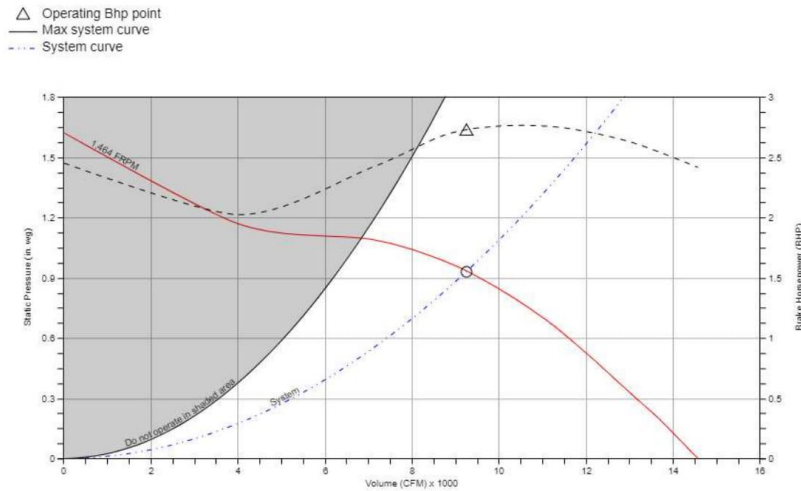
#### Performance

Actual Volume (CFM)	9,240
External Static Pressure (in. wg)	0.93
Total Static Pressure (in. wg)	0.93
Operating Power (Bhp)	2.72
Fan RPM	1,464
Percent within max fan RPM	19%
Inlet Sones	39
Inlet dBA	84

#### Pricing

Budget Price (USD)	\$2,628
Operating Cost / yr (USD)	\$565
<b>Features</b>	
Impeller	Propeller, cast aluminum.
Housing	Tubular painted steel housing.
Drive Type	Belt driven motor mounted out of the airstream.

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Returning Line:

30% of air returns to the machine room to be heated again, and returning duct is along the v  
Airflow rate in returning duct:

$$Q_{\text{retn}} := 0.3 \cdot Q = 7920 \text{ cfm}$$

Section	Air flow rate (cfm)	Length (ft)	Circular
1	7920	$L_{1.\text{retn}} := 85 \text{ ft}$	35 in
2	3960	$L_{2.\text{retn}} := 15 \text{ ft}$	28 in

To size in rectangular duct:

Section	x	y	circular	Ratio	Velocity (fpm)	Pressure Drop (inWg)
1	36	32	$D_{1.\text{retn}} := 35.4 \text{ in}$	1.17	1159	0.0467
2	30	22	$D_{2.\text{retn}} := 28 \text{ in}$	1.37	926	0.0406

Section 1:

$$L_{\text{retn.elbow}} := 15 \cdot D_{1.\text{retn}} = 44.25 \text{ ft}$$

$$L_{\text{retn.entrance}} := 12 \cdot D_{1.\text{retn}} = 35.4 \text{ ft}$$

$$\Delta P_{1.\text{retn}} := \frac{0.0467 \text{ inWg}}{100 \text{ ft}} \cdot (L_{1.\text{retn}} + L_{\text{retn.elbow}} + L_{\text{retn.entrance}}) = 0.0769 \text{ inWg}$$

Section 2:

$$L_{\text{retn.tee.through}} := 40 \cdot D_{2.\text{retn}} = 93.3333 \text{ ft}$$

$$L_{\text{retn.elbow.2}} := 15 \cdot D_{2.\text{retn}} = 35 \text{ ft}$$



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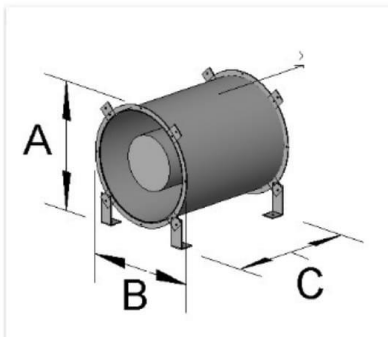
$$L_{\text{retn.branch}} := 20 \cdot D_{2.\text{retn}} = 46.67 \text{ ft} \quad (\text{Return line to inlet line})$$

$$\Delta P_{2.\text{retn}} := \frac{0.0406 \text{ inWg}}{100 \text{ ft}} \cdot (L_{2.\text{retn}} + L_{\text{retn.elbow.2}} + L_{\text{retn.tee.through}} + L_{\text{retn.elbow.2}}) = 0.07 \text{ inWg}$$

$$\Delta P_{\text{retn}} := \Delta P_{1.\text{retn}} + \Delta P_{2.\text{retn}} + \Delta P_{\text{filter}} = 0.35 \text{ inWg}$$

According to the information provided by GreenHeck, an inline fan was selected based on system flow rate of 7920 cfm, the system pressure drop of 0.35inWg, and the average altitude of Alberta is 2000ft. Inline fan AX-72-190-0618 is selected for return line.

## Dimensions



Label	Value (in.)	Description
A	33.313	Overall Height
B	31.625	Overall Width
C	34	Overall Length

## Performance

Actual Volume (CFM)	7,936
External Static Pressure (in. wg)	0.35
Total Static Pressure (in. wg)	0.35
Operating Power (Bhp)	1.00
Fan RPM	1,170
Percent within max fan RPM	-
Inlet Sones	17.0
Inlet dBA	69

## Pricing

Budget Price (USD)	\$2,818
Operating Cost / yr (USD)	\$214
<b>Features</b>	
Impeller	Axial propeller, cast aluminum.
Housing	Tubular painted steel housing.
Drive Type	Direct driven motor in the airstream.

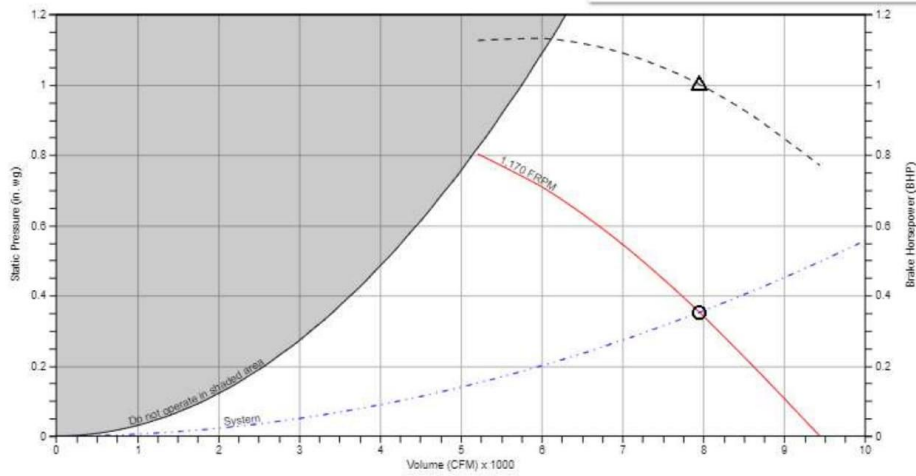
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Operating Conditions

- Fan curve
- - - Brake horsepower curve
- Operating Point SP
- △ Operating Bhp point
- Max system curve
- - - System curve

Static Pressure Calculations

Name	Value (in. wg)
External SP	0.350
Direct Drive RPM Adjust.	0.001
<b>Total External SP</b>	<b>0.351</b>



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## Calculation #2: Heating System

Author: Shengnan Chen

Checked By: Alex Madsen

Revision Number: 0

Revision Details: No changes in Phase III

Revision Checked By:

### Objective:

To determine the coil configuration, number of coils, size and performance of a heat exchanger with finned tubes and boiler size for heating the air to require temperature.

### Data Given or Known:

Length of building:	$L_{bldg} := 110 \text{ ft}$
Width of building:	$W_{bldg} := 100 \text{ ft}$
Height of building:	$H_{bldg} := 18 \text{ ft}$
Outsiade temperature:	$T_{\infty} := 233 \text{ K} = -40.27 \text{ }^{\circ}\text{F}$
Return air temperature:	$T_{return} := 39.2 \text{ }^{\circ}\text{F}$
Desire mixed air temperature:	$T_{req} := 39.2 \text{ }^{\circ}\text{F}$
The entering hot water temperature:	$T_{w.in} := 150 \text{ }^{\circ}\text{F}$
Heat loss from building:	$q_{loss} := 106000 \frac{\text{BTU}}{\text{hr}}$
Heat General from beehive:	$q_{general} := 307092 \frac{\text{BTU}}{\text{hr}}$
Air exchange ratio:	$r := 8$

### Custom Units:

$\text{cfm} := 1 \frac{\text{ft}^3}{\text{min}}$	$\text{fpm} := 1 \frac{\text{ft}}{\text{min}}$	$\text{inWg} := 248.84 \text{ Pa}$	$\text{inWg}_{100} := 1 \frac{\text{inWg}}{100 \text{ ft}}$
$\text{gpm} := 1 \frac{\text{gal}}{\text{min}}$	$\text{ftWg} := 0.434 \text{ psi}$		

### Assumptions:

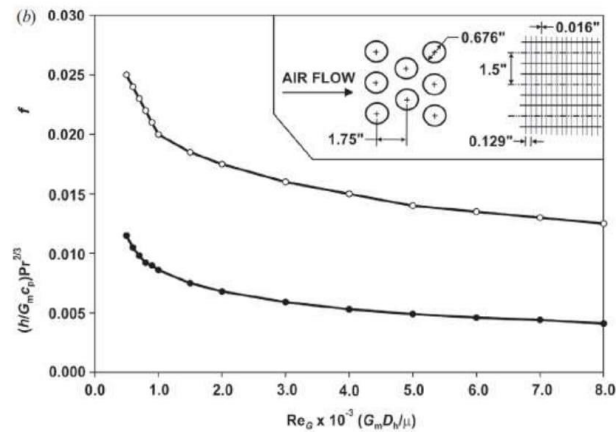
- 1) Air is moving slow enough to be assumed incompressible ( $< 0.3 \times \text{Speed of Sound}$ )
- 2) Ducts will be made of galvanized steel
- 3) Duct airflow rate is 4 times of building volume
- 4) Heating system is able to heat the air from minimum outside temperature of  $-40^{\circ}\text{F}$
- 5) Counter flow, finned tube heating coil is used in this system.
- 6) Flow velocity of water in tube be 4fps. (Erosion limit of copper is 6fps)
- 7) The tube is made by copper, and fin material is aluminum.
- 8) The tube wall thickness is small compare to its outer diameter.
- 9) 30% of air return back to the building
- 10) Tube bank information are shown in figure below
- 11) Two symmetry inlet lines are used to reduce the size of duct.

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## Variable Definition:

A: Area  
c: Capacity ratio  
cp: Specific heat capacity  
D: Diameter  
  
g: Gravitational acceleration  
Gm: Mass flow rate per unit minimum flow area between the tubes in the bank  
h: Convective heat transfer coefficient  
H: Height  
Hl: Heat loss  
j: j-factor  
k: Conductive coefficient  
L: Length  
N: Integer count  
Nu: Nusselt number  
Pr: Prandtl number  
q: Heat transfer  
Q: Volumetric flow rate  
r: Air exchange ratio  
R: Thermal resistance  
Re: Reynolds number  
t: Thickness  
T: Temperature  
U: Overall heat transfer coefficient  
v: Velocity  
V: Volume  
W: Width  
 $\alpha$ : Heat transfer area/total volume (defined below in figure)  
 $\gamma$ : Inner/outer pipe surface area ratio  
 $\delta$ : Area ratio  
 $\Delta P$ : Pressure drop  
 $\Delta T$ : Temperature difference  
 $\varepsilon$ : Effectiveness  
 $\eta$ : Efficiency  
 $\mu$ : Dynamic viscosity  
 $\rho$ : Density  
 $\sigma$ : Free-flow area/frontal area (defined in figure below)  
 $\Omega$ : Total heat transfer volume

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#### DATA

Tube outside diameter: 0.676 in.

Fin pitch: 7.75 fins per in.

Fin thickness: 0.016 in.

Hydraulic diameter,  $D_h$ : 0.0114 ft

Free-flow area/Frontal area,  $\sigma$ : 0.481

Heat transfer area/Total volume,  $a$ : 169  $\text{ft}^2/\text{ft}^3$

Fin area/Total area: 0.950

Note: Minimum free-flow area is in the spaces transverse to the flow

## Sketch:

Refer to cross-section shown in diagram above. Heating coil will follow that pattern

## Analysis:

Air flow rate required:

$$V_{bldg} := L_{bldg} \cdot H_{bldg} \cdot W_{bldg} = 1.98 \cdot 10^5 \text{ ft}^3$$

$$Q := 8 \cdot V_{bldg} \cdot \frac{1}{60 \text{ min}} = 26400 \text{ cfm}$$

Building heat by beehives:

$$q_{building} := q_{general} - q_{loss} = 2.01 \cdot 10^5 \frac{\text{BTU}}{\text{hr}}$$

Building temperature raise by:

Aire properties are take at 4 degree:

$$c_p := 1.005 \frac{\text{kJ}}{\text{kg K}} \quad \rho_{air\_building} := 1.2 \frac{\text{kg}}{\text{m}^3}$$

$$\Delta T := \frac{q_{building}}{Q \cdot c_p \cdot \rho_{air\_building}} = 7.06 \Delta^\circ \text{F}$$

Air temperature in duct after heating coil:

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$$T_{air.out} := T_{req} - \Delta T = 32.14 \text{ }^{\circ}\text{F}$$

With 30% return air:

$$T_{air.in} := 0.3 \cdot T_{req} + 0.7 \cdot T_{\infty} = -16.43 \text{ }^{\circ}\text{F}$$

Heating coil in this system will heat the air from -16.43F to 32.14F

Air density in the heating coil is take at average temperature:

$$\rho_{coil} := 1.356 \frac{\text{kg}}{\text{m}^3}$$

With 2 inlet line, each branch has heat transfer:

$$Q_{coil} := 0.5 \cdot Q = 13200 \text{ cfm}$$

$$Q_{inlet} := Q_{coil} \cdot c_p \cdot \rho_{coil} \cdot (T_{air.out} - T_{air.in}) = 7.82 \cdot 10^5 \frac{\text{BTU}}{\text{hr}}$$

Therefor each branch need heat  $7.85 \cdot 10^5$  BTU/hr with air flow rate 13200cfm

Air velocity required:

Low velocity system desired to reduce "wind" speeds and noise in the building. Therefore air velocity over the tube is 1000fpm

Low-Velocity Systems			
Designation	Private Residences	Schools, Theaters, Public Buildings	Industrial Buildings
Maximum Velocities (fpm)			
Main ducts	800–1200	1100–1600	1300–2200
Branch ducts	700–1000	800–1300	1000–1800
Branch risers	650–800	800–1200	1000–1600
Typical Velocities (fpm) <sup>a</sup>			
Throwaway filter	200–800		
Heating coil	400–500 (200 min, 1500 max)		
Cooling coil	500–600		

Source: Howell, Sauer, and Coad [9].

<sup>a</sup>Ductulator, Trane US Inc., La Crosse, Wisconsin.

Air temperature changes:

$$\Delta T_{air} := T_{air.out} - T_{air.in} = 48.5692 \text{ }^{\circ}\text{F}$$

Water has a heat capacity 4 time higer than air, therefore, the water temperature chan

4 times slower than air temperature changes:

$$\Delta T_{water} := \frac{\Delta T_{air}}{4} = 12.1423 \text{ }^{\circ}\text{F}$$

Average water temperature:

$$T_{w.avg} := 145 \text{ }^{\circ}\text{F} \quad V := 4 \frac{\text{ft}}{\text{s}}$$

For water at 151F:

$$Pr := 2.73$$

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$$\rho_{water} := 61 \frac{\text{lb}}{\text{ft}^3} \quad k := 0.38 \frac{\text{BTU}}{\text{hr ft } \Delta^\circ\text{F}} \quad \mu := 2.9 \cdot 10^{-4} \frac{\text{lb}}{\text{ft s}}$$

Inner diameter of tube:  $D_i := 0.676 \text{ in} - 0.08 \text{ in} = 0.596 \text{ in}$

The Reynolds number is:  $Re_{Di} := \frac{\rho_{water} \cdot V \cdot D_i}{\mu} = 41788.5057$

The heat transfer coefficient for flow in the tube is found from the Dittus-Boelter correlation equation:

$$Nu := 0.023 \cdot Re_{Di}^{0.8} \cdot Pr^{0.3} = 154.6757$$

$$h_i := 1183 \frac{\text{BTU}}{\text{hr ft}^2 \Delta^\circ\text{F}}$$

The average heat transfer coefficient for airflow over the finned tube bank is found from charts and appropriate correlation equation:

For air at average temperature 34.69F, the air properties are:

$$\rho_{air} := 0.0847 \frac{\text{lb}}{\text{ft}^3} \quad \mu_{air} := 1.16 \cdot 10^{-5} \frac{\text{lb}}{\text{ft s}} \quad c_p := 0.24 \frac{\text{BTU}}{\text{lb } \Delta^\circ\text{F}}$$

$$V_{air} := 1000 \text{ fpm} \quad \sigma := 0.481 \quad D_h := 0.0114 \text{ ft} \quad Pr_{air} := 0.73$$

$$G_m := \frac{\rho_{air} \cdot V_{air}}{\sigma} = 2.9349 \frac{\text{lb}}{\text{s ft}^2}$$

Reynolds number based on  $G_m$ :

$$Re_{Gm} := \frac{G_m \cdot D_h}{\mu_{air}} = 2884.2569$$

From the j-factor chart:  $j := 0.0065$

The average heat transfer coefficient for airflow over the finned tube bank is found by Chilton - Colburn equation:

$$j := \frac{h_o}{G_m \cdot c_p} \cdot Pr_{air}^{\frac{2}{3}}$$

$$h_o := 19.19 \frac{\text{BTU}}{\text{hr ft}^2 \Delta^\circ\text{F}}$$

The fin surface effectiveness is found by some arrangement data from the figure:

For aluminum fin:  $k_{fin} := 100 \frac{\text{BTU}}{\text{hr ft } \Delta^\circ\text{F}}$

Fin thickness is found from chart:  $t := 0.016 \text{ in} = 0.0013 \text{ ft}$

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$$m := \left( \frac{2 \cdot h_o}{k_{fin} \cdot t} \right)^{\frac{1}{2}} = 16.9661 \frac{1}{ft}$$

Tube outer diameter is:

$$r := \frac{0.676}{2} in = 0.0282 ft$$

from the figure above:

$$x_t := 1.5 in \quad x_L := 1.75 in$$

$$M := \frac{x_t}{2} = 0.75 in$$

$$L := \frac{\left( \left( \frac{x_t}{2} \right)^2 + x_L^2 \right)^{\frac{1}{2}}}{2} = 0.952 in$$

$$\beta := \frac{L}{M} = 1.2693 \quad \psi := \frac{M}{r} = 2.2189$$

$$1.27 \cdot \psi \cdot (\beta - 0.3)^{\frac{1}{2}} = 2.7744$$

$$\varphi := (2.77 - 1) \cdot (1 + 0.35 \cdot \ln(2.77)) = 2.4012$$

Fin efficiency is found as:

$$\eta_o := \frac{\tanh(m \cdot r \cdot \varphi)}{m \cdot r \cdot \varphi} = 0.7119$$

The fin surface effectiveness is:

From figure we found fin area/total area is 0.95

$$\eta_{so} := 1 - 0.95 \cdot (1 - \eta_o) = 0.7263$$

Find the inner surface area/outer surface area as ratio  $\gamma$ :

$$\alpha := 169 \frac{ft^2}{ft^3}$$

$$\gamma := \frac{3.1415 \cdot D_i}{\alpha \cdot x_t \cdot x_L} = 0.0506$$

fouling resistance on the outside wall of tube and inside wall of the tube are found in the table below:

$$R_{fi} := \frac{0.0011 \frac{hr \cdot ft^2 \cdot \Delta^\circ F}{BTU}}{}$$

$$R_{fo} := \frac{0.00199 \frac{hr \cdot ft^2 \cdot \Delta^\circ F}{BTU}}{}$$



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Fluid	$R_f ((ft^2 h ^\circ F)/Btu)$
Gas oil	0.00051
Transformer oil	0.00102
Lubrication oil	0.00102
Heat transfer oil	0.00102
Hydraulic oil	0.00102
Fuel oil	0.0051
Hydrogen	0.00999
Engine exhaust	0.00999
Steam (oil-free)	0.00051
Steam with oil traces	0.0010
Cooling fluid vapors with oil traces	0.00199
Organic solvent vapors	0.0010
Alcohol vapors	0.00057
Refrigerants (vapor)	0.0023
Compressed air	0.00199
Natural gas	0.0010
Distilled water, seawater, river water, boiler feedwater: below 122°F	0.00057
Distilled water, seawater, river water, boiler feedwater: above 122°F	0.0011
Refrigerants (liquid)	0.0011
Cooling fluid	0.0010
Organic heat transfer fluids	0.0010
Salts	0.00051
Liquefied petroleum gas (LPG), liquefied natural gas (LNG)	0.0010
MEA and DEA (amines) solutions	0.00199
DEG and TEG (glycols) solutions	0.00199
Vegetable oils	0.0030

$\epsilon$ -NTU method is used to determine the overall heat transfer coefficient ( $U_{FT}$ ):

$$\frac{1}{h_i \cdot Y} + \frac{R_{fi}}{Y} + R_{fo} + \frac{1}{h_o \cdot \eta_{so}} = 0.1121 \frac{hr ft^2 \Delta^\circ F}{BTU}$$

$$U_{FT} := \frac{1}{\frac{1}{h_i \cdot Y} + \frac{R_{fi}}{Y} + R_{fo} + \frac{1}{h_o \cdot \eta_{so}}} = 8.92 \frac{BTU}{hr ft^2 \Delta^\circ F}$$

The capacity ratio  $c$ :

$$T_{w.out} := 2 \cdot T_{w.avg} - T_{w.in} = 140^\circ F$$

$$c := \frac{T_{w.in} - T_{w.out}}{T_{air.out} - T_{air.in}} = 0.2059$$

The effectiveness is:

$$\epsilon := \frac{T_{req} - T_{air.in}}{T_{w.in} - T_{air.in}} = 0.3343$$

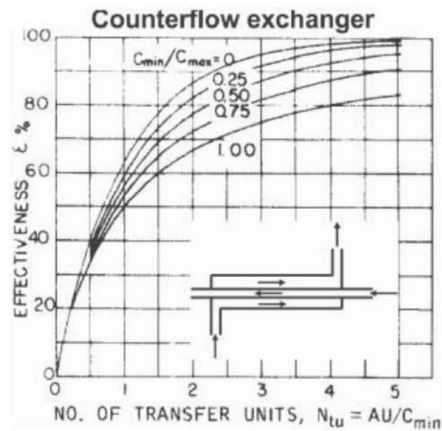
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Therefore, the heat exchanged in the heat exchanger can be determined as:

(with return system, there is only 30% fresh air introduced to the HVAC system)

Heat transfer in the heating coil 785000 BTU/hr. For one shell pass HEX  $\varepsilon=30\%$ ,  $c=0.2$

With  $c$  and  $\varepsilon$  known, the NTU value can be read from figure below:



$NTU := 0.35$  (NTU small than 3, acceptable)

The heat transfer area is:

$$C_{min} := \rho_{air} \cdot Q_{coil} \cdot c_p = 8493.08 \frac{W}{K}$$

Heat transfer area:

$$A_o := \frac{C_{min} \cdot NTU}{U_{FT}} = 631.9261 \text{ ft}^2$$

This value for the heat transfer surface area includes the extended surface area of the fins. The total heat transfer volume is found from the ratio of heat transfer area to the total volume:

$$\Omega := \frac{A_o}{\alpha} = 3.7392 \text{ ft}^3$$

Face area normal to air flow direction:

$$A_f := \frac{Q_{coil}}{V_{air}} = 13.2 \text{ ft}^2$$

Depth of heat exchange system  $W$ :

$$W := \frac{\Omega}{A_f} = 3.3993 \text{ in}$$

The number of tube row:

$$N_r := \frac{W}{x_L} = 2 \quad (\text{No more than 6, acceptable})$$

The tube number per row:

$$C_h := C_{min} \cdot \frac{T_{air.out} - T_{air.in}}{T_{w.in} - T_{w.out}} = 41250.176 \frac{W}{K}$$

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$$c_{p.w} := 4 \cdot c_p = 4.0193 \frac{\text{kJ}}{\text{kg K}}$$

$$N_{tube} := \frac{4 \cdot C_h}{2 \cdot c_{p.w} \cdot \rho_{water} \cdot V \cdot 3.14 \cdot D_i^2} = 24$$

Total number of tubes along the length of the heat exchanger will be 24 tubes.

The total height of the heating coil is:

$$H := N_{tube} \cdot x_t = 36 \text{ in}$$

Length of the heating coil is

$$l := \frac{A_f}{H} = 52.9247 \text{ in}$$

The total length of the tubes in the heat exchanger is :

$$l_{tot} := l \cdot N_{tube} \cdot N_r = 205.12 \text{ ft}$$

Pressure loss of air across the tube coils is:

From the j-factor chart  $f := 0.016$

The area ratio  $\delta$ :  $\delta := \frac{4 \cdot W}{D_h} = 99.3941$

The pressure drop of the air across the tube coil is:

$$\rho_{air.in} := 0.0847 \frac{\text{lb}}{\text{ft}^3} \quad \rho_{air.o} := 0.0806 \frac{\text{lb}}{\text{ft}^3}$$

$$\Delta P_{bank} := \frac{G_m^2}{2 \cdot \rho_{air.in}} \cdot \left( (1 + \sigma^2) \cdot \left( \frac{\rho_{air.in}}{\rho_{air.o}} - 1 \right) + f \cdot \delta \cdot \frac{\rho_{air.in}}{\rho_{air}} \right) = 0.5026 \text{ inWg}$$

pressure drop of air across the tube bank smaller than 1 inWg

Pressure loss of water in the tube coils:

$$g := 32.2 \frac{\text{ft}}{\text{s}^2}$$

From Moody chart, Re=41789, for copper tube,  $\epsilon/d=0.0001$

$$f_w := 0.022$$

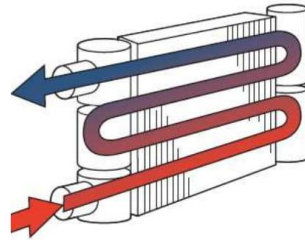
$K := 2$  for 180 bend

$$H_{IT} := f_w \cdot \left( \frac{l_{tot}}{D_i} + 2 \cdot N_{tube} \right) \cdot \frac{V^2}{2 \cdot g} \quad 32.126 \text{ ftWg}$$

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From Daikun water heating speedsheet:

use 2 row 5WS type hot water coil:



5WS  
1 (Single) Serpentine (2 Row)

From Table below:

**Table 4: Coil Sizes (Face Area on sq. ft.)**

Finned Height - FH (Inches)	Finned Length - FL (Inches)																			
	12	15	18	21	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114
*6	0.5	0.6	0.8	0.9	1.0	1.3	1.5	1.8	2.0	2.2	2.5	—	—	—	—	—	—	—	—	—
*9	0.8	0.9	1.1	1.3	1.5	1.9	2.3	2.6	3.0	3.4	3.7	—	—	—	—	—	—	—	—	—
12	1.0	1.3	1.5	1.8	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
15	—	1.6	1.9	2.19	2.5	3.1	3.8	4.9	5.0	5.6	6.2	6.9	7.5	8.1	8.7	9.4	10.0	10.6	11.2	11.9
18	—	—	2.3	2.62	3.0	3.8	4.5	5.3	6.0	6.7	7.5	8.2	9.0	9.7	10.5	11.2	12.0	12.7	13.5	14.2
21	—	—	—	3.06	3.5	4.4	5.3	6.1	7.0	7.9	8.7	9.6	10.5	11.4	12.2	13.1	14.0	14.9	15.7	16.6
24	—	—	—	—	40.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0
27	—	—	—	—	—	5.6	6.8	7.9	9.0	10.1	11.2	12.4	13.5	14.6	15.7	16.9	18.0	19.1	20.2	21.4
30	—	—	—	—	—	6.3	7.5	8.8	10.0	11.2	12.5	13.7	15.0	16.2	17.5	18.7	20.0	21.2	22.5	23.7
33	—	—	—	—	—	—	8.3	9.6	11.0	12.4	13.7	15.1	16.5	17.9	19.2	20.6	22.0	23.4	24.7	26.1
36	—	—	—	—	—	—	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	21.0	22.5	24.0	25.5	27.0	28.5
39	—	—	—	—	—	—	—	11.4	13.0	14.6	16.2	17.9	19.5	20.1	22.7	24.4	26.0	27.6	29.2	30.9
42	—	—	—	—	—	—	—	12.3	14.0	15.7	17.5	19.2	21.0	22.7	24.5	26.2	28.0	29.7	31.5	33.2
45	—	—	—	—	—	—	—	—	15.0	16.9	18.8	20.6	22.5	24.4	26.3	28.1	30.0	31.9	33.8	35.7
48	—	—	—	—	—	—	—	—	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0
51	—	—	—	—	—	—	—	—	19.1	21.3	23.4	25.5	27.6	29.8	31.9	34.0	36.1	38.3	40.4	42.5
54	—	—	—	—	—	—	—	—	20.3	22.5	24.8	27.0	29.3	31.5	33.8	36.0	38.3	40.5	42.8	45.0

In addition to the standard fin lengths listed above, any required length can be supplied. \* Standard on Type 5B coils.  
Booster coil sizes in shaded areas.

Finend length will be 54 inches and finned height will be 35 inches for a face area 13.5 ft<sup>2</sup> coil. this value very close to the calculation result.

And for a 24 tubes coil the fin height for this coil is found from table below:

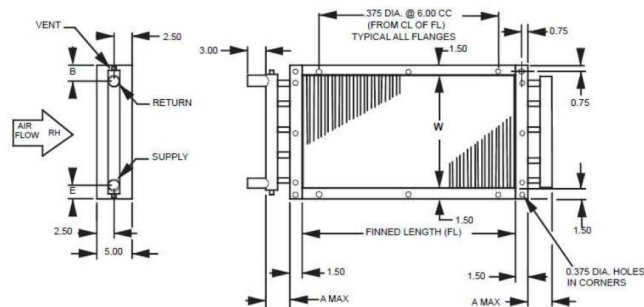
**Table 3: Standard Water Coil Circulating (Number of Tubes Fed)**

Type	Rows	FH Dimensions (Inches)															
		6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51
5BB, 5BS	1, 2	1	1	1	1	1	1	1	—	—	—	—	—	—	—	—	—
5BD	2	2	2	2	2	2	2	2	—	—	—	—	—	—	—	—	—
5MS	2	—	—	—	—	—	—	—	—	—	—	—	—	—	30	32	34
5MH	1, 2	—	—	4	5	6	7	8	9	10	11	12	13	14	15	16	17
5MQ	1	—	—	2	—	3	—	4	—	5	—	6	—	7	—	8	—
5WB, 5WQ	1	—	—	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	—	—	—
5WH	1, 2, 3, 4	—	—	4	5	6	7	8	9	10	11	12	13	14	15*	16*	17*
5WB	2	—	—	4	4	6	7	8	9	10	11	12	13	14	—	—	—
5WL	3, 4	—	—	6	7	9	10	12	13	15	16	18	19	21	22	24	25
5WS	2	—	—	8	10	12	14	16	18	20	22	24	26	28	—	—	—
5WS	3, 4	—	—	8	10	12	14	16	18	20	22	24	26	28	30	32	34
5WM	4	—	—	12	15	18	21	24	27	30	33	36	39	42	45	48	51
5WD	4	—	—	16	20	24	28	32	36	40	44	48	52	56	60	64	68

\* 3 & 4 row coil only. See 5MH for 1 & 2 rows.

Therefore, the fin height will be 36 inches.

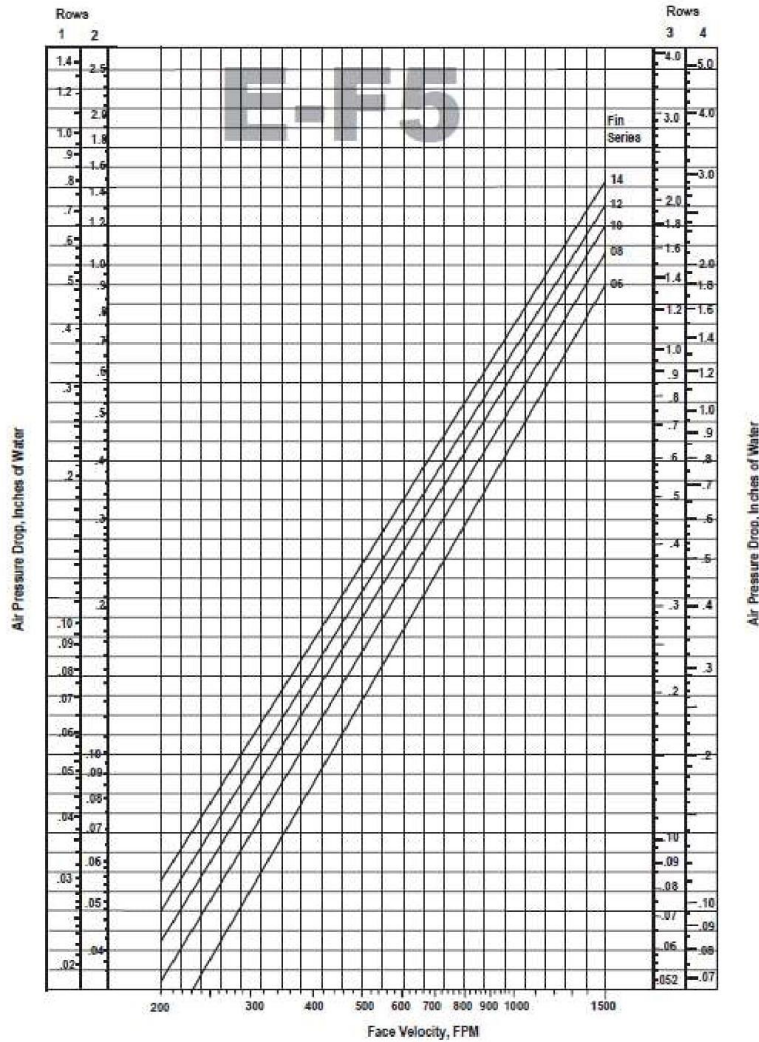
Row	Model Type	Conn Size	A	B	E	W
1	5WH, 5WQ	1-1/2	2.75	2.67	2.67	12.00–42.00
1	5WB	1-1/2	2.75	3.42	3.42	12.00–42.00
2	5WH, 5WS	2-1/2	3.38	3.17	3.17	12.00–42.00
2	5WB	2-1/2	3.38	3.92	3.17	12.00–42.00



The presusre drop is 0.5inWg, and the air velocity assumed to be 100fpm  
From the Figure below, the coil is type E-F5 and the fin series is 08



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### Nomenclature

5W H - 10 02 C - 033.0 - 090.0			
<b>Coil Type</b>		<b>Finned Length</b>	Inches
Water: 5M, 5W		<b>Fin Height</b>	Inches
Booster: 5B		<b>Fin Design</b>	
<b>Circuiting</b>		B = E-F5	
Water:		C = HI-F5	
Q = 1/4 Serpentine	<b>Booster:</b>	A = Flat	
H = 1/2 Serpentine	S = 1 Circuit	<b>Rows Deep</b>	01,02, 03, 04, 05, 06, 08, 10, 12
L = 3/4 Serpentine	D = 2 Circuit	<b>Fins per Inch</b>	06, 07,08, 09, 10,11, 12,13, 14
S = 1 Serpentine	B = 3" Tube Center		
M = 1-1/2 Serpentine			
D = 2 Serpentine			
B = 3" Tube Center			

Heating coil: 5WS-0805B-36.0-54

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**Conclusion:**

With the return system, only 70% of fresh air introduce to the system. and 30% of air fr  
The building at 4 degree will preheat the air from -40F to -16.43F.

Comparing the calculated data with the heating coil information provided by supplier  
The DaikinHeating coil: 5WS-0805B-36.0-54 water coiler should be selected in order to h  
air from -16.43F to 32.14F, and the heat generate by beehive will heat the air from 32.1  
to 39.2F which is the require building temperature.

In order to maintain the certain CO2 level, the air exchange rate will be srt as 8 which  
equivlent to air flow rate of 26400cfm for this 110ft\*100ft\*18ft building.

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## Calculation #3: Boiler System

Author: Shengnan Chen

Checked By: Alex Madsen

Revision Number: 2  
Revision Details: Minor corrections and formatting

Revision Checked By: Alex Madsen

## Objective:

To select the water boiler and pump required to provide enough energy for heating coil.

## Custom Units:

$$\text{cfm} := 1 \frac{\text{ft}^3}{\text{min}} \quad \text{fpm} := 1 \frac{\text{ft}}{\text{min}} \quad \text{inWg} := 248.84 \text{ Pa} \quad \text{inWg}_{100} := 1 \frac{\text{inWg}}{100 \text{ ft}} \quad \text{fps} := 1 \frac{\text{ft}}{\text{s}} \quad \text{gpm} := 1 \frac{\text{gal}}{\text{min}}$$

$$\text{ftWg} := 2.99 \text{ kPa}$$

## Assumptions:

- 1) Assume that the spaces will be lightly occupied (by people). Therefore, the boiler OSF is 1.23.
- 2) Average inlet temperature of water is 40F for Alberta.
- 3) The heater tube size is 1 inch and the tube material is copper wrapped with insulation.
- 4) The air flow rate in the tube will not exceed 6fps to prevent erosion of the copper.
- 5) All properties of the water used for sizing the system will be the average temperature.
- 6) The pressure loss with in the duct should be about 0.1inWg per 100ft.
- 7) All calculations based on the worst outside temperature.
- 8) The total length of pipe is 25ft.
- 9) The friction loss in the pipe is about 3ftWg per 100 ft.
- 10) All valve is flanged for better pressure drop.

## Known Data:

Water velocity in heating coil:	$V_{coil} := 4 \frac{\text{ft}}{\text{s}}$	
Inner diameter of heating coil:	$D_{i,coil} := 0.596 \text{ in}$	
Inlet water temperature:	$T_{in} := 40 \text{ }^\circ\text{F}$	
Outlet water temperature:	$T_{out} := 150 \text{ }^\circ\text{F}$	
Oversizing factor:	$OFS := 1.23$	
Pressure drop in heating coil:	$H_{coil} := 32.124 \text{ ft}$	
Total pipe length:	$L_{tot} := 205.12 \text{ ft}$	(From heating coil calculation)

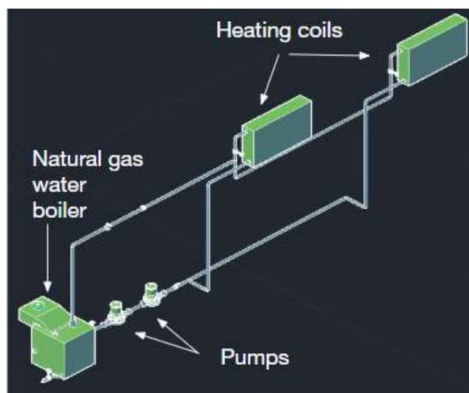


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## Variable Definitions:

cp: Heat capacity  
 D: Diameter  
 H: Fluid head loss  
 K: Pipe loss coefficient  
 L: Length  
 m: Volumetric flow rate  
 P: Pressure loss  
 Q: Heat  
 T: Temperature  
 V: Velocity  
 SF:Boiler oversize filter  
 ρ: Density

## Sketch:



## Analysis:

Total heat required to keep the room temperature at 4 degree:

Heat needed to heat the water:

$$T_{ave} := \frac{T_{in} + T_{out}}{2} = 95 \text{ }^{\circ}\text{F}$$

water property at 95F:

$$\rho_{water} := 62.057 \frac{\text{lb}}{\text{ft}^3} \quad c_p := 1 \frac{\text{BTU}}{\text{lb } ^{\circ}\text{F}}$$

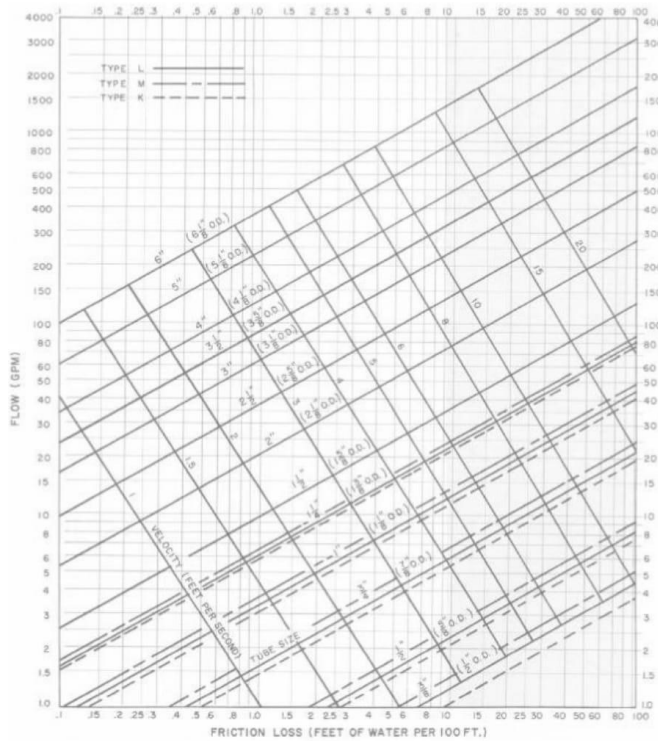
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water flow rate in boiler system:

$$m_{water} := 2 \cdot \frac{3.14 \cdot D_{i,coil}^2}{4} \cdot V_{coil} = 6.95 \text{ gpm}$$

Sizing the pipe:

Since air flow rate is 3.48GPM, assume pressure loss as 3ft/100ft from figure below:



flow velocity:  $V_{branch} := 2.5 \text{ fps}$

Pressure loss  $P_{branch} := 4 \frac{\text{ft}}{100 \text{ ft}}$

Diameter:  $D_{branch} := \frac{3}{4} \text{ in}$

Length:  $L_{coil,1} := 15.8 \text{ ft}$   $L_{coil,2} := 47.86 \text{ ft}$

For main loop:

Water flow rate:

$$m_{main} := 2 \cdot m_{water} = 13.91 \text{ gpm}$$

From figure above, main loop Pipe size:

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$$\begin{aligned} \text{Diameter:} \quad D_{main} &:= 1 \text{ in} \\ \text{flow velocity:} \quad V_{main} &:= 2.7 \text{ fps} \\ \text{Pressure loss} \quad P_{tube} &:= 3.2 \frac{\text{ft}}{100 \text{ ft}} \\ L_{main} &:= 34.3 \text{ ft} \end{aligned}$$

Major Head loss:

Main line:

$$H_{LM} := \frac{3.2 \text{ ft}}{100 \text{ ft}} \cdot L_{main} = 1.1 \text{ ft}$$

Heating coil 1:

$$H_{L1} := \frac{4 \text{ ft}}{100 \text{ ft}} \cdot L_{coil.1} = 0.63 \text{ ft}$$

Heating coil 2:

$$H_{L2} := \frac{4 \text{ ft}}{100 \text{ ft}} \cdot L_{coil.2} = 1.91 \text{ ft}$$

**Table A.14** Loss coefficients for pipe fittings

Nominal Diameter (in.)	Screwed				Flanged				
	1/2	1	2	4	1	2	4	8	20
<b>Valves (FO)</b>									
Globe	14	8.2	6.9	5.7	13	8.5	6.0	5.8	5.5
Gate	0.30	0.24	0.16	0.11	0.80	0.35	0.16	0.07	0.03
Swing check	5.1	2.9	2.1	2.0	2.0	2.0	2.0	2.0	2.0
Angle	9.0	4.7	2.0	1.0	4.5	2.4	2.0	2.0	2.0
Ball valve <sup>d</sup>	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Gate valve <sup>d</sup>	1/4 C	1/2 C	3/4 C						
	0.3	2.1	17						
Foot valve with strainer <sup>d,e</sup>	Poppet disk	Hinged disk							
	7	1.25							
<b>Elbows</b>									
45° regular	0.39	0.32	0.30	0.29					
45° long radius					0.21	0.20	0.19	0.16	0.14
90° regular	2.0	1.5	0.95	0.64	0.50	0.39	0.30	0.26	0.21
90° long radius	1.0	0.72	0.41	0.23	0.40	0.30	0.19	0.15	0.10
180° regular	2.0	1.5	0.95	0.64	0.41	0.35	0.30	0.25	0.20
180° long radius					0.40	0.30	0.21	0.15	0.10
<b>Tees</b>									
Line flow	0.90	0.90	0.90	0.90	0.24	0.19	0.14	0.10	0.07
Branch flow	2.4	1.8	1.4	1.1	1.0	0.80	0.64	0.58	0.41
<b>Expansion<sup>f</sup></b>									
	d/D	d/D	d/D	d/D					
	0.2	0.4	0.6	0.8					
K <sub>expansion</sub>	0.30	0.25	0.15	0.10					
<b>Contraction<sup>f</sup>:</b>									
	60° contraction angle								
	0.07								

Minor Loss:

$$K_L := \sum K_L \frac{V^2}{2g}$$

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Main Line:

The main pipe line contains a 90 degree bends, 2 ball valves and 1 gate valve and a check valve and 2 tee line flow,

The minor head losses, the loss coefficients for the bends, fittings, and valves are given below for 3/4 inches:

90 degree bend:	$K_{90.bend} := 0.05$	
Ball Valve:	$K_{ball} := 0.05$	
Gate Valve:	$K_{gate} := 0.8$	$g := 32.2 \frac{ft}{s^2}$
entrance:	$K_{entrance} := 0.5$	
Check valve:	$K_{check} := 2.1$	
Tee line flow	$K_{Tee} := 1$	

$$H_L := (K_{90.bend} + 2 \cdot K_{ball} + K_{gate} + K_{entrance} + K_{check} + 2 \cdot K_{Tee}) \cdot \frac{\left(2.7 \frac{ft}{s}\right)^2}{2 \cdot g} = 0.6283 \text{ ft}$$

Heating coil 1:

The heating coil 1 loop contain 3 elbow bends and 1 ball valve, and 2 tee branches.

Tee branch	$K_{Tee.branch} := 1.8$
90 degree bend:	$K_{90.bend} := 1.5$
Ball Valve:	$K_{ball} := 0.05$

$$H_{LM.1} := (3 \cdot K_{90.bend} + K_{ball} + 2 \cdot K_{Tee.branch}) \cdot \frac{\left(2.5 \frac{ft}{s}\right)^2}{2 \cdot g} = 0.79 \text{ ft}$$

Heating coil 2:

The heating coil 2 loop contain 6 elbow bends and 1 ball valve, and 2 tee branches.

Tee branch	$K_{Tee.branch} := 1.8$
90 degree bend:	$K_{90.bend} := 1.5$
Ball Valve:	$K_{ball} := 0.05$

$$H_{LM.2} := (6 \cdot K_{90.bend} + K_{ball} + 2 \cdot K_{Tee.branch}) \cdot \frac{\left(2.5 \frac{ft}{s}\right)^2}{2 \cdot g} = 1.2277 \text{ ft}$$

Total pressure loss:

$$\text{Heating coil 1 loop: } H_1 := H_{LM} + H_{L1} + H_L + H_{LM.1} + H_{coil} = 35.27 \text{ ft}$$

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Heating coil 2 loop:  $H_2 := H_{LM} + H_{L2} + H_L + H_{LM.2} + H_{coil} = 36.9919 \text{ ft}$

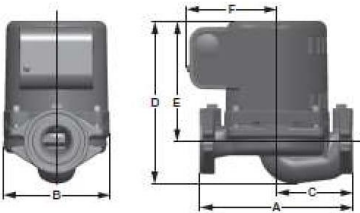
## Conclusion:

The system will be balanced by install balance valve in heating coil 1 loop

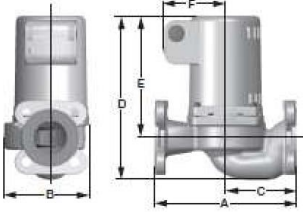
The pump head will be 37ft with 14GPM water flow rate, so in order to reduce the pump head each pump, we use two identical pump connected in series. Therefore, each pump has pump head 13.5ft with same water flow rate.

two Pump 2400-30-3p from Taco Company are used in this system.

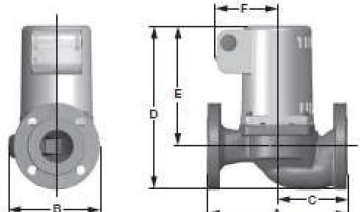
**Models 2400-10-3P thru 2400-50S/2-3P**



**Models 2400-60-3P thru 2400-70S-3P**



**Models 2400-70/3-3P and 2400-70S/3-3P**



**PUMP DIMENSIONS & WEIGHTS**

All dimensions and weights are approximate.

CAST IRON MODEL	STAINLESS STEEL MODEL	A		B		C		D		E		F		SHIP WEIGHT	
		IN.	MM	IN.	MM	IN.	MM	IN.	MM	IN.	MM	IN.	MM	LBS.	KG
2400-10-3P	2400-10S-3P	6 5/8	162	4 1/2	114	3 9/16	82	6 7/8	175	5	127	3 3/4	95	11.5	5.3
2400-20-3P	2400-20S-3P	6 5/8	162	4 1/2	114	3 9/16	82	6 7/8	175	5	127	3 3/4	95	12.0	5.5
2400-30-3P	2400-30S-3P	8 1/2	216	4 9/8	121	4 1/4	108	8	203	5 1/4	133	3 3/4	95	14.5	6.6
2400-40-3P	2400-40S-3P	8 1/2	216	4 9/8	121	4 1/4	108	8	203	5 1/4	133	3 3/4	95	14.5	6.6
2400-45-3P	2400-45S-3P	6 5/8	162	4 5/8	119	3 9/16	82	6 7/8	222	6 7/8	175	3 3/4	95	15.0	6.8
2400-50-3P	2400-50S-3P	6 5/8	162	4 5/8	119	3 9/16	82	6 7/8	222	6 7/8	175	3 3/4	95	16.0	7.3
2400-50/2-3P	2400-50S/2-3P	6 5/8	162	5 1/4	133	3 9/16	82	6 7/8	222	6 7/8	175	3 3/4	95	16.5	7.5
2400-60-3P	2400-60S-3P	8 1/2	216	5 9/16	132	4 1/4	108	7 7/8	200	5 1/4	133	3 3/4	95	18.0	8.2
2400-65-3P	2400-65S-3P	8 1/2	216	5 1/2	140	4 1/4	108	9 7/8	251	7 1/4	184	3 3/4	95	22.0	10.0
2400-70-3P	2400-70S-3P	8 1/2	216	5 1/2	140	4 1/4	108	9 7/8	251	7 1/4	184	3 3/4	95	23.0	10.4
2400-70/3-3P	2400-70S/3-3P	8 1/2	216	6 5/8	168	4 1/4	108	10 1/2	267	7 1/4	184	3 3/4	95	29.0	13.2

Pump electrical data and pump curve are shown below.

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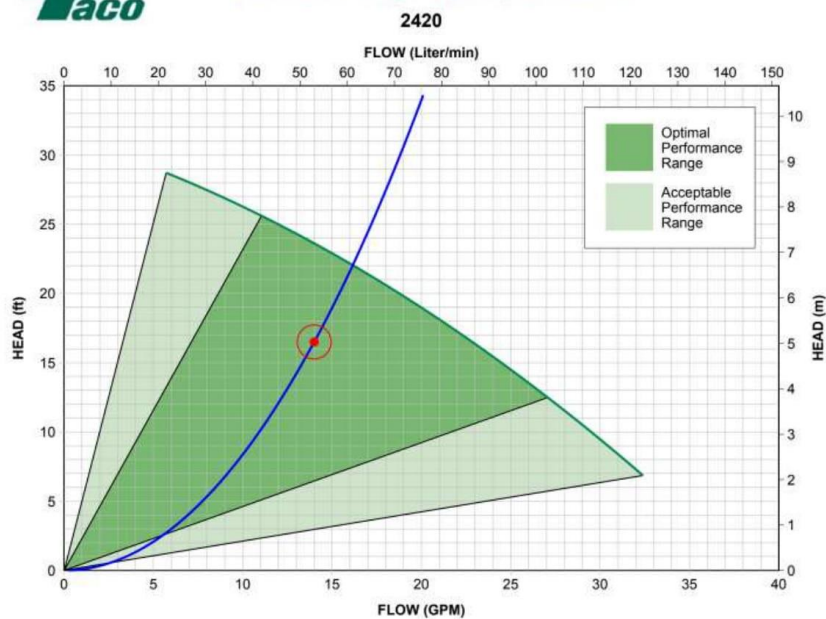
## Electrical Data

Model No.	Hz	Ph	115V	230V	RPM	HP
			Amps	Amps		
2400-10 -3P	60	1	1.4	.54	3450	1/10
2400-20 -3P	60	1	1.9	1.0	3450	1/6
2400-30 -3P	60	1	1.9	1.0	3450	1/6
2400-40 -3P	60	1	1.9	1.0	3450	1/6
2400-45 -3P	60	1	3.6	1.7	3450	1/3
2400-50 -3P	60	1	4.9	2.4	3450	1/2
2400-60 -3P	60	1	1.9	1.0	3450	1/6
2400-65 -3P	60	1	3.6	1.7	3450	1/3
2400-70 -3P	60	1	4.9	2.4	3450	1/2
Motor Type	Open Drip Proof, Permanent Split Capacitor, Thermally Protected					

Noryl® is a registered trademark of General Electric Co.



## 2400 Series - High Capacity Circulators



Boiler selected:

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Heat required to keep the building

$$Q := \rho_{\text{water}} \cdot 2 \cdot m_{\text{water}} \cdot c_p \cdot (T_{\text{out}} - T_{\text{in}}) = 7.61 \cdot 10^5 \frac{\text{BTU}}{\text{hr}}$$

With the consideration of boiler OFS:

$$Q_{boiler} := Q \cdot OFS = 9.37 \cdot 10^5 \frac{\text{BTU}}{\text{hr}}$$

Mach condensing boiler C1050 from Patterson Kelley.

Natural gas water boiler

Max thermal output: 985,950 BTU/hr ( 25hp)

Fuel flow rate: 14cfm



# MACH®

## Condensing Boilers

BOILER RATINGS	C300	C350	C500	C750	C900	C1050	C1300	C1800	C2300	C3800	C4000
INPUT RATING	31.7kW	34.9kW	51.7kW	74.2kW	103kW	141.9kW	217.6kW	344kW	447kW	747kW	847kW
NET STEAM INPUT	101,000	109,000	159,000	236,000	330,000	452,000	690,000	1,090,000	1,400,000	2,300,000	2,500,000
NET GAS INPUT	80	100.9	145.8	209.6	293.8	403.8	609	967.4	1247.5	1970.2	2177.5
NET STEAM OUTPUT	277,000	310,000	440,000	740,000	1,040,000	1,440,000	2,140,000	3,400,000	4,300,000	7,100,000	7,900,000
NET GAS OUTPUT	62	80.9	116.6	198.4	277.7	388.9	574	910.4	1160.5	1892.5	2107.5
HEATING CAPACITY (WATERSIDE GPM)	26.5	31.5	43.5	74.5	105	145	215	345	435	715	795
HEATING CAPACITY (WATERSIDE BTU)	1,000,000	1,100,000	1,500,000	2,700,000	3,800,000	5,300,000	7,800,000	12,000,000	15,000,000	26,000,000	29,000,000
NET STEAM INPUT	101,000	109,000	159,000	236,000	330,000	452,000	690,000	1,090,000	1,400,000	2,300,000	2,500,000
NET GAS INPUT	80	100.9	145.8	209.6	293.8	403.8	609	967.4	1247.5	1970.2	2177.5
HEATING CAPACITY (WATERSIDE GPM)	26.5	31.5	43.5	74.5	105	145	215	345	435	715	795
HEATING CAPACITY (WATERSIDE BTU)	1,000,000	1,100,000	1,500,000	2,700,000	3,800,000	5,300,000	7,800,000	12,000,000	15,000,000	26,000,000	29,000,000
NET STEAM INPUT	101,000	109,000	159,000	236,000	330,000	452,000	690,000	1,090,000	1,400,000	2,300,000	2,500,000
NET GAS INPUT	80	100.9	145.8	209.6	293.8	403.8	609	967.4	1247.5	1970.2	2177.5
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HEATING CAPACITY (WATERSIDE BTU)	1,000,000	1,100,000	1,500,000	2,700,000	3,800,000	5,300,000	7,800,000	12,000,000	15,000,000	26,000,000	29,000,000
NET STEAM INPUT	101,000	109,000	159,000	236,000	330,000	452,000	690,000	1,090,000	1,400,000	2,300,000	2,500,000
NET GAS INPUT	80	100.9	145.8	209.6	293.8	403.8	609	967.4	1247.5	1970.2	2177.5
HEATING CAPACITY (WATERSIDE GPM)	26.5	31.5	43.5	74.5	105	145	215	345	435	715	795
HEATING CAPACITY (WATERSIDE BTU)	1,000,000	1,100,000	1,500,000	2,700,000	3,800,000	5,300,000	7,800,000	12,000,000	15,000,000	26,000,000	29,000,000
NET STEAM INPUT	101,000	109,000	159,000	236,000	330,000	452,000	690,000	1,090,000	1,400,000	2,300,000	2,500,000
NET GAS INPUT	80	100.9	145.8	209.6	293.8	403.8	609	967.4	1247.5	1970.2	2177.5
HEATING CAPACITY (WATERSIDE GPM)	26.5	31.5	43.5	74.5	105	145	215	345	435	715	795
HEATING CAPACITY (WATERSIDE BTU)	1,000,000	1,100,000	1,500,000	2,700,000	3,800,000	5,300,000	7,800,000	12,000,000	15,000,000	26,000,000	29,000,000
NET STEAM INPUT	101,000	109,000	159,000	236,000	330,000	452,000	690,000	1,090,000	1,400,000	2,300,000	2,500,000
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## Calculation #4: Solar Air Heater

Author: Alex Madsen

Checked By: Shengnan Chen, Manel Ajbouni

Revision Number: 2  
Revision Details: Adapted for the selected concept (length of building changed)

Revision Checked By: Shengnan Chen

### Objective:

To obtain the heat transfer potential of a solar air heater mounted on the south side of the honeybee overwintering building

### Custom Units:

$\text{cfm} := 1 \frac{\text{ft}^3}{\text{min}}$      $\text{fpm} := 1 \frac{\text{ft}}{\text{min}}$      $\text{Dollars} := 1$      $\text{cents} := \frac{1}{100} \text{Dollars}$      $\text{inWg} := 248.84 \text{ Pa}$

### Known Data:

Transmittance of glass:  $\Omega_{\text{glass}} := 0.83$  (Engineering Toolbox)

Length of South facing wall:  $L_{\text{wall}} := 70 \text{ ft}$  (Blow-Through Concept Floor Plan)

Height of South Facing Wall:  $H_{\text{wall}} := 15 \text{ ft}$  (Blow-Through Concept Floor Plan)

Airflow through Air Heater:  $Q_{\text{airflow}} := 26400 \text{ cfm}$  (Calculation #C1.3)

Thermal Conductivity of Glass:  $k_{\text{glass}} := 0.96 \frac{\text{W}}{\text{m K}}$  (Engineering Toolbox)

Average Thickness of Glass:  $t_{\text{glass}} := 4 \text{ mm}$  (Engineering Toolbox)

Stony Plain Winter Average Temperature:  $T_{\infty} := 265.25 \text{ K} = -7.9 \text{ }^{\circ}\text{C}$  (RETscreen Energy Software)

Stony Plain average winter Wind Speed:  $v_{\text{wind}} := 4.1 \frac{\text{m}}{\text{s}}$  (RETscreen Energy Software)

Alberta Cost of Electricity:  $C_{\text{elec}} := 6.8 \frac{\text{cents}}{\text{kWhr}}$  (Alberta Utilities Commission)

### Assumptions:

- 1) Agricultural environment where there are no large structures or trees inhibiting solar irradiation.
- 2) Location is assumed to be Stony Plain, AB, to check a location in AB with average level: of sun, without experiencing chinooks
- 3) Air is moving slow enough to be assumed incompressible ( $< 0.3 \times \text{Speed of sound}$ )
- 4) Heat absorbed into the building wall through the solar air heater is assumed to be included, as that heat is still entering the building in some fashion.

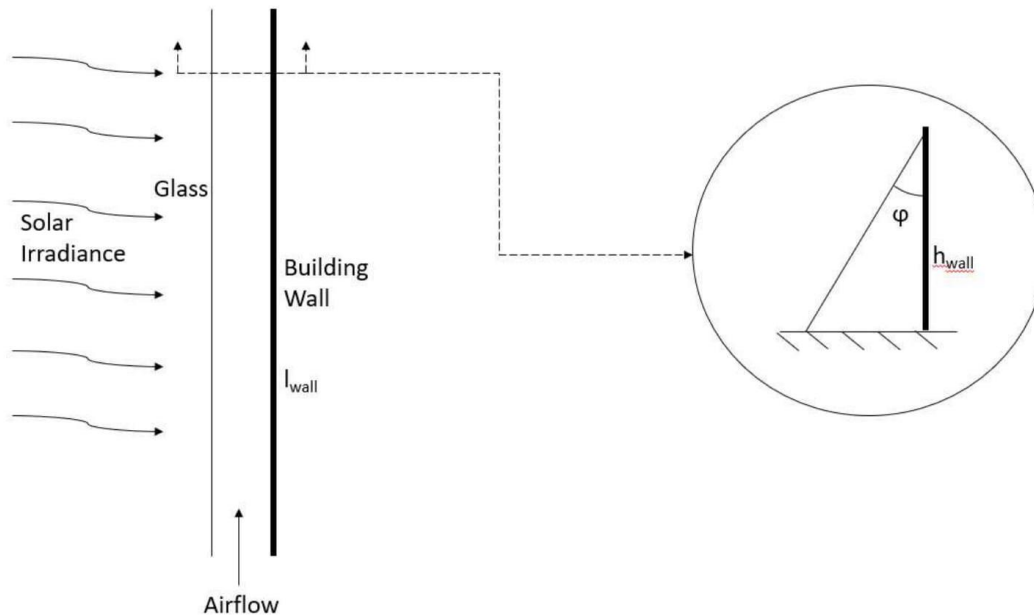


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## Variable Definitions:

A: Area  
 C: Cost  
 Cp: Specific heat capacity  
 D<sub>h</sub>: Hydraulic diameter  
 E: Solar irradiance  
 f: Friction factor  
 g<sub>e</sub>: Gravitational acceleration  
 h: Convective heat transfer coefficient  
 H: Height  
 H<sub>l</sub>: Head loss  
 k: Thermal conductivity  
 L: Length  
 M: Mach number  
 Nu: Nusselt Number  
 P: Perimeter  
 Pr: Prandtl Number  
 q: Heat transfer  
 Q: Volumetric Flow Rate  
 R: Thermal Resistance  
 Re: Reynolds Number  
 T: Temperature  
 v: Velocity  
 ΔP: Pressure drop  
 ε: Roughness  
 μ: Dynamic viscosity  
 ρ: Density  
 φ: Angle of glass wall as defined in sketch below  
 Ω: Transmittance (the amount of solar energy passing through a translucent material)

## Sketch:



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## Analysis:

**Properties of Air at Design Temperature:**  $T_{\infty} = -7.9^{\circ}\text{C}$

Dynamic Viscosity:  $\mu_{air} := 0.3499 \cdot 10^{-6} \frac{\text{lbf s}}{\text{ft}^2}$

Air Density:  $\rho_{air} := 1.33 \frac{\text{kg}}{\text{m}^3}$

Specific Heat:  $Cp_{air} := 1.004 \frac{\text{kJ}}{\text{kg K}}$

Thermal Conductivity:  $k_{air} := 23.75 \frac{\text{mW}}{\text{m K}}$

Prandtl Number:  $Pr := \frac{\mu_{air} \cdot Cp_{air}}{k_{air}} = 0.7082$

**Optimum Angle of Glass for Winter Performance:** For optimum solar irradiation in the winter, glass wall should be steeper than latitude due to Sun being lower on horizon.  
(Solar Electricity Handbook)

For Stony Plain:  $\varphi_{opt} := 21 \text{ deg}$

**Dimensions:**

$$L_{glass} := \frac{H_{wall}}{\cos(\varphi_{opt})} = 16.0672 \text{ ft} \quad W_{base} := H_{wall} \cdot \tan(\varphi_{opt}) = 5.758 \text{ ft}$$

**Area of Solar Irradiance:**  $A_{glass} := L_{wall} \cdot L_{glass} = 104.4883 \text{ m}^2$

**Solar Irradiance:** Average solar irradiance for varying locations is measured by weather stations across Canada for varying months. For Stony Plain:

$$\begin{aligned} E_{Jan} &:= 1.84 \frac{\text{kW hr}}{\text{m}^2 \text{ day}} = 76.6667 \frac{\text{W}}{\text{m}^2} & E_{Oct} &:= 2.99 \frac{\text{kW hr}}{\text{m}^2 \text{ day}} = 124.5833 \frac{\text{W}}{\text{m}^2} \\ E_{Feb} &:= 2.97 \frac{\text{kW hr}}{\text{m}^2 \text{ day}} = 123.75 \frac{\text{W}}{\text{m}^2} & E_{Nov} &:= 2.07 \frac{\text{kW hr}}{\text{m}^2 \text{ day}} = 86.25 \frac{\text{W}}{\text{m}^2} \\ E_{Mar} &:= 4.06 \frac{\text{kW hr}}{\text{m}^2 \text{ day}} = 169.1667 \frac{\text{W}}{\text{m}^2} & E_{Dec} &:= 1.24 \frac{\text{kW hr}}{\text{m}^2 \text{ day}} = 51.6667 \frac{\text{W}}{\text{m}^2} \end{aligned} \quad \text{(Solar Electricity Handbook)}$$

**Average Solar Heat Generation:**

$$\begin{aligned} q_{JanSolar} &:= \Omega_{glass} \cdot E_{Jan} \cdot A_{glass} = 6648.9361 \text{ W} & q_{OctSolar} &:= \Omega_{glass} \cdot E_{Oct} \cdot A_{glass} = 10804.5212 \text{ W} \\ q_{FebSolar} &:= \Omega_{glass} \cdot E_{Feb} \cdot A_{glass} = 10732.2501 \text{ W} & q_{NovSolar} &:= \Omega_{glass} \cdot E_{Nov} \cdot A_{glass} = 7480.0531 \text{ W} \\ q_{MarSolar} &:= \Omega_{glass} \cdot E_{Mar} \cdot A_{glass} = 14671.0221 \text{ W} & q_{DecSolar} &:= \Omega_{glass} \cdot E_{Dec} \cdot A_{glass} = 4480.8048 \text{ W} \end{aligned}$$

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**Average Overwintering Solar Heat Generation:** Typically bees reside in building from Nov to March.

$$q_{solar} := \frac{q_{NovSolar} + q_{DecSolar} + q_{JanSolar} + q_{FebSolar} + q_{MarSolar}}{5} = 8.8026 \text{ kW}$$

**Internal Convection Coefficient:**

Hydraulic Diameter of Area:  $P := H_{wall} + W_{base} + L_{glass} = 36.8251 \text{ ft}$

$$A_{xsection} := H_{wall} \cdot W_{base} \cdot 0.5 = 43.1847 \text{ ft}^2$$

$$D_h := \frac{4 \cdot A_{xsection}}{P} = 56.2894 \text{ in}$$

Speed of Airflow:  $v_{avg} := \frac{Q_{airflow}}{A_{xsection}} = 611.3276 \text{ fpm}$

Check Incompressibility Assumption:  $M := \frac{v_{avg}}{343 \frac{\text{m}}{\text{s}}} = 0.0091$  Much lower than limit of  $M = 0.3$ , so incompressibility assumption is valid

Reynolds Number:  $Re_{int} := \frac{\rho_{air} \cdot v_{avg} \cdot D_h}{\mu_{air}} = 3.5249 \cdot 10^5$

Flow inside solar air heater is turbulent, since Re is greater than internal critical Re number of 2300

Nusselt Number:  
(For turbulent internal flow)  $Nu := 0.023 \cdot Re_{int}^{0.8} \cdot Pr^{0.4} = 548.9283$

Convective Heat Transfer Coefficient:  $h_{int} := \frac{Nu \cdot k_{air}}{D_h} = 1.6058 \frac{\text{BTU}}{\text{ft}^2 \text{ hr } \Delta^\circ\text{F}}$

**Heat Conduction Through Glass:**

Check if conduction is significant compared to convection:

$$R_{intconv} := \frac{1}{h_{int} \cdot A_{glass}} = 0.0006 \frac{\Delta^\circ\text{F hr}}{\text{BTU}} \quad R_{cond} := \frac{t_{glass}}{k_{glass} \cdot A_{glass}} = 2.1036 \cdot 10^{-5} \frac{\Delta^\circ\text{F hr}}{\text{BTU}}$$

$$\frac{R_{cond}}{R_{intconv}} = 0.038$$

Since conduction is less than 5% of the internal convection, can assume conduction is negligible. This implies the internal and external glass surface temperature can be considered as the same

**External Convection Coefficient:** Since outside in an open area, assume forced convection over a flat plate with average wind speed

$$v_{wind} = 4.1 \frac{\text{m}}{\text{s}}$$

Check Incompressibility Assumption:  $M := \frac{v_{wind}}{343 \frac{\text{m}}{\text{s}}} = 0.012$  Much lower than limit of  $M = 0.3$ , so incompressibility assumption is valid

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Reynolds Number:  $Re_{ext} := \frac{\rho_{air} \cdot v_{wind} \cdot L_{wall}}{\mu_{air}} = 6.9446 \cdot 10^6$  Much higher than critical Re of 500,000

Critical Length:  $L_{critical} := \frac{500000 \cdot \mu_{air}}{\rho_{air} \cdot v_{wind}} = 5.0399 \text{ ft}$  Compared with length of building, this laminar length is negligible

Nusselt Number:  $Nu_{ext} := 0.037 \cdot Re_{ext}^{0.8} \cdot Pr^{\frac{1}{3}} = 9807.9224$

Convective Heat Transfer Coefficient:  $h_{ext} := \frac{Nu_{ext} \cdot k_{air}}{L_{wall}} = 1.9227 \frac{\text{BTU}}{\text{ft}^2 \text{ hr } \Delta^\circ\text{F}}$

## Finding Heat Loss in Solar Heater Due to Convection:

Total thermal resistance:  $R_{total} := R_{intconv} + \frac{1}{h_{ext} \cdot A_{glass}} = 0.001 \frac{\Delta^\circ\text{F hr}}{\text{BTU}}$

Convection heat transfer:  $q_{conv}(T) := \frac{(T - T_\infty)}{R_{total}}$

## Calculating Overall Heat Transfer and Final Temperature:

\*\*\*This is an iterative process as the maximum  $T_{int}$  value will vary. As a first guess we will pick the Max  $T_{int}$  created by only solar power.

$$q_{total} := q_{solar}$$

$$T_{intMax} := \frac{q_{total}}{Q_{airflow} \cdot \rho_{air} \cdot Cp_{air}} + T_\infty = -7.3709^\circ\text{C}$$

$$T_{avg} := \frac{T_{intMax} + T_\infty}{2} = -7.6355^\circ\text{C}$$

Iteration 1:

$$q_{total} := q_{solar} - q_{conv}(T_{avg})$$

$$T_{intMax} := \frac{q_{total}}{Q_{airflow} \cdot \rho_{air} \cdot Cp_{air}} + T_\infty = -7.3792^\circ\text{C}$$

$$T_{avg} := \frac{T_{intMax} + T_\infty}{2} = -7.6396^\circ\text{C}$$

Iteration 2:

$$q_{total} := q_{solar} - q_{conv}(T_{avg})$$

$$T_{intMax} := \frac{q_{total}}{Q_{airflow} \cdot \rho_{air} \cdot Cp_{air}} + T_\infty = -7.379^\circ\text{C}$$

$$T_{avg} := \frac{T_{intMax} + T_\infty}{2} = -7.6395^\circ\text{C}$$

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Iteration 3:

$$q_{total} := q_{solar} - q_{conv}(T_{avg})$$

$$T_{intMax} := \frac{q_{total}}{Q_{airflow} \cdot \rho_{air} \cdot Cp_{air}} + T_{\infty} = -7.379 \text{ }^{\circ}\text{C}$$

$$T_{avg} := \frac{T_{intMax} + T_{\infty}}{2} = -7.6395 \text{ }^{\circ}\text{C}$$

Iteration 4:

$$q_{total} := q_{solar} - q_{conv}(T_{avg})$$

$$T_{intMax} := \frac{q_{total}}{Q_{airflow} \cdot \rho_{air} \cdot Cp_{air}} + T_{\infty} = -7.379 \text{ }^{\circ}\text{C}$$

$$T_{avg} := \frac{T_{intMax} + T_{\infty}}{2} = -7.6395 \text{ }^{\circ}\text{C}$$

$$q_{total} = 8.6674 \text{ kW}$$

$$T_{intMax} = -7.379 \text{ }^{\circ}\text{C}$$

## Average Savings:

Assuming operation from November to March (151 days):

$$q_{NovMar} := q_{total} \cdot 151 \text{ day} = 31410.5919 \text{ kWhr}$$

$$Savings_{elec} := q_{NovMar} \cdot C_{elec} = 2135.9202 \text{ Dollars}$$

$$Savings_{elec\_day} := \frac{Savings_{elec}}{151} = 14.1452 \text{ Dollars}$$

## Pressure Drop:

Relative Pipe Roughness: Assuming the roughness can be approximated as riveted steel and concrete:

$$\varepsilon := 0.9 \text{ mm}$$

$$\frac{\varepsilon}{D_h} = 0.0006$$

Friction Factor:

$$f := \left( \frac{1}{-1.8 \cdot \log_{10} \left( \frac{6.9}{Re_{int}} + \left( \frac{\varepsilon}{D_h} \right)^{1.11} \right)} \right)^2 = 0.0186$$

Head Loss:

$$H_L := f \cdot \frac{L_{wall}}{D_h} \cdot \frac{v_{avg}^2}{2 g_e} = 0.1367 \text{ m}$$

Converting the head loss to pressure drop:

$$\Delta P := \rho_{air} g_e \cdot H_L = 0.0072 \text{ inWg}$$

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## Conclusion:

A solar air heater was investigated, to determine whether it had the capacity to significantly reduce load on the heating system. This solar heater can provide an average of ~31kW over the course of winter, providing a savings of up to \$7919 in heating energy cost if using electricity.

It should be noted that an installation like this may have to altered if installed in a region of Alberta that experiences chinooks. As heat is not desired in these cases, a large bypass door near the end of the heater should be available to manually open if a beekeeper sees that a chinook is in the forecast or occurring.

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## Calculation #5: Exhaust & Ceiling Fans

Author: Shengnan Chen

Checked By: Alex Madsen

Revision Number: 1  
Revision Details: Minor corrections not affecting numbers (format, grammar, etc)

Revision Checked By: Alex Madsen

### Objective:

To select the exhaust fans and ceiling fans required by design.

### Custom Units:

 $\text{cfm} := 1 \frac{\text{ft}^3}{\text{min}}$        $\text{inWg} := 248.84 \text{ Pa}$ 

### Known Data:

Required Flow Rate:  $Q := 26400 \text{ cfm}$ 

Length of building:  $L_{\text{bldg}} := 110 \text{ ft}$ 

Width of building:  $W_{\text{bldg}} := 100 \text{ ft}$ 

Height of building:  $H_{\text{bldg}} := 18 \text{ ft}$ 

### Assumptions:

- 1) Air is moving slow enough to be assumed incompressible ( $< 0.3 \times \text{Speed of Sound}$ )
- 2) Honeybee heat generation is negligible (honeybee hive thermoregulation is quite efficient resulting in the generated heat staying contained within the hive)
- 3) Motor inefficiencies get converted entirely into heat
- 4) Low velocity system desired, as honeybee comfort requires little wind.
- 5) Galvanized steel used as duct material.
- 6) Entrance to system is assumed to be a bellmouth entrance to minimize pressure drop
- 7) Elbows will be pleated as this is the industry standard and cheaper.

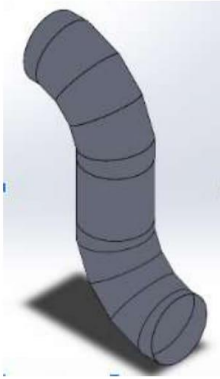
### Variable Definitions:

D: Diameter  
FL: Friction Loss  
H: Height  
L: Length or equivalent length  
n: Integer count  
Q: Volumetric flow rate  
V: Volume  
v: Velocity  
W: Width  
 $\Delta P$ : Pressure Drop



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## Sketch:

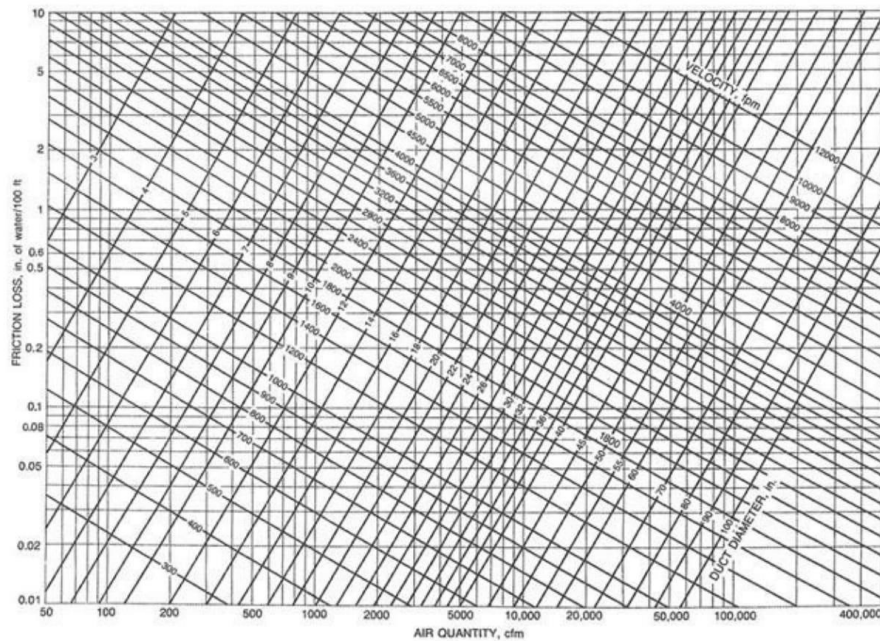


## Analysis:

The only pressure drop seen in this system will be from a small section of duct outside prevent light penetration. This section will consist of two 3' sections connected with 90 degree elbow. The inner side of the duct will be painted black so that light isn't reflected.

Upon checking requirements, it appears a system of 4 exhaust fans is optimal both financially and to encourage air mixing in the building. Assuming an equal amount air goes through each fan:

$$Q_{fan} := \frac{0.7 \cdot Q}{4} = 4620 \text{ cfm}$$





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**Duct Size:** Designing the duct out to low-velocity requirements gives a diameter of:

$$D := 26 \text{ in} \quad v := 1200 \text{ fpm} \quad FL := 0.055 \frac{\text{inWg}}{100 \text{ ft}}$$

**Equivalent Length:** The small section of duct consists of a bellmouth entrance, a 90 degree elbow and a abrupt expansion:

$$L_{eqv} := 3 \text{ ft} + \left( \frac{15 \text{ ft}}{1 \text{ ft}} \cdot D \right) + 3 \text{ ft} + \left( \frac{60 \text{ ft}}{1 \text{ ft}} \cdot D \right) + \left( 12 \frac{\text{ft}}{1 \text{ ft}} \cdot D \right) = 194.5 \text{ ft}$$

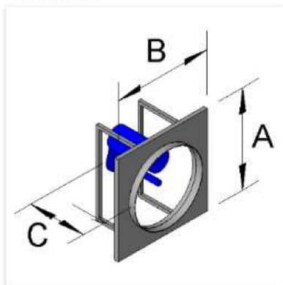
**Pressure Drop:**

$$\Delta P := L_{eqv} \cdot FL = 0.107 \text{ inWg}$$

**Fan Selection:** Wall mounted fans were selected due to their high volume capability for low static pressures.

By inputting pressure drop, CFM, and altitude into eCAPS by Greenheck, it was found that we should get 4 SBE-1L24 Fans, operating at 590 RPM. This fan meets the requirements and is the most economical option. See cut sheet for more details.

Dimensions



Label	Value (in.)	Description
A	26	Overall Height
B	26	Overall Width
C	19.5	Overall Length

Performance	
Actual Volume (CFM)	4,620
External Static Pressure (in. wg)	0.11
Total Static Pressure (in. wg)	0.11
Operating Power (Bhp)	0.32
Fan RPM	590
Percent within max fan RPM	27%
Inlet Sones	10.9
Inlet dBA	60

Pricing	
Budget Price (USD)	\$728
Operating Cost / yr (USD)	\$97
Features	
Impeller	Propeller, steel.
Housing	Galvanized steel panel with fabricated galvanized steel drive frame (optional wall housing or wall collar).
Drive Type	Belt driven motor in the air stream.

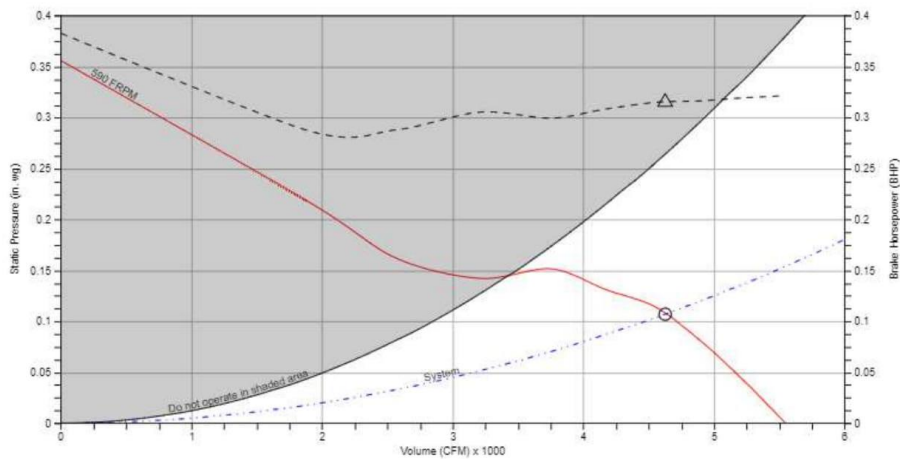
10 Apr 2019 10:41:36 - 05 - Exhaust\_Ceiling.sm

## Fan Curves

Fan Chart Type

Operating Conditions

- Fan curve
- - - Brake horsepower curve
- Operating Point SP
- △ Operating Bhp point
- Max system curve
- - - System curve



## Ceiling fan

There will be 4 ceiling fan introduce to this building to circular the air in the building. With the building size

Air flow rate required:

$$V_{bldg} := L_{bldg} \cdot H_{bldg} \cdot W_{bldg} = 1.98 \cdot 10^5 \text{ ft}^3$$

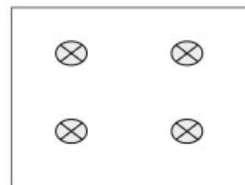
$$Q := 8 \cdot V_{bldg} \cdot \frac{1}{60 \text{ min}} = 26400 \text{ cfm}$$

From ecap 4 ceiling fan DS-8 are amounted on the ceiling.

## Dimensions



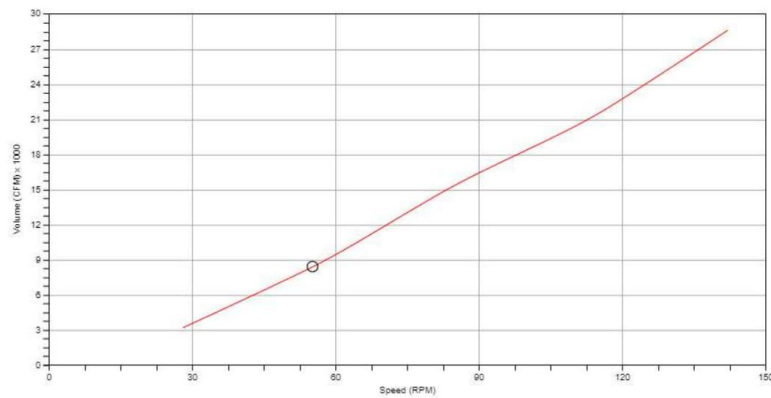
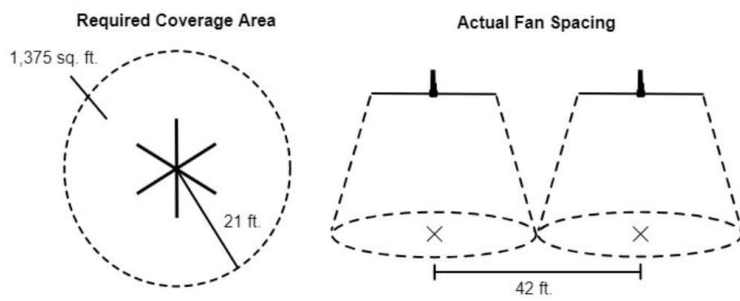
Label	Value	Description
A	8 ft.	Fan Diameter
B	42 in.	Drop Length
C	3 in.	Hub Height



Model Name	Fan Qty	Budget Price (USD) ?	Actual CFM per Fan	Avg Air Speed (ft/min)	Avg Air Speed Max (ft/min)	Total Operating Cost/yr (USD) ?
<div><div></div><div>DS-8</div><div>+</div></div>	1	\$7,700	8,414	72	200	\$10

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## Coverage & Spacing



## Conclusion:

4 x SBE-1L24 exhaust fans  
4 x DS-8 ceiling fans

See details above

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## Calculation #6: Standard CO2 Level

Author: Alex Madsen

Checked By: Shengnan Chen, Manel Ajbouni

Revision Number: 0

Revision Details: No issues

Revision Checked By: Shengnan Chen

### Objective:

To find the steady state level of CO2 concentration in the honeybee overwintering building

### Custom Units:

dollars:=1

cents:= $\frac{1}{100}$  dollar

### Known Data:

CO2 produced by bees, per hive:  $CO2_{bee} := 5 \frac{g}{hr}$ 

Number of hives:  $n := 6000$ 

Atomic weight of CO2:  $m_{CO2} := 44 \frac{g}{mol}$ 

Volume of building:  $V := (110 \text{ ft} \cdot 100 \text{ ft} \cdot 15 \text{ ft}) + (3 \text{ ft} \cdot 100 \text{ ft} \cdot 110 \text{ ft} \cdot 0.5) = 5139.5077 \text{ m}^3$ 

Atomic weight of air (average):  $m_{air} := 28 \frac{g}{mol}$ 

Atmospheric CO2 level:  $CO2_{atm} := 405 \text{ ppm}$ 

Air changes per hour:  $ACH := \frac{8}{hr}$ 

Density of air:  $\rho_{air} := 1.2 \frac{kg}{m^3}$ 

Proportion of fresh air supplied:  $p := 0.7$ 

### Assumptions:

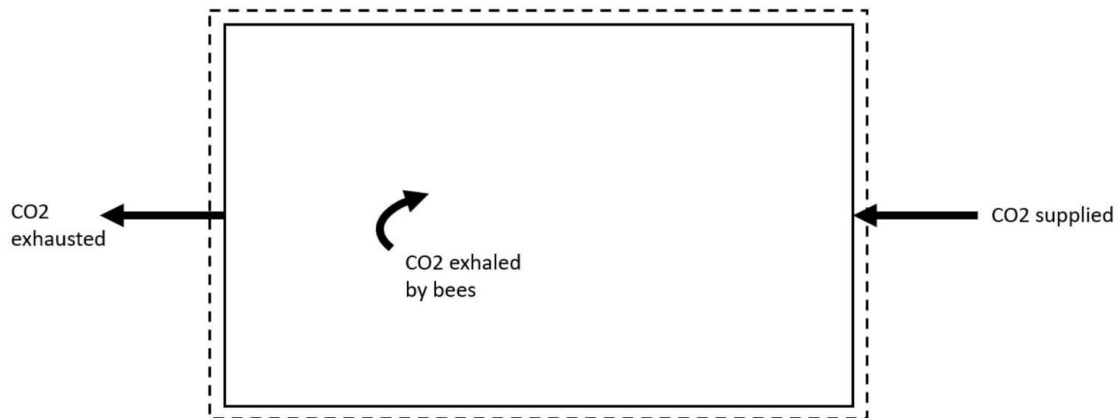
- 1) Assume atmospheric CO2 levels are constant
- 2) Assume CO2 is evenly mixed throughout building

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## Variable Definitions:

ACH: Air changes per hour  
 CO2: CO2 level in building  
 CO2\_ACH: CO2 generated by bees per air change, mols  
 CO2\_atm: Atmospheric CO2 level  
 CO2\_bee: CO2 generated per hour per hive  
 CO2\_ppm: PPM increase of CO2 by bees, per air change  
 m\_air: Average atomic weight of air  
 m\_CO2: Atomic weight of CO2  
 M\_air: Mass of air in building  
 n: Number of honeybee hives in building  
 p: proportion of supply air that is fresh air  
 V: Volume of building  
 ρ\_air: Density of air

## Sketch:



## Analysis:

Mols of CO2 generated by bees every hour:

$$CO2_{bee\_mol} := \frac{CO2_{bee} \cdot n}{m_{CO2}} = 681.8182 \frac{\text{mol}}{\text{hr}}$$

Per air change:

$$CO2_{ACH} := \frac{CO2_{bee\_mol}}{ACH} = 85.2273 \text{ mol}$$

Mass of air in building:

$$M_{air} := V \cdot \rho_{air} = 6167.4092 \text{ kg}$$

Mols of air in building:

$$mol_{air} := \frac{M_{air}}{m_{air}} = 2.2026 \cdot 10^5 \text{ mol}$$

2 / 3

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CO2 added to air every air change, in ppm:

$$CO2_{ppm} := \frac{CO2_{ACH}}{mol_{air}} = 386.9313 \text{ ppm}$$

Main iteration, starting from atmospheric until a steady state is hit. Each iteration represents one air change (7.5 minutes).

$$CO2 := CO2_{atm} = 405 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 791.9313 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 908.0107 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 942.8345 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 953.2816 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 956.4158 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.356 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.6381 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.7227 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.7481 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.7557 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.758 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.7587 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.7589 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.759 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.759 \text{ ppm}$$

$$CO2 := CO2 + (p \cdot CO2_{atm}) - (p \cdot CO2) + CO2_{ppm} = 957.759 \text{ ppm}$$

## Conclusion:

Given 30% return air with 8 air changes per hour, the building CO2 levels will settle to 957.8 ppm under standard, steady state operating conditions. The settling time of this system is approximately 1 to 2 hours.

## APPENDIX D: MATLAB HOURLY WEATHER SCRIPT

See following pages for the MATLAB script used to calculate true operation cost and track important parameters throughout a winter. It requires an excel file inputting hourly temperature, humidity, wind speed, solar beam irradiation, and solar diffuse irradiation. It outputs an excel document with columns for electrical power, electrical cost, natural gas power, natural gas cost, internal temperature, humidity, and CO2 levels for every hour in the original data set. Weather data is compiled from the Government of Canada via historical weather stations and CWEEDS, a solar database released by the Government of Canada.

```
% This script calculates the energy requirements for the  
% overwintering building in different locations with hourly data
```

```
function PowerAnalysis_Br(filename)
```

```
%Input Variable definitions - certain variables need to be  
changed for
```

```
%differing locations
```

```
Q_total = 10.694; %Total airflow [m3/s]  
angle = 24; %angle of tilt of solar heater, [deg]  
p_supply = 0.7; %Proportion of supply air that is fresh  
Tr_glass = 0.83; %Transmittance of glass  
L_wall = 21.3; %Length of wall (m)  
H_wall = 4.57; %Height of wall (m)  
C_elec = 6.32; %Cost of electricity, cents per kWh  
C_NG = 1.91; %Cost of natural gas, dollars per GJ  
T_desired = 4; %Desired entering temperature  
C_min = 909; %From HEx calcs [W/K]  
T_w_in = 65; %Water temperature into HEx [C]  
Eff_boiler = 0.9; %Efficiency of boiler  
CO2_limit = 3000; %Limit at which system goes into CO2 Exhaust  
mode  
CO2_ext = 408; %Outside CO2 concentration [ppm]  
P_f_ret = 0.7755; %Operating power of return fan [kW]  
P_f_sup = 11.558; %Operating power of supply fan [kW]  
P_f_exh = 0.2237; %Operating power of a single exhaust fan [kW]  
P_f_pump = 0.1243; %Operating power of the pump [kW]  
CO2_bees = 30000; %Additional CO2 added to system from bees  
[g/hr]  
Vol_bldg = 6905; %Volume of building [m3]  
ACH = 8; %Number of air changes per hour  
q_bees = 58000; %Energy given off by bees - building heat loss[W]  
H2O_bees = 30000; %g/hr of water vapour  
HumLim = 85; %Humidity limit
```

```
%Air properties (taken at average winter temperature of -10C)
```

```
dvis_air = 16.65e-6; %Dynamic viscosity [Ns/m2]  
dens_air = 1.33; %Density of air [kg/m3]  
cp_air = 1004; %heat capacity air [J/kgK]  
k_air = 0.02375; %Thermal conductivity of air [W/mK]  
Pr_air = (dvis_air * cp_air) / k_air; %Prandtl number
```

```
%Calculated variables (constants not requiring iteration)
```

```
CO2_bees_ppm = ((CO2_bees / ACH / 44.01) / ((dens_air /  
0.02897) * ...  
Vol_bldg)) * 1000000; %ppm of CO2 generated per ACH
```



```

%Finding glass surface area (Solar Heater)
L_glass = H_wall / cosd(angle); %Length of glass (hypotenuse)
A_glass = L_glass * L_wall; %Area of heat transfer
W_SAH = H_wall * tand(angle); %Width of base of triangle

%Transferring data from excel into matrices
Temp = xlsread(filename,'Temp');
Hum = xlsread(filename,'Hum');
WSpd = xlsread(filename,'WSpd');
SolB = xlsread(filename,'SolB');
Sold = xlsread(filename,'Sold');
n = length(Temp);

%Checking to ensure length of matrices is the same
if isequal(length(Temp),length(Hum),length(WSpd),length(SolB)) ==
0
    fprintf('Datasets not equal. Check excel lengths. ');
    return
end

%Solar Air Heater - Internal Convection coefficient (doesn't
change with
%hourly climate data)
Perim = H_wall + W_SAH + L_glass; %Perimeter of triangular x-
section [m]
A_SAH = H_wall * W_SAH * 0.5; %X-sectional area of SAH [m2]
Q_SAH = Q_total * p_supply; %Airflow thru SAH [m3/s]
v_SAH = Q_SAH / A_SAH; %velocity of air thru SAH [m/s]
D_h = (4 * A_SAH) / Perim; %Hydraulic diameter of SAH [m]
Re_SAH = (dens_air * v_SAH * D_h) / dvis_air; %Reynolds # of SAH
airflow
Nu_SAH = 0.023 * (Re_SAH^0.8) * (Pr_air^0.4); %Nusselt # of SAH
airflow
h_int = (Nu_SAH * k_air) / D_h; %Internal SAH convection
coefficient

                                %[W/m2K]

%Initial weight of water in building
AHum = zeros(1,n-1);
AHum(1) =
(6.112*exp((17.67*Temp(1))/(Temp(1)+243.5))*Hum(1)*2.1674) / ...
    (Temp(1)+273.15);
AHum_old = AHum(1);

%Main FOR loop, iterating per hour of winter (Oct - Mar)
%Initial values for tracked info:
CO2_old = CO2_ext;

```

```

Ins = zeros(1,n-1);
P_elec = zeros(1,n-1);
P_gas = zeros(1,n-1);
CO2 = zeros(1,n-1);
T = zeros(1,n-1);
T_ent = zeros(1,n-1);
CostE = zeros(1,n-1);
CostNG = zeros(1,n-1);
HumInt = zeros(1,n-1);
for i = 1:(n-1)

    %Gathering solar data via NREL's program
    i_angle = spa_Br(i);1

    %Picking data out of initial matrices
    v_ext = WSpd(i) / 3.6; %Wind speed, converting to [m/s]
    T_ext = Temp(i);
    Hum_ext = Hum(i);
    Ins(i) = (SolB(i)*sind(i_angle)) + (SolD(i)); %Solar
insolation
    %is the sum of direct and diffuse irradiation [kJ/m2/hr]

    %Finding convection coefficient of outside of SAH (glass)
    Re_ext = (dens_air * v_ext * L_wall) / dvis_air;
    Nu_ext = 0.037 * (Re_ext^0.8) * (Pr_air^(1/3));
    h_ext = (Nu_ext * k_air) / L_wall;

    %Total thermal resistance
    R = (1/(h_int*A_glass)) + (1/(h_ext*A_glass)); %[K/W]

    %Finding Solar energy transmitted into SAH
    q_solar = (Ins(i)*(1000/3600)) * A_glass * Tr_glass; %[W]

    %Finding heat loss out of SAH due to convection on glass
    q_SAH_tot = q_solar;
    %Iterative process, from initial calculations it takes 5
    %iterations to converge
    for j = 1:5
        T_SAH_f = (q_SAH_tot / (Q_total * dens_air * cp_air))
+ ...
        T_ext; %Calculating final temperature of SAH
        T_avg = (T_SAH_f + T_ext) / 2; %[C]
        q_SAH_tot = q_solar - abs((T_avg - T_ext)/R);
    %Updating total q
    end

```

<sup>1</sup> spa.m is an external MATLAB function released by NREL to track the position of the sun.  
<https://www.mathworks.com/matlabcentral/fileexchange/59903-nrel-s-solar-position-algorithm-spa>

```

T_ent(i) = (T_SAH_f*p_supply) + (T_desired*(1-p_supply));

%Entering absolute humidity
AHum_ent =
(6.112*exp((17.67*T_ext)/(T_ext+243.5))*Hum_ext*...
2.1674)/(T_ext+273.15);

%If statement depending on temperature
if (T_ent(i) < T_desired)

    %Power required from HEx
    Eff_HEx = (T_desired - T_ent(i)) / (T_w_in - T_ent(i));
%HEx Eff.
    q_HEx = Eff_HEx * C_min * (T_w_in - T_ent(i)); %Heat
required for H.

                                %coil [W]
    P_boiler = q_HEx / Eff_boiler; %Fuel usage in boiler [W]

    %Fan Power
    P_fans = P_f_ret + P_f_sup + (4*P_f_exh);

    %Calculating the increase in the CO2 concentration
    CO2(i) = CO2_old;
    for k = 1:ACH %air changes per hour
    CO2(i) = CO2(i) + (p_supply*CO2_ext) - (p_supply*CO2(i))
+ ...
        CO2_bees_ppm;
    end

    CO2_old = CO2(i);
    T(i) = T_desired;

    P_elec(i) = P_fans + P_f_pump; %Fans + pump
    P_gas(i) = P_boiler * 0.0000036; %Boiler is the source of
natural
                                %gas usage, convert to
GJ

    %Humidity Changes:
    for m = 1:ACH
        AHum(i) = (AHum_ent*p_supply) + AHum_old +
(H2O_bees/(ACH*Vol_bldg)) - ...
        (p_supply*AHum_old);
        AHum_old = AHum(i);

```

```

end

%Relative humidity
HumInt(i) =
abs((AHum(i)*(273.15*T(i)))/(6.112*exp((17.67*T(i))/...
(T(i)+243.4))*10.1674));

else
T_ent(i) = T_ext; %If entering temperature too high, open
up solar
%heater bypass.

P_gas(i) = 0;

CO2(i) = CO2_old;
T(i) = T_desired;
P_fans = 0;
for k = 1:ACH %air changes per hour
if or((CO2(i) >= CO2_limit), (AHum_old > HumLim))
CO2(i) = CO2(i) - (p_supply*CO2(i)) +
CO2_bees_ppm;
T(i) = (T(i)*(1-p_supply)) + (T_ent(i)*p_supply);
P_fans = P_fans + ((4*P_f_exh)/ACH); %Pump turned
off

AHum(i) = AHum_old - (p_supply*AHum_old) + ...
(H2O_bees/(ACH*Vol_bldg));
AHum_old = AHum(i);

else
CO2(i) = CO2(i) + CO2_bees_ppm;
T(i) = T(i) + (q_bees/(Q_total*(1-
p_supply)*dens_air*...
cp_air*(3600/ACH)));
P_fans = P_fans + (P_f_ret/ACH); %No pump in this
mode

%Relative humidity
AHum(i) = AHum_old + (H2O_bees/(ACH*Vol_bldg));
AHum_old = AHum(i);

end
end

P_elec(i) = P_fans;
CO2_old = CO2(i);

HumInt(i) = abs((AHum(i)*(273.15*T(i)))/(6.112*...

```

```
exp((17.67*T(i))/(T(i)+243.4))*21.674));

end

%Cost calcs
CostE(i) = (C_elec * P_elec(i)) / 100;
CostNG(i) = C_NG * P_gas(i);

fprintf('\n %i %.2f %.2f %.2f %.2f
%.2f', i, HumInt(i), T(i), CO2(i), sum(CostE), sum(CostNG));

end

fprintf('\n');

%Combining data into 1 large array
Data = vertcat(P_elec, CostE, P_gas, CostNG, T, CO2, HumInt);
Data = transpose(Data);

%Writing data to an excel file
excelfile = 'BrooksData.xlsx';
xlswrite(excelfile, Data);

end
```

## **APPENDIX E: DETAILED COST ANALYSIS**

See Table 13 below for the cost of the final detailed design. Note that where freight and tax are considered to be zero, this indicates that these costs are already included in the unit cost.

**Table 13:** Construction cost analysis

Total Cost							
\$493,717	Description	Quantity	Product/Part Unit Cost	Extra (Freight, Manufacturing, Tax, handling, etc)	Material	Reference	Total Price
Building	Structure	1	\$145,886.00	\$0.00	-	Appendix G	\$145,886
	Grade Perimeter	524	\$135/ft perimeter	\$0.00		G. Zakhem, Interviewee, <i>Chief Estimator, Olympia Steel Buildings Canada</i> . [Interview]. 20 February 2019.	\$70,740
	Concrete Slab	11,800	\$7/sf	\$0.00	Concrete	G. Zakhem, Interviewee, <i>Chief Estimator, Olympia Steel Buildings Canada</i> . [Interview]. 20 February 2019.	\$82,600
	Roof Insulation (Quantity measured in s.f)	11872	\$1.83	\$6,435.00	Fiberglass	Appendix G	\$28,149
	Wall Insulation (Quantity measured in s.f)	5764	\$1.55	\$0.00	Fiberglass	Appendix G	\$8,911
	Energy Saver Patch Tape	2	\$30.00	\$0.00	-	Appendix G	\$60
	Fuel Surcharge	1	\$516.33	\$0.00	-	Appendix G	\$516
HVAC	Daikin Water Heating Coil 5WS-0805B-36.0-54	2	\$12,000.00	\$0.00	Copper Tube	Appendix C	\$24,000
	Patterson Kelley C1050 Condensing Boiler	1	\$25,499.00	\$0.00	-	Appendix C	\$25,499
	Greenheck Inline Fan AX-72-190-0618	1	\$2,410.00	\$0.00	-	Appendix C	\$2,410
	Greenheck Inline Fan TBI-CA-3H30	2	\$4,827.00	\$0.00	-	Appendix C	\$9,654
	Greenheck Wall-Mounted Fan SBE-1L20	4	\$715.00	\$0.00	-	Appendix C	\$2,860
	Greenheck Ceiling Fan DS-8	4	\$7,700	\$0.00	-	Appendix C	\$30,800
	Taco Inline Pump 2400 series	2	\$340.00	\$0.00	-	Appendix C	\$680
	Ductwork	384 ft	\$70/ft (avg)	\$0.00	Copper	Appendix C	\$26,880
	Water Piping	87.6 ft	\$53.49/12ft	\$0.00	Copper	Appendix C	\$5,135
	Ductwork insulation	10% of Duct Cost	-	\$0.00	Fibreglass	Appendix C	\$2,688
	Piping Insulation	10% of Pipe cost	-	\$0.00	Foam	Appendix C	\$514
	Ball Valves and Actuators	4	\$28.99	\$0.00	Lead Free Brass	Appendix C	\$116
	Check Valves	2	\$21.99	\$0.00	Threaded Brass	Appendix C	\$44
	Gate Valve	10	\$14.62	\$0.00	Threaded Brass	Appendix C	\$146
	Duct Supply Air Temperature Gauges	2	\$46.00	\$0.00	-	Appendix C	\$92
	Filter Media	2	\$140/roll	\$0.00	-	Appendix C	\$140
	Duct Butterfly Damper	7	\$85.00	\$0.00	Galvanized Steel	Appendix C	\$595

	Installing new natural gas connection to building	1	\$2,500.00	\$0.00	-	-	\$2,500
	Solar Heater Mount	600 ft HSS	\$8.71 per ft HSS	\$0.00	Aluminum HSS	Appendix C	\$5,226
	Glass Mount	28	\$400.00	\$0.00	Aluminum Angle	Appendix C	\$11,200
	Glass Sheet	28 x 23 sqft	\$12 per sqft	\$0.00	Glass	Appendix C	\$7,728
<b>Sensors</b>	Beecons	600	\$32.90	\$3,956.89	-	Appendix G	\$23,697
	Beecons Software Subscription	1	\$4,998.00	-	-	Appendix G	\$4,998
	Building sensors	6	\$5.50	\$20.00		Appendix H	\$53



10 Apr 2019 10:51:26 - LongTermCost.sm

## Calculation: Payback Period

Author: Alex Madsen

Checked By: Shengnan Chen, Manel Ajbouni

Revision Number: 0

Revision Details: No issues

Revision Checked By: Shengnan Chen

## Objective:

To provide a preliminary long-term cost analysis and payback period

## Custom Units:

dollars:=1

cents:= $\frac{1}{100}$  dollar

## Known Data:

Average Operational Cost per Winter:  $C_{op} := 8200$  dollars

Cost of construction (upfront cost):  $C_{con} := 493717$  dollars

Cost of alternative overwintering technique (hive wraps):  $C_{wrap} := 25$  dollars (per hive)

Number of hives:  $n := 6000$ 

Annual cost of maintenance in building, per square foot:  $C_{mt} := 1.63 \frac{\text{dollars}}{\text{ft}^2}$ 

Square footage of building:  $Sqft := 11800 \text{ ft}^2$ 

## Assumptions:

- 1) Assume the land is already owned and therefore property tax is the same for either method.
- 2) Assume the hive wraps cannot be reused.
- 3) Assume losses are equal in both cases. If the overwintering building does reduce losses, payback period decreases depending on difference in losses.

## Variable Definitions:

$C_{con}$ : Upfront construction cost of honeybee overwintering building  
 $C_{mt}$ : Annual maintenance cost of honeybee overwintering building, per square foot  
 $C_{op}$ : Operational cost of honeybee overwintering building  
 $C_{wrap}$ : Cost of wrapping one hive in insulation for the winter  
 $n$ : Number of hives in honeybee overwintering building  
 $Sqft$ : Square footage of honeybee overwintering building

## Sketch:

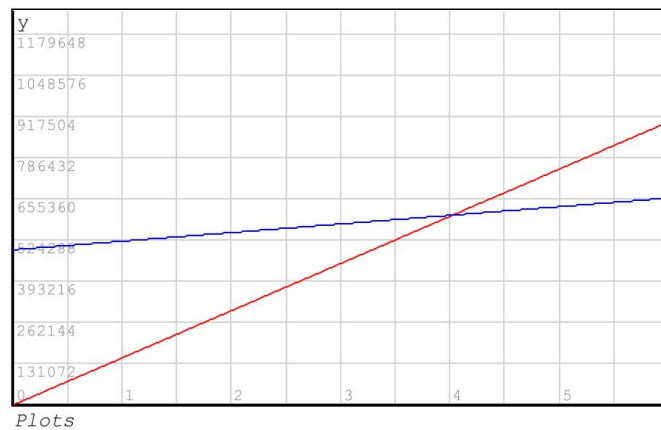
Not applicable.

10 Apr 2019 10:51:26 - LongTermCost.sm

**Analysis:** Overwintering Building Function:  $C_{bldg}(x) := C_{con} + C_{op} \cdot x + C_{mt} \cdot Sqft \cdot x$

Alternative hive wrap function:  $C_{alt}(x) := C_{wrap} \cdot 6000 \cdot x$

$$Plots := \begin{cases} C_{bldg}(x) \\ C_{alt}(x) \end{cases}$$



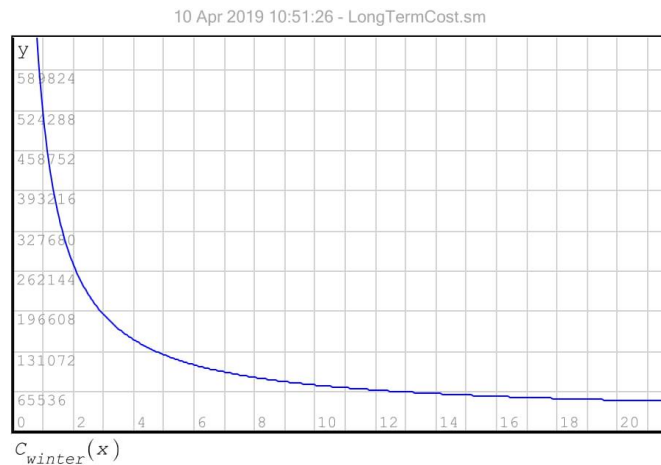
Functions cross at 4.0282 years, indicating the payback period.

**Savings:** Assuming a minimum equipment lifetime of 10 years, savings over that period are...

$$Savings := C_{alt}(10) - C_{bldg}(10) = 731943$$

**Cost per winter:**

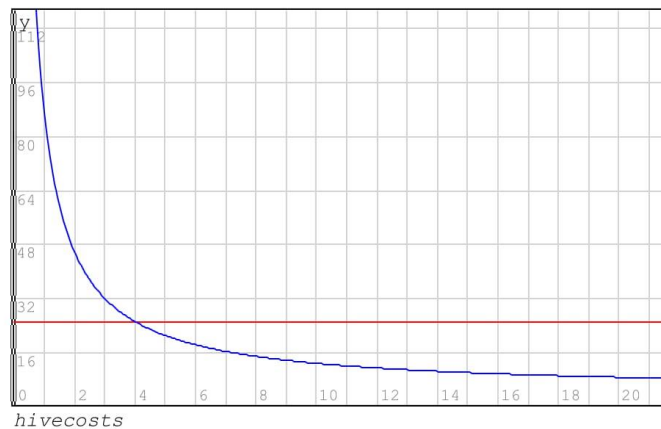
$$C_{winter}(x) := \frac{C_{bldg}(x)}{x}$$



Cost per hive per winter:

$$C_{hive}(x) := \frac{C_{winter}(x)}{n} \quad C_{hive\_wrap}(x) := C_{wrap}$$

$$hivecosts := \begin{cases} C_{hive}(x) \\ C_{hive\_wrap}(x) \end{cases}$$



## Conclusion:

Payback period of overwintering building is 4.0282 years. However, certain out-of-scope costs are not considered. This includes the cost of electrical system installations, which will increase the payback period slightly. Assuming a short building lifetime of 10 years (when the first equipment starts needing replacing), total cumulative savings of \$731943 is provided.

## **APPENDIX F: DESIGN COMPLIANCE - CLIENT CONFIRMATION**

• **Connie Phillips** @  
RE: MECE E 460: Group 21  
To: Manel Ajbouni

7:25 AM



Good Morning Manel,  
I've had a chance to go through the compliance matrix.  
Based on the meetings and presentations your team did for the Commission, the building design has met the parameters we discussed and outlined in the matrix

This was a great project!!

Best  
Connie

**Connie Phillips**  
Executive Director  
C: 780-289-5604  
11434-168 Street #102, Edmonton, AB T5M 3T9  
[albertabeekeepers.ca](http://albertabeekeepers.ca)

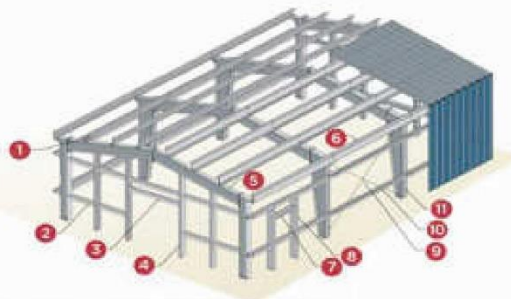


## **APPENDIX G: BUILDING & SENSOR QUOTES**



<b>SITE LOCATION</b>		Street: _____ City: CALGARY Province: AB Postal Code: _____		<b>PROJECT NAME / NUMBER</b>	
				Quote #: SonLe Date: 2/20/19 Page: 1 Of 2	
<b>CONTACT INFORMATION</b>		Name: SON LE Phone: _____ Email: _____		Fax: _____ Mobile: _____	
<b>BUILDING CODES</b>		Wind: 90 Roof Snow: 20.48 Live Load: 21 Seismic Sa (0.2): 0.15 Value Sa (1.0): 0.04		Collateral Load: 3 Dead Load: 2.2 Sa (0.5): 0.09 Sa (2.0): 0.02	
Building Code: AB14 LS Use Category: Normal				<b>BUILDING SPECS</b> Width: 110 Length: 136 Eave Height: 15 Roof Pitch: 1.0:12 Peak Offset: 55	
<b>BUILDING DETAILS</b>					
<b>Endwall Framing</b> Post & Rigid Exp. Beam Frame Endwall REW Y LEW Y		<b>Roof Panel</b> Gauge: 26 TYPE: CP		<b>Wall Panel</b> Gauge: 26 TYPE: CG	
<b>Endwall Column Spacing</b> REW 22 LEW 22		<b>Sidewall Bay Spacing</b> 7 at 19.43		<b>Interior Columns</b> NONE	
<b>Bracing</b> REW Cable Diagonal Bracing LEW Cable Diagonal Bracing FSW Cable Diagonal Bracing BSW Cable Diagonal Bracing		<b>Purlin Depth</b> 8 <b>Base Condition</b> Angle: _____ Channel: Y None: _____		<b>Girt Condition</b> REW: Flush LEW: Flush FSW: Bypass BSW: Bypass	
				<b>Roof Extensions</b> Dim. Gauge REW LEW FSW BSW	



- 1 Purlin
- 2 Endwall Girt
- 3 Door Header
- 4 Door Jamb
- 5 Endwall Rafter
- 6 Eave Strut
- 7 Window Header
- 8 Window Jamb
- 9 Wind Bracing
- 10 Sidewall Girt
- 11 Sidewall Column



37 SANDIFORD DRIVE, STE 413, STOUFFVILLE, ON L4A 7X5

1-844-937-8335

www.olympiasteelbuildings.ca

	
	
<b>BUILDING DETAILS</b>	
<b>Framed Openings:</b> LEW: 3x7 REW: FSW: 6x7 BSW: 3x7 FSW Gutters: 136 Insulation Package: Excluded	<b>Liner Panel:</b> Roof: LEW: REW: FSW: BSW: BSW Gutters: 136
<b>PROJECT NAME / NUMBER</b> Quote #: SonLe Date: 2/20/19 Page: 2 Of 2	

<b>AVAILABLE COLOURS</b>  <p><small>Actual colour may vary slightly from colour samples shown. If color choice is critical, request a colour sample. Because of changing trends in colour popularity, the colours shown are subject to change without notice.</small></p>	<b>STANDARD COLOUR SELECTION</b> Roof Panel: Galvalume/Plain Roof Trim: NEED COLOR Wall Panel: NEED COLOR Jamb Trim: NEED COLOR Corner Trim: NEED COLOR Eave Trim: NEED COLOR Base Trim: NEED COLOR Gutters & Downspouts: NEED COLOR
--	--

<b>BUILDING COST</b>	<b>NOTES</b>																		
<table border="1"> <tr> <td><b>Building:</b></td> <td>\$145,886</td> <td>CAD</td> </tr> <tr> <td><b>Freight:</b></td> <td>INCLD.</td> <td></td> </tr> <tr> <td><b>Taxes:</b></td> <td>EXTRA</td> <td></td> </tr> <tr> <td><b>25% ENG Deposit</b></td> <td>\$36,500</td> <td>CAD</td> </tr> <tr> <td><b>25% MFG Deposit</b></td> <td>\$36,500</td> <td>CAD</td> </tr> <tr> <td><b>Balance:</b></td> <td>\$72,886</td> <td>CAD</td> </tr> </table>	<b>Building:</b>	\$145,886	CAD	<b>Freight:</b>	INCLD.		<b>Taxes:</b>	EXTRA		<b>25% ENG Deposit</b>	\$36,500	CAD	<b>25% MFG Deposit</b>	\$36,500	CAD	<b>Balance:</b>	\$72,886	CAD	Broker Service Fee is Included in Quote Industrial Gutters/Downs + Full Trim package incl. Climatic & Seismic Loads Verified for Calgary, AB Engineered Stamped Structural Alberta Drawings incl. 40 Yr Structural, 40 yr Paint, 35 Yr Perf Warranties Actual Doors included Insulation priced seperately Quote Valid for 14 Days
<b>Building:</b>	\$145,886	CAD																	
<b>Freight:</b>	INCLD.																		
<b>Taxes:</b>	EXTRA																		
<b>25% ENG Deposit</b>	\$36,500	CAD																	
<b>25% MFG Deposit</b>	\$36,500	CAD																	
<b>Balance:</b>	\$72,886	CAD																	

I appreciate the opportunity to work with you on your project. If you have any further questions, please feel free to contact me.

Sincerely, GEORGE ZAKHEM

37 SANDIFORD DRIVE, STE 413, STOUFFVILLE, ON L4A 7X5	1-844-937-8335	<a href="http://www.olympiasteelbuildings.ca">www.olympiasteelbuildings.ca</a>
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90 Whybank Drive Brampton, ON L7A 0N7  
(905) 495-9393  
(905) 495-9993 (Fax)

DATE: Feb 20, 2019

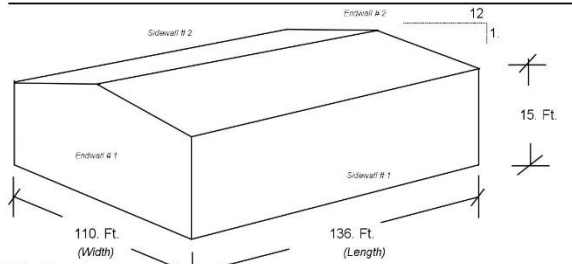
This proposal is effective for materials  
shipping by Apr 21, 2019

## QUOTATION

<b>CUSTOMER</b> George W Zakhem Olympia Steel Buildings - Builder 413-37 Sandiford Stouffville, ON L4A 7X5 905-642-9416 -- (Fax)				<b>PROJECT</b> SONLE  CALGARY, AB T1X		<b>QUOTE #</b> #1-114071-1035250																																																																									
<b>BUILDING SIZE 1</b> WIDTH: 110. Ft. LENGTH: 136. Ft. HEIGHT: 15. Ft. ROOF PITCH: 1: 12 Double Slope																																																																															
<b>BUILDING SIZE 2</b> WIDTH: LENGTH: HEIGHT: ROOF PITCH:																																																																															
<b>BUILDING SIZE 3</b> WIDTH: LENGTH: HEIGHT: ROOF PITCH:																																																																															
<b>ROLL WIDTH(S):</b>		<b>ROOF</b>	<b>WALLS</b>	<i>Silvercote Roof system prices do NOT include spacer blocks and the lead time is 3-4 weeks once we have the erection drawings. To properly control condensation, every effort should be made to fill the purlin cavity with insulation. Additional charges may apply if the final purlin spaces or heights require custom widths or added thickness to be designed properly.</i>																																																																											
Starter Rolls:		48 In.																																																																													
Primary Rolls:		72 In.																																																																													
Split Rolls:		BLDG 1: BLDG 2: BLDG 3:																																																																													
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V0/2.5.19-PSInd18--2.75N--21.5-FT6435Volume=1TLs (51#)

## Silvercote LLC



Customer	Olympia Steel Buildings - Builder
Project	SONLE
Address	
City	CALGARY, AB T1X
Description	
Roof Insulation:	Wall Insulation:
R=40 White Energy Saver System	R=30 White Energy Saver System
60 inches wide	

*\*Note: Building dimensions are not drawn to scale.*

WALL DEDUCTIONS FOR BUILDING # 1			
Sidewall # 1	Sidewall # 2	Endwall # 1	Endwall # 2

*Please notify us if the building width and length are not correctly oriented.*

**Approx. Weight = 14247 lbs / Approx. Cubic Feet = 4541 for all Buildings**

Quote# 1

### TERMS AND CONDITIONS

**THIS DOCUMENT DOES NOT INCLUDE SALES TAX.** This document IS NOT an invoice and DOES NOT include any applicable sales, use, excise or other taxes, tariffs, or duties that may be due with respect to this order. **It is the responsibility of each customer to pay the sales tax invoiced unless a legal exemption applies.** If you need to know what the invoice total will be, please contact our credit department at (844) 232-3701.

**TERMS AND CONDITIONS.** All sales by Silvercote LLC (Silvercote) to customer are subject to the credit application executed by customer, including without limitation the Terms and Conditions of Sale included in such application.

**TECHNICAL ADVICE.** Any recommendations, technical advice, or assistance furnished by Silvercote concerning the characteristics, properties, or performance of the products are based on data believed to be reliable, and are furnished solely on a gratis basis. Since Silvercote does not control or supervise the subsequent installation of its products or their use after sale, no guarantee of accuracy is made as to such statements and such statement should not be construed as warranties or as the basis therefore. In no event shall Silvercote be liable for such recommendations, advice, or assistance, or the result obtained.

**WARRANTY AND REMEDY.** (a) Final determination of the suitability of the products for any use contemplated by Customer is the sole responsibility of Customer; Silvercote shall under no circumstances be responsible for the suitability of any product for any particular end-use. (b) The Customer takes all responsibility and Silvercote shall have no liability due to problems relating to failure of the insulation blanket or facing material due to condensation damage caused by a concrete slab being poured after the building has been erected, insulated, roofed, and sided. This practice is known to introduce excessive amounts of moisture into the building and can cause condensation problems. The thermal efficiency of fiberglass blanket can be significantly reduced when wet and metalized surface of the vapor retarder (facing) can be corroded by the presence of moisture.

**WARRANTY - TAPE AND ADHESIVE PRODUCTS.** Our suppliers do not warranty their products as to use. They state that final determination of the suitability for use is that of the buyer. As distributors of these items, we cannot accept responsibility for their failure.

CUSTOMER: Olympia Steel Buildings - Builder  
PROJECT NAME: SONLE  
ORDER NUMBER:

110' W x 136' L x 15' Eave 1:12 Pitch



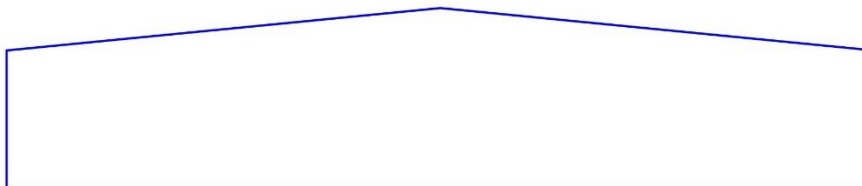
Energy Saver System

Sheeting Direction →



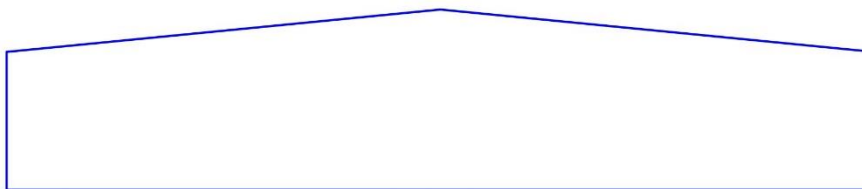
Energy Saver System

Sheeting Direction →



Energy Saver System

Sheeting Direction →

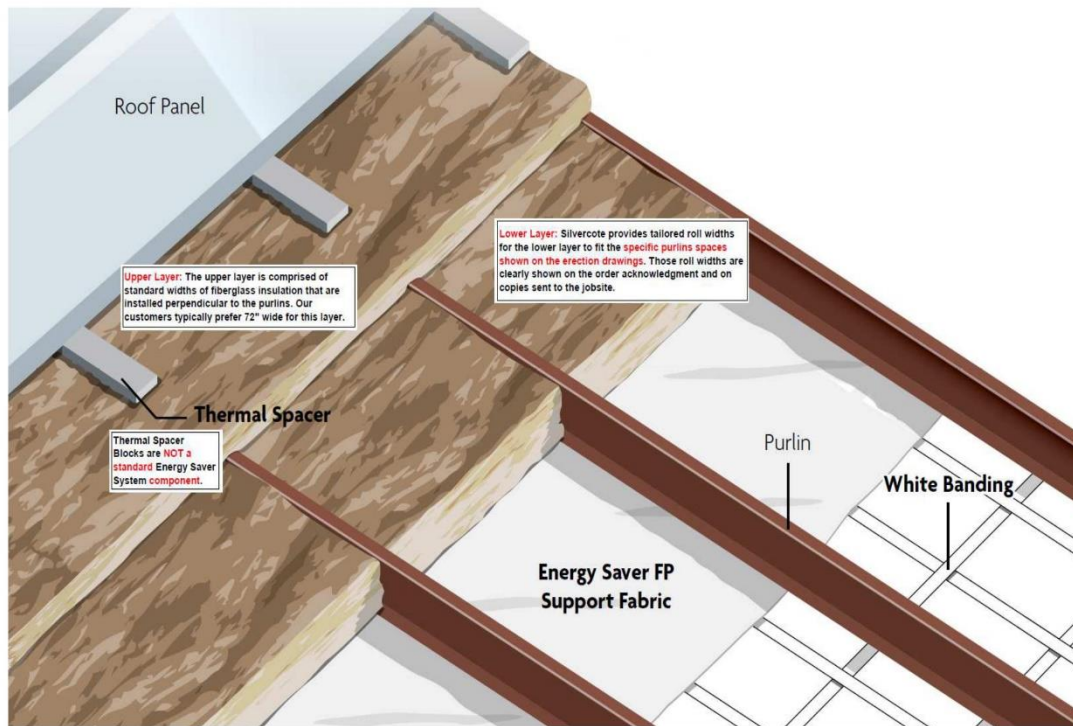


Energy Saver System

Sheeting Direction →

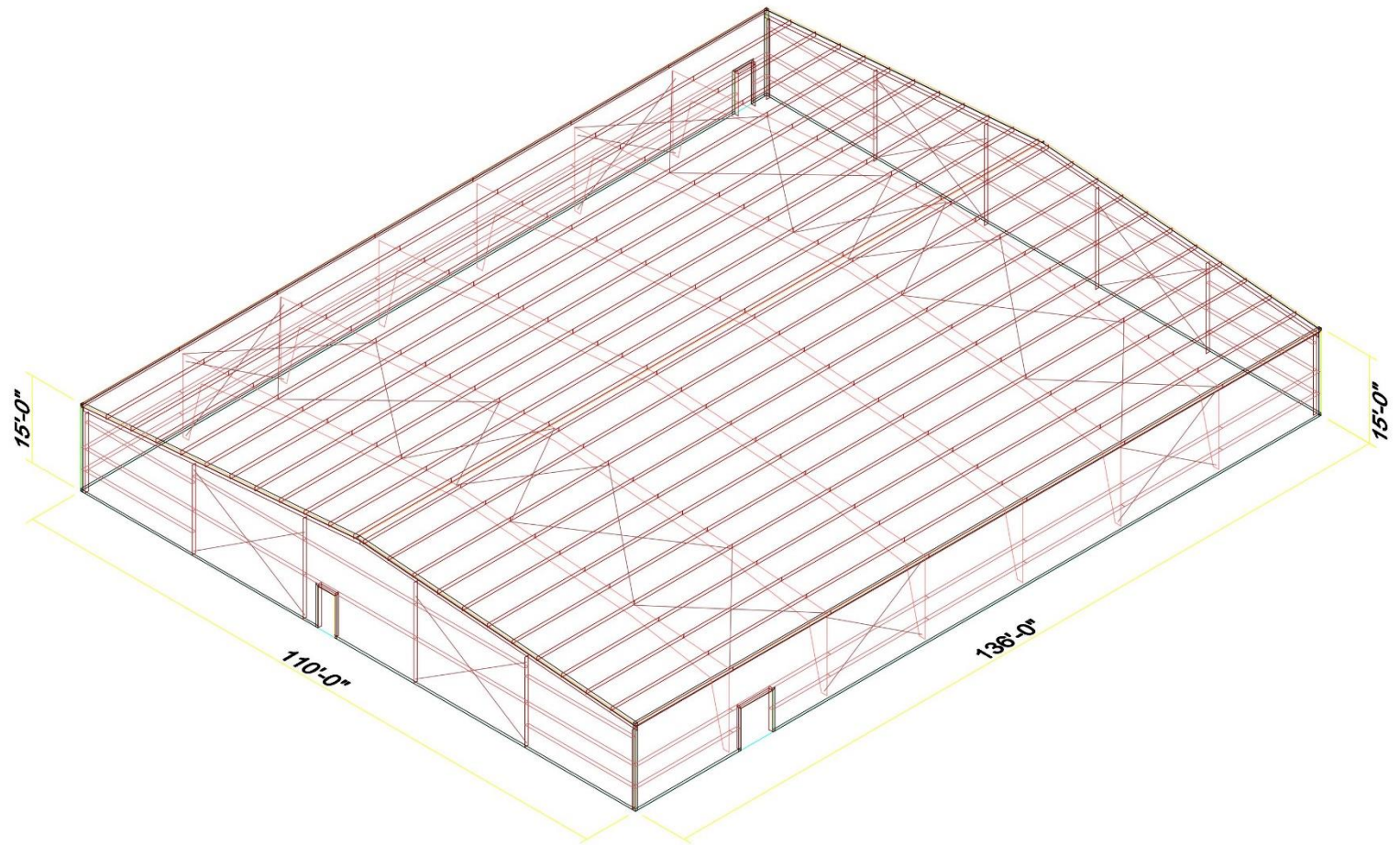
CUSTOMER: Olympia Steel Buildings - Builder  
PROJECT NAME: SONLE  
ORDER NUMBER:

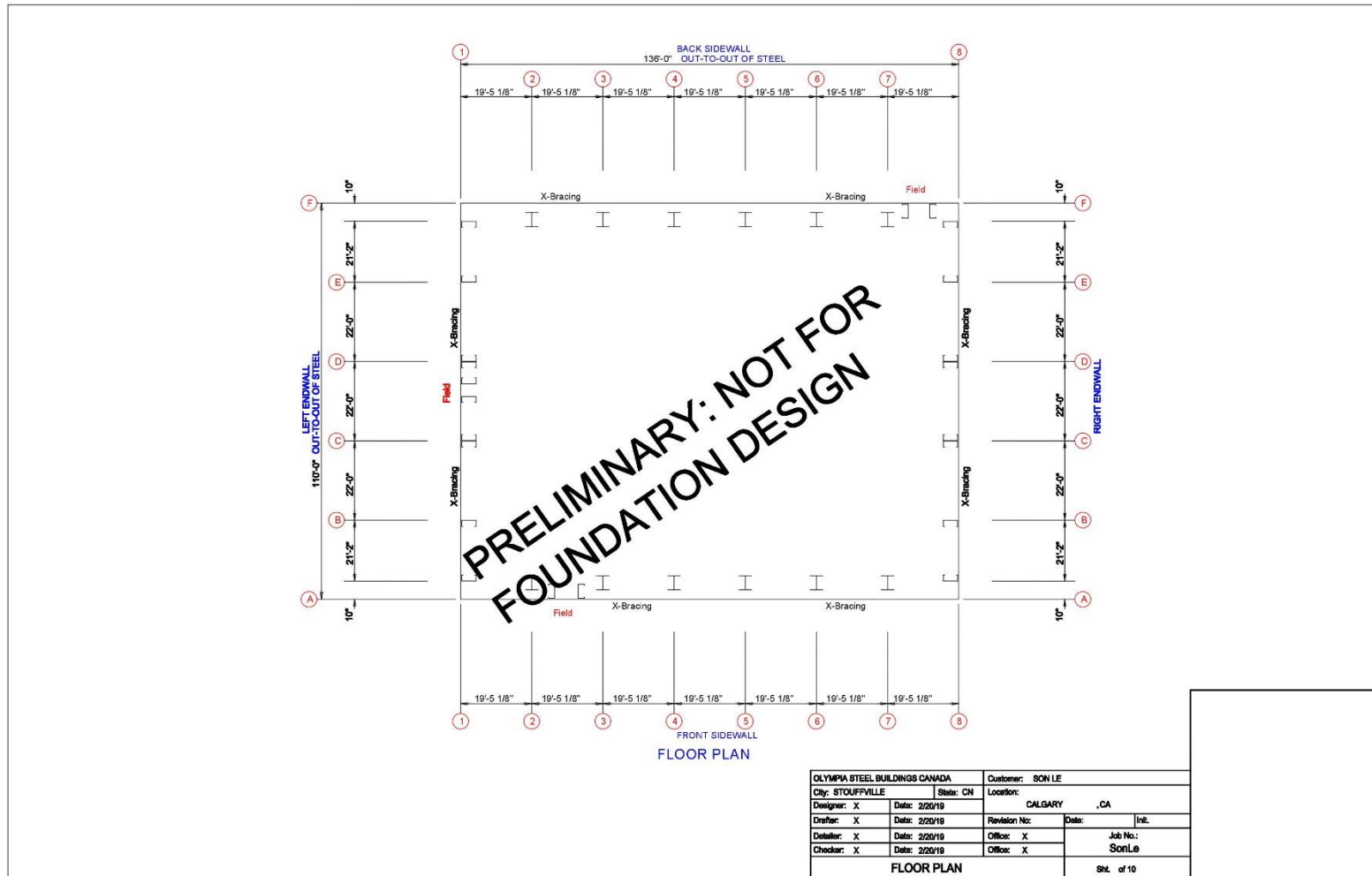
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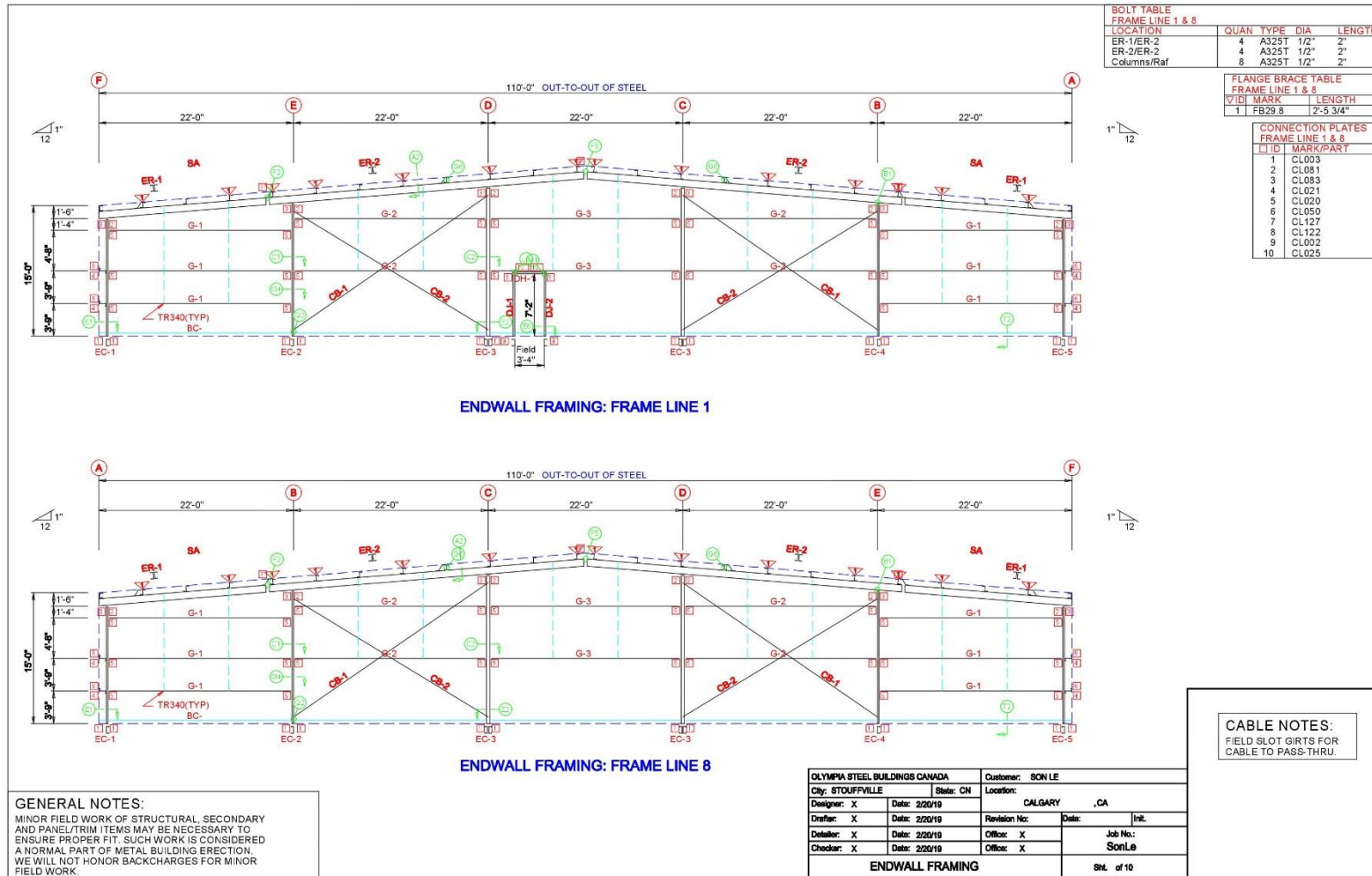


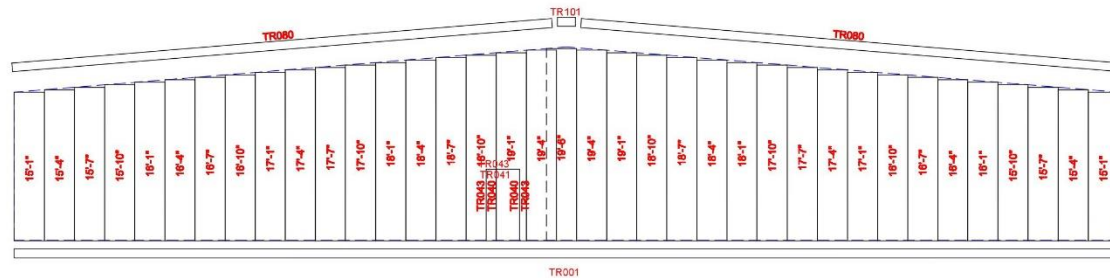
R=40 White Energy Saver System consisting of 9 1/4 Inch R-30 lower layer & R-10 upper layer.



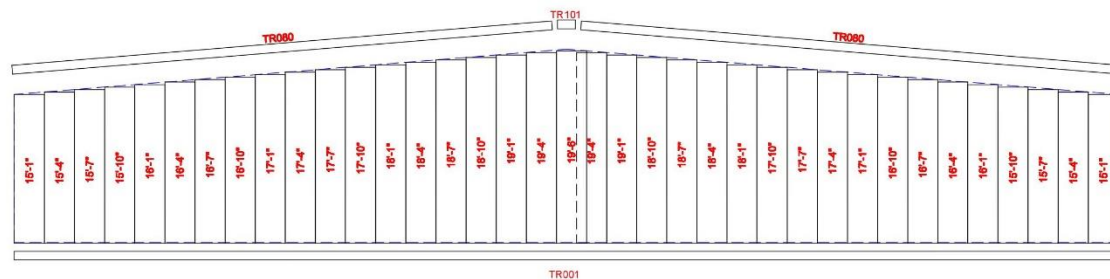








**ENDWALL SHEETING & TRIM: FRAME LINE 1**  
PANELS: 26 Ga. CGR - NEED COLOR



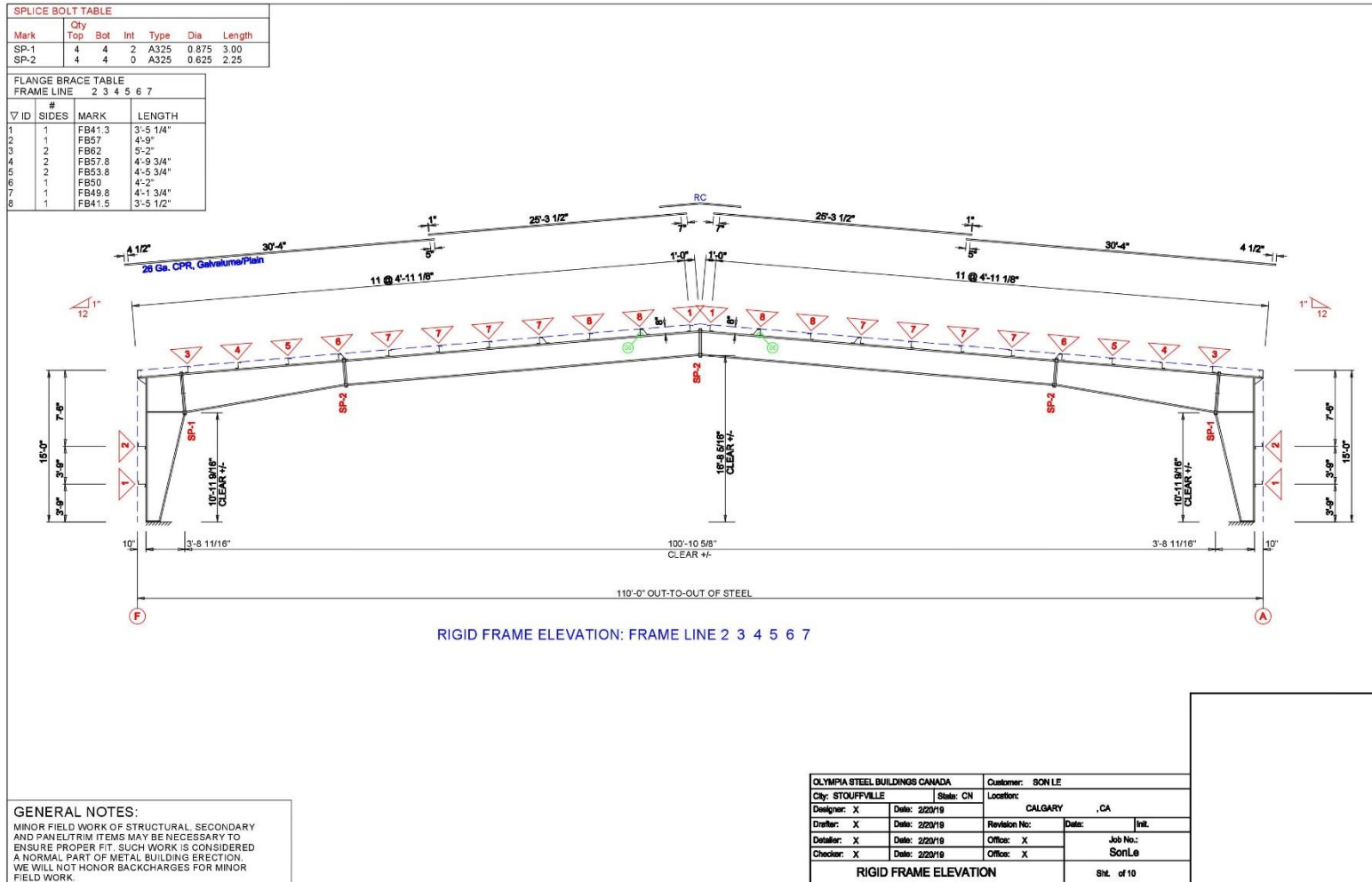
**ENDWALL SHEETING & TRIM: FRAME LINE 8**  
PANELS: 26 Ga. CGR - NEED COLOR

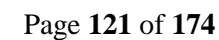
GENERAL NOTES:

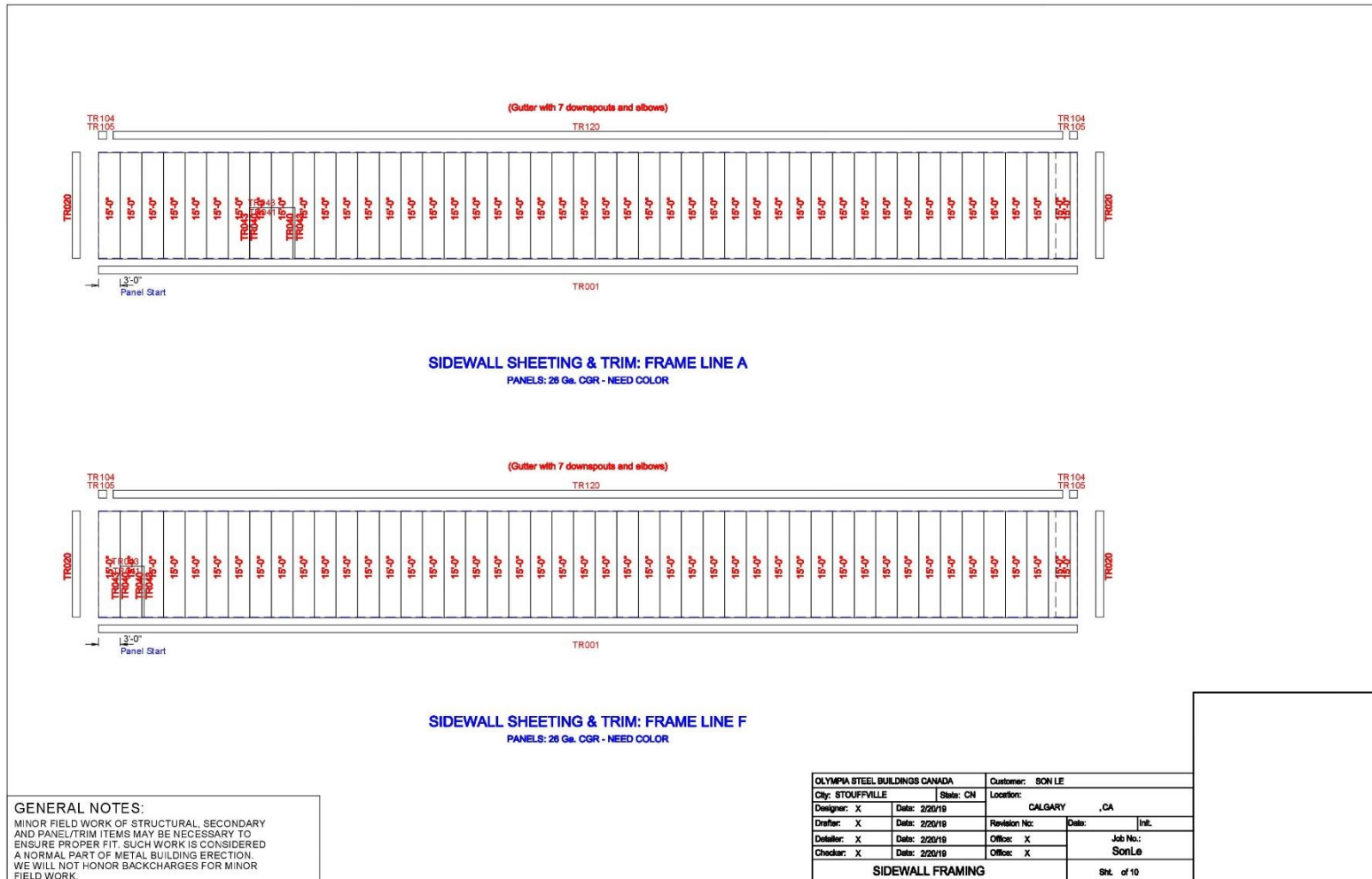
MINOR FIELD WORK OF STRUCTURAL, SECONDARY AND PANEL/TRIM ITEMS MAY BE NECESSARY TO ENSURE PROPER FIT. SUCH WORK IS CONSIDERED A NORMAL PART OF METAL BUILDING ERECTION. WE WILL NOT HONOR BACKCHARGES FOR MINOR FIELD WORK.

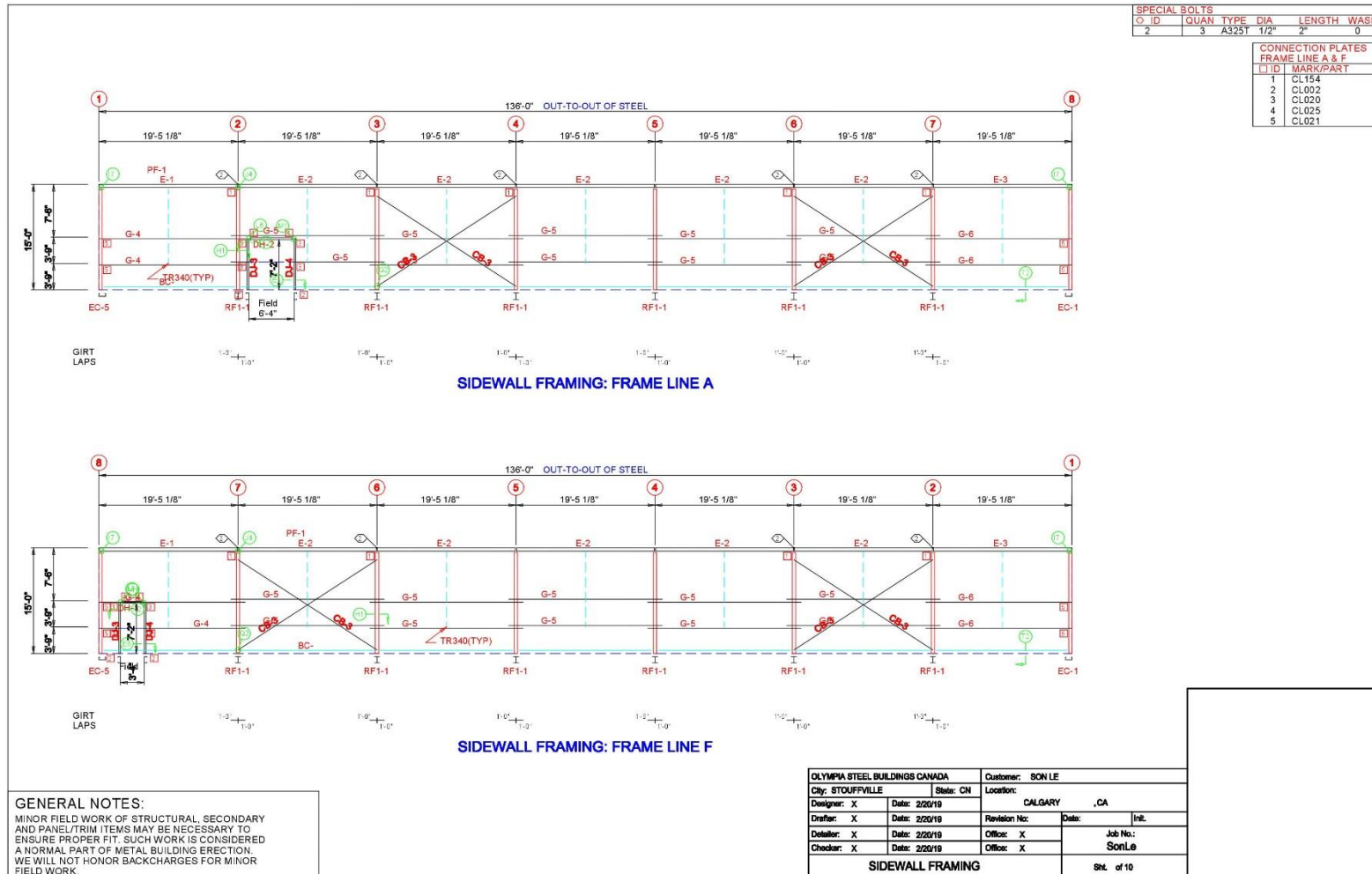
OLYMPIA STEEL BUILDINGS CANADA		Customer: SON LE	
City: STOUFFVILLE	State: CN	Location: CALGARY, CA	
Designer: X	Date: 2/20/19	Revision No:	Date: Init.
Drafter: X	Date: 2/20/19	Office: X	Job No.: SonLe
Detailer: X	Date: 2/20/19	Office: X	
Checker: X	Date: 2/20/19		
ENDWALL FRAMING			Sht. of 10













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P +1 (514-941-6457)  
max@nectar.buzz  
W www.nectar.buzz

## Quote Details

Prepared by Maximilian Cherney  
Email max@nectar.buzz

Created Date 2/25/2019  
Shipping Period Fall 2019

## Payment Terms

Hardware 100% upon purchase  
Software 100% upon purchase

## Quote items

Product	Product Code	(CAD)	Quantity	Total Price
Beecons	BCN-AD	32.90 \$	600	19,740.00 \$
Software Subscription (6 months)*	YRD-SW	4,998.00 \$	1	4,998.00 \$

\*Includes lease of sufficient quantity of BeeHubs to connect purchased Beecons.

Sub-total 24,738.00 \$

TPS Tax (5%) 1,236.90 \$

TVQ Tax (9.975%) 2,591.00 \$

Shipping and Handling 1,000.00 \$

**Total 29,565.90 \$**

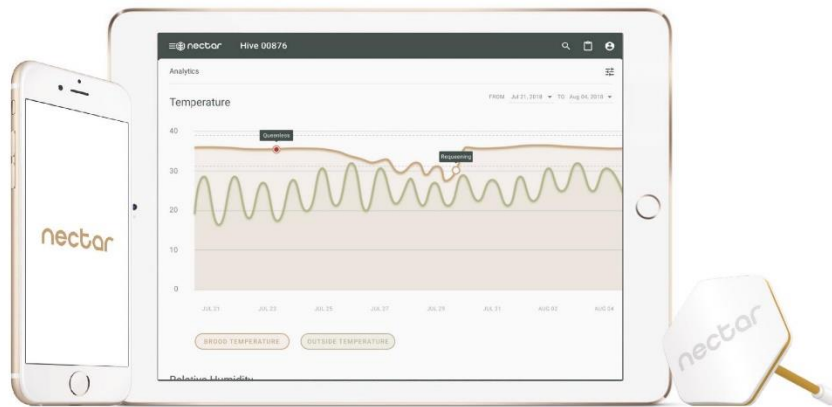
## **APPENDIX H: SENSOR TECHNICAL INFORMATION**



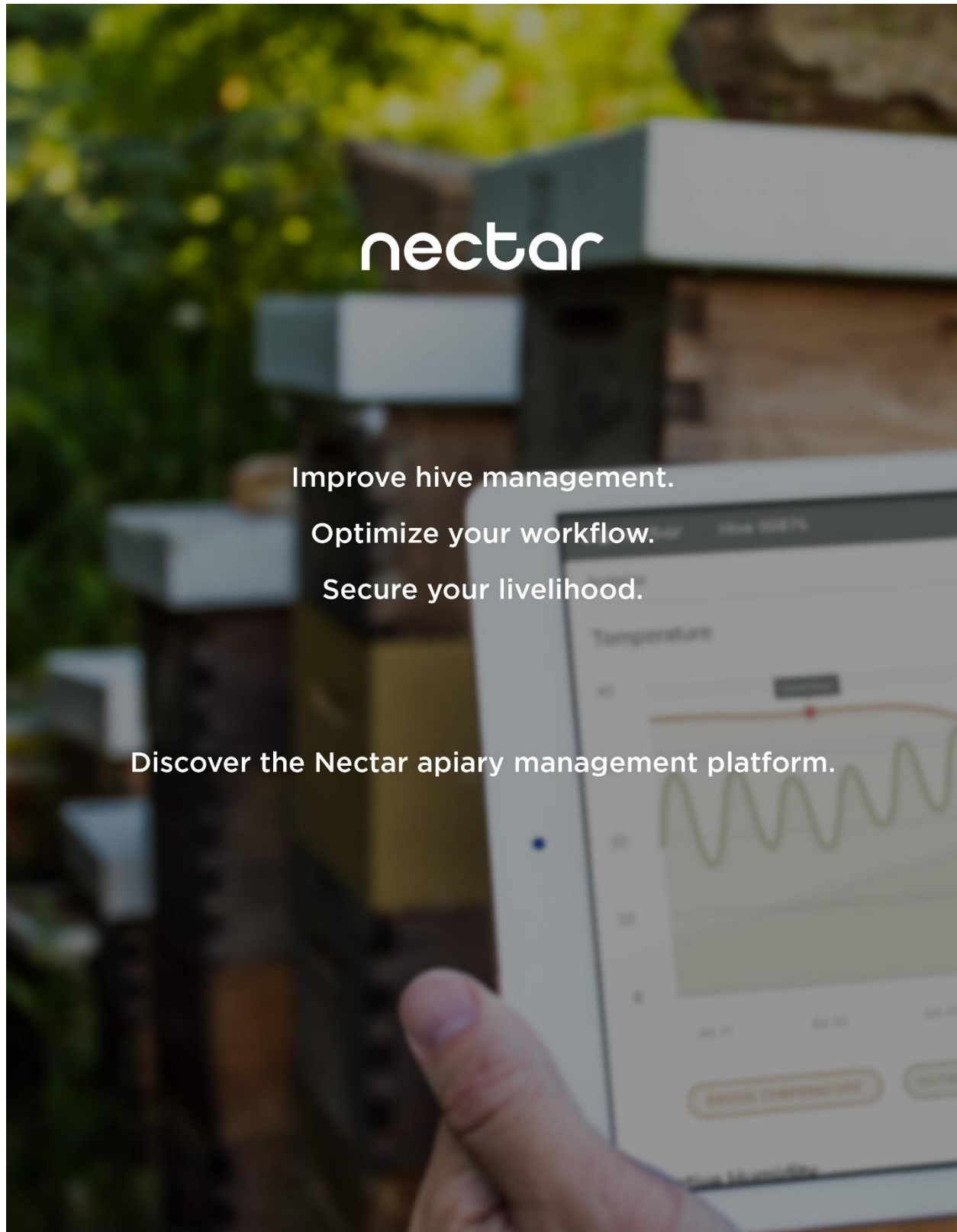
**nectar**

# **Precision Beekeeping Technology**





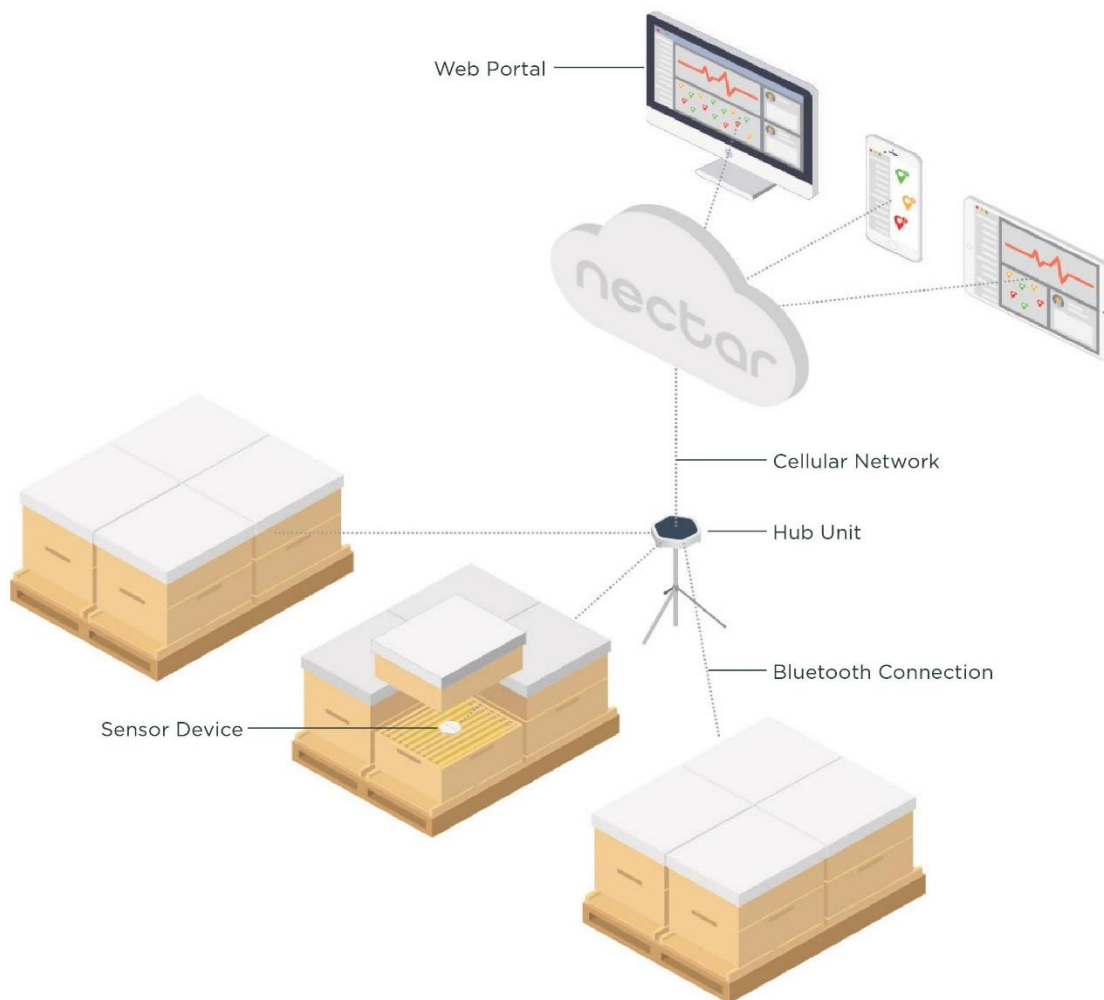




## How it works

The Nectar platform is enabled by a single BeeHub in a yard connected to all closeby Beecons. The BeeHub creates its own reliable, wireless, encrypted network and connects to the cloud, even in low connectivity zones.

Save countless hours of labor by remotely following your hives' statuses and improve your decision making through receiving alerts and recommendations.



## The Beecon Sensor Device

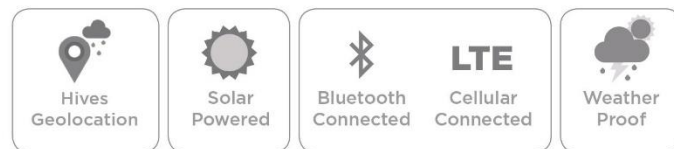


The Beecon is a wireless, bee friendly device capable of measuring temperature, humidity, position, and frequencies inside the supers to assess your hive's activity, strength and behavior.



## The BeeHub

Nectar's BeeHub is in charge of transmitting the hives data online, double as your on-site weather station and will track your hives' and yards locations.



## Secured Hives

Protect your livelihood with Nectar's theft detection & alerts.

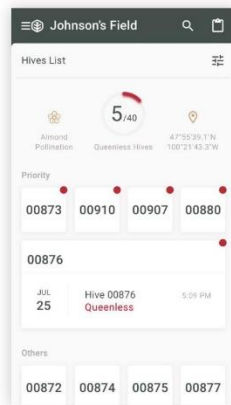


## Hive Movement Alerts

Nectar's in-hive sensor will detect any undesired hive movement and alert you right away with a text message.

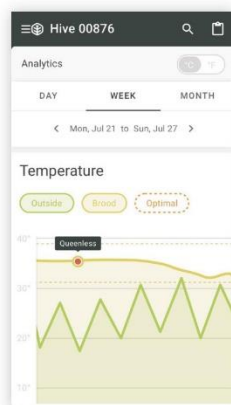
## Improved Hive Management

Make better decisions with Nectar's real-time, remote data.



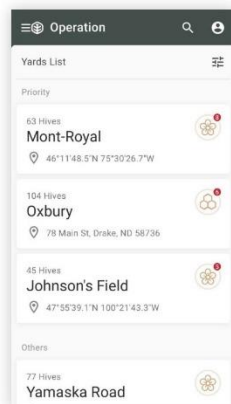
### Real Time Queen Status

Save time and money. Nectar's Queen Status tool tells you when a hive is queenless, in real time, without having to send someone to the field.



### Key Data Measurements

An informed beekeeper is a better one. Visualize the impact of your management practices on your bees' health

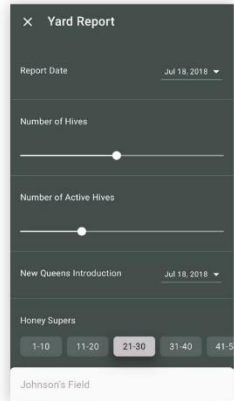


### Yard Visits Prioritization

Send your team to the right yards and plan visits with Nectar's yard prioritization tool.

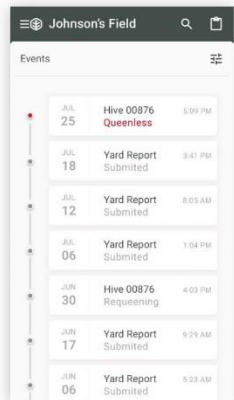
## Optimized Workflow

Improve your operation's efficiency.



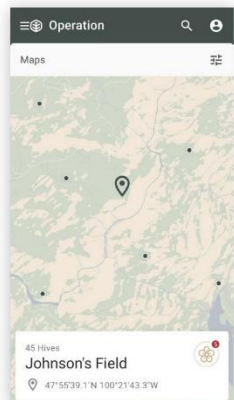
### Digitized Field Reports

For beekeepers - Keep tidy records of your inspections and actions on the field with the yard and hive inspection reports.



### Online Field Reports

For apiary manager - Track your team's progress with user-friendly yard and hive reporting tools.



### Automated Yard Mapping

Keep track of the location of your yards with Nectar's automated yard mapping tool - enabled by the Nectar BeeHub.





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## Datasheet SHTC3

### Humidity and Temperature Sensor IC

- Ultra-low power consumption
- Full battery supply voltage range (1.62 - 3.6 V)
- Small DFN package: 2 × 2 × 0.75 mm<sup>3</sup>
- Typical accuracy: ±2 %RH and ±0.2 °C
- Fully calibrated and reflow solderable
- Power-up and measurement within 1 ms



#### Product Summary

The SHTC3 is a digital humidity and temperature sensor designed especially for battery-driven high-volume consumer electronics applications. This sensor is strictly designed to overcome conventional limits for size, power consumption, and performance to price ratio in order to fulfill current and future requirements. Sensirion's CMOSens® technology offers a complete sensor system on a single chip, consisting of a capacitive humidity sensor, a bandgap temperature sensor, analog and digital signal processing, A/D converter, calibration data memory, and a digital communication interface supporting I<sup>2</sup>C Fast Mode Plus. The small 2 × 2 × 0.75 mm<sup>3</sup> DFN package enables applications in even the most limited of spaces.

The sensor covers a humidity measurement range of 0 to 100 %RH and a temperature measurement range of -40 °C to 125 °C with a typical accuracy of ±2 %RH and ±0.2 °C. The broad supply voltage of 1.62 V to 3.6 V and an energy budget below 1 µJ per measurement make the SHTC3 suitable for mobile or wireless applications powered by batteries. With the industry-proven quality and reliability of Sensirion's humidity and temperature sensors and constant accuracy over a large measurement range, the SHTC3 offers best performance-to-price ratio. Tape and reel packaging together with suitability for standard SMD assembly processes make the SHTC3 predestined for high-volume applications.

#### Benefits of Sensirion's CMOSens® Technology

- High reliability and long-term stability
- Industry-proven technology with a track record of more than 15 years
- Designed for mass production
- Optimized for lowest cost
- High signal-to-noise ratio

#### Contents of this Data Sheet

1	Humidity and Temperature Sensor Specifications .....	2
2	Electrical Specifications .....	3
3	Timing Specifications .....	4
4	Interface Specifications .....	6
5	Operation and Communication .....	6
6	Quality .....	9
7	Packaging and Traceability .....	9
8	Ordering Information .....	9
9	Technical Drawings .....	10
10	Further Information .....	11

#### Block diagram

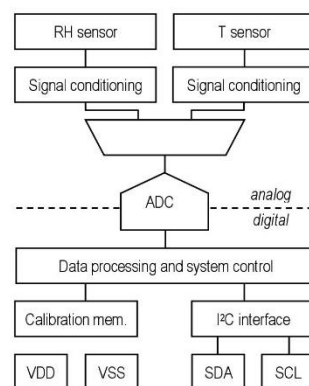


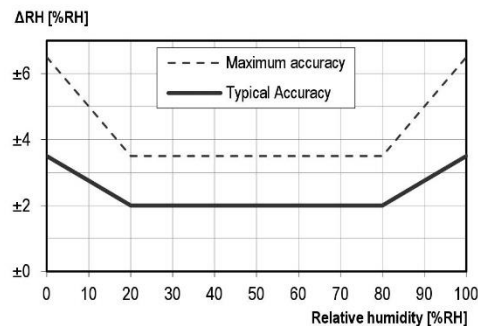
Figure 1 Functional block diagram of the SHTC3.

## 1 Humidity and Temperature Sensor Specifications

### Relative Humidity

Parameter	Condition	Value	Unit
Accuracy tolerance <sup>1</sup>	Typ.	±2.0	%RH
	Max.	see Figure 2	%RH
Repeatability <sup>2</sup>	-	0.1	%RH
Resolution <sup>3</sup>	-	0.01	%RH
Hysteresis	-	±1	%RH
Specified range <sup>4</sup>	extended <sup>5</sup>	0 to 100	%RH
Response time <sup>6</sup>	τ 63%	8	s
Long-term drift <sup>7</sup>	Typ.	<0.25	%RH/y

**Table 1** Humidity sensor specifications.

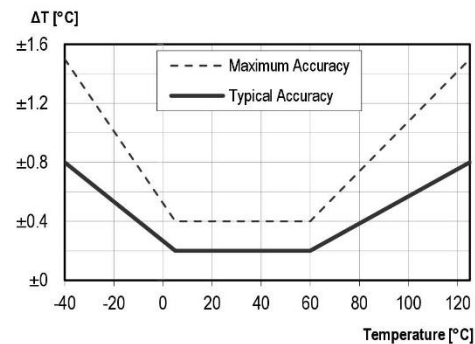


**Figure 2** Typical and maximal tolerance for relative humidity in %RH at 25 °C.

### Temperature

Parameter	Condition	Value	Unit
Accuracy tolerance <sup>1</sup>	Typ.	±0.2	°C
	Max.	see Figure 3	°C
Repeatability <sup>2</sup>	-	0.1	°C
Resolution <sup>3</sup>	-	0.01	°C
Specified range <sup>4</sup>	-	-40 to +125	°C
Response time <sup>6</sup>	τ 63%	<5 to 30	s
Long-term drift <sup>9</sup>	Typ.	<0.02	°C/y

**Table 2** Temperature sensor specifications.



**Figure 3** Typical and maximal tolerance for temperature sensor in °C.

<sup>1</sup> For definition of typ. and max. accuracy tolerance, please refer to the document "Sensirion Humidity Sensor Specification Statement". Specification applies to normal mode.

<sup>2</sup> The stated repeatability is 3 times the standard deviation (3σ) of multiple consecutive measurement values at constant conditions and is a measure for the noise on the physical sensor output. Specification applies to normal mode.

<sup>3</sup> Resolution of A/D converter. Specification applies to normal mode.

<sup>4</sup> Specified range refers to the range for which the humidity or temperature sensor specification is guaranteed.

<sup>5</sup> For details about recommended humidity and temperature operating range, please refer to section 1.2.

<sup>6</sup> Time for achieving 63% of a humidity step function, valid at 25°C and 1 m/s airflow. Humidity response time in the application depends on the design-in of the sensor.

<sup>7</sup> Typical value for operation in normal RH/T operating range. Max. value is < 0.5% RH/y. Value may be higher in environments with vaporized solvents, out-gassing tapes, adhesives, packaging materials, etc. For more details please refer to Handling Instructions.

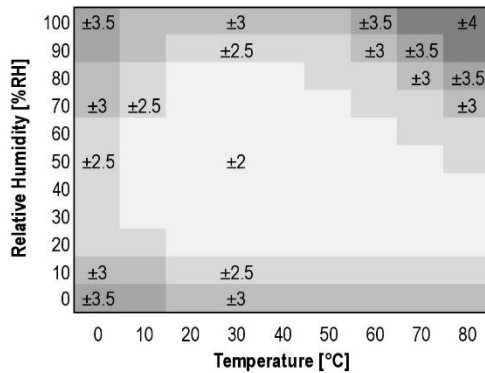
<sup>8</sup> Temperature response time depends on heat conductivity of sensor substrate and design-in of sensor in application.

<sup>9</sup> Max. value is < 0.04°C/y.



## 1.1 RH Accuracy at Various Temperatures

Typical RH accuracy at 25°C is defined in Figure 2. For other temperatures, typical accuracy has been evaluated to be as displayed in Figure 4.



**Figure 4** Typical accuracy of relative humidity measurements given in %RH for temperatures 0°C ... 80°C.

## 1.2 Recommended Operating Conditions

The sensor performs best when operated within the recommended normal temperature and humidity range of 5 – 60 °C and 20 – 80 %RH, respectively. Long-term exposure to conditions outside the normal range, especially at high humidity, may temporarily offset the RH signal (e.g. +3%RH after 60h at >80%RH). After returning to normal temperature and humidity range the sensor will slowly come back to its calibration state by itself. Prolonged exposure to extreme conditions may accelerate ageing.

To ensure stable operation of the humidity sensor, the conditions described in the document "SHTxx Assembly of SMD Packages", section "Storage and Handling Instructions" regarding exposure to volatile organic compounds have to be met. Please note as well that this does apply not only to transportation and manufacturing, but also to operation of the SHTC3.

## 2 Electrical Specifications

### 2.1 Electrical Characteristics

Default conditions of 25 °C and 3.3 V supply voltage apply to values in the table below, unless otherwise stated.

Parameter	Symbol	Conditions	Min	Typ.	Max	Units	Comments	
Supply voltage	V <sub>DD</sub>		1.62	3.3	3.6	V	-	
Power-up/down level	V <sub>POR</sub>	Static power supply	1.28	1.4	1.55	V	-	
Supply current	I <sub>DD</sub>	Idle state		-	45	70	µA	After power-up the sensor remains in the idle state unless a sleep command is issued or other data transmission is active
		Sleep Mode		-	0.3	0.6	µA	When in sleep mode, the sensor requires a dedicated wake-up command to enable further I <sup>2</sup> C communication
		Measurement	Normal Mode	-	430	900	µA	Average current consumption while the sensor is measuring
			Low Power M.	-	270	570	µA	
		Average	Normal Mode	-	4.9	-	µA	Average current consumption (continuous operation with one measurement per second)
			Low Power M.	-	0.5	-	µA	Average current consumption (continuous operation with one measurement per second)
Low level input voltage	V <sub>IL</sub>	-	-	-	0.42 V <sub>DD</sub>	V	-	
High level input voltage	V <sub>IH</sub>	-	0.7 V <sub>DD</sub>	-	-	V	-	
Low level output voltage	V <sub>OL</sub>	3 mA sink current	-	-	0.2 V <sub>DD</sub>	V	-	

**Table 3** Electrical specifications.

## 2.2 Absolute Maximum Ratings

Stress levels beyond the limits listed in Table 4 may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these conditions cannot be guaranteed. Exposure to the absolute maximum rating conditions for extended periods may affect the reliability of the device. Parameters are only tested each at a time.

Parameter	Rating
Supply voltage, $V_{DD}$	-0.3 to +4 V
Operating temperature range	-40 to +125 °C
Storage temperature range <sup>10</sup>	-40 to +125 °C
ESD HBM (human body model) <sup>11</sup>	-2 to 2 kV
ESD CDM (change device model) <sup>12</sup>	-500 to 500 V
Latch up, JESD78 Class II, 125°C	-100 to 100 mA

**Table 4** Absolute maximum ratings.

## 3 Timing Specifications

### 3.1 Sensor System Timings

Default conditions of 25 °C and 3.3 V supply voltage apply to values the table below, unless otherwise stated. Max. values are measured at -40 °C.

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units	Comments
Power-up time	$t_{PU}$	After hard reset, $V_{DD} \geq V_{POR}$	-	180	240	$\mu s$	Time between $V_{DD}$ reaching $V_{PU}$ and sensor entering the idle state
Soft reset time	$t_{SR}$	After soft reset.	-	180	240	$\mu s$	Time between ACK of soft reset command and sensor entering the idle state
Measurement duration	$t_{MEAS}$	Average	Normal Mode	-	10.8	ms	Duration for a humidity and temperature measurement
			Low Power M.	-	0.7		

**Table 5** System timing specifications.

<sup>10</sup> The recommended storage temperature range is 10-50°C. Please consult the document "SHTxx Handling Instructions" for more information.

<sup>11</sup> According to ANSI/ESDA/JEDEC JS-001-2014; AEC-Q100-002.

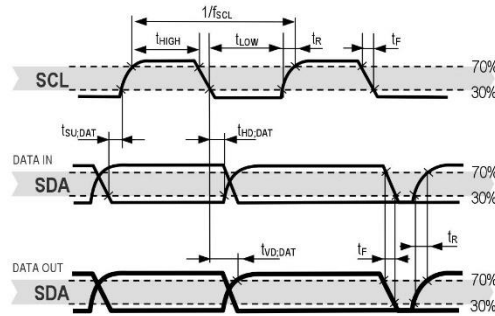
<sup>12</sup> According to ANSI/ESD S5.3.1-2009; AEC-Q100-011.

## 3.2 Communication Timings

Default conditions of 25 °C and 3.3 V supply voltage apply to values in the table below, unless otherwise stated.

Parameter	Symbol	Conditions	Standard-mode		Fast-mode		Fast-mode Plus		Units
			Min.	Max.	Min.	Max.	Min.	Max.	
SCL clock frequency	$f_{SCL}$	-	0	100	0	400	0	1000	kHz
Hold time (repeated) START condition	$t_{HD,STA}$	After this period, the first clock pulse is generated	4.0	-	0.6	-	0.26	-	$\mu s$
LOW period of the SCL clock	$t_{LOW}$	-	4.7	-	1.3	-	0.5	-	$\mu s$
HIGH period of the SCL clock	$t_{HIGH}$	-	4.0	-	0.6	-	0.26	-	$\mu s$
Set-up time for a repeated START condition	$t_{SU,STA}$	-	4.7	-	0.6	-	0.26	-	$\mu s$
SDA hold time	$t_{HD,DAT}$	-	0	-	0	-	0	-	$\mu s$
SDA set-up time	$t_{SU,DAT}$	-	250	-	100	-	50	-	ns
SCL/SDA rise time	$t_R$	-	-	1000	20	300	-	120	ns
SCL/SDA fall time	$t_F$	-	-	300	$20 \times (V_{DD} / 5.5V)$	300	$20 \times (V_{DD} / 5.5V)$	120	ns
SDA valid time	$t_{VD,DAT}$	-	-	3.45	-	0.9	-	0.45	$\mu s$
Set-up time for STOP condition	$t_{SU,STO}$	-	4.0	-	0.6	-	0.26	-	$\mu s$
Capacitive load on bus line	$C_B$	-	-	400	-	400	-	550	pF

**Table 6** Communication timing specifications. The numbers above are values according to the I<sup>2</sup>C specification.

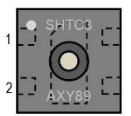


**Figure 5** Timing diagram for digital input/output pads. SDA directions as seen from the sensor. Bold SDA lines are controlled by the sensor, plain SDA lines are controlled by the micro-controller. Note that SDA valid read time is triggered by falling edge of preceding toggle.

## 4 Interface Specifications

The SHTC3 supports I<sup>2</sup>C Normal, Fast Mode and Fast Mode Plus (SCL clock frequency from 0 to 1 MHz) with clock stretching. Please choose the protocol most suited to your application and refer to its specific specifications. For detailed information on the I<sup>2</sup>C protocol, refer to NXP I<sup>2</sup>C-bus specification and user manual UM10204, Rev. 6, April 4<sup>th</sup>, 2014.

The SHTC3 comes in a 4-pin package – see Table 7.

Pin	Name	Comments	
1	VDD	Supply voltage	
2	SCL	Serial clock, bidirectional	
3	SDA	Serial data, bidirectional	
4	VSS	Ground	

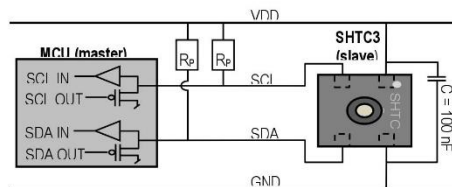
**Table 7** SHTC3 pin assignment (top view). The center pad is internally connected to VSS.

Power-supply pins supply voltage (VDD) and ground (VSS) must be decoupled with a 100 nF capacitor that shall be placed as close to the sensor as possible – see Figure 6.

SCL is used to synchronize the communication between the microcontroller and the sensor. The master must keep the clock frequency within 0 to 1 MHz as specified in Table 6. The SHTC3 may pull down the SCL line when clock stretching is enabled.

The SDA pin is used to transfer data in and out of the sensor. For safe communication, the timing specifications defined in the I<sup>2</sup>C manual must be met.

To avoid signal contention, the microcontroller must only drive SDA and SCL low. External pull-up resistors (e.g. 10 kΩ) are required to pull the signal high. For dimensioning resistor sizes please take the bus capacity requirements into account. Note that pull-up resistors may be included in I/O circuits of microcontrollers.



**Figure 6** Typical application circuit, including pull-up resistors  $R_P$  and decoupling of VDD and VSS by a capacitor.

For good performance of the SHTC3 in the application, the center pad of the SHTC3 offers the best thermal contact to

the temperature sensor. For more information on design-in, please refer to the document “SHTxx Design Guide”.

For mechanical reasons the center pad should be soldered. Electrically, the center pad is internally connected to GND and may be connected to the GND net on the PCB additionally.

## 5 Operation and Communication

All commands and memory locations of the SHTC3 are mapped to a 16-bit address space which can be accessed via the I<sup>2</sup>C protocol.

### 5.1 I<sup>2</sup>C Address

The I<sup>2</sup>C device address is given Table 8:

SHTC3	Hex. Code	Bin. Code
I <sup>2</sup> C address	0x70	111'0000

**Table 8** SHTC3 I<sup>2</sup>C device address.

Each transmission sequence begins with START condition (S) and ends with an (optional) STOP condition (P) as described in the I<sup>2</sup>C-bus specification.

### 5.2 Power-Up, Sleep, Wakeup

Upon VDD reaching the power-up voltage level  $V_{POR}$ , the SHTC3 enters the idle state after a duration of  $t_{PU}$ . After that, the sensor should be set to sleep mode with the command given in Table 9<sup>13</sup>.

Command	Hex. Code	Bin. Code
Sleep	0xB098	1011'0000'1001'1000

**Table 9** Sleep command of the sensor.

When the sensor is in sleep mode, it requires the following wake-up command before any further communication, see Table 10:

Command	Hex. Code	Bin. Code
Wake-up	0x3517	0011'0101'0001'0111

**Table 10** Wake-up command of the sensor.

### 5.3 Measurement Commands

The SHTC3 provides a clock-stretching option and the order of the signal return can be selected. These parameters are selected by dedicated measurement commands as summarized in Table 11. N. B.: Each measurement command triggers always both, a temperature *and* a relative humidity measurement.

<sup>13</sup> If an immediate sensor signal is desired, sending the sensor to sleep mode can be omitted. Not sending the sensor to sleep mode for an extended amount of time keeps up the current consumption of the sensor.



	Clock Stretching Enabled		Clock Stretching Disabled	
	Read T First	Read RH First	Read T First	Read RH First
Normal Mode	0x7CA2	0x5C24	0x7866	0x58E0
Low Power M.	0x6458	0x44DE	0x609C	0x401A

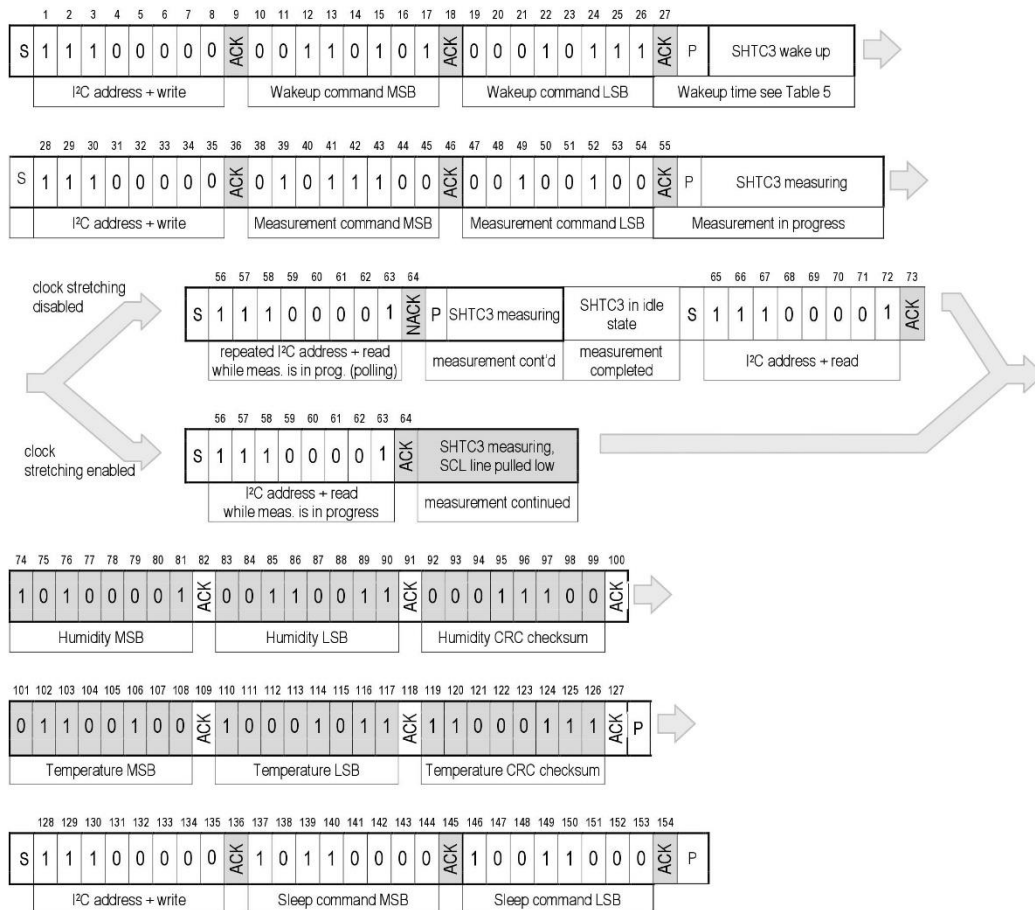
**Table 11** Measurement commands.

## 5.4 Measuring and Reading the Signals

Each measurement cycle contains a set of four commands, each initiated by the I2C START condition and ended by the I2C STOP condition:

1. Wakeup command
2. Measurement command
3. Read out command
4. Sleep command

An exemplary measurement set is shown in Figure 7



**Figure 7** Communication sequence for waking up the sensor, starting a measurement and reading measurement results displaying both clock stretching options.

The numerical example corresponds to a read humidity-first command with clock stretching enabled. The physical values of the transmitted measurement results are 63 %RH and 23.7 °C. Clear blocks are controlled by the microcontroller, grey blocks by the SHTC3.

## 5.5 Sensor Behavior during Measurement and Clock Stretching

In general, the sensor does not respond to any I<sup>2</sup>C activity during measurement, i.e. I<sup>2</sup>C read and write headers are not acknowledged (NACK). However, when clock stretching has been enabled by using a corresponding measurement command, the sensor responds to a read header with an ACK and subsequently pulls down the SCL line until the measurement is complete. As soon as the measurement is complete, the sensor starts sending the measurement results.

During measurement, the sensor has a current consumption according to Table 3.

For best possible repeatability of humidity and temperature measurements, it is recommended to avoid any communication on the I<sup>2</sup>C bus while the SHTC3 is measuring. For more information, see the application note "Optimization of Repeatability".

## 5.6 Readout of Measurement Results

After a measurement command has been issued and the sensor has completed the measurement, the master can read the measurement results by sending a START condition followed by an I<sup>2</sup>C read header. The sensor will acknowledge the reception of the read header and send two bytes of data followed by one byte CRC checksum and another two bytes of data followed by one byte CRC checksum. Each byte must be acknowledged by the microcontroller with an ACK condition for the sensor to continue sending data. If the SHTC3 does not receive an ACK from the master after any byte of data, it will not continue sending data.

The I<sup>2</sup>C master can abort the read transfer with a NACK condition after any data byte if it is not interested in subsequent data, e.g. the CRC byte or the second measurement result, in order to save time.

In case the user needs humidity and temperature data but does not want to process CRC data, it is recommended to read the first two bytes of data with the CRC byte (without processing the CRC data) and abort the read transfer after reading the second two data bytes with a NACK. This procedure is more time efficient than starting two different measurements and aborting the read transfer after the first two data bytes each time.

## 5.7 Soft Reset

The SHTC3 provides a soft reset mechanism that forces the system into a well-defined state without removing the power supply. If the system is in its idle state (i.e. if no measurement is in progress) the soft reset command can be sent to SHTC3 according to Table 12. This triggers the

sensor to reset all internal state machines and reload calibration data from the memory.

Command	Hex. Code	Bin. Code
Software reset	0x805D	1000'0000'0101'1101

**Table 12** Soft reset command.

## 5.8 Reset through General Call

Additionally, a reset of the sensor can also be generated using the "general call" mode according to I<sup>2</sup>C-bus specification<sup>14</sup>. This generates a reset which is functionally identical to using the nReset pin. It is important to understand that a reset generated in this way is not device specific. All devices on the same I<sup>2</sup>C bus that support the general call mode will perform a reset. Additionally, this command only works when the sensor is able to process I<sup>2</sup>C commands. The appropriate command consists of two bytes and is shown in Table 13.

Command	Code
Address byte	0x00
Second byte	0x06
Reset command using the general call address	0x0006

**Table 13** Reset through the general call address (clear blocks are controlled by the microcontroller, grey blocks by the sensor)

## 5.9 Read-out of ID Register

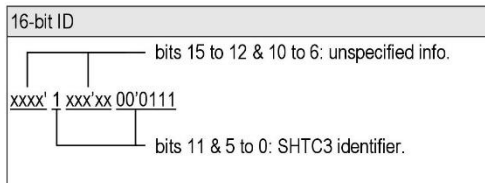
The SHTC3 has an ID register which contains an SHTC3-specific product code. The read-out of the ID register can be used to verify the presence of the sensor and proper communication. The command to read the ID register is shown in Table 14.

Command	Hex. Code	Bin. Code
Read ID register	0xEFC8	1110'1111'1100'1000

**Table 14** Read-out command of ID register.

It needs to be sent to the SHTC3 after an I<sup>2</sup>C write header. Once the SHTC3 has acknowledged the proper reception of the command, the master can send an I<sup>2</sup>C read header and the SHTC3 submits the 16-bit ID followed by 8 bits of CRC. The structure of the ID is described in Table 15.

<sup>14</sup> [http://www.nxp.com/documents/user\\_manual/UM10204.pdf](http://www.nxp.com/documents/user_manual/UM10204.pdf)



**Table 15** Structure of the 16-bit ID. Bits 15:12 & 10:6 of the ID contain unspecified information (marked as "x"), which may vary from sensor to sensor, while bits 11 & 5:0 contain the SHTC3-specific product code.

## 5.10 Checksum Calculation

The 8-bit CRC checksum transmitted after each data word is generated by a CRC algorithm with the properties displayed in Table 16. The CRC covers the contents of the two previously transmitted data bytes.

Property	Value
Name	CRC-8
Width	8 bits
Polynomial	0x31 ( $x^8 + x^5 + x^4 + 1$ )
Initialization	0xFF
Reflect input	False
Reflect output	False
Final XOR	0x00
Examples	CRC (0x00) = 0xAC CRC (0xBEEF) = 0x92

**Table 16** SHTC3 I<sup>2</sup>C CRC properties.

## 5.11 Conversion of Sensor Output

Measurement data is always transferred as 16-bit values. These values are already linearized and temperature compensated by the SHTC3. Humidity and temperature values can be calculated with the formulas in given below.

Relative humidity conversion formula (result in %RH):

$$RH = 100 \cdot \frac{S_{RH}}{2^{16}}$$

Temperature conversion formula (result in °C):

$$T = -45 + 175 \cdot \frac{S_T}{2^{16}}$$

$S_{RH}$  and  $S_T$  denote the raw sensor output (as decimal values) for humidity and temperature, respectively.

## 6 Quality

### 6.1 Environmental Stability

Qualification of the SHTC3 is performed based on the JEDEC JESD47 qualification test method.

## 6.2 Material Contents

The device is fully RoHS, REACH and Halogen-Free compliant, e.g. free of Pb, Cd, and Hg.

## 7 Packaging and Traceability

SHTC3 sensors are provided in a DFN package with an outline of  $2 \times 2 \times 0.75 \text{ mm}^3$  and a terminal pitch of 1 mm. DFN stands for dual flat no leads. The humidity sensor opening is centered on the top side of the package.

The sensor chip is made of silicon and is mounted to a lead frame. The latter is made of Cu plated with Ni/Pd/Au. Chip and lead frame are overmolded by an epoxy-based mold compound. Please note that the sidewalls of sensor are diced and therefore these diced lead frame surfaces are not covered with the respective plating.

The Moisture Sensitivity Level classification of the SHTC3 is MSL1, according to IPC/JEDEC J-STD-020.

All SHTC3 sensors are laser marked for easy identification and traceability. The marking on the sensor consists of two lines and a pin-1 indicator. The top line contains the sensor type (SHTC3), the bottom line contains a 5-digit alphanumeric tracking code. The pin-1 indicator is located in the top left corner. See Figure 8 for illustration.



**Figure 8** Laser marking on SHTC3, the top line with the pin-1 indicator and the sensor type, the bottom line with the 5-digit alphanumeric tracking code.

Reels are also labeled and provide additional traceability information.

## 8 Ordering Information

The SHTC3 can be ordered in tape and reel packaging with different sizes, see Table 17. The reels are sealed into antistatic ESD bags. A drawing of the packaging tape with sensor orientation is shown in Figure 11.

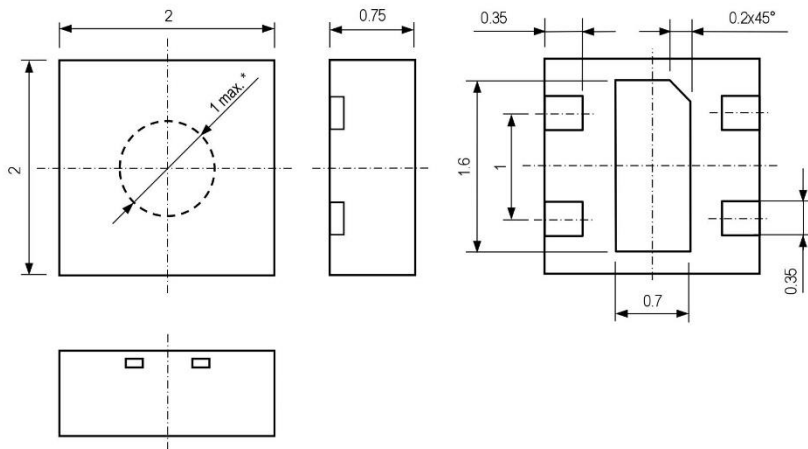
Quantity	Packaging	Reel Diameter	Order Number
2500	Tape & Reel	180 mm (7 inch)	3.000.047
10'000	Tape & Reel	330 mm (13 inch)	1-101681-01

**Table 17** SHTC3 ordering options.



## 9 Technical Drawings

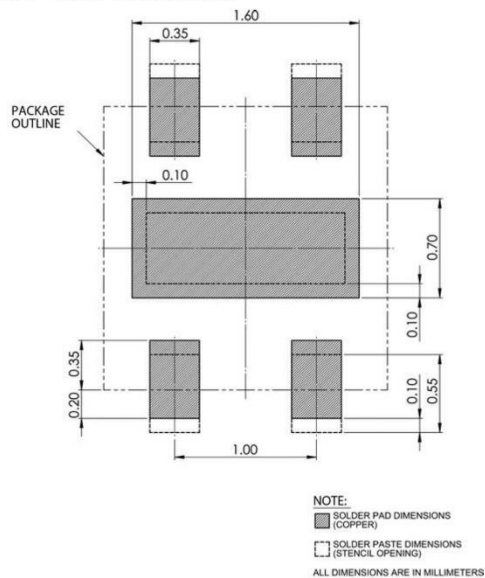
### 9.1 Package Outline



\* Mold opening shows smooth transition to package surface. Therefore this dimension is not well defined and given for reference only.

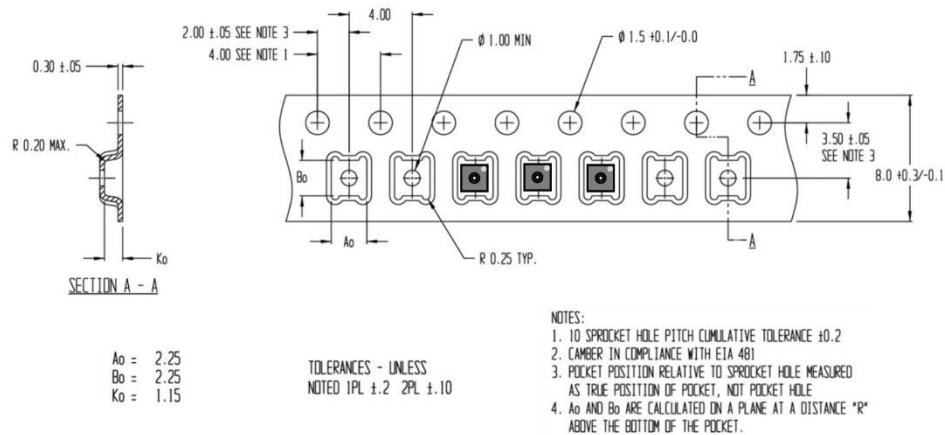
**Figure 9** Package outline drawing of the SHTC3. Dimensions are given in millimeters.

### 9.2 Metal Land Pattern



**Figure 10** Recommended metal land pattern for SHTC3 (all dimensions are in mm). Recommended solder paste stencil thickness is 100µm, pads on PCB are recommended to be non solder mask defined (NSMD).

### 9.3 Tape and Reel Package



**Figure 11** Technical drawing of the packaging tape with sensor orientation in tape. Header tape is to the right and trailer tape to the left on this drawing. Dimensions are given in millimeters.

## 10 Further Information

For more in-depth information on the SHTC3 and its application please consult the following documents:

Document Name	Description	Source
SHTxx Assembly of SMD Packages	Instructions on soldering and processing of the SHTC3 in a production environment	Available for download from the SHTC3 product website: <a href="http://www.sensirion.com/humidity-download">www.sensirion.com/humidity-download</a>
SHTxx Design Guide	Design guidelines for designing SHTxx humidity sensors into applications	Available for download at the Sensirion humidity sensors download center: <a href="http://www.sensirion.com/humidity-download">www.sensirion.com/humidity-download</a>
SHTxx Handling Instructions	Guidelines for proper handling of SHTxx humidity sensors	Available for download at the Sensirion humidity sensors download center: <a href="http://www.sensirion.com/humidity-download">www.sensirion.com/humidity-download</a>
Sensirion Humidity Sensor Specification Statement	Definition of sensor specifications.	Available for download at the Sensirion humidity sensors download center: <a href="http://www.sensirion.com/humidity-download">www.sensirion.com/humidity-download</a>

**Table 18** Documents containing further information relevant for the SHTC3.

**Revision History**

Date	Version	Page(s)	Changes
July 2018	1	all	Initial version
Januray 2019	1.1	5	Added explicit specifications of normal and fast I <sup>2</sup> C mode.

## Important Notices

### Warning, Personal Injury

Do not use this product as safety or emergency stop devices or in any other application where failure of the product could result in personal injury. Do not use this product for applications other than its intended and authorized use. Before installing, handling, using or servicing this product, please consult the data sheet and application notes. Failure to comply with these instructions could result in death or serious injury.

If the Buyer shall purchase or use SENSIRION products for any unintended or unauthorized application, Buyer shall defend, indemnify and hold harmless SENSIRION and its officers, employees, subsidiaries, affiliates and distributors against all claims, costs, damages and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if SENSIRION shall be allegedly negligent with respect to the design or the manufacture of the product.

### ESD Precautions

The inherent design of this component causes it to be sensitive to electrostatic discharge (ESD). To prevent ESD-induced damage and/or degradation, take customary and statutory ESD precautions when handling this product.

See application note "ESD, Latchup and EMC" for more information.

### Warranty

SENSIRION warrants solely to the original purchaser of this product for a period of 12 months (one year) from the date of delivery that this product shall be of the quality, material and workmanship defined in SENSIRION's published specifications of the product. Within such period, if proven to be defective, SENSIRION shall repair and/or replace this product, in SENSIRION's discretion, free of charge to the Buyer, provided that:

- notice in writing describing the defects shall be given to SENSIRION within fourteen (14) days after their appearance;

- such defects shall be found, to SENSIRION's reasonable satisfaction, to have arisen from SENSIRION's faulty design, material, or workmanship;
- the defective product shall be returned to SENSIRION's factory at the Buyer's expense; and
- the warranty period for any repaired or replaced product shall be limited to the unexpired portion of the original period.

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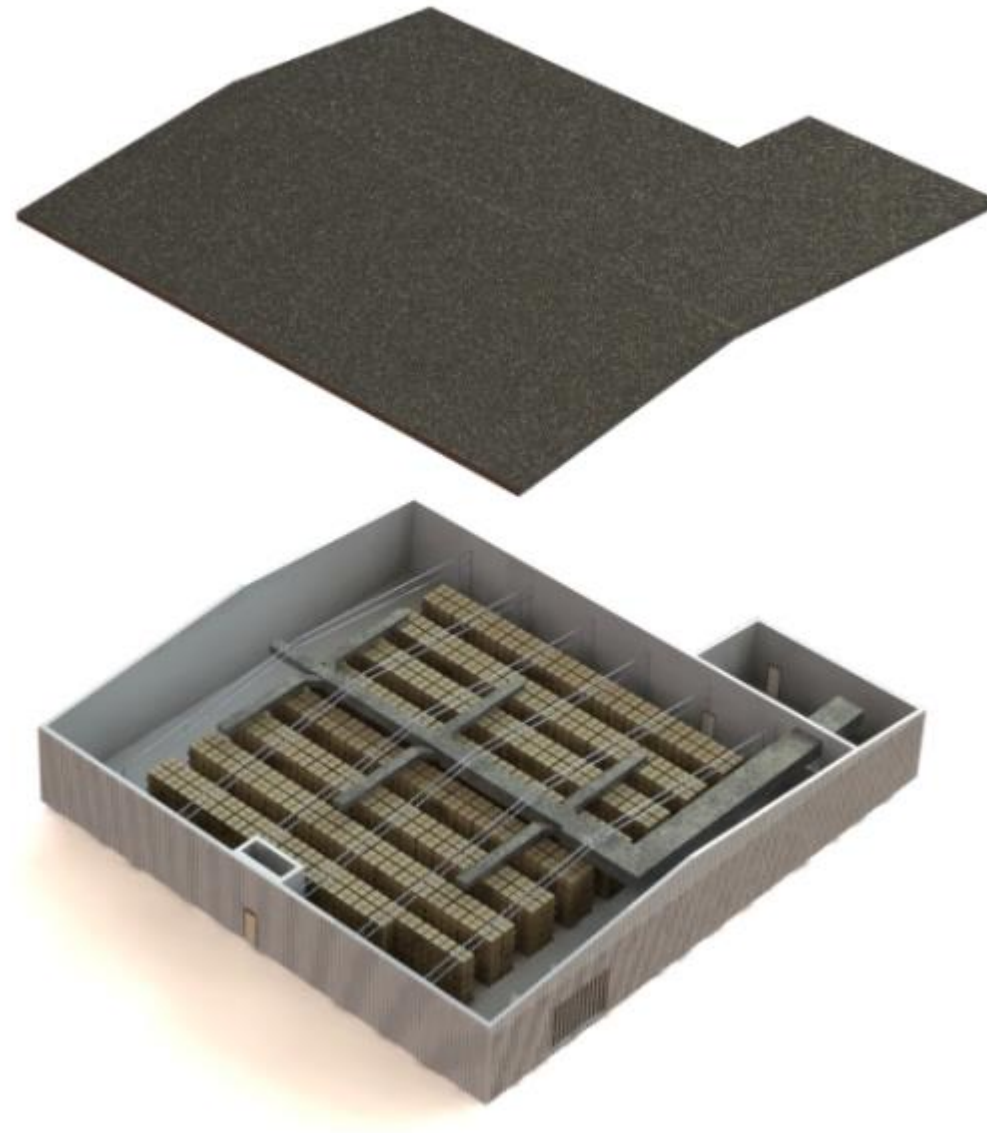
[SHTC3](#) [SHTC3-10k](#)

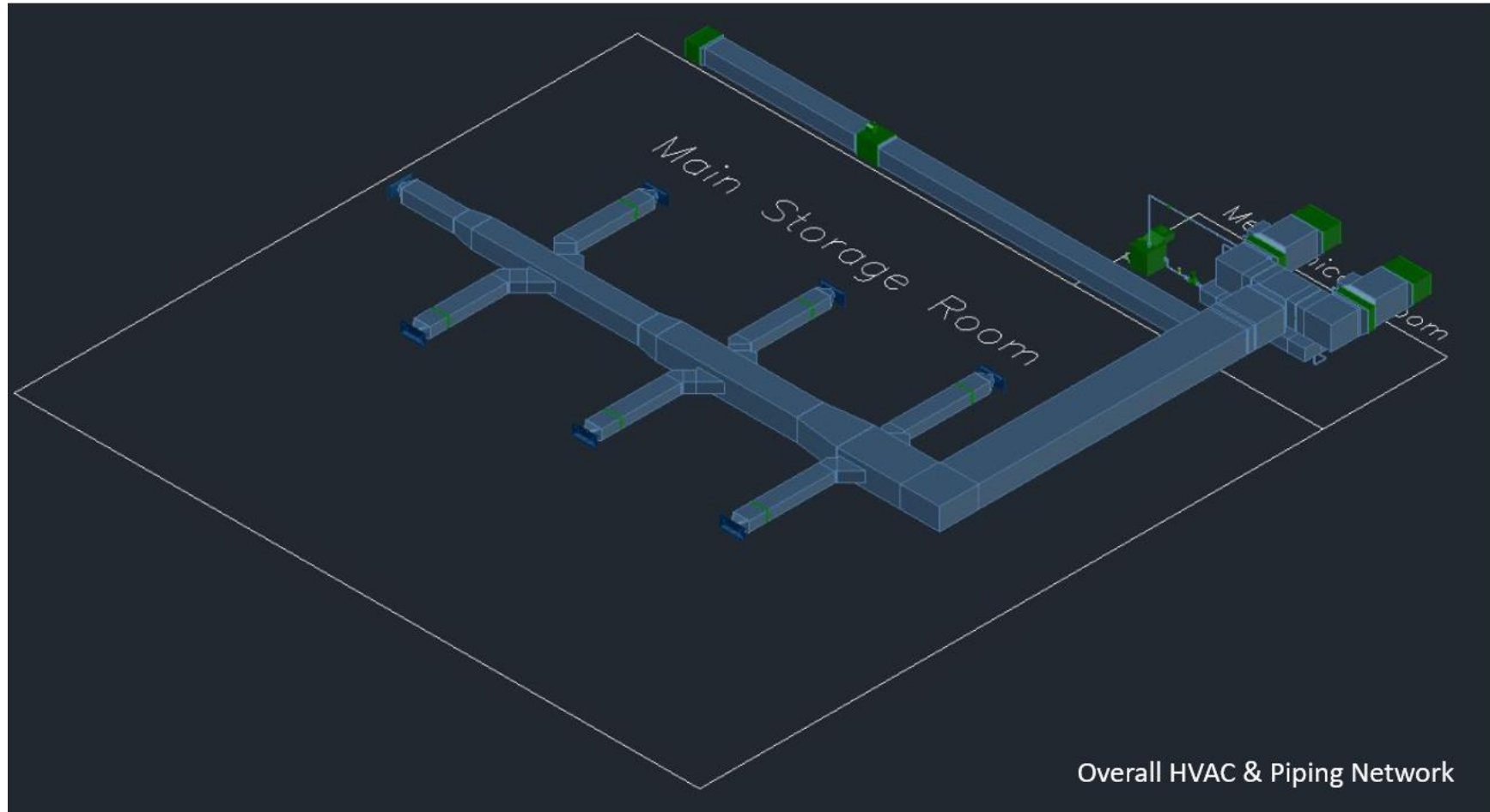
## **APPENDIX I: EQUIPMENT SCHEDULE**

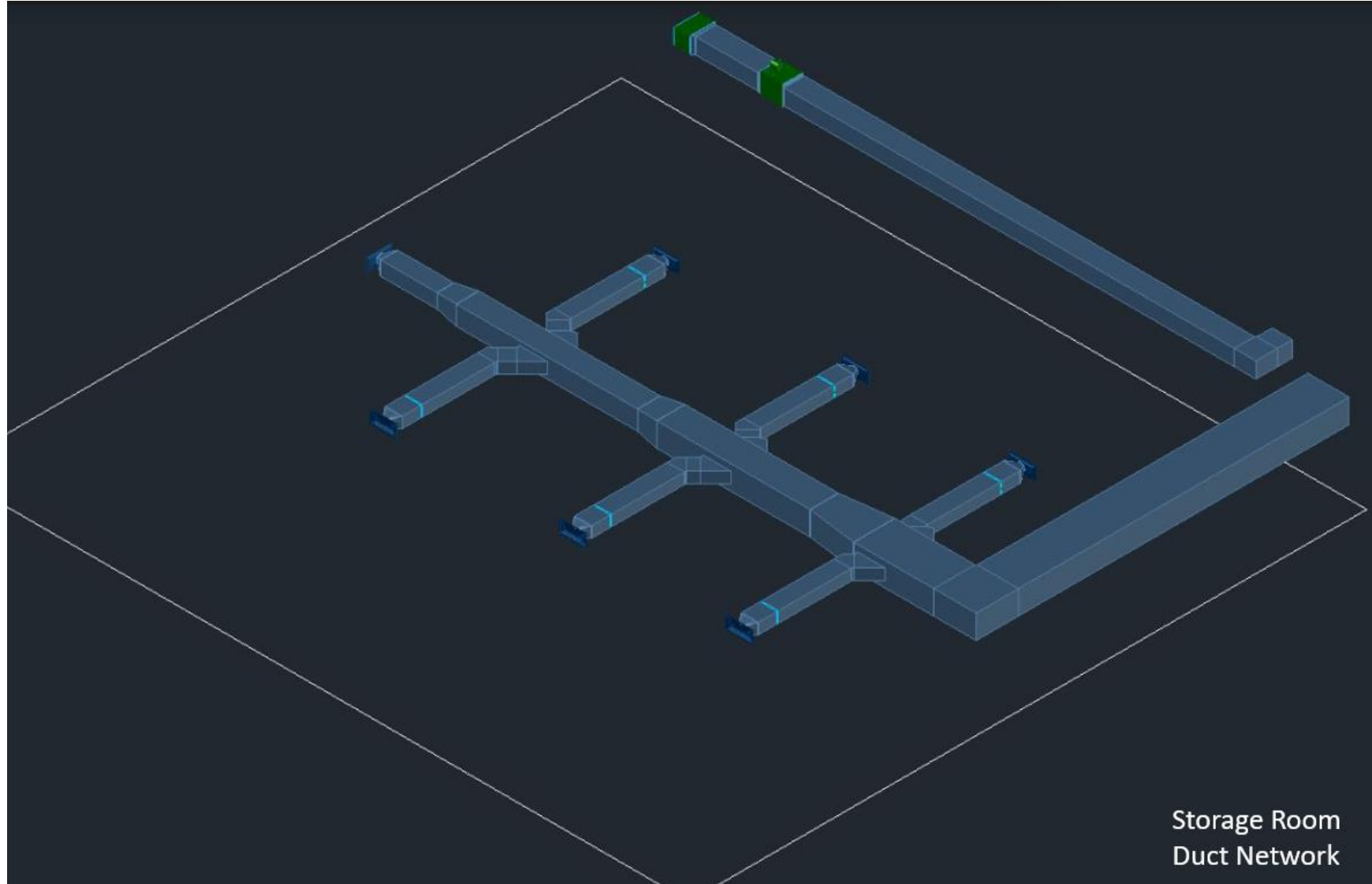
Equipment	Model	Quantity	Supplier	Function
Inlet line fan	TBI-CA-3H30	2	Greenheck	Bring in fresh air
Return line fan	AX-72-190-0618	1	Greenheck	Recycle air from building
Exhaust fan	SBE-1L24	4	Greenheck	Exhaust air to outside
Ceiling fan	DS-8	4	Greenheck	Circulate air in the building
Water Pump	2400-30S-3P	2	TACO	Pump water into water boiler
Natural gas condensing water boiler	C1050	1	Patterson Kelley	Heat the water
Water heating coil	5WS-0805B-36.0-54	2	DAIKIN	Heat the air
Sensor (hives)	BeeCon	600	Nectar	Monitoring of honeybees
Sensor (building)	SHTC3	37	Mouser Electronics	Measure ambient temperature and humidity inside the building
Hub (hives)	BeeHub	6	Nectar	Collection and distribution of data from BeeCons.

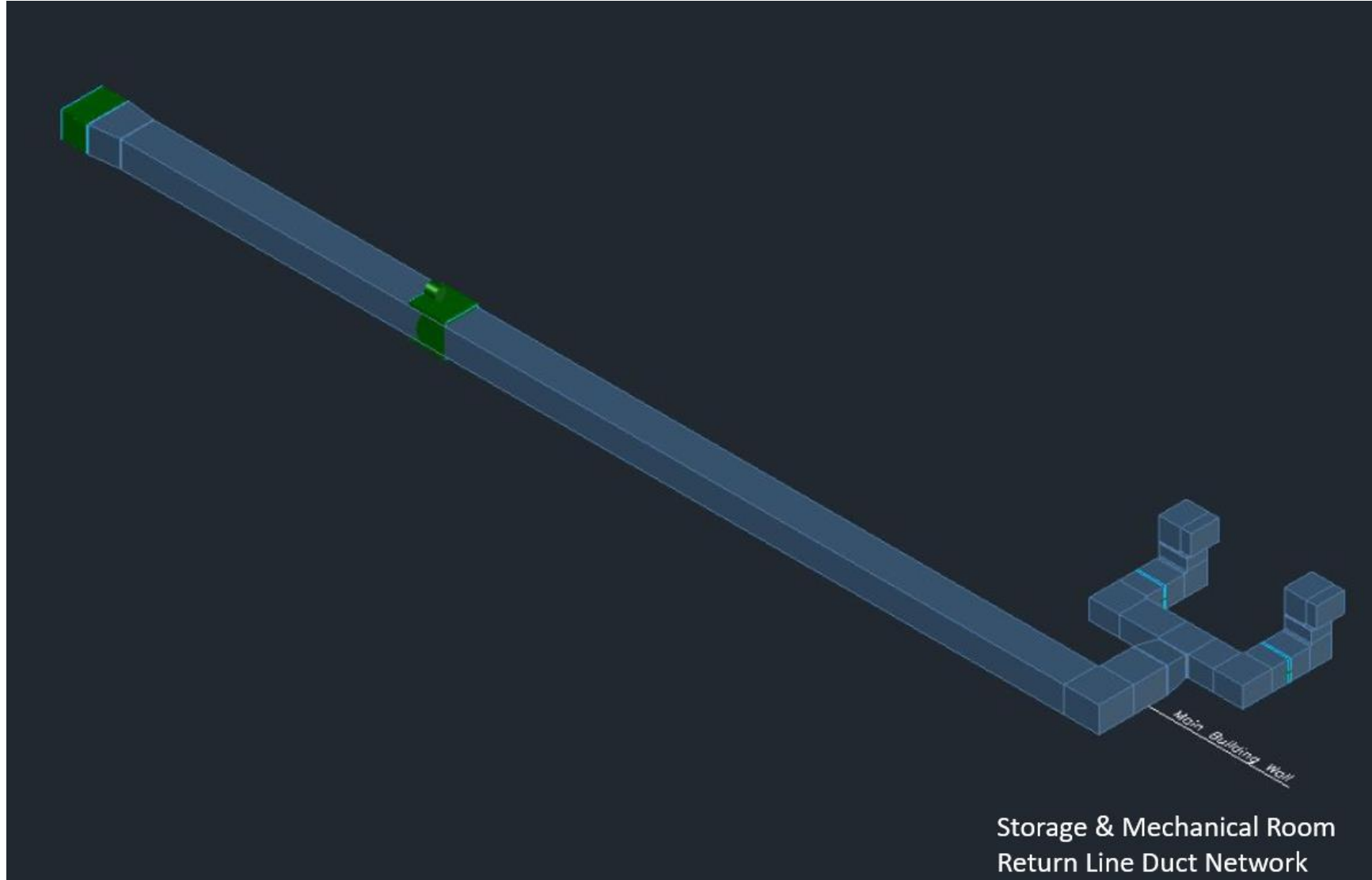


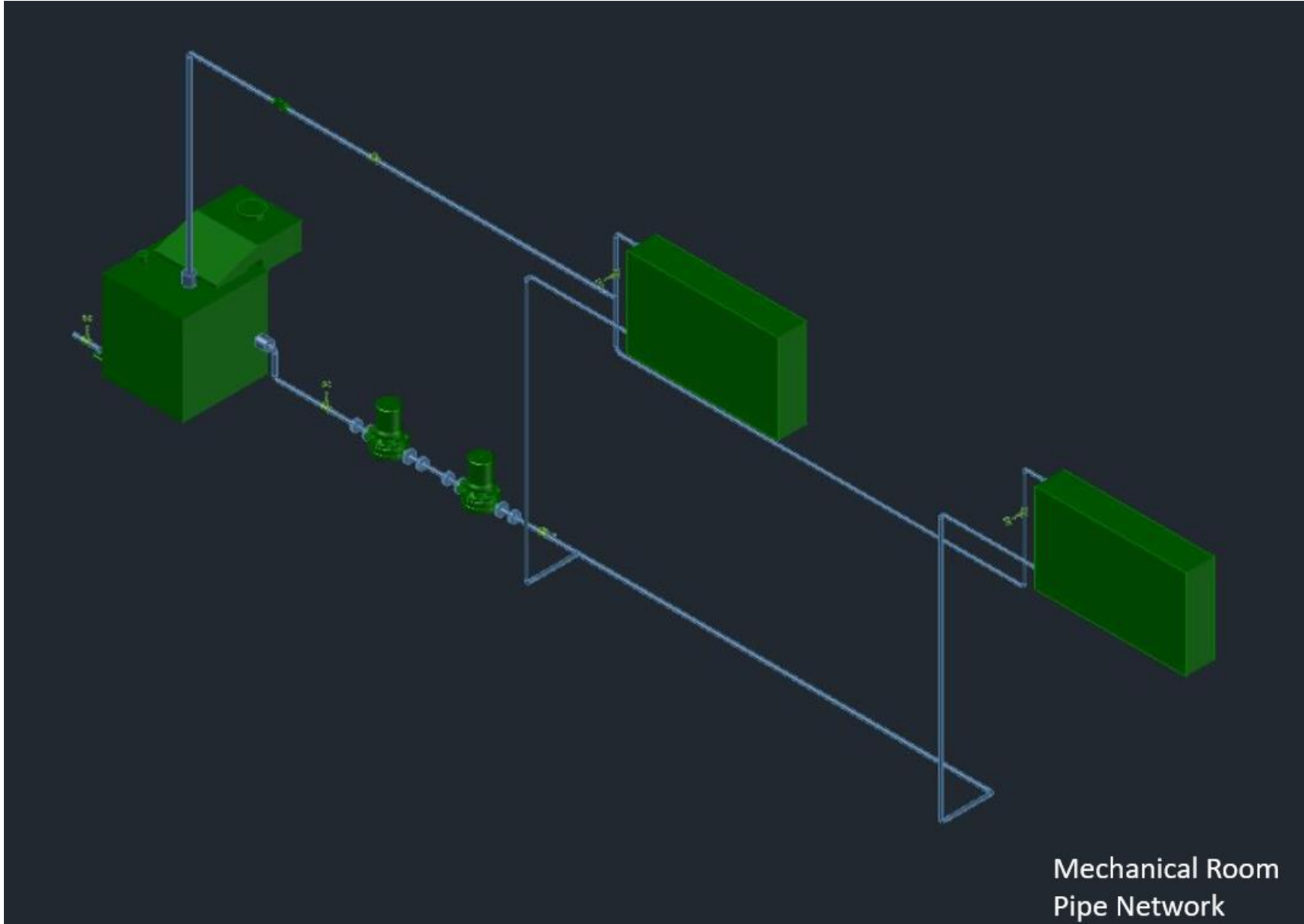
## **APPENDIX J: 3D BUILDING RENDERINGS**











## **APPENDIX K: DRAWING PACKAGE**



Sub-Assembly

Part

AutoCAD drawing

## Overall Building Assembly

Exploded building

One stack  
of 20  
colonies

One  
stack of 4  
colonies

Solar Heater

Solar Mount

Glass Mount

Glass Sheet

Floorplan/ Building layout

Overall  
HVAC

Building  
sensor  
location

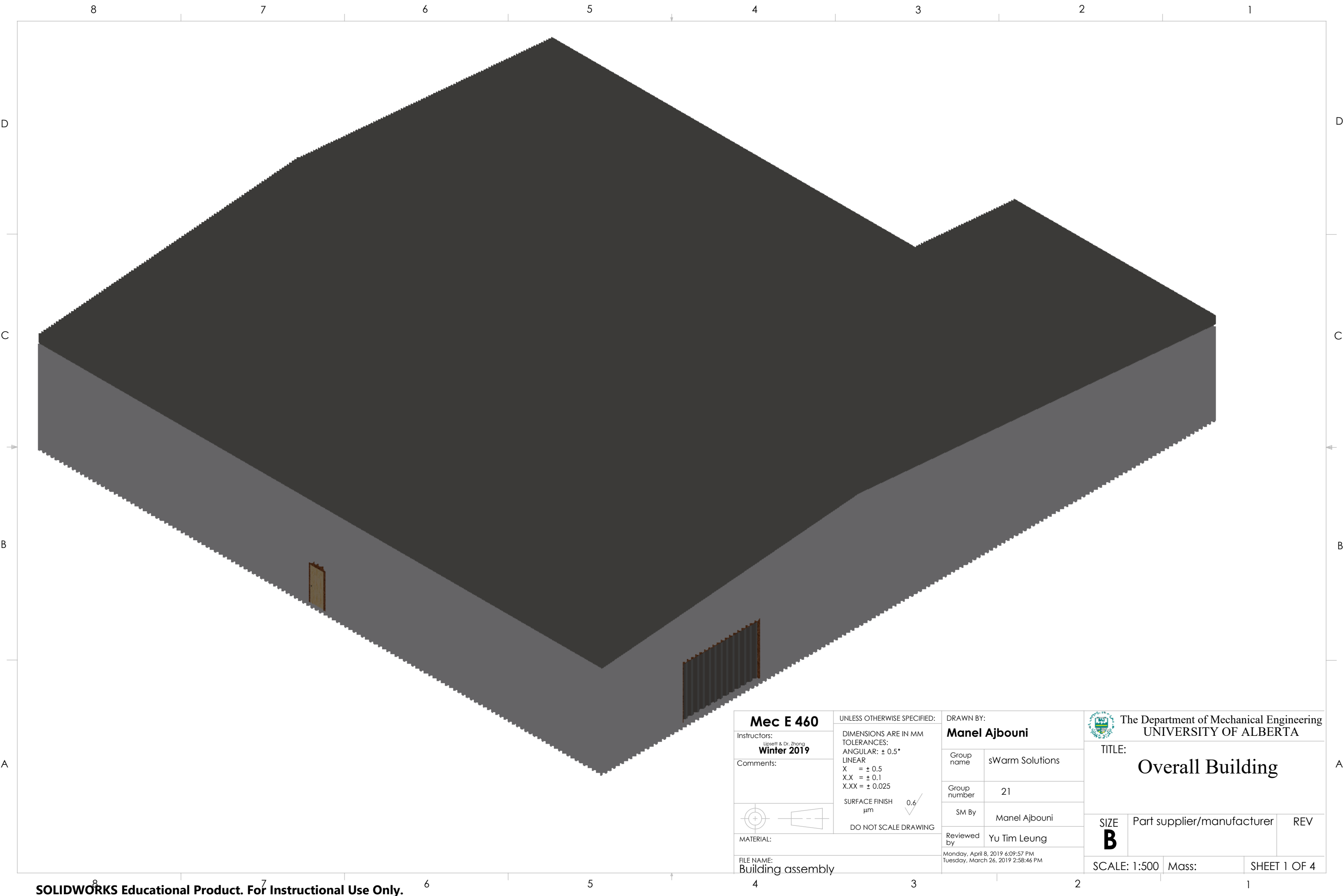
Ceiling



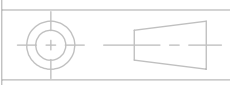
Main Storage  
room detailed

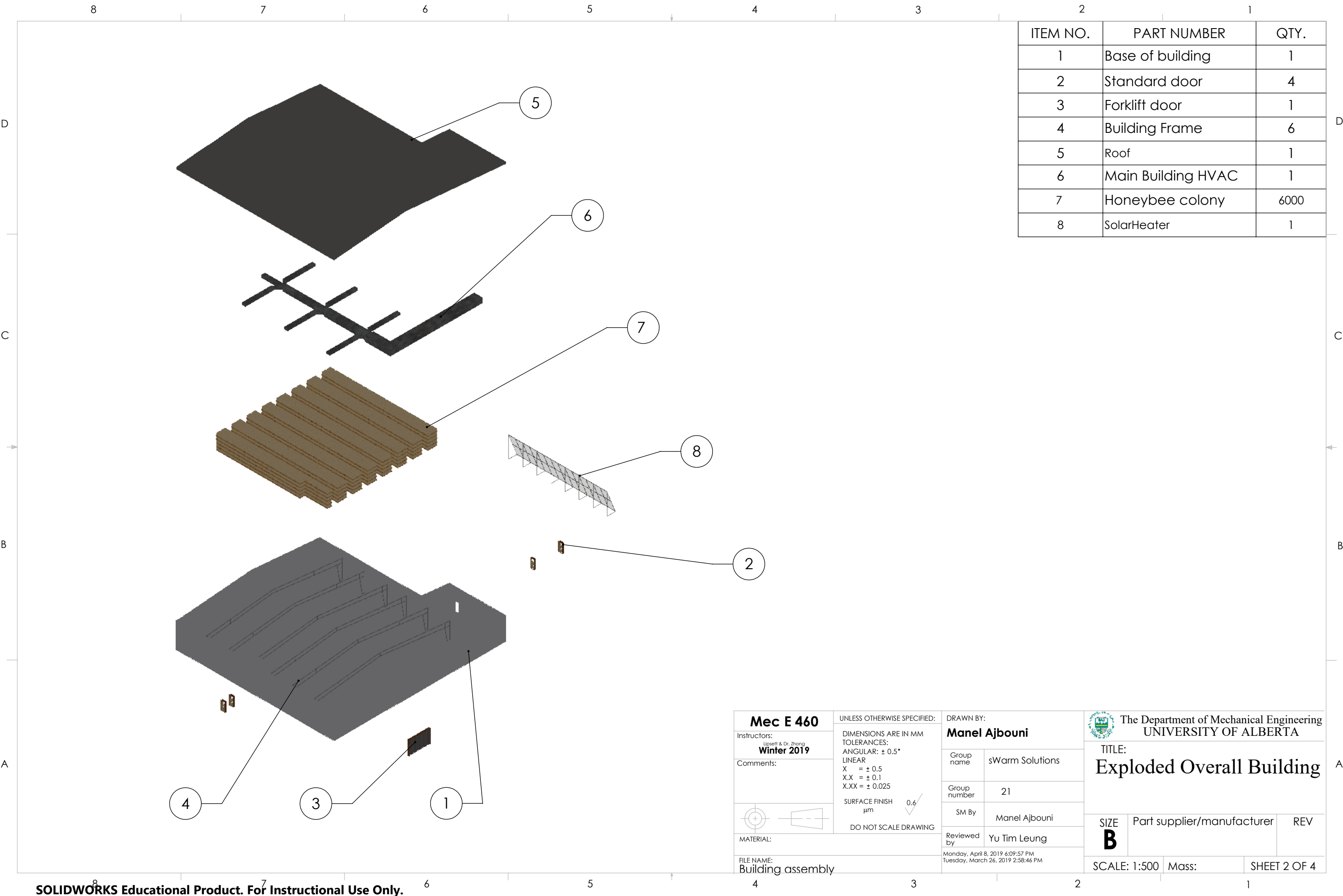
Return  
line

Duct  
Network

Piping  
network



<b>Mec E 460</b>		UNLESS OTHERWISE SPECIFIED:		DRAWN BY:		 The Department of Mechanical Engineering UNIVERSITY OF ALBERTA			
Instructors: Upsett & Dr. Zhong <b>Winter 2019</b>		<div>DIMENSIONS ARE IN MM</div> <div>TOLERANCES:</div> <div>ANGULAR: <math>\pm 0.5^\circ</math></div> <div>LINEAR</div> <div>X = <math>\pm 0.5</math></div> <div>X.X = <math>\pm 0.1</math></div> <div>X.XX = <math>\pm 0.025</math></div> <div>SURFACE FINISH <math>\mu\text{m}</math></div> <div>0.6 </div> <div>DO NOT SCALE DRAWING</div>		<b>Manel Ajbouni</b>		TITLE:  <b>Overall Building</b>			
Comments:				Group name	sWarm Solutions				
				Group number	21	SM By	Manel Ajbouni		
				Reviewed by	Yu Tim Leung	SIZE <b>B</b>		Part supplier/manufacturer	REV
		FILE NAME: Building assembly		Monday, April 8, 2019 6:09:57 PM Tuesday, March 26, 2019 2:58:46 PM					
						SCALE: 1:500		Mass:	SHEET 1 OF 4



ITEM NO.	PART NUMBER	QTY.
1	Base of building	1
2	Standard door	4
3	Forklift door	1
4	Building Frame	6
5	Roof	1
6	Main Building HVAC	1
7	Honeybee colony	6000
8	SolarHeater	1

**Mec E 460**

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Upsett & Dr. Zhong

Winter 2019

Comments:

MATERIAL:

FILE NAME:  
Building assembly

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MM

TOLERANCES:

ANGULAR:  $\pm 0.5^\circ$

LINEAR

X =  $\pm 0.5$

X.X =  $\pm 0.1$

X.XX =  $\pm 0.025$

SURFACE FINISH

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DO NOT SCALE DRAWING

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Group name

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Tuesday, March 26, 2019 2:58:46 PM

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TITLE:

**Exploded Overall Building**

SIZE

**B**

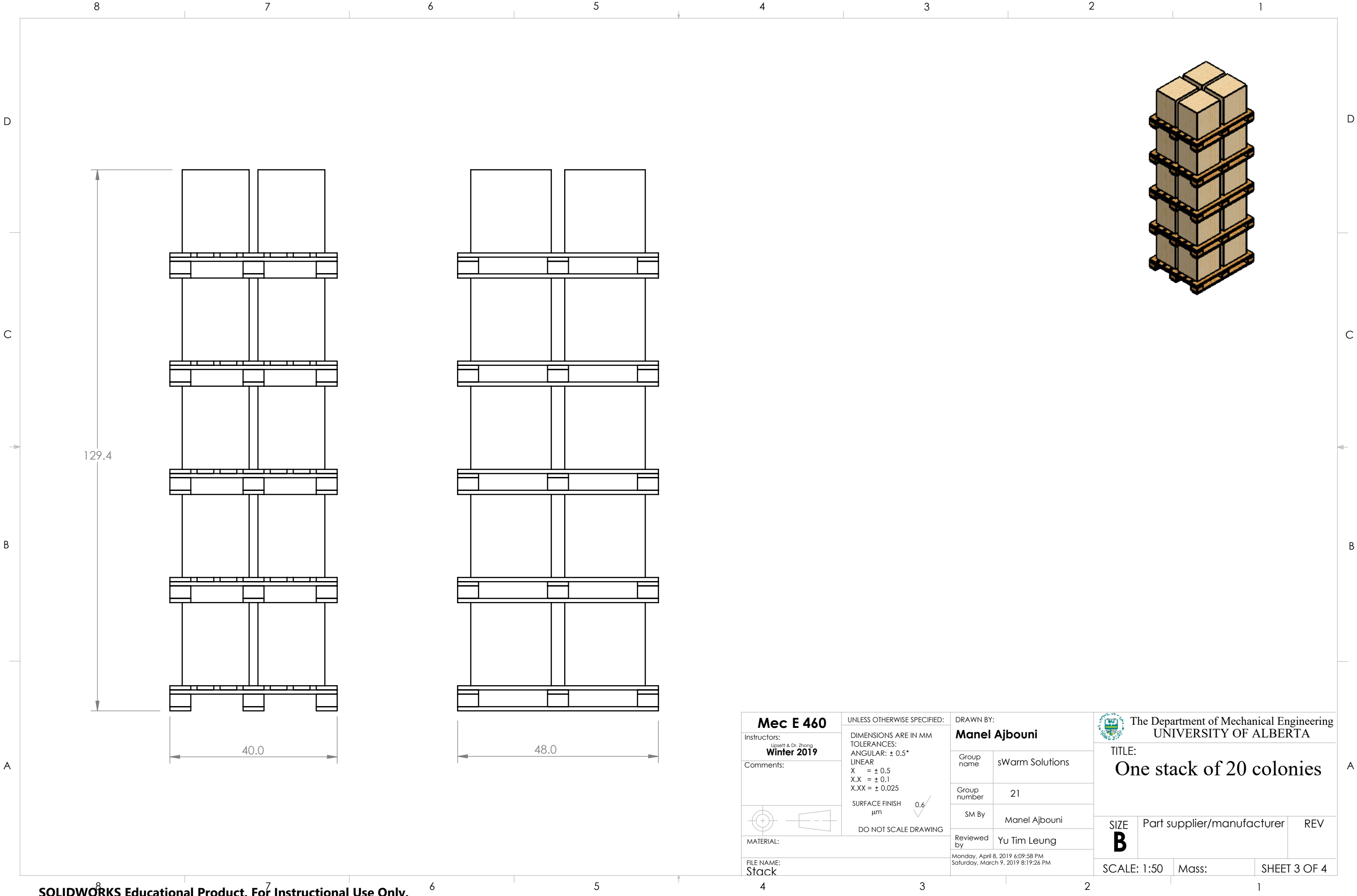
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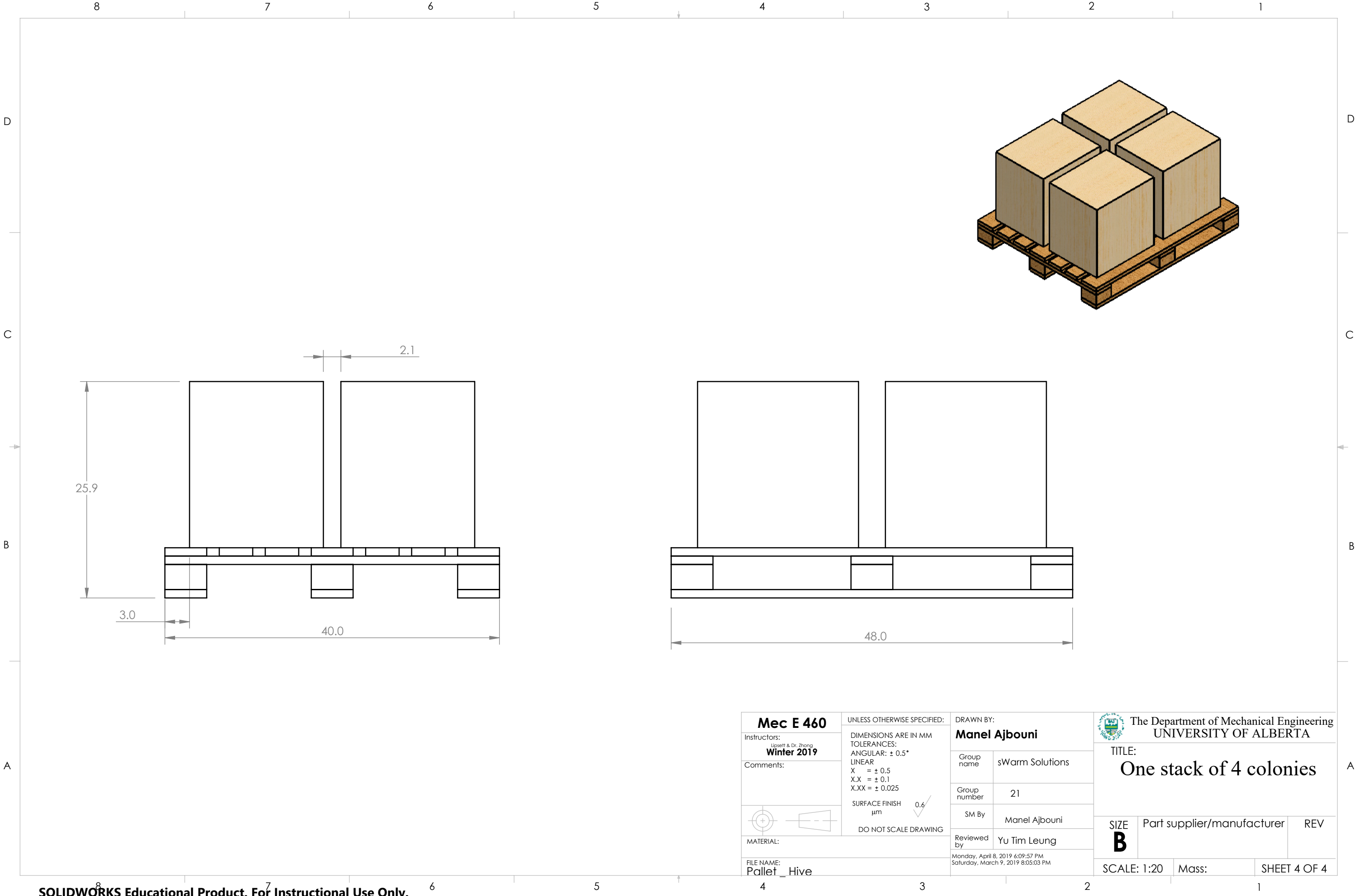
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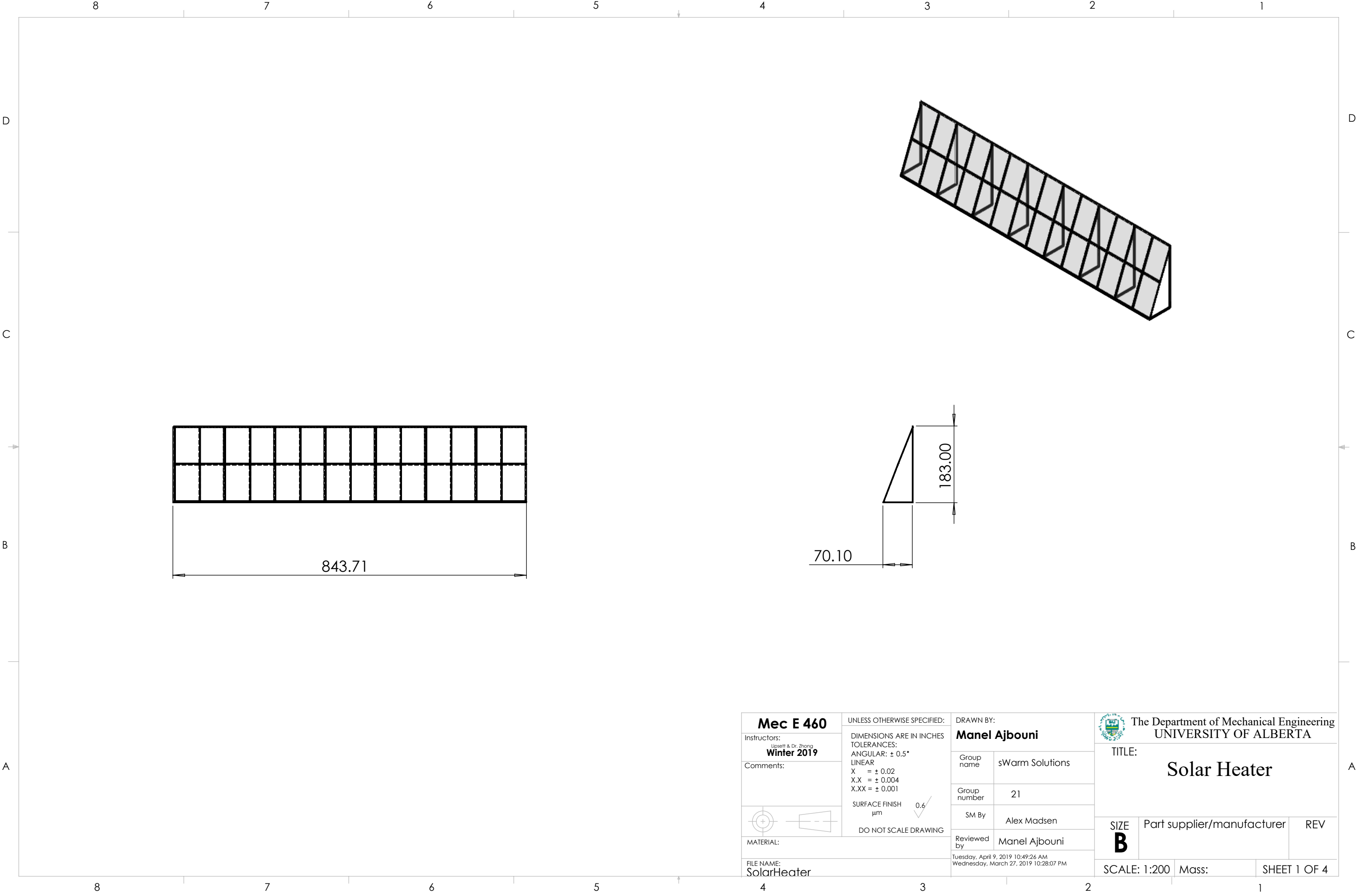
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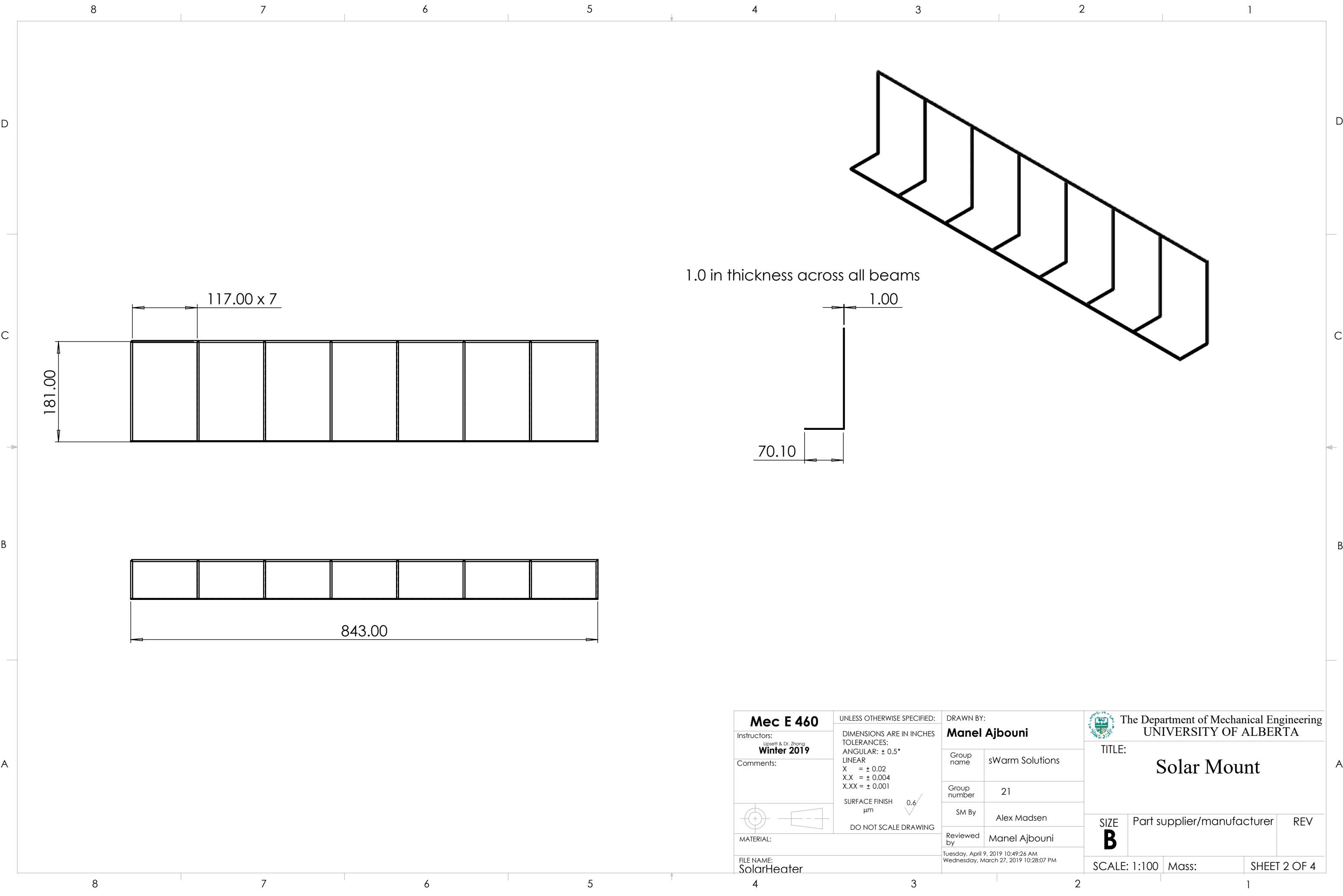
SHEET 2 OF 4


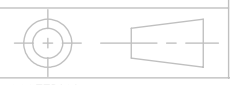




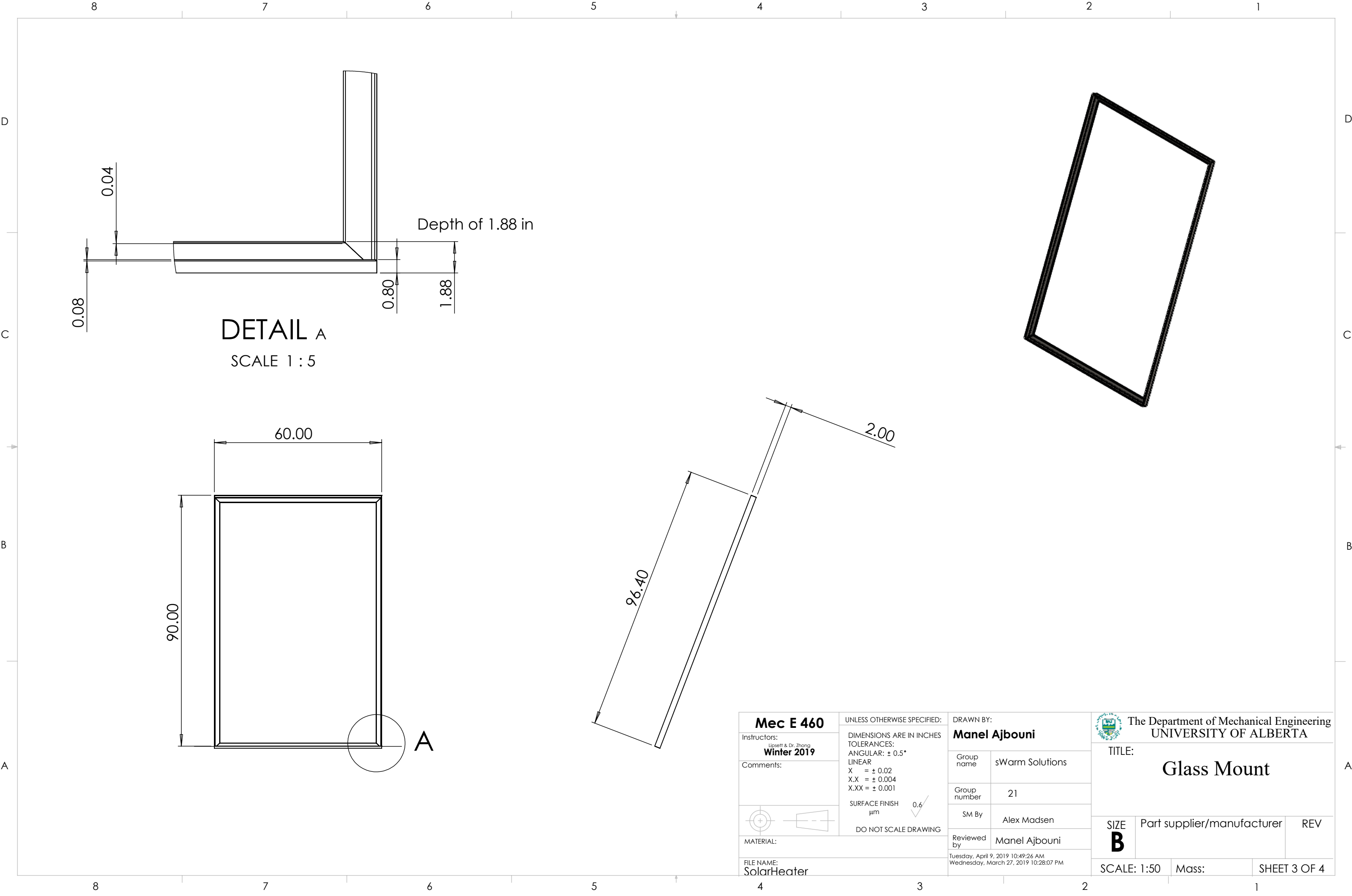


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Instructors: Upsett & Dr. Zhong <b>Winter 2019</b>		DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 0.5° LINEAR X = ± 0.02 X.X = ± 0.004 X.XX = ± 0.001  SURFACE FINISH 0.6 μm ✓  DO NOT SCALE DRAWING		<b>Manel Ajbouni</b>		TITLE:  <b>Solar Heater</b>		
Comments:				Group name	sWarm Solutions			
				Group number	21			
				SM By	Alex Madsen			
				Reviewed by	Manel Ajbouni			
MATERIAL:				Tuesday, April 9, 2019 10:49:26 AM Wednesday, March 27, 2019 10:28:07 PM		SIZE <b>B</b>	Part supplier/manufacturer	REV
FILE NAME: <b>SolarHeater</b>						SCALE: 1:200    Mass:    SHEET 1 OF 4		





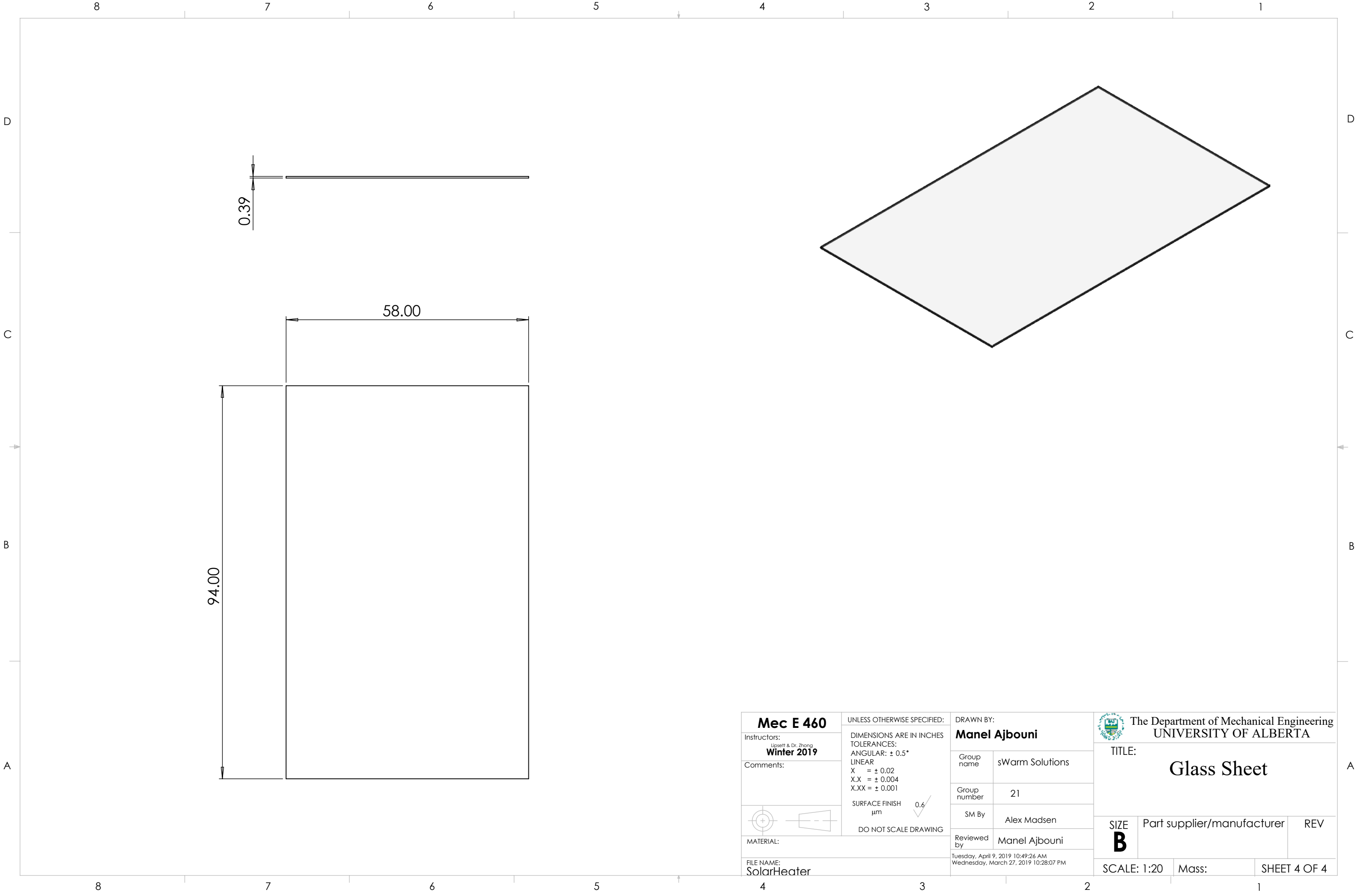
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Instructors: Upsett & Dr. Zhong		DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: $\pm 0.5^\circ$ LINEAR X = $\pm 0.02$ X.X = $\pm 0.004$ X.XX = $\pm 0.001$  SURFACE FINISH $\mu\text{m}$ 0.6 ✓  DO NOT SCALE DRAWING		<b>Manel Ajbouni</b>		TITLE:  <b>Solar Mount</b>		
Winter 2019				Group name	sWarm Solutions			
Comments:				Group number	21			
				SM By	Alex Madsen			
	MATERIAL:			Reviewed by	Manel Ajbouni			
FILE NAME: SolarHeater		Tuesday, April 9, 2019 10:49:26 AM Wednesday, March 27, 2019 10:28:07 PM				SIZE <b>B</b>	Part supplier/manufacturer	REV
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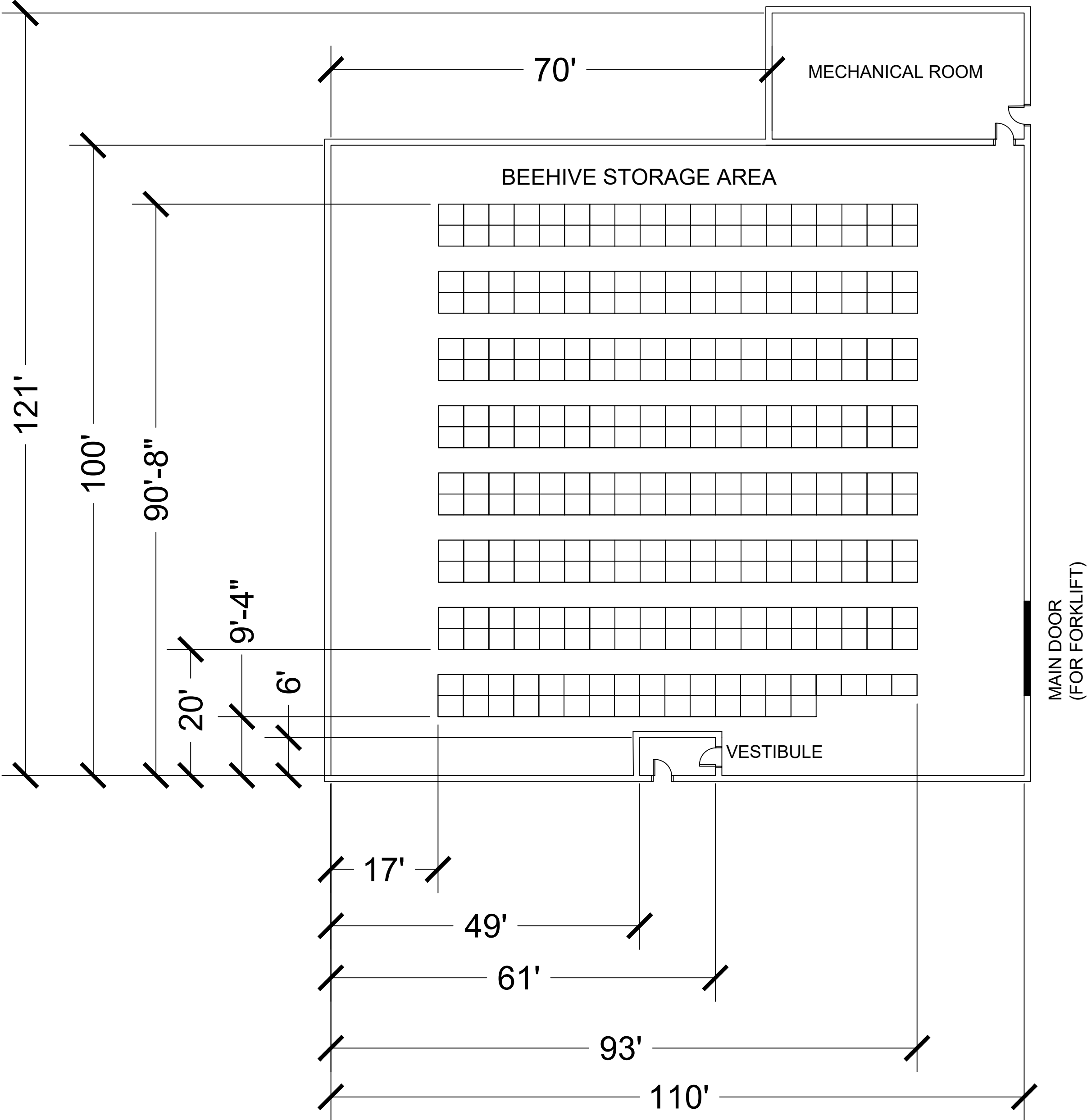


DETAIL A  
SCALE 1 : 5

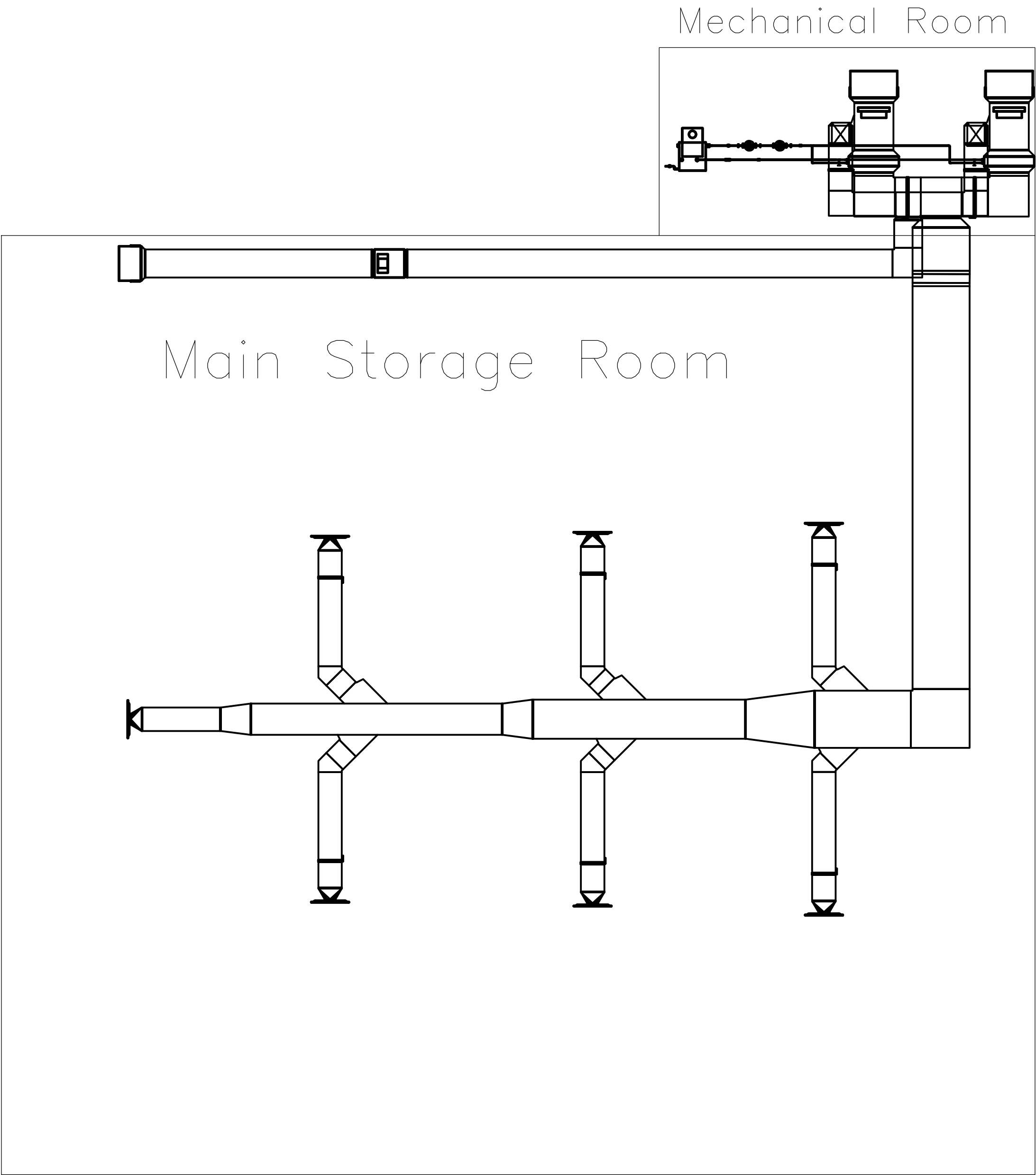
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Instructors: Upsett & Dr. Zhong <b>Winter 2019</b>	<div>DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: <math>\pm 0.5^\circ</math> LINEAR X = <math>\pm 0.02</math> X.X = <math>\pm 0.004</math> X.XX = <math>\pm 0.001</math>  SURFACE FINISH <math>\mu\text{m}</math> 0.6 ✓  DO NOT SCALE DRAWING</div>	<b>Manel Ajbouni</b>		TITLE:		<b>Glass Mount</b>		
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FILE NAME: SolarHeater								



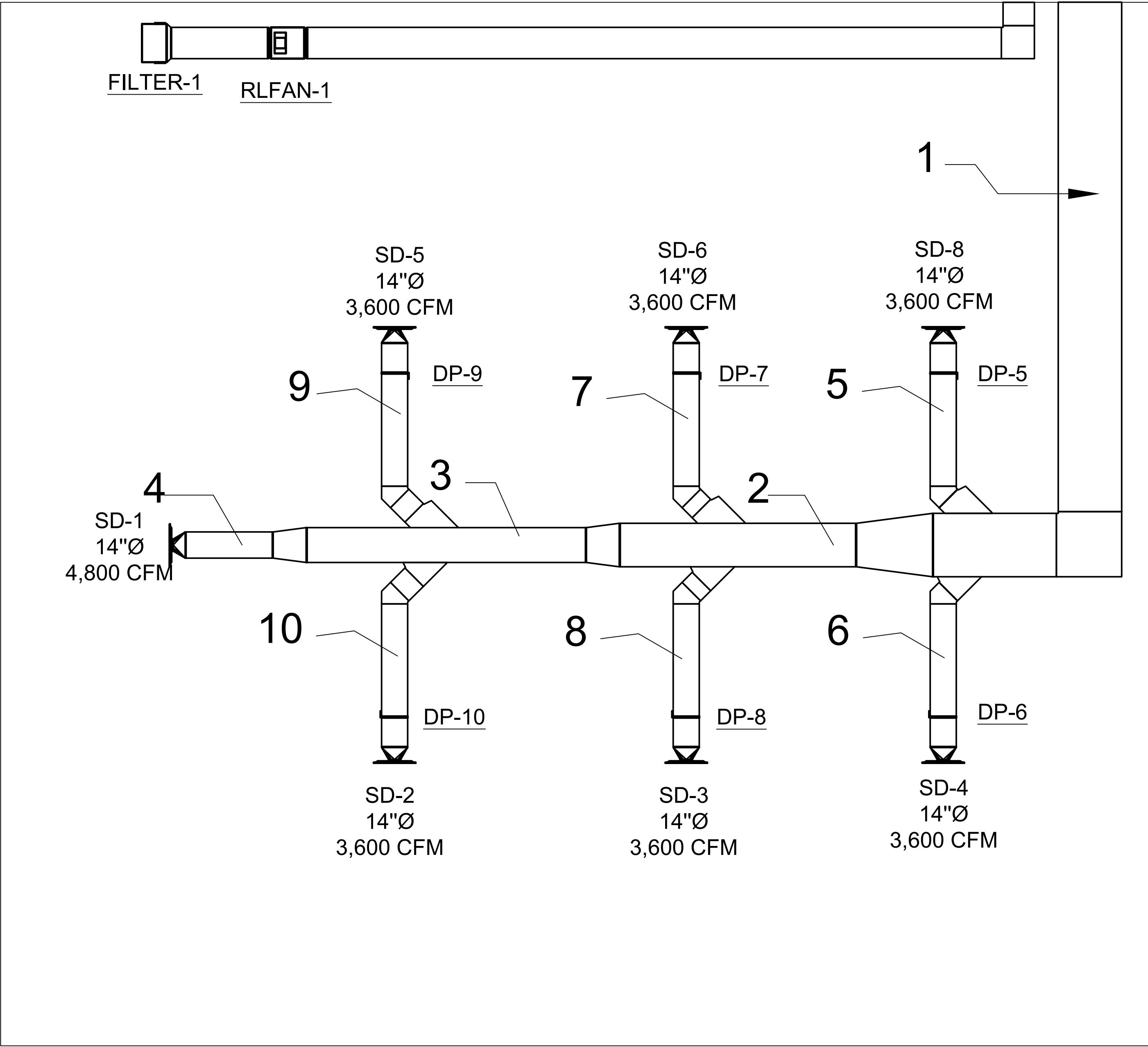
<b>Mec E 460</b>		UNLESS OTHERWISE SPECIFIED:		DRAWN BY:		 The Department of Mechanical Engineering UNIVERSITY OF ALBERTA						
Instructors: Upsett & Dr. Zhong <b>Winter 2019</b>		<div><div></div><div></div></div> <div>DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: ± 0.5° LINEAR X = ± 0.02 X.X = ± 0.004 X.XX = ± 0.001  SURFACE FINISH 0.6 μm  DO NOT SCALE DRAWING</div>		<b>Manel Ajbouni</b>		TITLE:  <b>Glass Sheet</b>						
Comments:				Group name	sWarm Solutions							
				Group number	21	SIZE <b>B</b>			Part supplier/manufacturer		REV	
				SM By	Alex Madsen							
				MATERIAL:		Reviewed by	Manel Ajbouni					
FILE NAME: <b>SolarHeater</b>				Tuesday, April 9, 2019 10:49:26 AM Wednesday, March 27, 2019 10:28:07 PM								
						SCALE: 1:20		Mass:		SHEET 4 OF 4		



Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering, University of Alberta
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Ft-In Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00  Thickness of wall is 1' Height is 18' Distance between each beehive row is 4"			Title: Honey Bees Storage Floor Plan
Comments:		Group name	sWarm Solutions	
Materials:		Group number	21	Date prepared: April 5th, 2019
		SM By	Son Le	File Name: Building Final
		Reviewed by	Alex Madsen	Prepared in AutoCAD MEP 2019 STUDENT VERSION

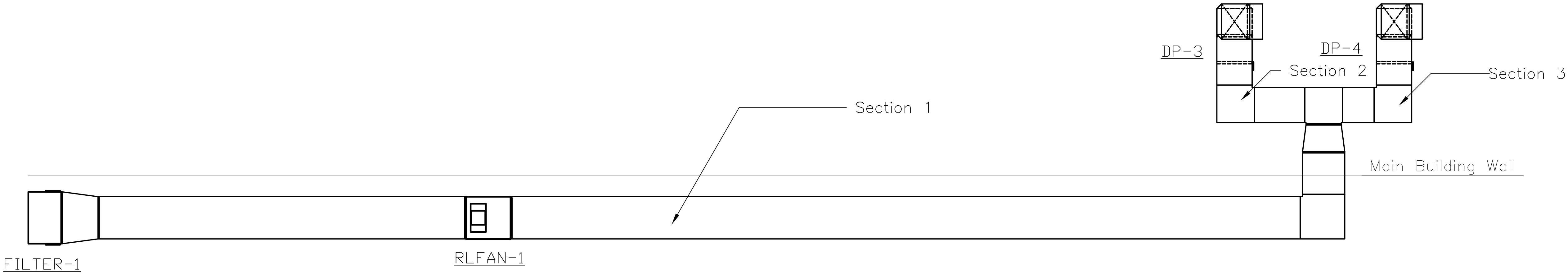


Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering, University of Alberta
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Ft-In Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00			Title: HVAC & Piping Network
Comments:		Group name	sWarm Solutions	Date prepared: April 5th, 2019
		Group number	21	
Materials:			SM By	Son Le
		Reviewed by	Yu Tim Leung	Prepared in AutoCAD MEP 2019 STUDENT VERSION



Duct Schedule					
Section	Size (in x in)	Length (ft)	Air flow rate (cfm)	Velocity (fpm)	Friction loss (in wg/100ft)
1	75x45	67	26400	1200	0.0255
2	55x45	30	19200	1200	0.0293
3	45x35	30	12000	1174	0.0374
4	30x25	15	4800	984	0.0421
5,6,7,8,9,10	30x20	15	3600	930	0.0435

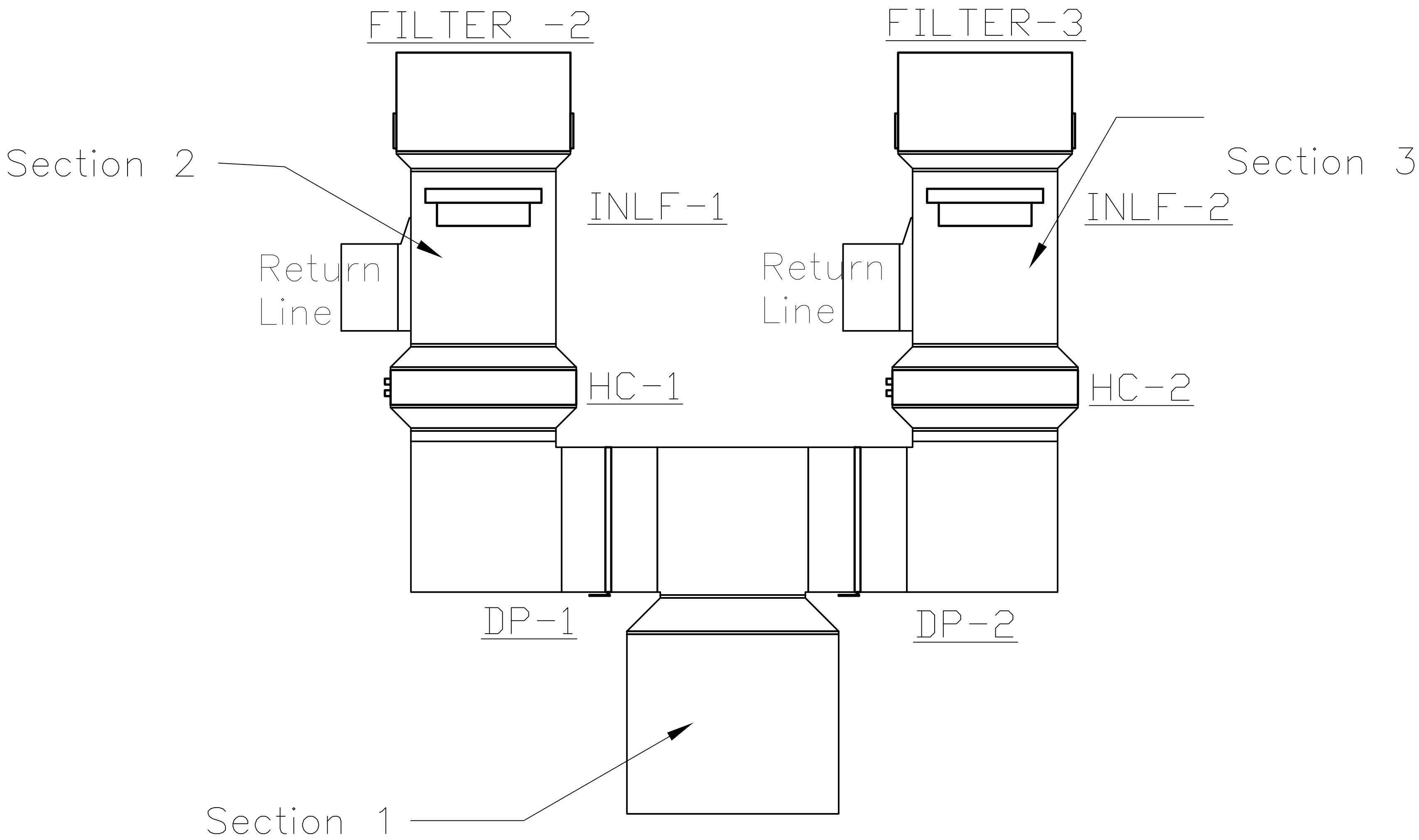
Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering, University of Alberta
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Ft-In Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00  DP = Damper RLFAN = Return Line Fan SD = Diffuser			Title: Building Storage's Duct Network
Comments: Height of ducts and equipment is 11.266 in		Group name	sWarm Solutions	Date prepared: April 5th, 2019
		Group number	21	
Materials:			SM By	Son Le
		Reviewed by	Alex Madsen	Prepared in AutoCAD MEP 2019 STUDENT VERSION



Duct Schedule					
Section	Size	Length (ft)	Air flow rate (cfm)	Velocity (fpm)	Friction loss (inwg/100ft)
1	38x28	85	7920	1149	0.0457
2, 3	30x22	16	3960	926	0.0406

Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering The University of Alberta
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Inches Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00	Group name sWarm Solutions		Title: Return Line Duct Network
Comments:	DP = DAMPER RLFAN = Return Line Fan	Group number	21	Date prepared: April 5th, 2019
Materials:		SM By	Son Le	File name: Return Line
		Reviewed by	Shengnan Chen	Prepared in AutoCAD MEP 2019 STUDENT VERSION

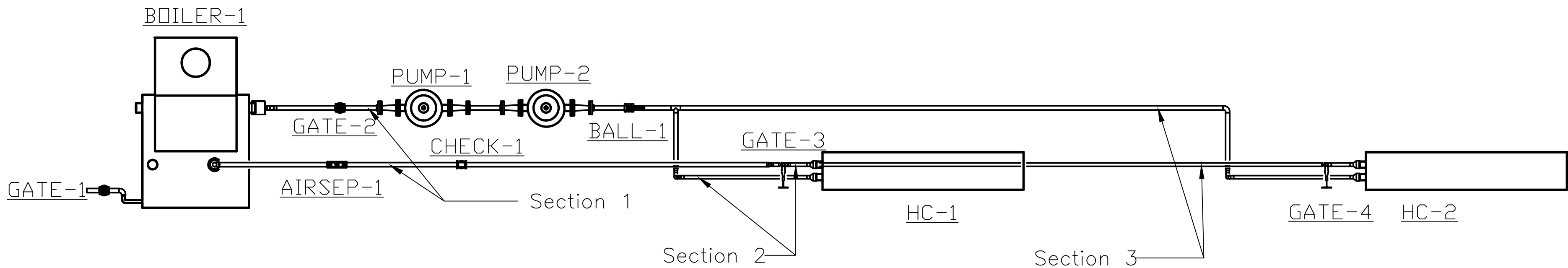
Duct Schedule					
Section	Size	Length (ft)	Air flow rate (cfm)	Velocity (fpm)	Pressure loss (in wg)
1	73x42	5	22600	1160	0.024
2, 3	50x45	15	11330	773	0.0136



Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering The University of Alberta
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Inches Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00  DP = Damper HC = Heating Coils INFL = Inline Fan			Title: Intake Duct Network
Comments:		Group name	sWArm Solutions	Date prepared: April 5th, 2019
		Group number	21	
Materials:		SM By	Son Le	File name: Duct Network
	Reviewed by	Shengnan Chen	Prepared in AutoCAD MEP 2019 STUDENT VERSION	



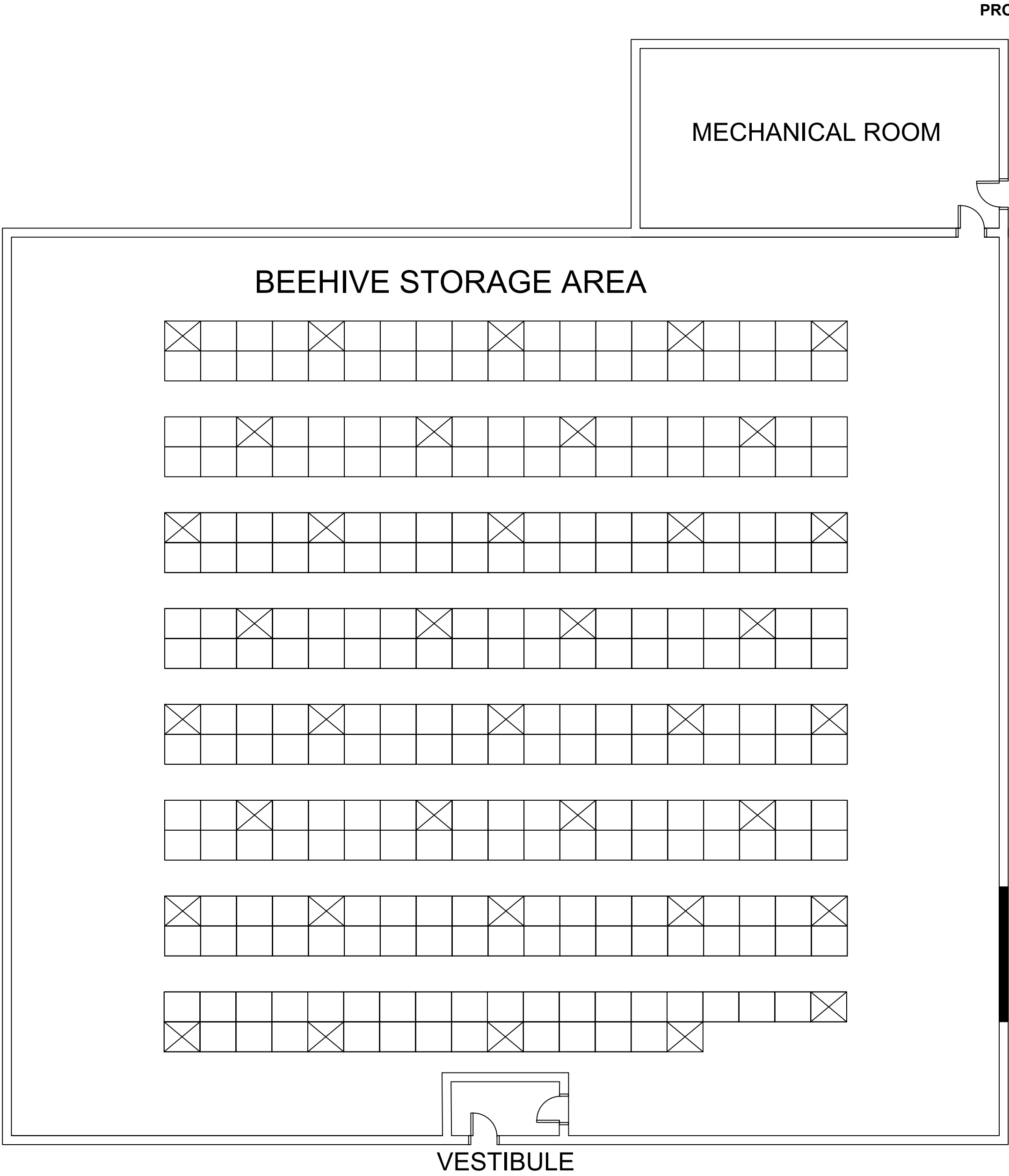
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


Pipe Schedule				
Section	Size	Length (ft)	Flow rate (gpm)	Friction loss (H2O/100ft)
1	1	34	14	1.8
2	$\frac{3}{4}$	12.6	7	1.2
3	$\frac{3}{4}$	41	7	2.0

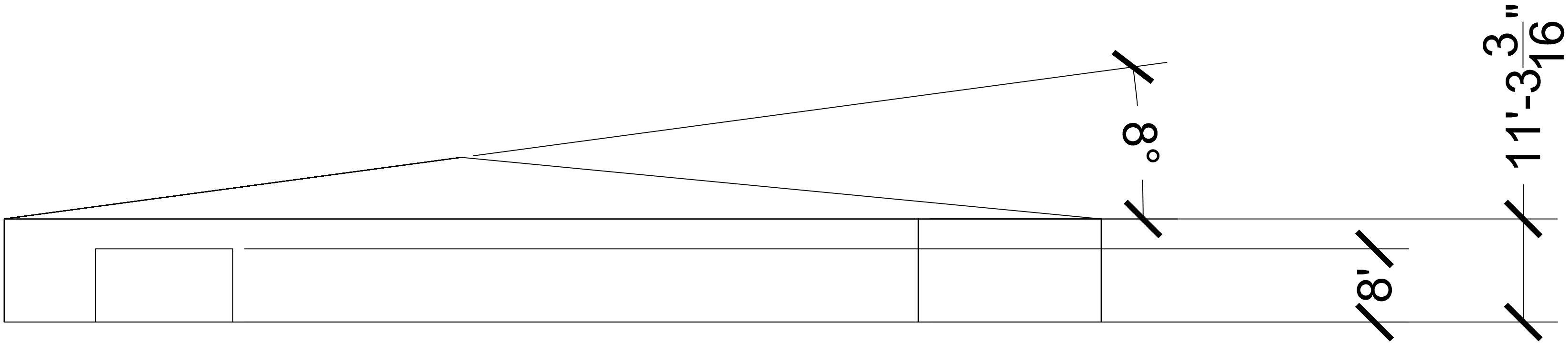
Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering The University of Alberta
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Inches Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00			Title: Pipe Network
Comments:	AIRSEP = Air Separator Ball = Ball Valve CHECK = Check Valve GATE = Gate Valve HC = Heating Coils	Group name	sWarm Solutions	
		Group number	21	Date prepared: April 5th, 2019
Materials:		SM By	Son Le	File name: Piping Network
		Reviewed by	Shengnan Chen	Prepared in AutoCAD MEP 2019 STUDENT VERSION

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-  Indicated Stack with Building Sensor
-  Regular Beehive Stack

Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering, University of Alberta
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Ft-In Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00  Thickness of wall is 1' Height is 18' Distance between each beehive row is 4"			Title: Building Sensor Layout
Comments: Each indicated Stack contains a building sensor				
Each beehive stack contains two Beecon sensors		Group name	sWarm Solutions	
Materials:		Group number	21	Date prepared: April 5th, 2019
	SM By	Son Le	File Name: Building Sensors	
	Reviewed by	Alex Madsen	Prepared in AutoCAD MEP 2019 STUDENT VERSION	



Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering, University of Alberta		
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Ft-In Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00  Thickness of wall is 1' Height is 18' Distance between each beehive row is 4"			Title: Honey Bees Storage Floor Plan		
Comments:				Group name	sWarm Solutions	
				Group number	21	Date prepared: April 5th, 2019
				SM By	Son Le	File Name: Building Final
Materials:		Reviewed by	Alex Madsen	Prepared in AutoCAD MEP 2019 STUDENT VERSION		