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April 10, 2019

Connie Phillips
Executive Director
Alberta Beekeepers Commission
11434 – 168 Street NW
Edmonton, Alberta, T5M 3T9

RE: Design of a Smart Overwintering Storage Building for Honeybees

Dear Ms. Phillips;

sWarms Solutions is pleased to present the final detailed design of a smart overwintered honeybee storage building for the Alberta Beekeepers Commission.

In this report, you will find the following:

- Design improvements from Phase II
- Detailed analysis of the project (building design, HVAC system layout and sensor selection and mapping)
- Design considerations and design compliance
- Project management overview
- Future works and recommendations

The cost of the project is $493,700 while the total working hour is 622 for junior engineers and 9 hours intermediate engineers, resulting in a total engineering cost of $57,330.

We would like to thank you for all your help and guidance over the past four months, it was a pleasure to work with the Alberta Beekeepers Commission and we hope to have more opportunities in the future. If you have any questions or concerns, please do not hesitate to contact us.

Thank you again and we look forward to hearing from you.

Sincerely,

Alex Madsen

encl.

cc. Dr. Lexuan Zhong, Faculty Advisor, University of Alberta
Dr. Michael Lipsett, Course Coordinator, University of Alberta
sWarm Solutions Team

PHASE III REPORT

Overwintering Honeybees: Detailed Design

APRIL 10TH, 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 CO2 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 CO2 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_2 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_2 levels within the building could not be controlled and the honeybees would soon run out of oxygen. To keep the CO_2 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_2 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.

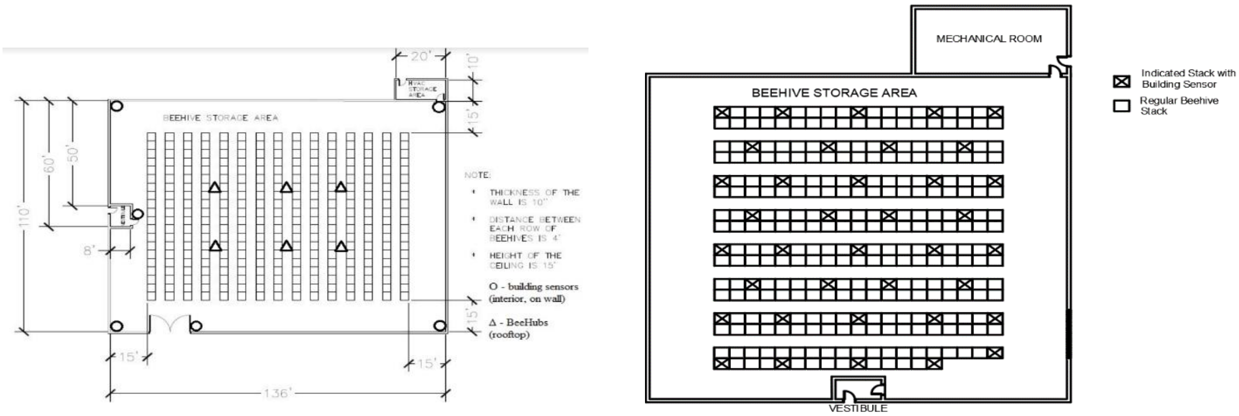

Figure 1: Phase II (left) and refined Phase III (right) sensor layouts. Circles indicate building sensor locations in Phase II on left while X's indicate hive stacks with building sensors near them in Phase III.

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.

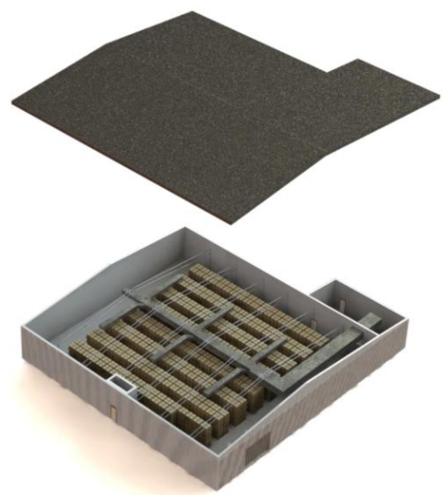

Figure 2: Final honeybee overwintering building - external view

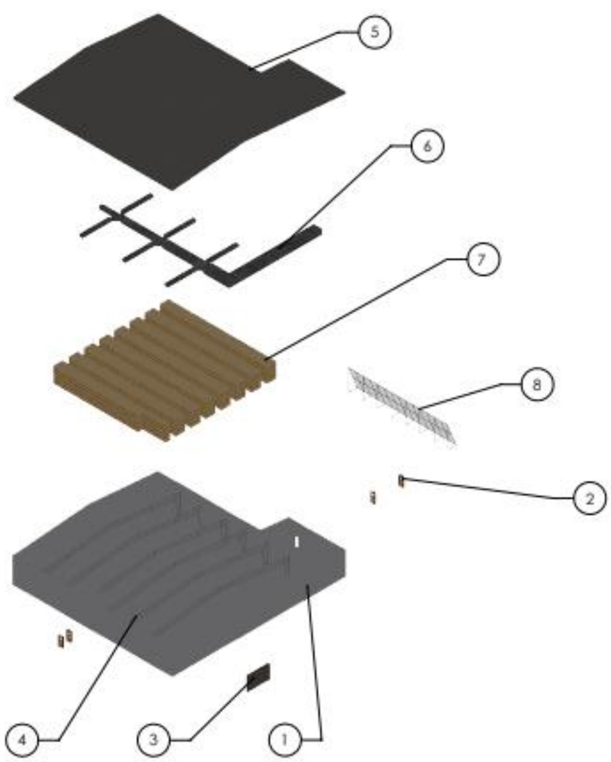

Figure 3: Final honeybee overwintering building - exploded view of primary parts

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

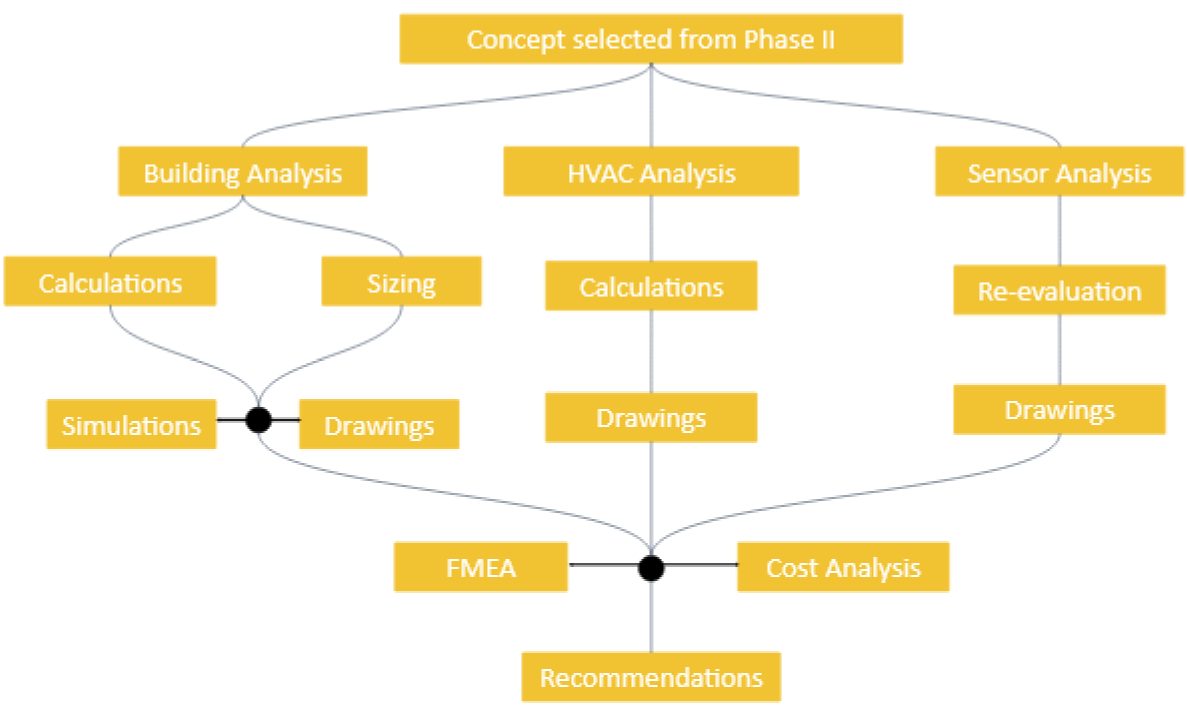

Figure 4: Phase III detailed design flow chart

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 19⅞" x 16" x 19¼" 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.

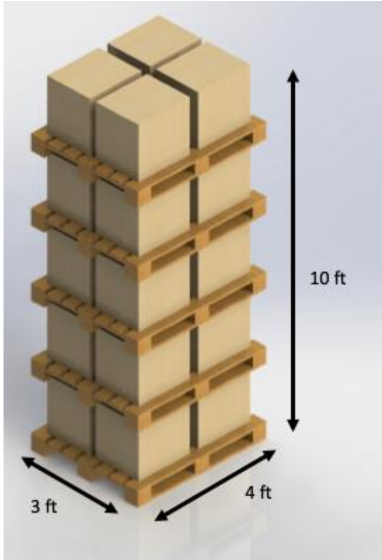

Figure 5: Layout and dimensions of a single hive stack

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.

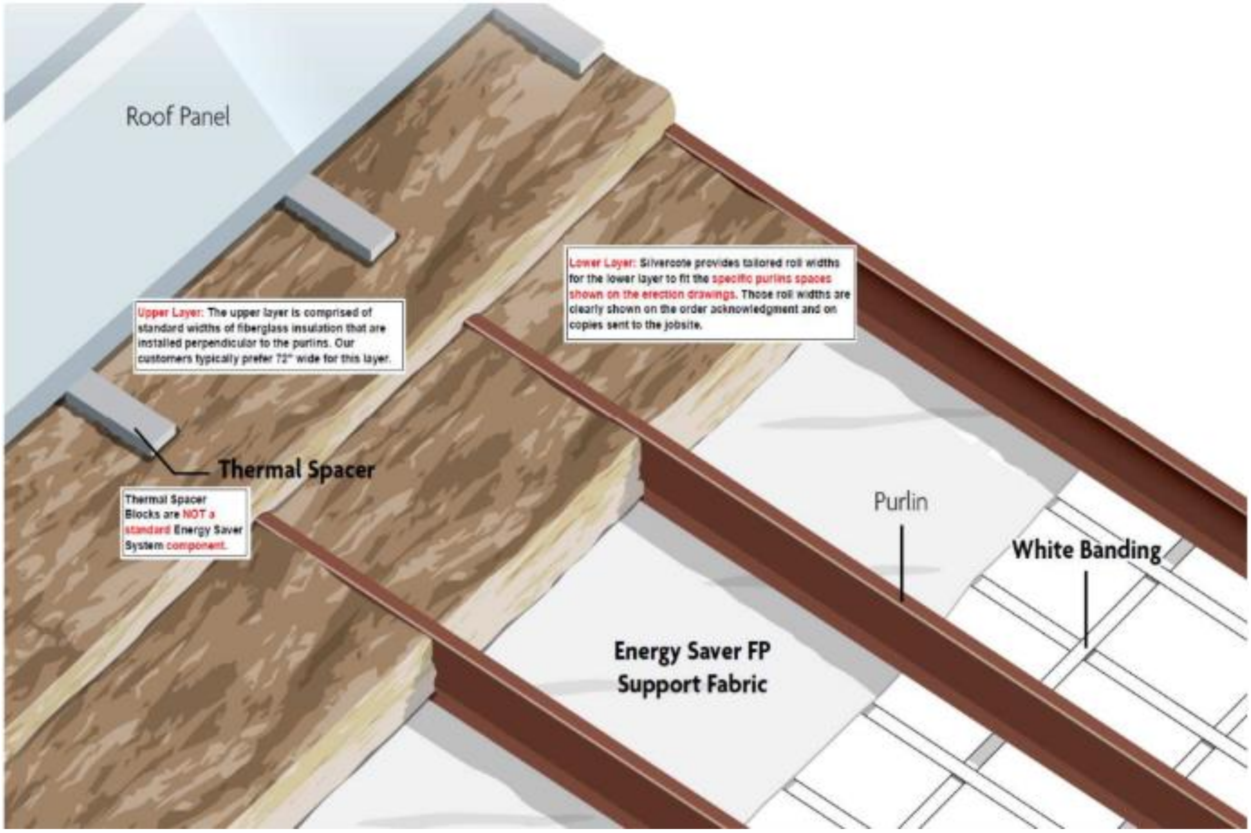

Figure 6: Building roof insulation detail **[2]**

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.

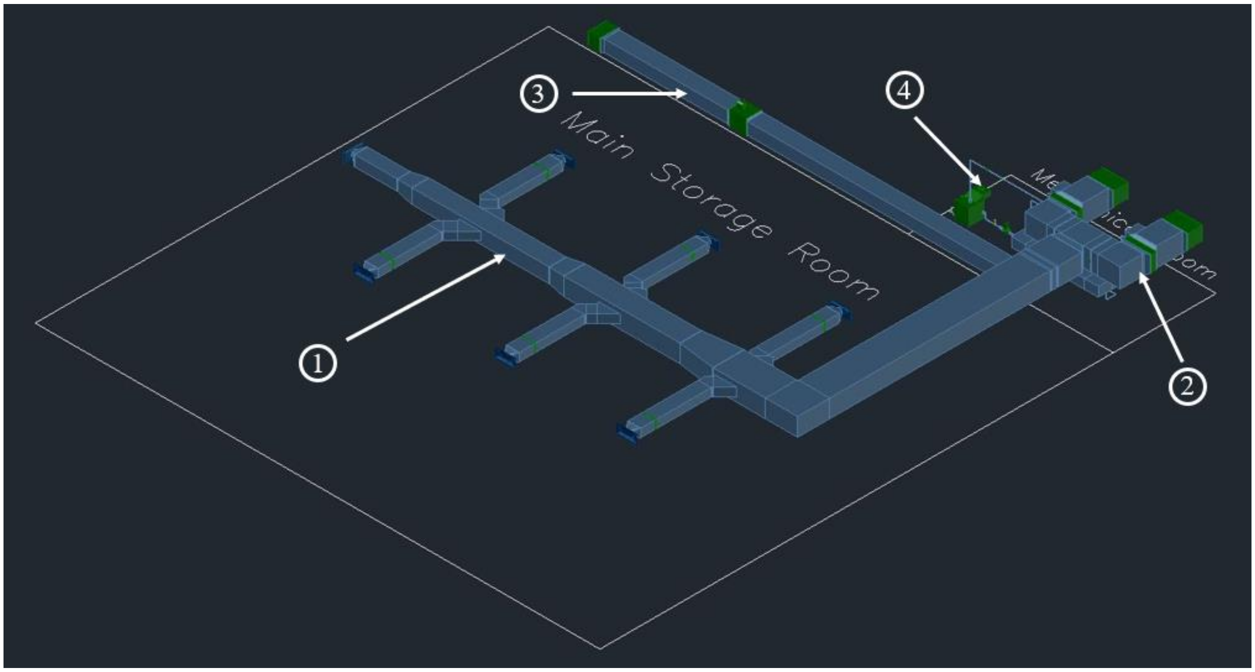

Figure 7: Overall HVAC layout - isometric view. 1 = storage room duct network, 2 = intake duct detail, 3 = return air line, 4 = heating water loop

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 ⅜" 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.

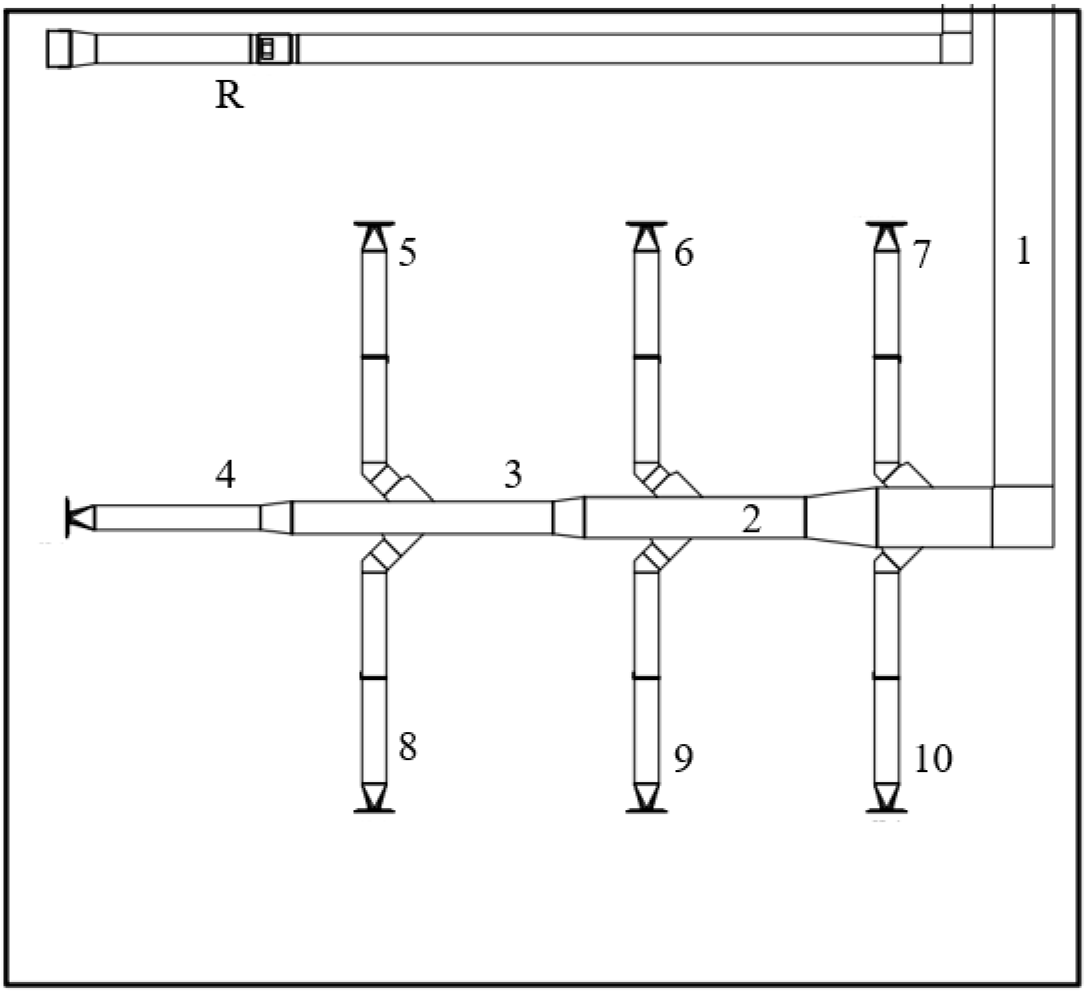

Figure 8: Main storage area duct layout

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.

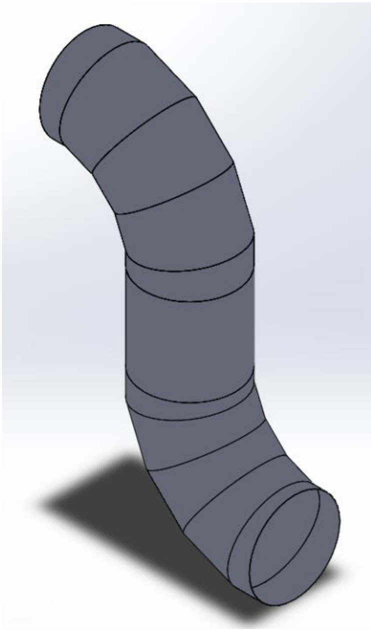

Figure 9: Double-bend exhaust duct for light prevention

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.

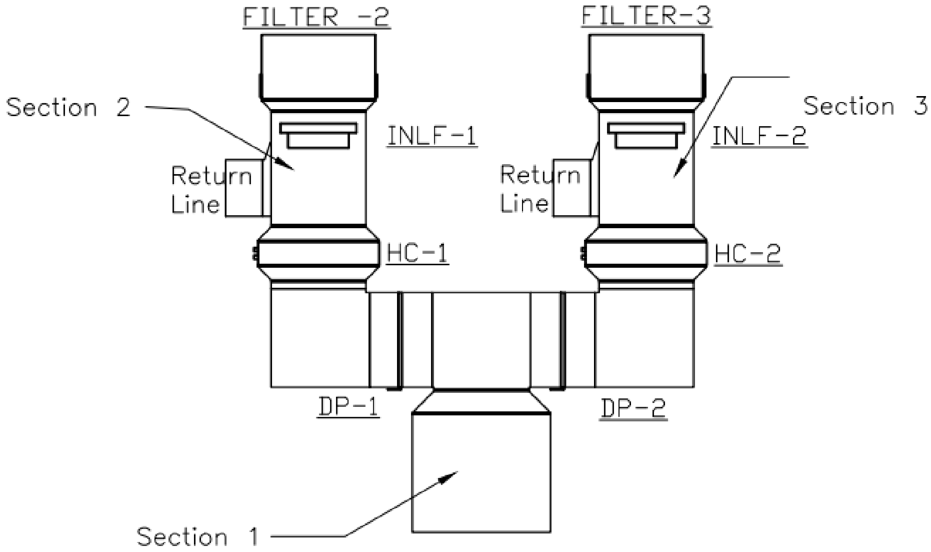

Figure 10: Split air intake detail

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.

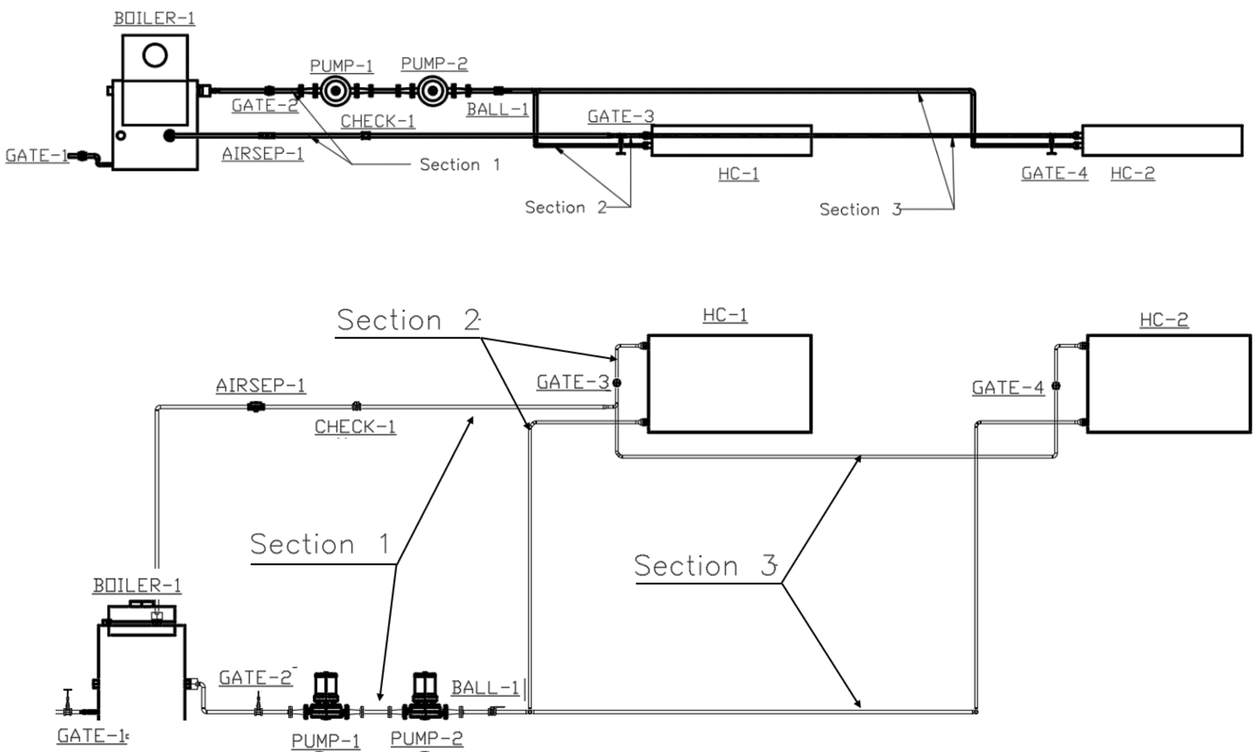

Figure 11: Top view (top) and side view (bottom) of heating water system

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	• System operates as usual, with all fans, boilers, and pumps on.
Cooling Mode	Intake air temperature is above 0°C	• Supply and exhaust fans shut off, conserving the temperature inside. Boiler shuts off ○ CO_2, humidity, and temperature slowly build due to honeybee respiration
Emergency Exhaust Mode	CO_2 above 2500 ppm (barring failure, this mode will only engage while in cooling mode)	• Return fan turns off, supply and exhaust fans turn on for one full cycled air exchange (7.5 minutes). Boiler remains off.

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].

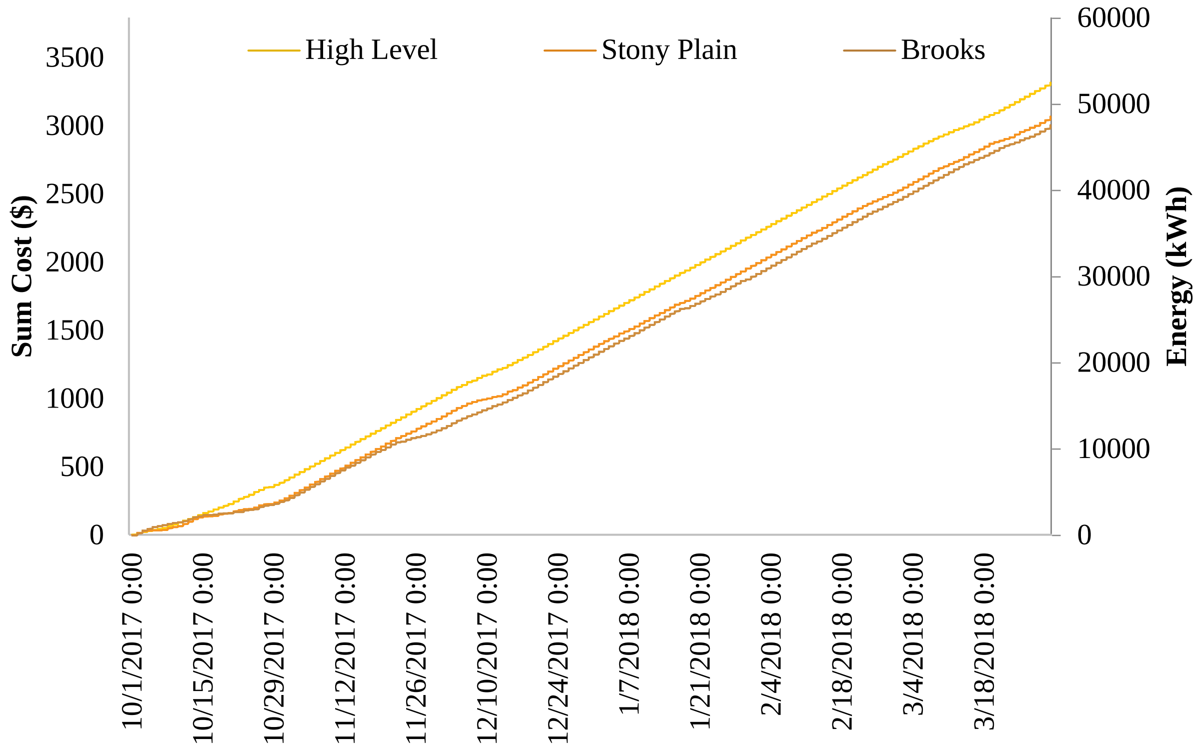

Figure 12: Sum cost and consumption of electricity over the course of winter, using 2017/18 data

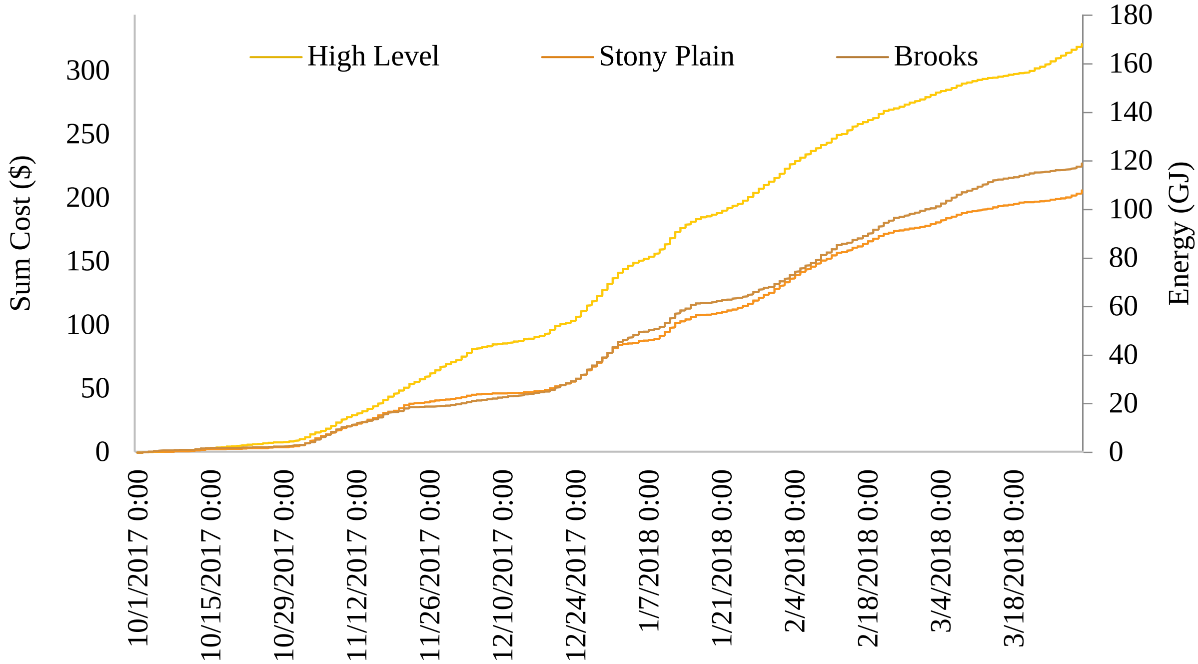

Figure 13: Sum cost and consumption of natural gas over the course of winter, using 2017/18 data

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 CO2, 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].

$$RPN = Severity \times Occurrence \qquad \textbf{Equation 1}$$

Table 7: Failure modes and effects analysis (FMEA)

Component	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occ	RPN	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	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occ	RPN	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	Occ	RPN	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.

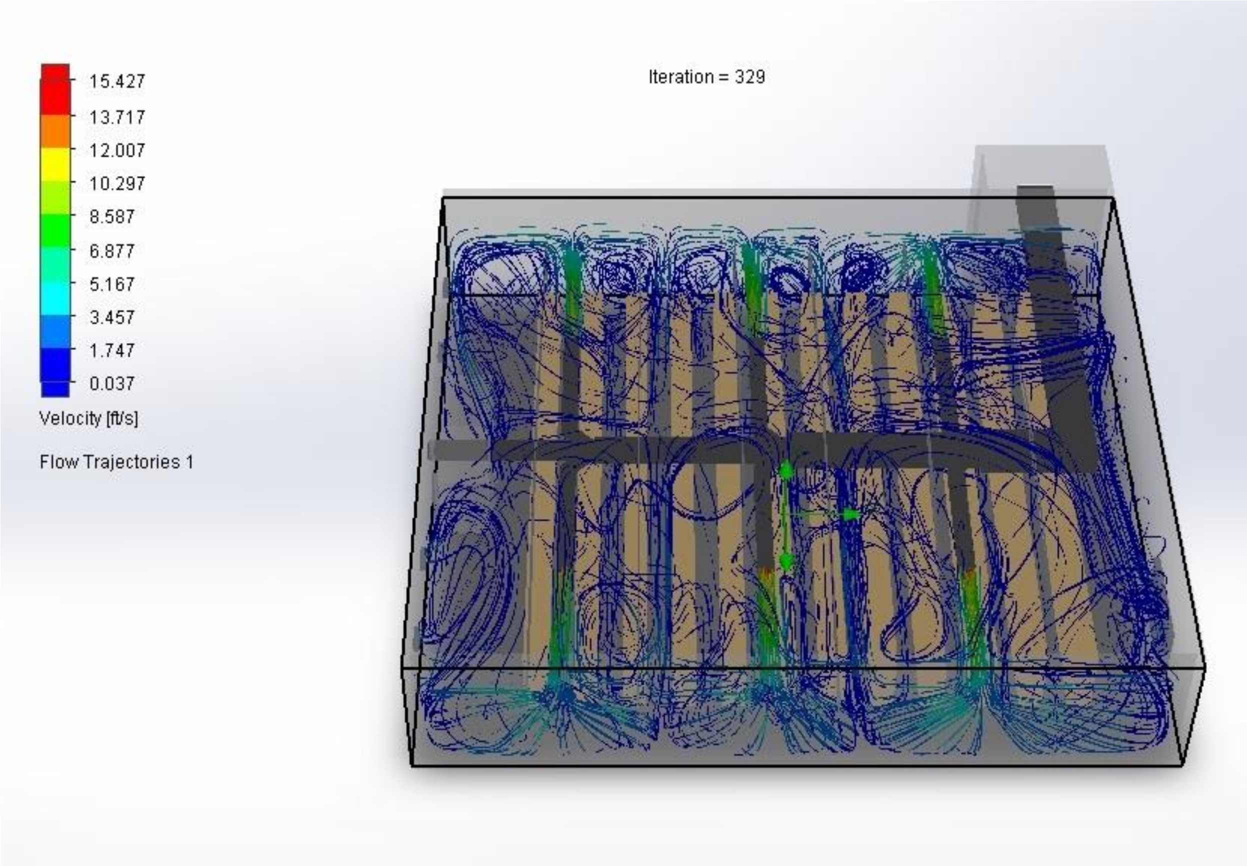

Figure 14: Air circulation simulation, flow trajectory and velocity

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_2 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_2 than previously thought [13] [1]. This change is reflected in item A.4 of Table 9.

Table 8: Design compliance matrix importance rating explanation

Importance Rating	Description
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 (Y/N)	Design Compliance Notes	Improvements
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. ~~500 ppm is an acceptable level of CO_2.~~ Building should maintain CO_2 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 (Y/N)	Design Compliance Notes	Improvements
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	**Building**						

Item	Description	Specification	Design Authority	Importance	Design Compliance (Y/N)	Notes	Improvements
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 (Y/N)	Design Compliance Notes	Improvements
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 (Y/N)	Design Compliance Notes	Improvements
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.

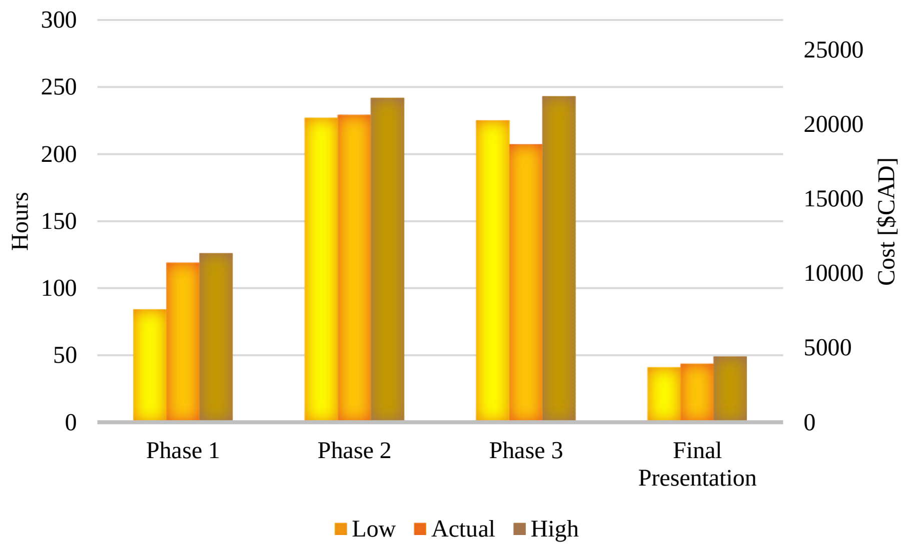

Figure 15: Final hours spent when compared to initial estimates of engineering time

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
Total	**622**	**9**	**$57,330.00**

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.

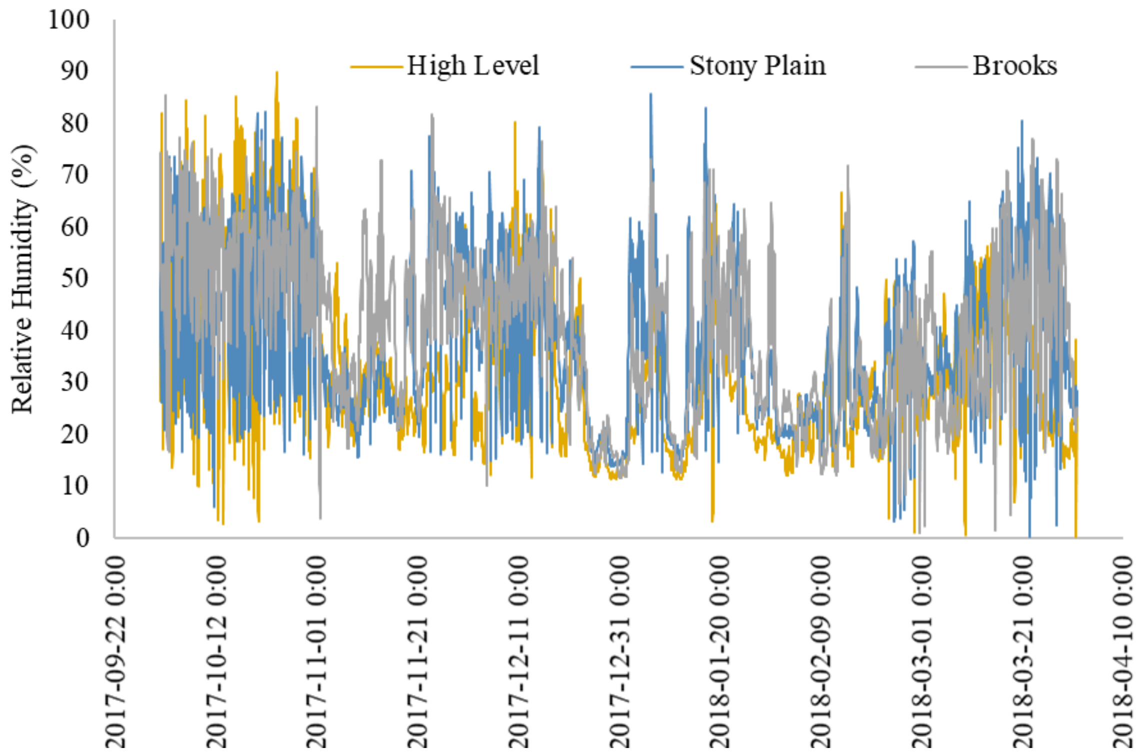

Figure 16: Internal building humidity over the course of winter, using 2017/18 data

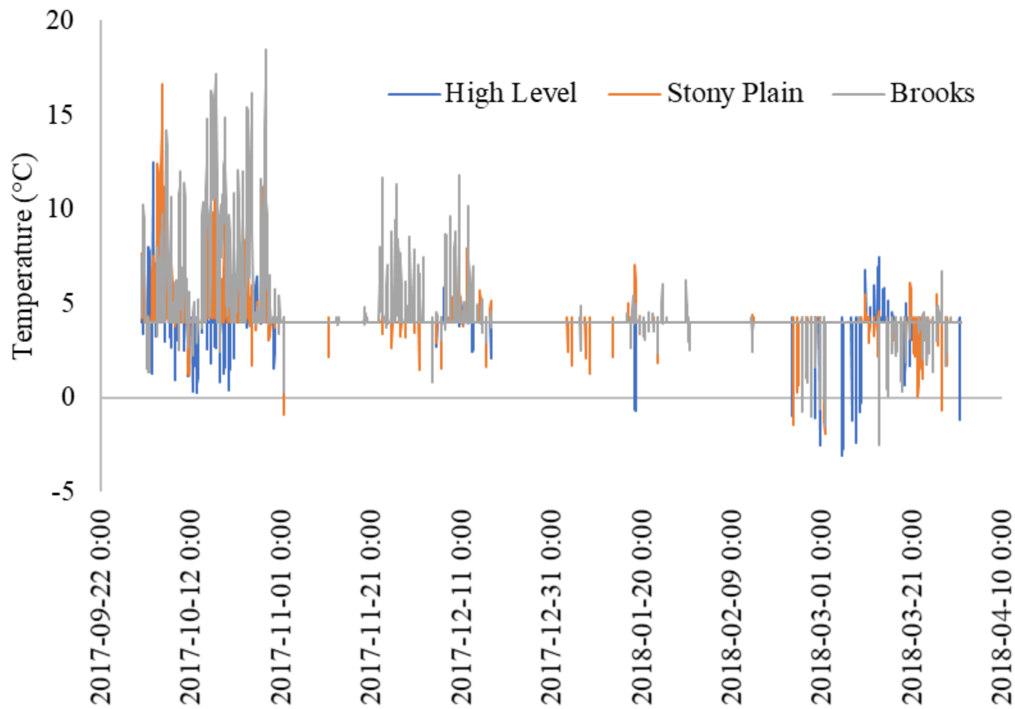

Figure 17: Internal building temperature throughout winter, using 2017/18 data

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

Problem	Recommendation
CO_2 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

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

$M_{bee} := 0.1\ g$

$N_c := 20000$

$M_{Bee} := 54.4\ kg$

$M_F := 3\ kg$

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

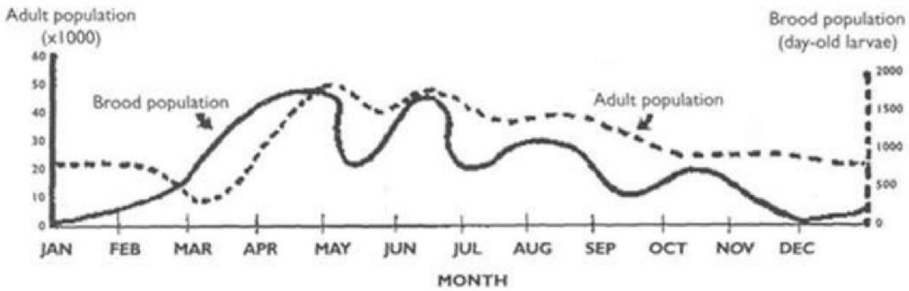
M.F = Mass of the food in a single beehive

Sketch

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

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.

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

$M_T = 59.4\ kg$

$m := 18\ kg$

$a := 0.5302\ m$

$b := 0.4064\ m$

$t := 0.0508\ m$

$S := 41.4\ MPa$

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

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

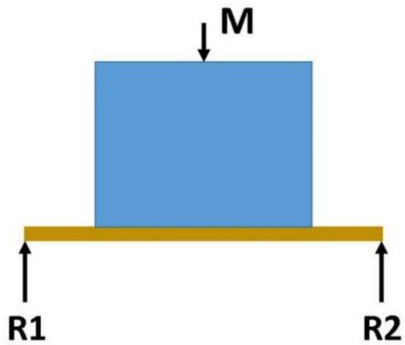
g = acceleration due to gravity

M_H = Mass applied on each beehive

p = Distributed load on each beehive

Sketch

Stacking of the beehives:



Analysis

Safety factor with 1 layer of beehives and pallet

1. Mass applied on each hive

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

2. Determine the distributed load on each beehive lid

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

3. Stress acting on the lid

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

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

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

1 Mar 2019 03:13:47 - Building Design Calculations.sm

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

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

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

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

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

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

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

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

2. Determine the distributed load on each beehive lid

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

3. Stress acting on the lid

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

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 determined if having 5 layers will result in low safety factor and ultimately cause the beehive to collapse. Safety factor of the lid w 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 du to height restrictions that a standard forklift can reach (10 ft).

Appendix B: Heat Transfer Calculations

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.

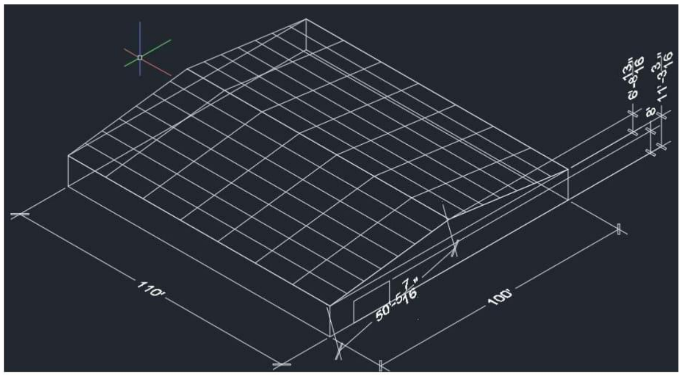
Variable Definitions:

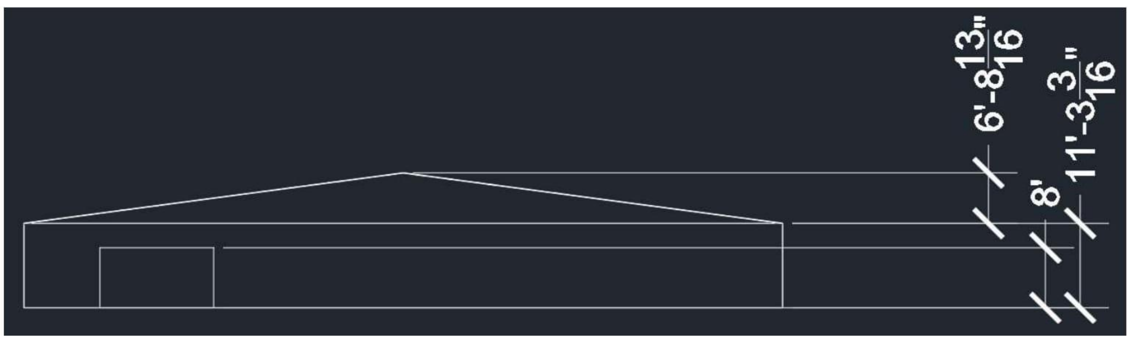
A1 : Cross-sectional area of the side walls
A2 : Cross-sectional area of the front and back walls
A3 : Cross-sectional area of the roof
A4 : Cross-sectional area of the wall between the ceiling and roof
ACH : Air changes per hour constant
Arf : The area of the roof panel
Cs : Air sensible heat factor
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

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

T_∞in : Interior wall ambient temperature
T_∞out: Exterior wall ambient temperature
Wid : Width of the wall
ΔT : The temperature difference between the inside and outside air

Sketches:





Known Data:

$Ht := 11.266\ ft$

$L := 100\ ft$

$Ht\_bld := 18\ ft$

$Wid := 110\ ft$

$T\_\infty in := 498.87\ °Ra$

$T\_\infty out := 419.67\ °Ra$

$HR\_out := 0.00008$

$HR\_in := 0.005$

$Cs := 1.10\ \frac{BTU\ min}{hr\ °Ra\ ft^3}$

$Htrf := Ht\_bld - Ht = 6.734\ ft$

$Cl := 4840\ \frac{BTU\ min}{hr\ ft^3}$

$Slrf := \sqrt{\left(\frac{L}{2}\right)^2 + (Htrf)^2} = 50.4514\ ft$

$ACH := 0.59 \cdot \frac{1}{hr}$

$Fp := 2.12\ \frac{BTU}{hr\ ft\ °Ra}$

$R\_ins := 30\ \frac{ft^2\ °Ra\ hr}{BTU}$

$R\_ins\_roof := 40\ \frac{ft^2\ °Ra\ hr}{BTU}$

$R\_foutw := 0.17\ \frac{ft^2\ °Ra\ hr}{BTU}$

$R\_finw := 0.68\ \frac{ft^2\ °Ra\ hr}{BTU}$

$R\_foutr := 0.17\ \frac{ft^2\ °Ra\ hr}{BTU}$

$R\_finr := 0.92\ \frac{ft^2\ °Ra\ hr}{BTU}$

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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.

$A1 := Wid \cdot Ht = 1239.26\ ft^2$

$A2 := L \cdot Ht = 1126.6\ ft^2$

$A3 := L \cdot Wid = 11000\ ft^2$

$Arf := Slrf \cdot L = 5045.143\ ft^2$

$Peri := (L + Wid) \cdot 2 = 420\ ft$

$A4 := \frac{L \cdot Htrf}{2} = 336.7\ ft^2$

The temperature difference is then calculated

$\Delta T := T\_\infty in - T\_\infty out = 79.2\ °Ra$

The air infiltration rate is:

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

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

$Rw\_tot := R\_ins + R\_finw + R\_foutw = 30.85\ \frac{°Ra\ ft^2\ hr}{BTU}$

$Rr\_tot := R\_ins\_roof + R\_finr + R\_foutr = 41.09\ \frac{°Ra\ ft^2\ hr}{BTU}$

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

$Qs := Cs \cdot Q\_dot\_infil \cdot \Delta T = 1828.9916\ \frac{BTU}{hr}$

$Ql := Cl \cdot Q\_dot\_infil \cdot (HR\_in - HR\_out) = 499.9244\ \frac{BTU}{hr}$

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

$Q\_side := 2 \cdot \frac{A1 \cdot \Delta T}{Rw\_tot} = 6363.0076\ \frac{BTU}{hr}$

$Q\_rm := 2 \cdot \frac{A4 \cdot \Delta T}{Rw\_tot} = 1728.7935\ \frac{BTU}{hr}$

$Q\_fb := 2 \cdot \frac{A2 \cdot \Delta T}{Rw\_tot} = 5784.5524\ \frac{BTU}{hr}$

$Q\_rf := 2 \cdot \frac{Arf \cdot \Delta T}{Rr\_tot} = 19448.7867\ \frac{BTU}{hr}$

$Q\_fl := Fp \cdot Peri \cdot \Delta T = 70519.68\ \frac{BTU}{hr}$

The total heating load on the building is:

$Q\_total := Qs + Ql + Q\_side + Q\_fb + Q\_rf + Q\_fl + Q\_rm = 1.0617 \cdot 10^5\ \frac{BTU}{hr}$

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 to used to calculate the heat th is required for the building.

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Tables:

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

Position of Surface	Direction of Heat Flow	Surface Emittance, ε: Non-reflective ε = 0.90		Reflective ε = 0.20		Reflective ε = 0.05	
		h_i	R	h_i	R	h_i	R
STILL AIR							
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
MOVING AIR (Any position)		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 2013 *ASHRAE Handbook—Fundamentals*)
1. Surface conductance h_i and h_o measured in Btu/h·ft²·°F; resistance R in °F·ft²·h/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 2013 *ASHRAE Handbook—Fundamentals* for more detailed information.
5. Condensate can have a significant impact on surface emittance.

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

Construction	Insulation	F_p, Btu/h·ft·°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).

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 68°F.

Appendix C: HVAC Calculations

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 t
honeybee environment.

Custom Units:

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

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*Speed of Sound)
2) Honeybee heat generation is negligible (honeybee hive thermoregulation is quite effi
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 1100fp
the velocity in branch duct is 800fpm (Accroding 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 20ft
9) Filters uesd in this system, and have a pressure drop about 0.2inWg.

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)[a]		
Throwaway filter	200–800		
Heating coil	400–500 (200 min, 1500 max)		
Cooling coil	500–600		

Source: Howell, Sauer, and Coad [9].
[a] *Ductulator*, Trane US Inc., La Crosse, Wisconsin.

Data known:

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

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

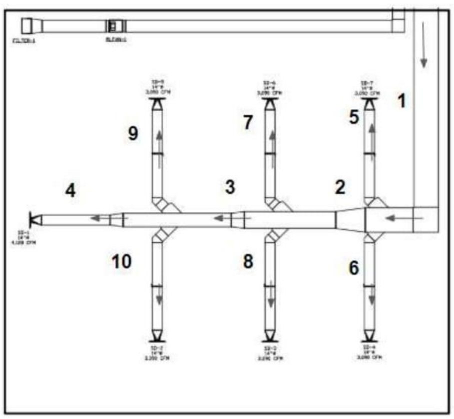
Width of building: $W_{bldg} := 100\ ft$

Air pressure drop from tube bank: $\Delta P_{bank} := 0.5\ inWg$

Variable Definition:

D:diameter
H: Height
L: Length
Q: Volumetric Flow Rate
V: Volume
W: Width
ΔP: Pressure Drop

Sketch:



Analysis:

Total Air flow Rate:

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

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

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

Section 1: 26400cfm

Section 2: 19200cfm

Section 3: 12000cfm

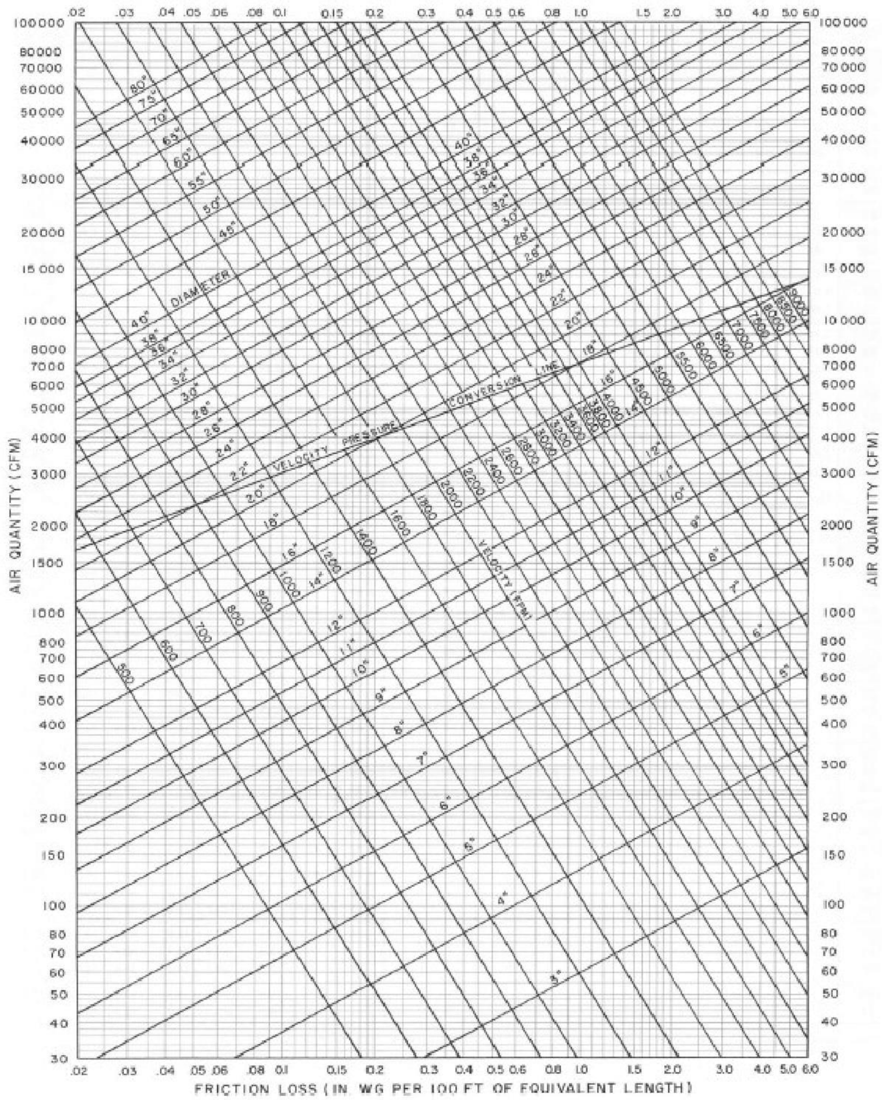
Section 4: 4800cfm

Section 5,6,7,8,9,10: 3600cfm

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 equivlent rectangular duct size fo

for each section will be:

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

$L_1 := 65\ ft$ $L_5 := 15\ ft$ $L_9 := 15\ ft$

$L_2 := 30\ ft$ $L_6 := 15\ ft$ $L_{10} := 15\ ft$

$L_3 := 30\ ft$ $L_7 := 15\ ft$

$L_4 := 15\ ft$ $L_8 := 15\ ft$ $L_{diffuser} := 20\ ft$

Pressure drop for each section:

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

		Equivalent Length (ft)			
Fitting	Diameter (in.)	6	8	10	12
Elbows					
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: Analys Design*. 5th edn. John Wiley & Sons, Inc., New York, p. 433.

Section 1

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

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

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

Section 2

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

$$L_{2.conv50\_45} := 4 \cdot D_1 = 21\ ft$$

$$\Delta P_2 := \frac{0.0293\ inWg}{100\ ft} \cdot \left(L_2 + 2 \cdot L_{2.wye.through} + L_{2.conv50\_45}\right) = 0.041\ inWg$$

Section 3:

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

$$L_{3.conv45\_32} := 4 \cdot D_2 = 18.1\ ft$$

$$\Delta P_3 := \frac{0.0374\ inWg}{100\ ft} \cdot \left(L_3 + 2 \cdot L_{3.wye.through} + L_{3.conv45\_32}\right) = 0.045\ inWg$$

Section 4:

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

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

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

Section 5:

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

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

Section 6:

$$\Delta P_6 := \Delta P_5 = 0.035\ inWg$$

Section 7:

$$\Delta P_7 := \Delta P_5 = 0.035\ inWg$$

Section 8:

$$\Delta P_8 := \Delta P_5 = 0.035\ inWg$$

Section 9:

$$\Delta P_9 := \Delta P_5 = 0.035\ inWg$$

Section 10:

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

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

$$\Delta P_{1\_2\_3\_4} := \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_4 = 0.179\ inWg$$

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:

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

$$\Delta P_{5.damper} := \Delta P_{1\_2\_3\_4} - \Delta P_{1\_5} = 0.092\ inWg$$

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

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

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

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

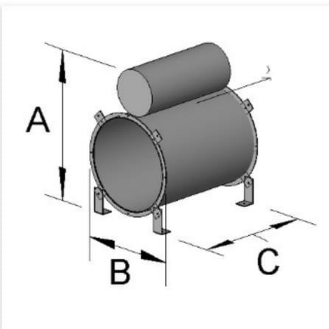
$$\Delta P_{room} := \Delta P_{1.room} + \Delta P_{2.room} + \Delta P_{filter} = 0.25\ inWg$$

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

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

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 airfow 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

Features	
Impeller	Propeller, cast aluminum.
Housing	Tubular painted steel housing.
Drive Type	Belt driven motor mounted out of the airstream.

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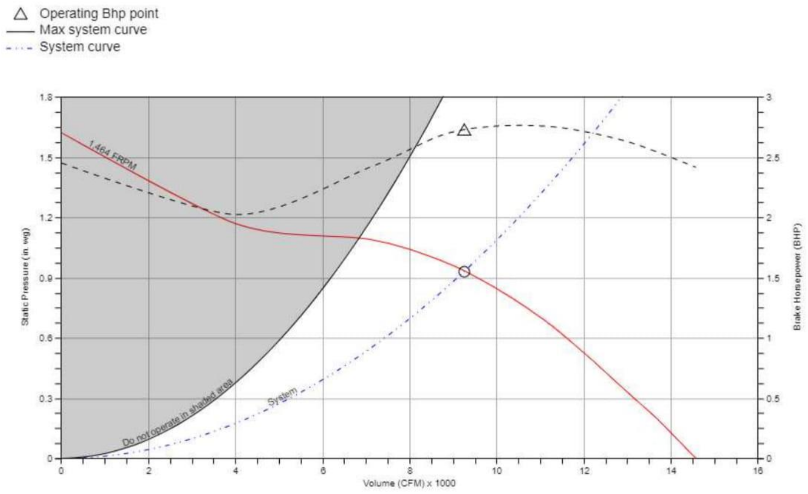

Returning Line:

30% of air returns to the machine room to heated again, and returing duct is along the w

Airflow rate in returning duct:

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

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

To size in rectangular duct:

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

Section 1:

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

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

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

Section 2:

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

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

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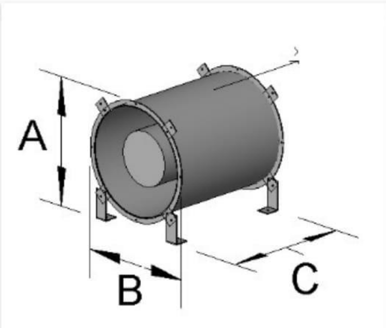
$$L_{retn.branch} := 20 \cdot D_{2.retn} = 46.67\ ft$$ (Return line to inlet line)

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

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

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 avearge alti 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

Features	
Impeller	Axial propeller, cast aluminum.
Housing	Tubular painted steel housing.
Drive Type	Direct driven motor in the airstream.

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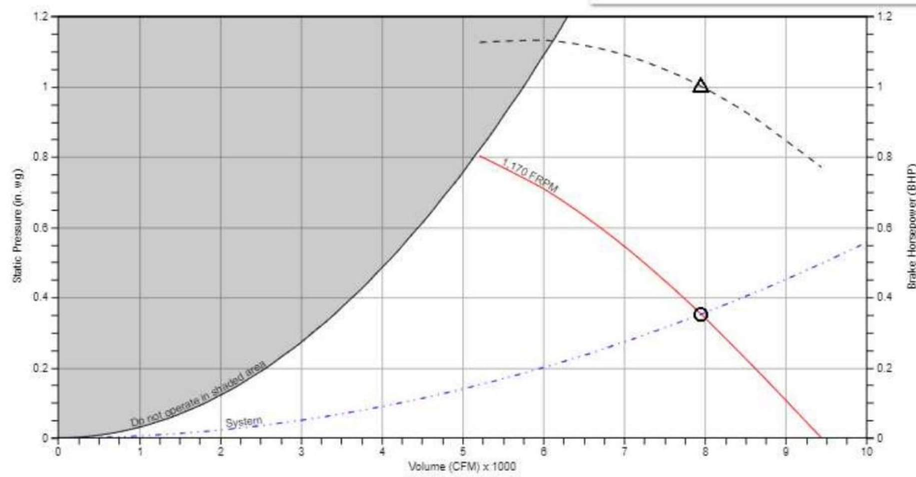
Operating Conditions

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
Total External SP	**0.351**



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

Custom Units:

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

$gpm := 1\ \frac{gal}{min}$ $ftWg := 0.434\ psi$

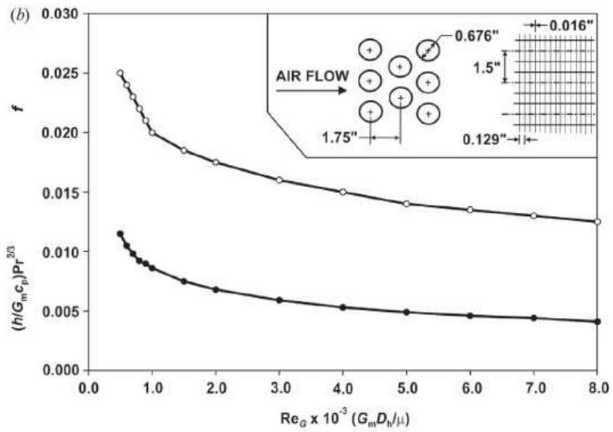
Assumptions:

1) Air is moving slow enough to be assumed incompressible (< 0.3*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°F
5) Counter flow, finned tube heating coil is uesd in this system.
6) Flow velosity of water in tube be 4fps.(Erosion limit of copper is 6fps)
7)The tube is made by copper, and fin materrial 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 infomation are shown in figure below
11) Two symmetry inlet lines are used to reduce the size of duct.

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 coefficent
v: Velocity
V: Volume
W: Width
α: Heat thansfer area/total volume (defined below in figure)
γ: Inner/outer pipe surface area ratio
δ: Area ratio
ΔP:Pressure drop
ΔT: Temperature difference
ε: Effectiveness
η: Efficiency
μ: Dynamic viscosity
ρ: Density
σ: Free-flow area/frontal area (defined in figure below)
Ω: Total heat transfer volume



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, σ: 0.481

Heat transfer area/Total volume, α: 169 ft^2/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:

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

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

Building heat by beehives:

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

Building temperature raise by:

Aire properties are take at 4 degree:

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

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

Air temperature in duct after heating coil:

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

With 30% return air:

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

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

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

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

With 2 inlet line, each branch has heat transfer:

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

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

Therefor each branch need heat 7.85*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)[a]		
Throwaway filter	200–800		
Heating coil	400–500 (200 min, 1500 max)		
Cooling coil	500–600		

Source: Howell, Sauer, and Coad [9].
[a] *Ductulator*, Trane US Inc., La Crosse, Wisconsin.

Air temperature changes:

$$\Delta T_{air} := T_{air.out} - T_{air.in} = 48.5692\ \Delta °F$$

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

4 times slower than air temperature changes:

$$\Delta T_{water} := \frac{\Delta T_{air}}{4} = 12.1423\ \Delta °F$$

Average water temperature: $T_{w.avg} := 145\ °F$ $V := 4\ \frac{ft}{s}$

For water at 151F:

$$Pr := 2.73$$

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

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

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 corrlation eqution:

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

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

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

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

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

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

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

Reynolds number based on Gm:

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

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:

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

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

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

For aluminnum fin: $k_{fin} := 100 \frac{BTU}{hr\ ft\ \Delta°F}$

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

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

Tube outer diameter is: $r := \frac{0.676}{2} \ in = 0.0282 \ ft$

from the figure above: $x_t := 1.5 \ in$ $x_L := 1.75 \ in$

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

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

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

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

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

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 γ:

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

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

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

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

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

Fluid	R_f ((ft^2 h °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

ε-NTU method is uesd to determine the overall heat transfer coefficient(U_FT):

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

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

The capacity ratio c:

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

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

The effectiveness is:

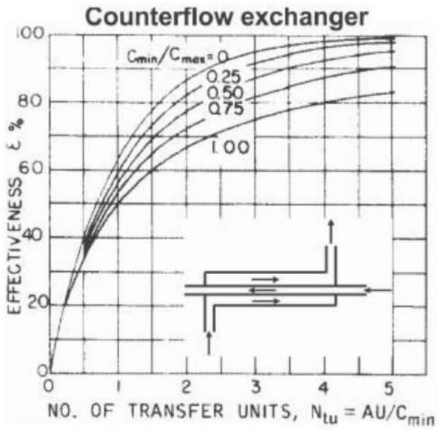
$$\varepsilon := \frac{T_{req} - T_{air.in}}{T_{w.in} - T_{air.in}} = 0.3343$$

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 ε=30%, c=0.2

With c and ε 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 thansfer area:

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

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 tranfer area to th total volume:

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

Face area normal to air flow direction:

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

Depth of heat exchange system W:

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

The number of tube row:

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

The tube number per row:

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

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

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

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

The total heigh of the heating coil is:

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

Lenght of the heating coil is

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

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

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

Pressure loss of air across the tube coils is:

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

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

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

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

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

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

Pressure loss of water in the tube coils:

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

From Moody chart, Re=41789, for copper tube, ε/d=0.0001

$$f_w := 0.022$$

$K := 2$ for 180 bend

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

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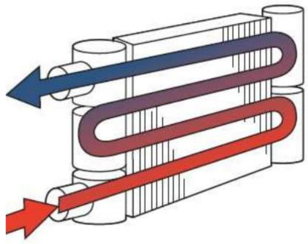
From Daikun water heating speedsheet:

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	120	126	132	138	141
*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	4.5	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	10.0	—	—	—	—
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	12.5	—	—	—	—
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	15.0	—	—	—	—
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	17.5	—	—	—	—
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	20.0	—	—	—	—
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	22.5	—	—	—	—
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	25.0	—	—	—	—
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	27.5	—	—	—	—
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	30.0	—	—	—	—
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	32.5	—	—	—	—
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	35.0	—	—	—	—
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	37.5	39.4	41.3	43.1	44.1
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	40.0	42.0	44.0	46.0	47.0
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	44.6	46.8	48.9	49.9
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	47.3	49.5	51.8	52.9

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^2 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	54
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	36
5MH	1, 2	—	—	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
5MQ	1	—	—	2	—	3	—	4	—	5	—	6	—	7	—	8	—	9
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*	18*
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	27
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	36
5WM	4	—	—	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54
5WD	4	—	—	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72

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

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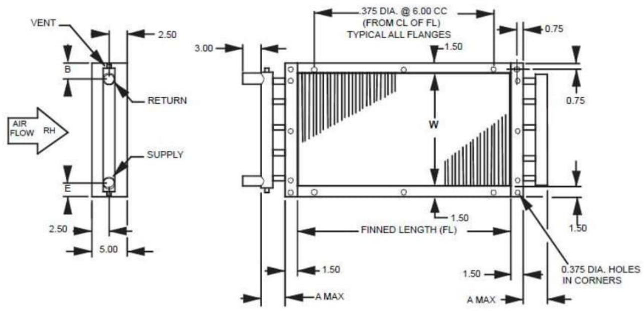
Therefore, the fin height will be 36 inches.

Figure 15: 5W Coils – 1- and 2-Row (12" to 42" Fin Height)

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 rows depth will be 5inches.

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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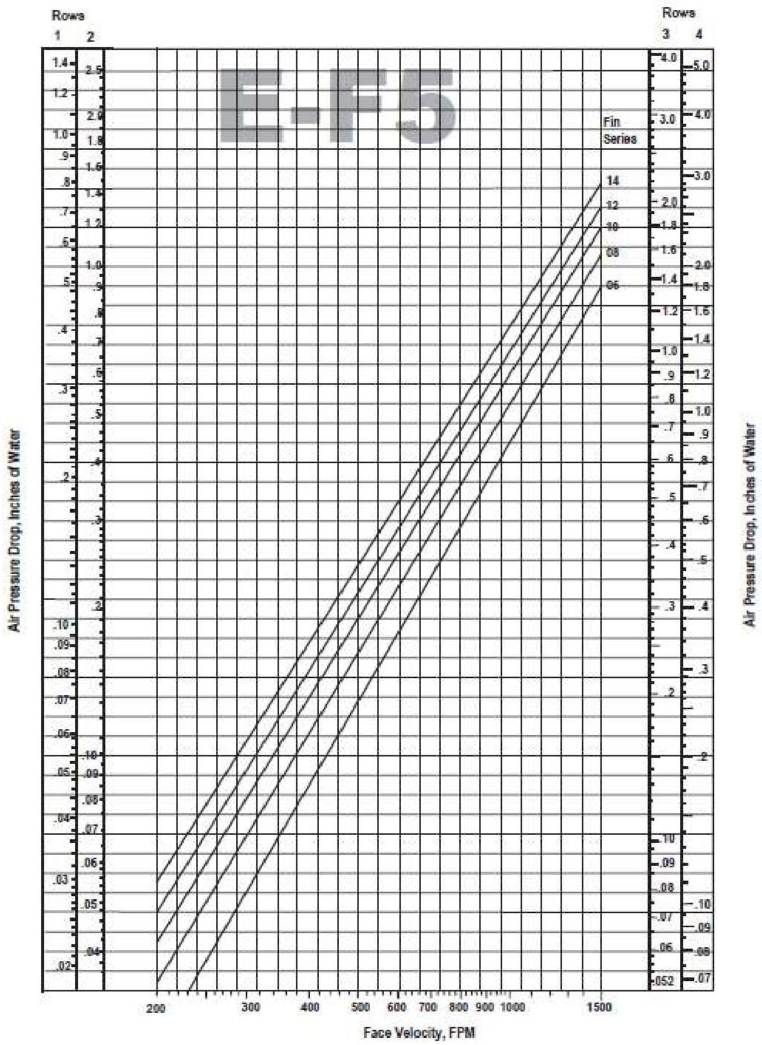

Nomenclature

5W H - 10 02 C - 033.0 – 090.0

Coil Type
Water: 5M, 5W
Booster: 5B

Circuiting

Water:
Q = 1/4 Serpentine
H = 1/2 Serpentine
L = 3/4 Serpentine
S = 1 Serpentine
M = 1-1/2 Serpentine
D = 2 Serpentine
B = 3" Tube Center

Booster:
S = 1 Circuit
D = 2 Circuit
B = 3" Tube Center

Finned Length
Inches

Fin Height
Inches

Fin Design
B = E-F5
C = HI-F5
A = Flat

Rows Deep
01,02, 03, 04, 05, 06, 08, 10, 12

Fins per Inch
06, 07,08, 09, 10,11, 12,13, 14

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.

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:

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

$ftWg := 2.99\ kPa$

Assumptions:

1) Assume that the spaces wil 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 inche 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: $V_{coil} := 4 \frac{ft}{s}$

Inner diameter of heating coil: $D_{i.coil} := 0.596\ in$

Inlet water temperature: $T_{in} := 40\ °F$

Outlet water temperature: $T_{out} := 150\ °F$

Oversizing factor: $OFS := 1.23$

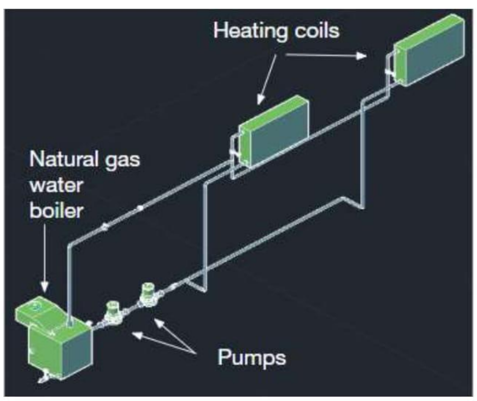
Pressure drop in heating coil: $H_{coil} := 32.124\ ft$

Total pipe length: $L_{tot} := 205.12\ ft$ (From heating coil calculation)

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:

$$T_{ave} := \frac{T_{in} + T_{out}}{2} = 95\ °F$$

water property at 95F:

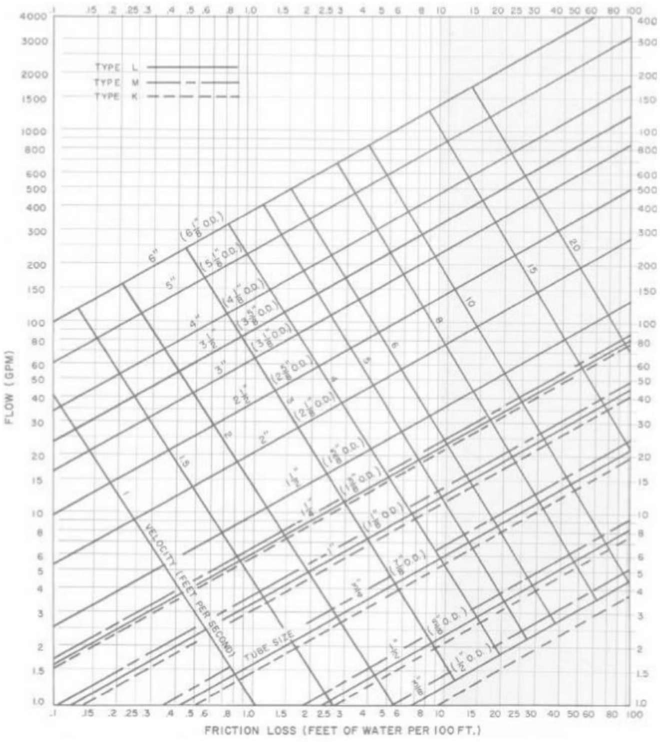
$$\rho_{water} := 62.057\ \frac{lb}{ft^3} \qquad c_p := 1\ \frac{BTU}{lb\ \Delta °F}$$

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:

Diameter: $D_{main} := 1\ in$

flow velocity: $V_{main} := 2.7\ fps$

Pressure loss $P_{tube} := 3.2\ \frac{ft}{100\ ft}$

$L_{main} := 34.3\ ft$

Major Head loss:

Main line:

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

Heating coil 1:

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

Heating coil 2:

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

Table A.14 Loss coefficients for pipe fittings

	Screwed				Flanged				
Nominal Diameter (in.)	½	1	2	4	1	2	4	8	20
Valves (FO)									
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[a]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Gate valve[a]	¼C	½ C	¾ C						
	0.3	2.1	17						
Foot valve with strainer[a,b]	Poppet disk	Hinged disk							
	7	1.25							
Elbows									
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
Tees									
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
Expansion[c]	*d/D*	*d/D*	*d/D*	*d/D*					
	0.2	0.4	0.6	0.8					
$K_{expansion}$	0.30	0.25	0.15	0.10					
Contraction[c]:	60° contraction angle								
	0.07								

Minor Loss:

$$K_1 := \Sigma K_1 \frac{V^2}{2\ g}$$

Main Line:

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

and 2 tee line flow,

The minor head losses, the loss coefficients for the bends, fittings, and values 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 $K_{Tee} := 1$

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

Heating coil 1:

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

Tee branch $K_{Tee.branch} := 1.8$

90 degree bend: $K_{90.bend} := 1.5$

Ball Valve: $K_{ball} := 0.05$

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

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: $K_{ball} := 0.05$

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

Total pressure loss:

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

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

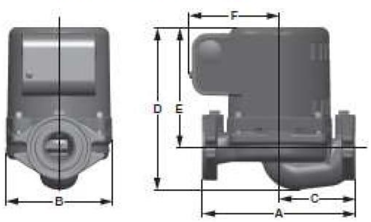
Conclusion:

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

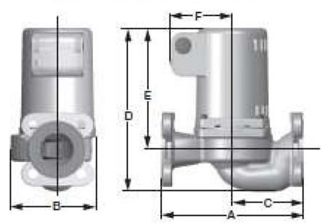
The pump head will be 37ft with 14GPM water flow rate, so in order to reduce the pump head each pump, we use two identical pump connected in series. Therefore, each pump has pump hea 13.5ft with same water flow rate.

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

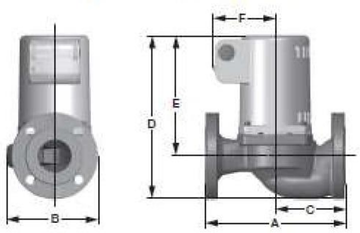
Models 2400-10-3P thru 2400-50S/2-3P



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.

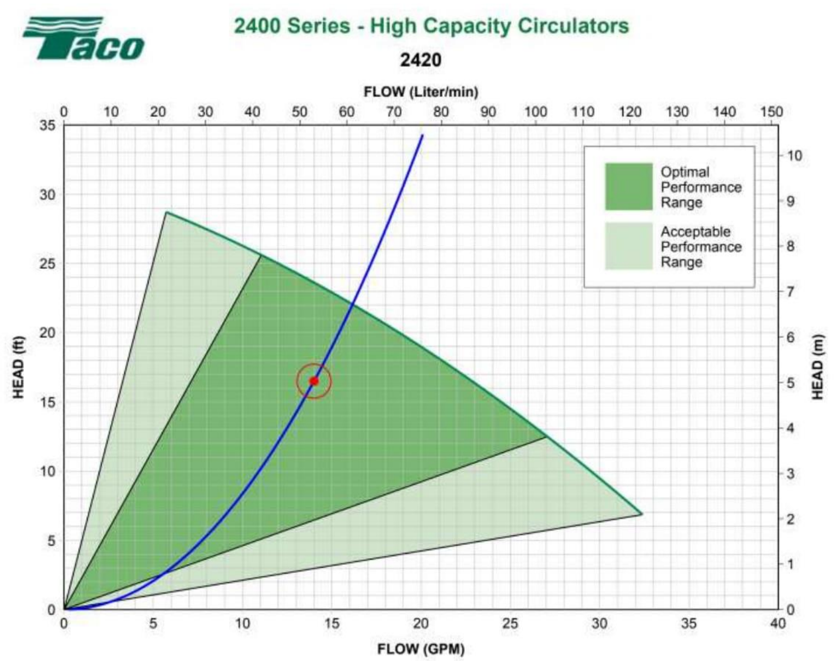
CAST IRON MODEL	STAINLESS STEEL MODEL	A		B		C		D		E		F		SHIP WEIGHT	
		IN.	MM	IN.	MM	IN.	MM	IN.	MM	IN.	MM	IN.	MM	LBS.	KG
2400-10-3P	2400-10S-3P	6 3/8	162	4 1/2	114	3 3/16	82	6 7/8	175	5	127	3 3/4	95	11.5	5.3
2400-20-3P	2400-20S-3P	6 3/8	162	4 1/2	114	3 3/16	82	6 7/8	175	5	127	3 3/4	95	12.0	5.5
2400-30-3P	2400-30S-3P	8 1/2	216	4 3/4	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 3/4	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 3/8	162	4 5/8	119	3 3/16	82	8 3/4	222	6 7/8	175	3 3/4	95	15.0	6.8
2400-50-3P	2400-50S-3P	6 3/8	162	4 5/8	119	3 3/16	82	8 3/4	222	6 7/8	175	3 3/4	95	16.0	7.3
2400-50/2-3P	2400-50S/2-3P	6 3/8	162	5 1/4	133	3 3/16	82	8 3/4	222	6 7/8	175	3 3/4	95	16.5	7.5
2400-60-3P	2400-60S-3P	8 1/2	216	5 3/16	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.

Electrical Data

Model No.	Hz	Ph	115V Amps	230V Amps	RPM	HP
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 Ptotected					

Noryl® is a registered trademark of General Electric Co.



Boiler selected:

Heat reqired to keep the building

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

With the consideration of boiler OFS:

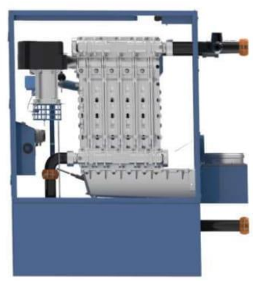
$$Q_{boiler} := Q \cdot OFS = 9.37 \cdot 10^5 \ \frac{\text{BTU}}{\text{hr}}$$

Mach condensing boiler C1050 from Patterson Kelley.

Natural gas water boiler

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

Fuel flow rate: 14cfm



BOILER RATINGS	CM300	CM399	CM500	C750	C900	C1050	C1500	C2000	C2500	C3000	C4000
EFFICIENCY	93.0%	93.1%	93.2%	93.9%	93.9%	93.9%	94.3%	95.7%	94.4%	93.1%	94.1%
MAX BTU/HR INPUT	300,000	399,000	500,000	750,000	900,000	1,050,000	1,500,000	2,000,000	2,500,000	3,000,000	4,000,000
MAX KW INPUT	88	116.9	146.5	219.8	263.8	307.7	439.6	586.1	732.7	879.2	1172.3
MAX BTU/HR OUTPUT	279,000	371,400	456,500	704,250	845,100	985,950	1,414,500	1,902,000	2,360,000	2,733,000	3,764,000
MAX KW OUTPUT	82	108.8	133.6	206.4	247.7	289.0	414.5	557.4	691.6	801.0	1103.1
MIN FLOW @ IGNITION (GPM)	16.0	16.5	16.1	38.3	40.9	44.7	69.4	62.4	145.3	128.6	150.9
MIN FLOW @ IGNITION (L/SEC)	1.0	1.0	1.0	2.5	2.6	2.8	4.4	4.8	9.2	8.1	9.6
MIN BTU/HR INPUT	60,000	79,800	100,000	150,000 / 75,000	180,000 / 90,000	210,000 / 105,000	300,000	400,000	500,000	600,000	800,000
MIN KW INPUT	17.6	23.4	29.3	44.0 / 22.0	52.8 / 26.4	61.5 / 30.8	87.9	117.2	146.5	175.8	234.5
MIN BTU/HR OUTPUT	55,800	74,294	91,200	140,850 / 70,425	169,020 / 84,510	197,190 / 98,595	282,900	380,400	472,000	546,600	752,800
MIN KW OUTPUT	16.4	21.8	26.7	41.3 / 20.6	49.5 / 24.8	57.8 / 28.9	82.9	111.5	138.3	160.2	220.6
INDOOR/OUTDOOR	INDOOR	INDOOR	INDOOR	INDOOR / OUTDOOR	INDOOR / OUTDOOR	INDOOR / OUTDOOR	INDOOR	INDOOR	INDOOR	INDOOR	INDOOR
TURNDOWN	5:1	5:1	5:1	5:1/10:1*	5:1/10:1*	5:1/10:1*	5:1	5:1	5:1	5:1	5:1
FUEL NG=NATURAL GAS, LP=PROPANE, DF=DUALFUEL	NG LP	NG LP	NG LP	NG LP DF	NG LP DF	NG LP DF	NG LP DF	NG LP DF	NG LP DF	NG LP DF	NG LP DF
DIMENSIONS	**CM300**	**CM399**	**CM500**	**C750**	**C900**	**C1050**	**C1500**	**C2000**	**C2500**	**C3000**	**C4000**
DEPTH (IN / MM)	21.75/552	21.75/552	42.625 / 1083	42.625 / 1083	42.625 / 1083	66.25 / 1736	72.5 / 1920	58.325 / 1483	58.325 / 1483	62.5 / 1587.5	62.5 / 1587.5
WIDTH (IN / MM)	36.5 / 927	36.5 / 927	28.125 / 713	28.125 / 713	28.125 / 713	30.25 / 769	30.25 / 769	31.75 / 806	31.75 / 806	31.75 / 806	31.75 / 806
HEIGHT (IN / MM)	34 / 862	34 / 862	54.625 / 1387	54.625 / 1387	54.625 / 1387	56 / 1423	56 / 1423	78.75 / 2000	78.75 / 2000	78.75 / 2000	78.75 / 2000

*P-K MACH® Models C750, C900, and C1050 with 10:1 mechanical turndown are only available for Natural Gas (NG) applications.

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:

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

Known Data:

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

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

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

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

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

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

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

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

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

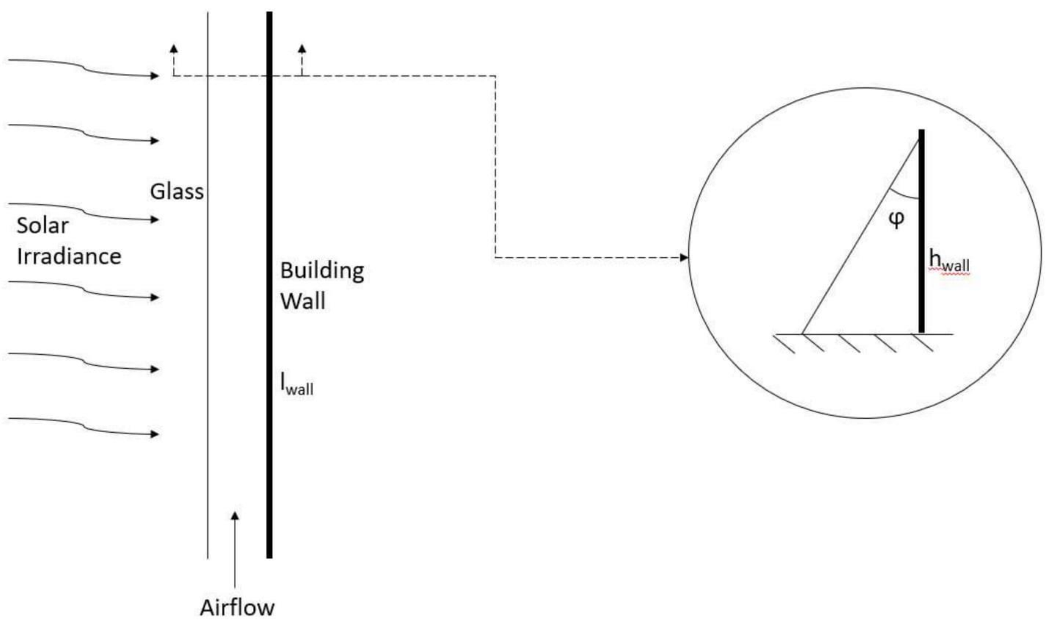
Assumptions:

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*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.

Variable Definitions:

```
  A: Area
  C: Cost
 Cp: Specific heat capacity
D_h: Hydraulic diameter
  E: Solar irradiance
  f: Friction factor
g_e: Gravitational acceleration
  h: Convective heat transfer coefficient
  H: Height
H_l: 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:



Analysis:

Properties of Air at Design Temperature: $T_\infty = -7.9\ °C$

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

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

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

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

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: $\varphi_{opt} := 21\ deg$

Dimensions:

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

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

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

$E_{Jan} := 1.84\ \frac{kW\ hr}{m^2\ day} = 76.6667\ \frac{W}{m^2}$

$E_{Feb} := 2.97\ \frac{kW\ hr}{m^2\ day} = 123.75\ \frac{W}{m^2}$

$E_{Mar} := 4.06\ \frac{kW\ hr}{m^2\ day} = 169.1667\ \frac{W}{m^2}$

$E_{Oct} := 2.99\ \frac{kW\ hr}{m^2\ day} = 124.5833\ \frac{W}{m^2}$

$E_{Nov} := 2.07\ \frac{kW\ hr}{m^2\ day} = 86.25\ \frac{W}{m^2}$

$E_{Dec} := 1.24\ \frac{kW\ hr}{m^2\ day} = 51.6667\ \frac{W}{m^2}$

(Solar Electricity Handbook)

Average Solar Heat Generation:

$q_{JanSolar} := \Omega_{glass} \cdot E_{Jan} \cdot A_{glass} = 6648.9361\ W$

$q_{FebSolar} := \Omega_{glass} \cdot E_{Feb} \cdot A_{glass} = 10732.2501\ W$

$q_{MarSolar} := \Omega_{glass} \cdot E_{Mar} \cdot A_{glass} = 14671.0221\ W$

$q_{OctSolar} := \Omega_{glass} \cdot E_{Oct} \cdot A_{glass} = 10804.5212\ W$

$q_{NovSolar} := \Omega_{glass} \cdot E_{Nov} \cdot A_{glass} = 7480.0531\ W$

$q_{DecSolar} := \Omega_{glass} \cdot E_{Dec} \cdot A_{glass} = 4480.8048\ W$

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

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

Internal Convection Coefficient:

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

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

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

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

Check Incompressibility Assumption: $M := \frac{v_{avg}}{343\ \frac{m}{s}} = 0.0091$ 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 t 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: $h_{int} := \frac{Nu \cdot k_{air}}{D_h} = 1.6058\ \frac{BTU}{ft^2\ hr\ \Delta°F}$

Heat Conduction Through Glass:

Check if conduction is significant compared to convection:

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

$\frac{R_{cond}}{R_{intconv}} = 0.038$ Since conduction is less than 5% of the internal convection, car 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

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

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

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: $L_{critical} := \frac{500000 \cdot \mu_{air}}{\rho_{air} \cdot v_{wind}} = 5.0399 \; ft$ 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: $h_{ext} := \frac{Nu_{ext} \cdot k_{air}}{L_{wall}} = 1.9227 \; \frac{BTU}{ft^{2} \; hr \; \Delta°F}$

Finding Heat Loss in Solar Heater Due to Convection:

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

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.

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

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

$$T_{avg} := \frac{T_{intMax} + T_{\infty}}{2} = -7.6355 \; °C$$

Iteration 1:

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

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

$$T_{avg} := \frac{T_{intMax} + T_{\infty}}{2} = -7.6396 \; °C$$

Iteration 2:

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

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

$$T_{avg} := \frac{T_{intMax} + T_{\infty}}{2} = -7.6395 \; °C$$

Iteration 3:

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

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

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

Iteration 4:

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

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

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

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

$$T_{intMax} = -7.379\ °C$$

Average Savings:

Assuming operation from November to March (151 days):

$$q_{NovMar} := q_{total} \cdot 151\ day = 31410.5919\ kW\ hr$$

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

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

Pressure Drop:

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

$$\varepsilon := 0.9\ mm$$

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

Friction Factor:

$$f := \left(\frac{1}{-1.8 \cdot \log10\left(\frac{6.9}{Re_{int}} + \left(\frac{\frac{\varepsilon}{D_h}}{3.7}\right)^{1.11}\right)}\right)^2 = 0.0186$$

Head Loss:

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

Converting the head loss to pressure drop:

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

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 heatin 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.

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:

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

Known Data:

Required Flow Rate: $Q := 26400\ cfm$

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

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

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

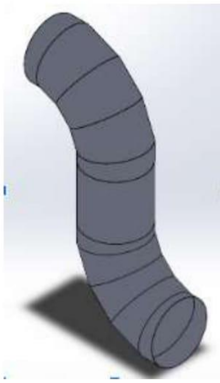
Assumptions:

1) Air is moving slow enough to be assumed incompressible (< 0.3*Speed of Sound)
2) Honeybee heat generation is negligible (honeybee hive thermoregulation is quite effi
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
ΔP: Pressure Drop

Sketch:

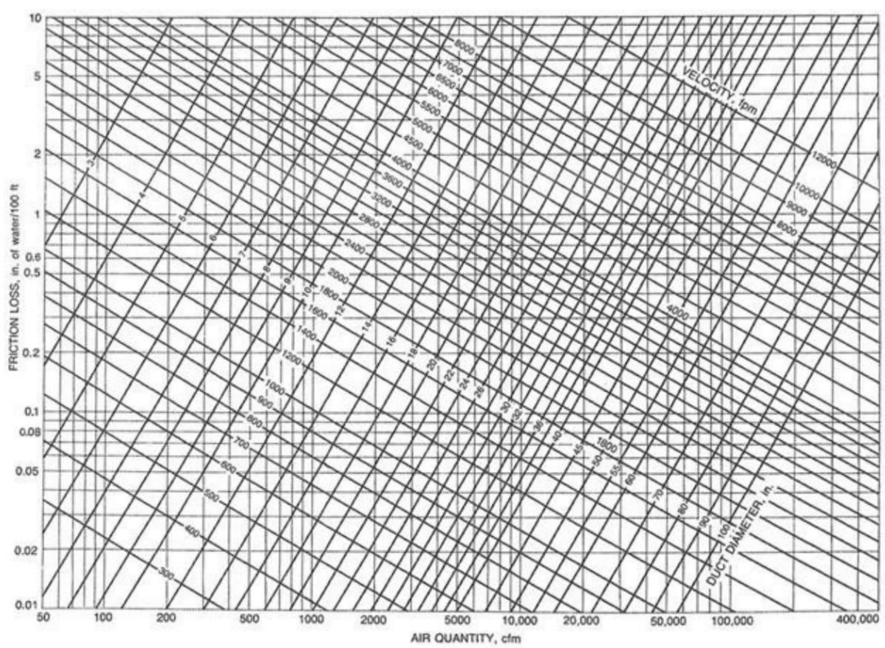


Analysis:

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:

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



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

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

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

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

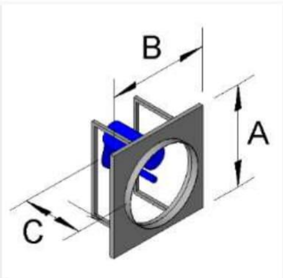
Pressure Drop:

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

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, operati 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.

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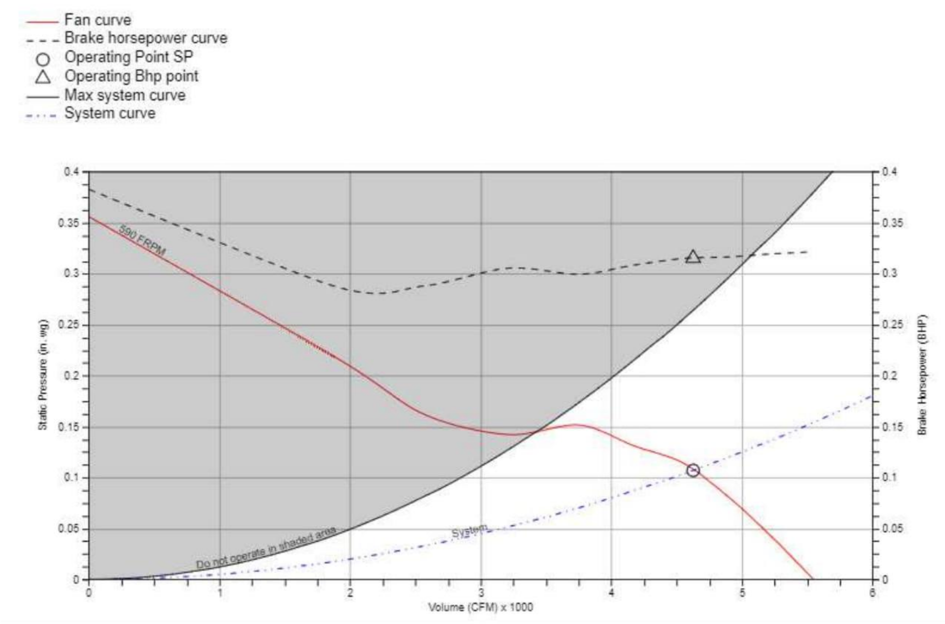
Fan Curves

Fan Chart Type

Operating Conditions



Ceiling fan

There will be 4 ceiling fan introduce to this builidng to circular the air in the buil

With the building size

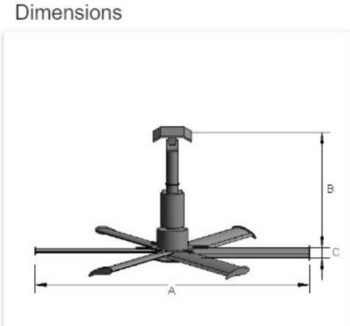
Air flow rate required:

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

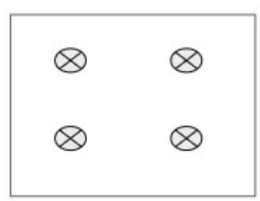
$$Q := 8 \cdot V_{bldg} \cdot \frac{1}{60\ min} = 26400\ cfm$$

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)
DS-8	1	$7,700	8,414	72	200	$10

4 / 5

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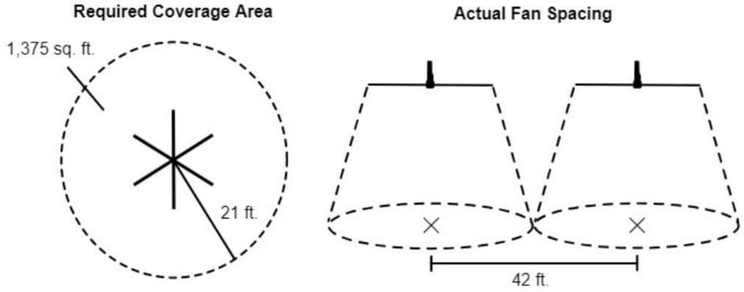
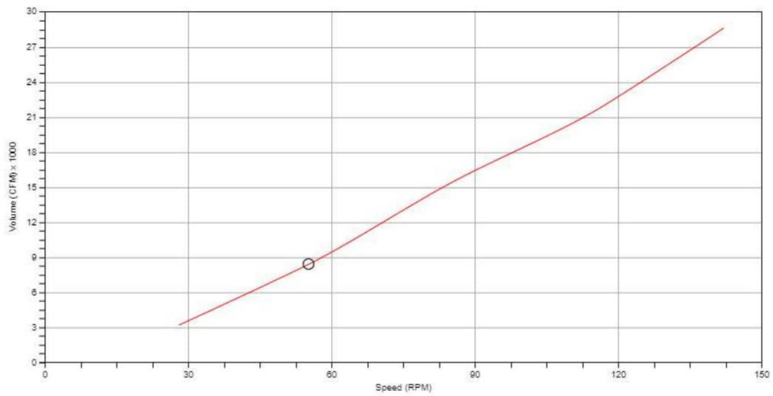
Coverage & Spacing





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: $V := (110\ ft \cdot 100\ ft \cdot 15\ ft) + (3\ ft \cdot 100\ ft \cdot 110\ ft \cdot 0.5) = 5139.5077\ m^3$

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

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

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:

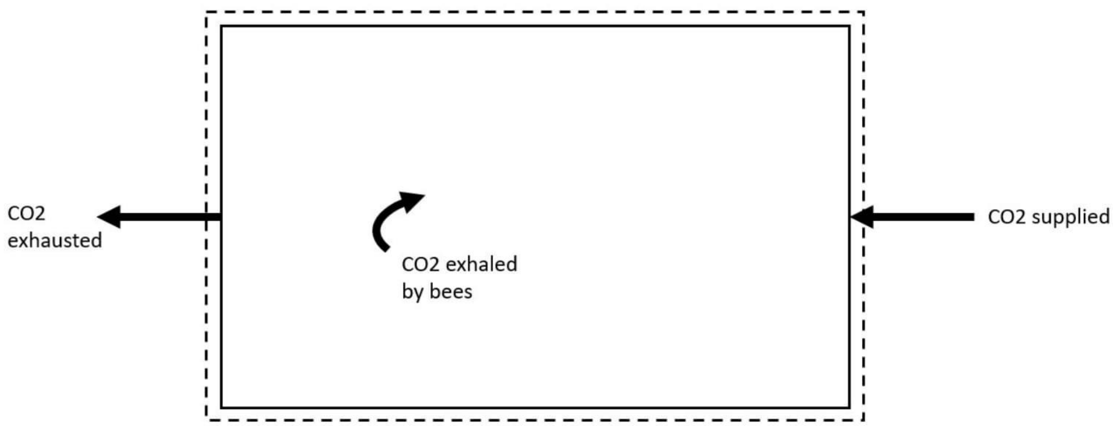
1) Assume atmospheric CO2 levels are constant
2) Assume CO2 is evenly mixed throughout building

1 / 3

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:

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

Per air change:

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

Mass of air in building:

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

Mols of air in building:

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

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 iteratic represents one air change (7.5 minutes).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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 settlinç 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
```

---

[1] 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, *Chief Estimator, Olympia Steel Buildings Canada.* [Interview]. 20 February 2019.	$70,740
	Concrete Slab	11,800	$7/sf	$0.00	Concrete	G. Zakhem, Interviewee, *Chief Estimator, Olympia Steel Buildings Canada.* [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
Sensors	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

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: $C_{mt} := 1.63\ \frac{dollars}{ft^2}$

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

Assumptions:

1) Assume the land is already owned and therefore property tax is the same for either meth
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:

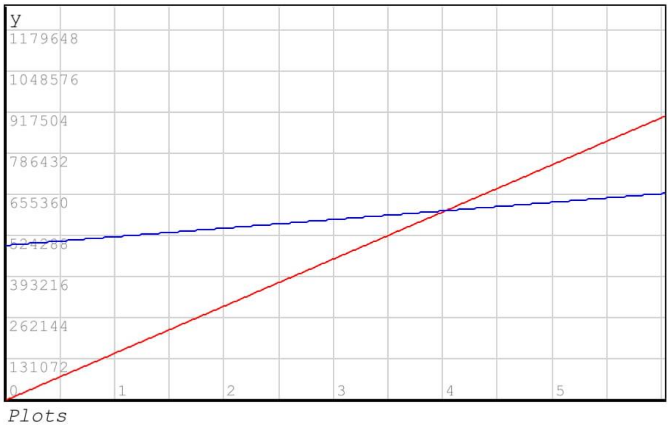
Not applicable.

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...

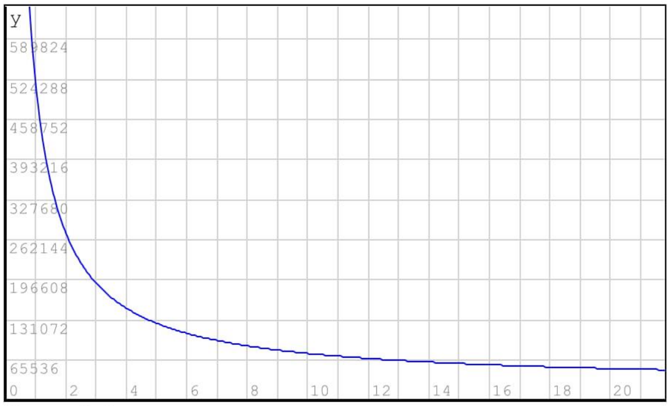
$$Savings := C_{alt}(10) - C_{bldg}(10) = 731943$$

Cost per winter:

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

2 / 3

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

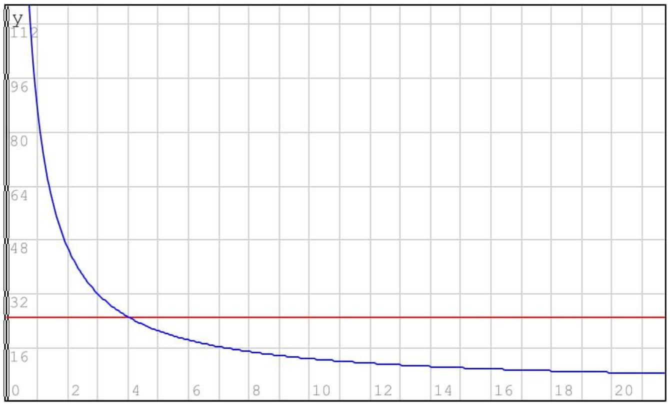


$C_{winter}(x)$

Cost per hive per winter:

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

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



hivecosts

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.

3 / 3

Appendix F: Design Compliance - Client Confirmation

Connie Phillips 7:25 AM CP
RE: MECE E 460: Group 21
To: Manel Ajbouni

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

ALBERTA BEEKEEPERS COMMISSION

APPENDIX G: BUILDING & SENSOR QUOTES

OLYMPIA STEEL BUILDINGS of Canada

SITE LOCATION

Street:
City: CALGARY
Province: AB
Postal Code:

PROJECT NAME / NUMBER

Quote #: SonLe
Date: 2/20/19
Page: 1 Of 2

CONTACT INFORMATION

Name: SON LE
Phone:
Email:
Fax:
Mobile:

BUILDING CODES

Building Code:	AB14 LS	Wind:	90	Collateral Load:	3
Use Category:	Normal	Roof Snow:	20.48	Dead Load:	2.2
		Live Load:	21		
		Seismic Sa (0.2):	0.15	Sa (0.5):	0.09
		Value Sa (1.0):	0.04	Sa (2.0):	0.02

BUILDING SPECS

Width:	110
Length:	136
Eave Height:	15
Roof Pitch:	1.0:12
Peak Offset:	55

BUILDING DETAILS

Endwall Framing

	Post & Beam	Rigid Frame	Exp. Endwall
REW	Y		
LEW	Y		

Roof Panel
Gauge: 26
TYPE: CP

Wall Panel
Gauge: 26
TYPE: CG

Endwall Column Spacing
REW 22
LEW 22

Sidewall Bay Spacing
7 at 19.43

Interior Columns
NONE

Purlin Depth 8

Bracing

REW	Cable Diagonal Bracing
LEW	Cable Diagonal Bracing
FSW	Cable Diagonal Bracing
BSW	Cable Diagonal Bracing

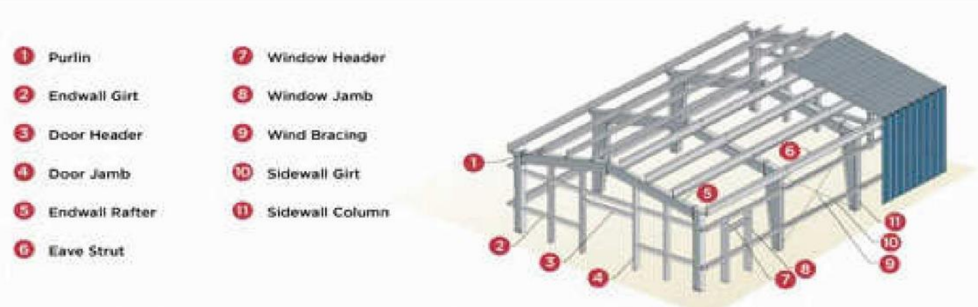
Base Condition
Angle:
Channel: Y
None:

Girt Condition

REW:	Flush
LEW:	Flush
FSW:	Bypass
BSW:	Bypass

Roof Extensions

	Dim.	Gauge
REW		
LEW		
FSW		
BSW		



37 SANDIFORD DRIVE, STE 413, STOUFFVILLE, ON L4A 7X5 1-844-937-8335 www.olympiasteelbuildings.ca

OLYMPIA STEEL BUILDINGS of Canada

BUILDING DETAILS

Framed Openings:

LEW:	3X7
REW:	
FSW:	6X7
BSW:	3X7

Liner Panel:

Roof:	
LEW:	
REW:	
FSW:	
BSW:	

FSW Gutters: 136 BSW Gutters: 136

Insulation Package: Excluded

PROJECT NAME / NUMBER

Quote #: SonLe

Date: 2/20/19

Page: 2 Of 2

STANDARD COLOUR SELECTION

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

BUILDING COST

Building:	$145,886	CAD
Freight:	INCLD.	
Taxes:	EXTRA	
25% ENG Deposit	$36,500	CAD
25% MFG Deposit	$36,500	CAD
Balance:	$72,886	CAD

NOTES

Broker Service Fee is Included in Quote

Industrial Gutters/Downs + Full Trim package incld.
Climatic & Seismic Loads Verified for Calgary, AB
Engineered Stamped Structural Alberta Drawings incld.
40 Yr Structural, 40 yr Paint, 35 Yr Perf Warranties
Actual Doors included
Insulation priced seperately
Quote Valid for 14 Days

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 www.olympiasteelbuildings.ca

Silvercote
A higher degree of insulation

90 Whybank Drive Brampton, ON L7A 0N7
(905) 495-9393
(905) 495-9993 (Fax)

QUOTATION

DATE: Feb 20, 2019

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

CUSTOMER	George W Zakhem Olympia Steel Buildings - Builder 413-37 Sandiford Stouffville, ON L4A 7X5 905-642-9416 -- (Fax)	PROJECT	SONLE CALGARY, AB T1X
QUOTE #	#1-114071-1035250	FOB:	Brampton, ON

BUILDING SIZE 1	WIDTH: 110. Ft.	LENGTH: 136. Ft.	HEIGHT:	15. Ft.	ROOF PITCH:	1. : 12	Double Slope
BUILDING SIZE 2	WIDTH:	LENGTH:	HEIGHT:		ROOF PITCH:		
BUILDING SIZE 3	WIDTH:	LENGTH:	HEIGHT:		ROOF PITCH:		

ROLL WIDTH(S):	ROOF	WALLS
Starter Rolls:	48 In.	
Primary Rolls:	72 In.	
Split Rolls @ Ridge? BLDG 1: No	BLDG 2:	BLDG 3:

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.

FACED INSULATION AND SYSTEMS	QUANTITY	UNIT	EXTENSION
ROOF			
R=40 White Energy Saver System	15,400 s.f.	$1829/msf	$28,166.60
		This quote is being provided in Canadian Currency.	
WALLS			
R=30 White Energy Saver System	8,460 s.f.	$1546/msf	$13,079.16

This price includes 48",60",72" fiberglass, Insul-hold coils, thermal tape, banding, & screws.

UNFACED INSULATION AND ACCESSORIES	QUANTITY		UNIT	EXTENSION
Energy Saver Patch Tape (3" x 150')	2	Roll(s)	$30.00	$60.00
Fuel Surcharge	1	Each	$516.33	$516.33

IMPORTANT - PLEASE READ

We accept responsibility for the accuracy of this estimate providing that you sign below indicating that all building dimensions, deductions, & material selections shown are correct. This quote 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

Silvercote LLC takes responsibility for the thermal performance of our insulation from design, to manufacturing the unfaced blanket, through lamination and delivery to your jobsite. Insulation products that fail to meet the intended R-value prior to installation will be replaced at our expense. For full details you can obtain a copy of our limited warranty on our website at "www.silvercote.com".

This proposal is in Canadian Dollars. Credit Terms: Pending Application Approval

Prepared By: IQ-Web

Randy Edger
Outside Territory Sales Manager
randy.edger@silvercote.cc 905-439-6673

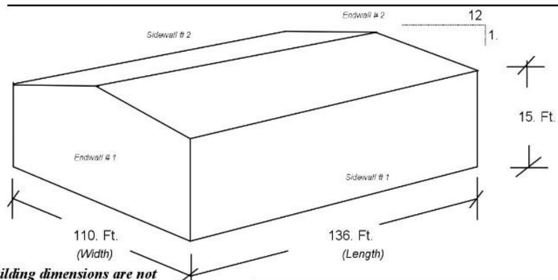
SUB TOTAL:	$41,822.09
FREIGHT:	$6,435.00
SALES TAX:	See Note Above
TOTAL:	$48,257.09

Accepted By: ______________________ Date: ______________

Olympia Steel Buildings - Builder - George W Zak *Visit our Website @ www.silvercote.com* V0/2.5.19-PSInd18--2.75N--21.5-FT6435Volume=1TLs (51ft)

Page 1 of 4

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.

<u>Approx. Weight = 14247 lbs / Approx. Cubic Feet = 4541 for all Buildings</u>

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.

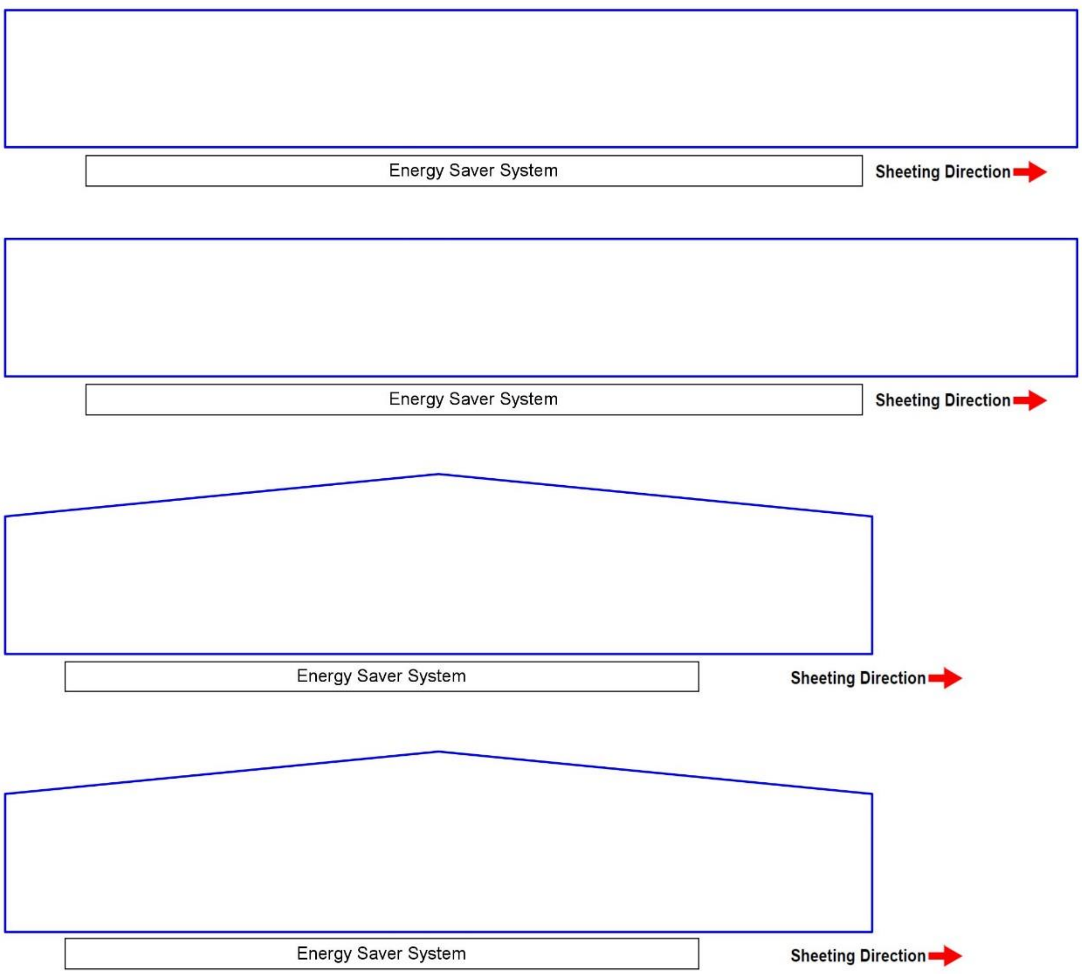
TECHNICAL ADVICE. Any recommendations, technical advice, or assistance furnished by Silvercote concerning the characteristics, properties, or performance of the products are based on data believed to be reliable, and are furnished solely on a gratis basis. Since Silvercote does not control or supervise 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.

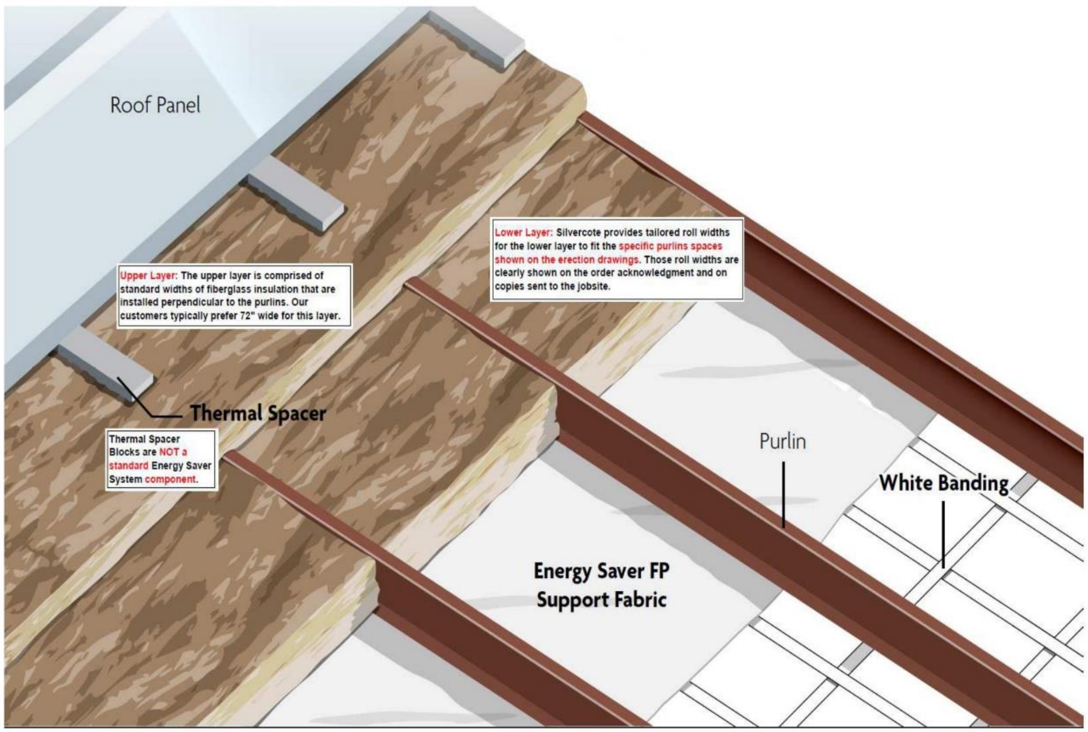
CUSTOMER: Olympia Steel Buildings - Builder
PROJECT NAME: SONLE
ORDER NUMBER:

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

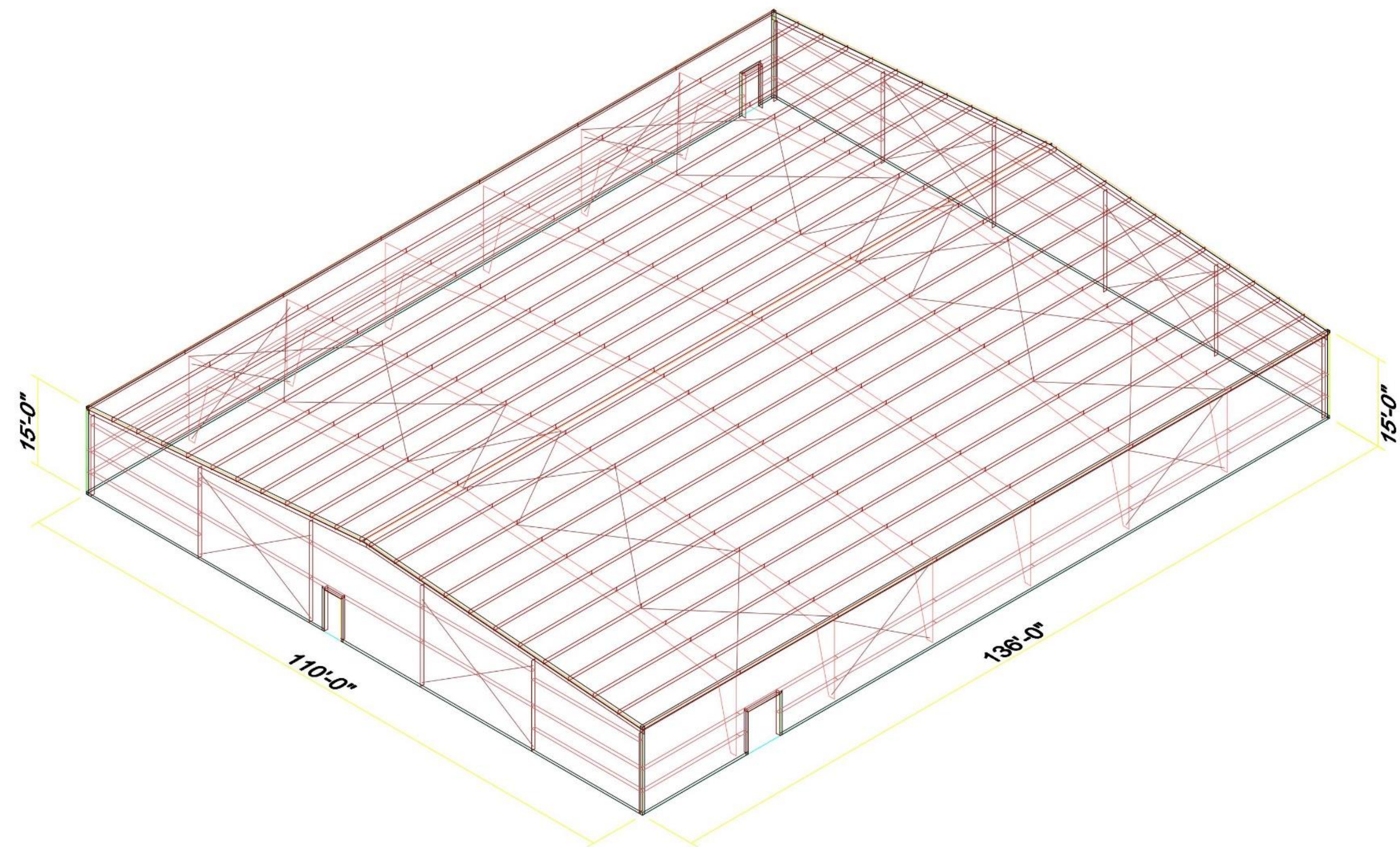


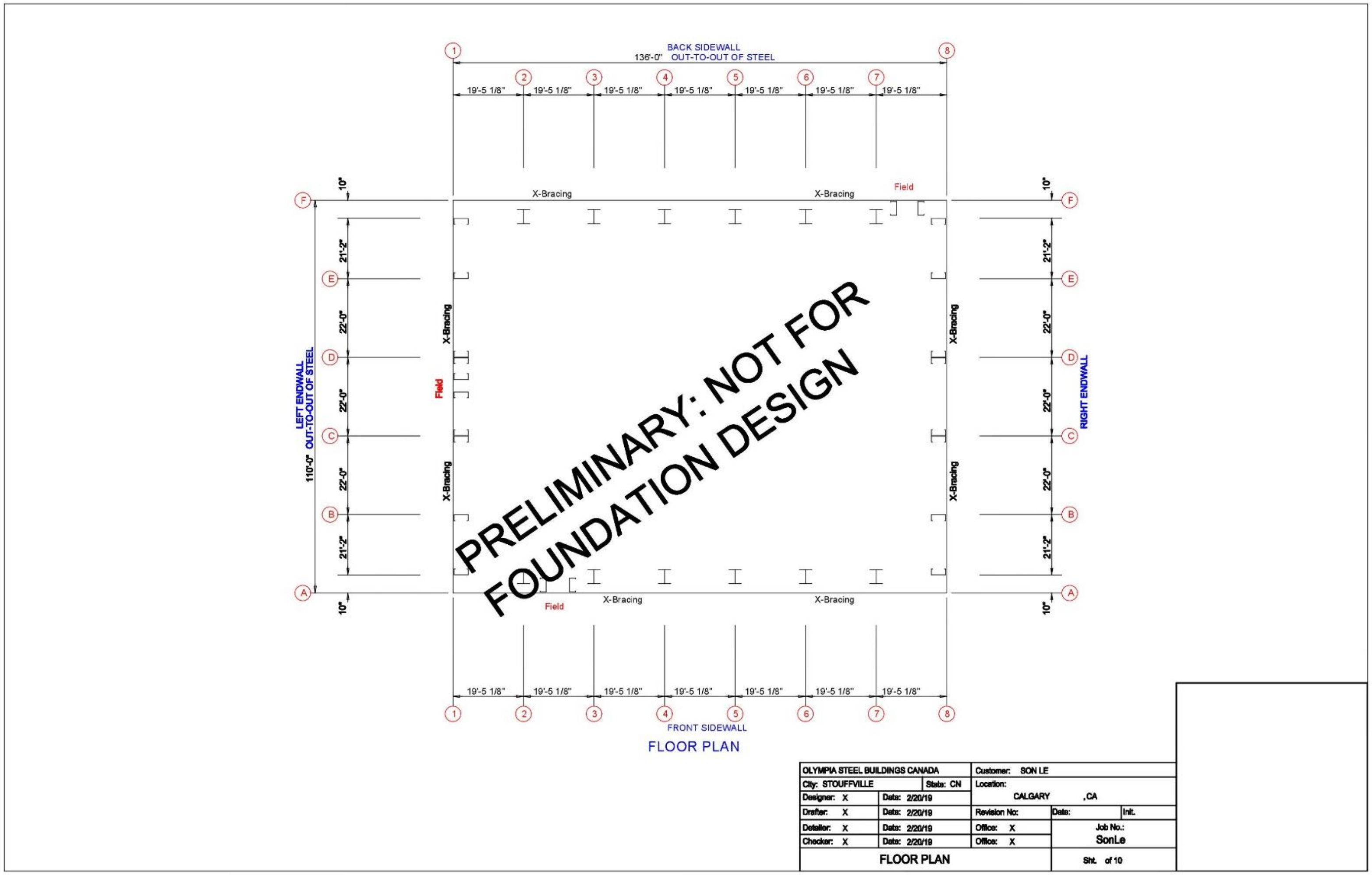
CUSTOMER: Olympia Steel Buildings - Builder
PROJECT NAME: SONLE
ORDER NUMBER:

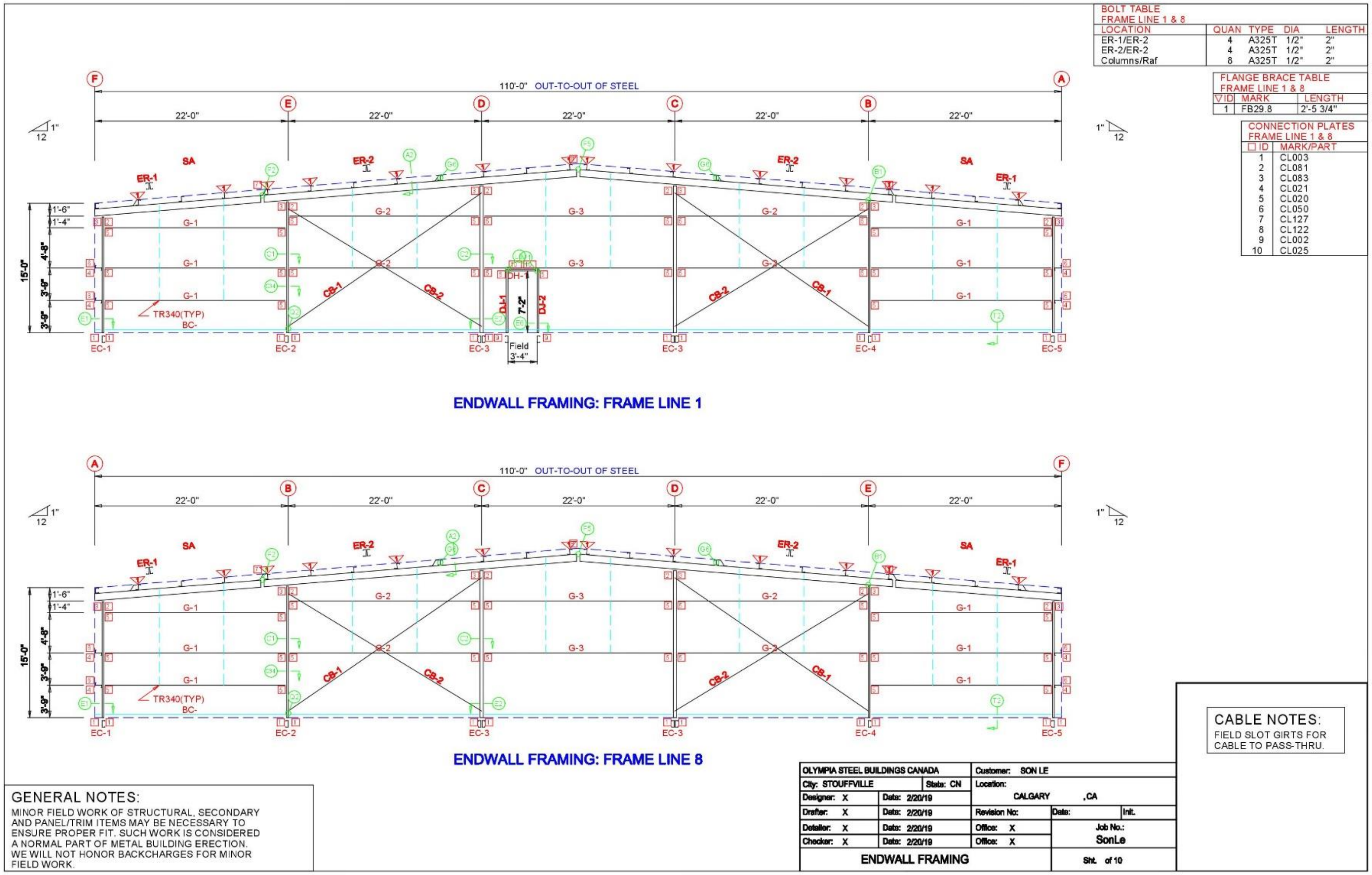
110' W x 136' L x 15' Eave 1:12 Pitch

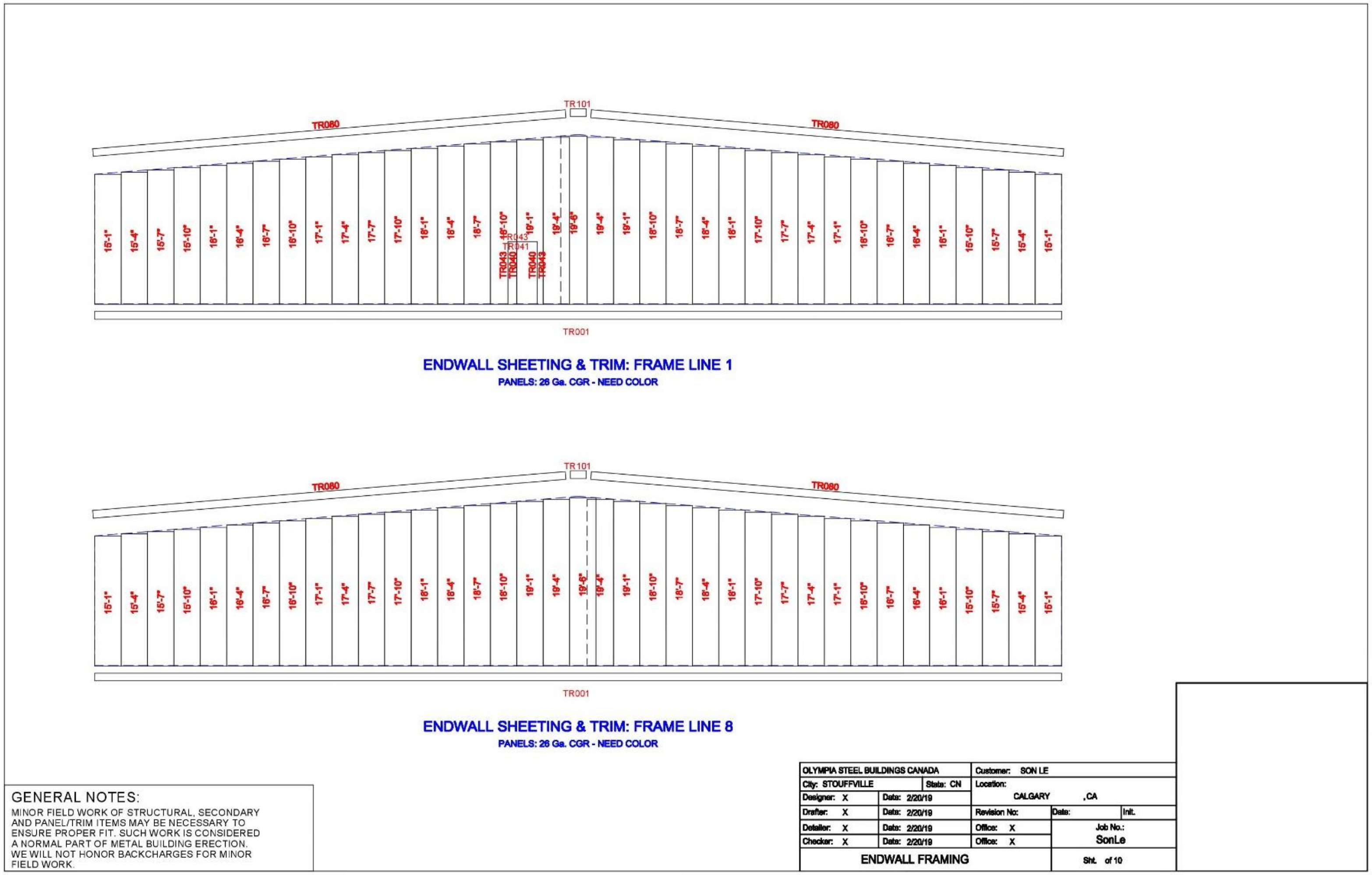


R=40 White Energy Saver System consisting of 9 1/4 Inch R-30 lower layer & R-10 upper layer.


15'-0"
15'-0"
110'-0"
136'-0"


BACK SIDEWALL
136'-0" OUT-TO-OUT OF STEEL
X-Bracing
Field
LEFT ENDWALL
110'-0" OUT-TO-OUT OF STEEL
RIGHT ENDWALL
PRELIMINARY: NOT FOR FOUNDATION DESIGN
FRONT SIDEWALL
FLOOR PLAN
OLYMPIA STEEL BUILDINGS CANADA
City: STOUFFVILLE State: CN
Customer: SON LE
Location: CALGARY ,CA
Designer: X Date: 2/20/19
Drafter: X Date: 2/20/19
Detailer: X Date: 2/20/19
Checker: X Date: 2/20/19
Revision No: Date: Init.
Office: X
Job No.: SonLe
FLOOR PLAN
Sht. of 10

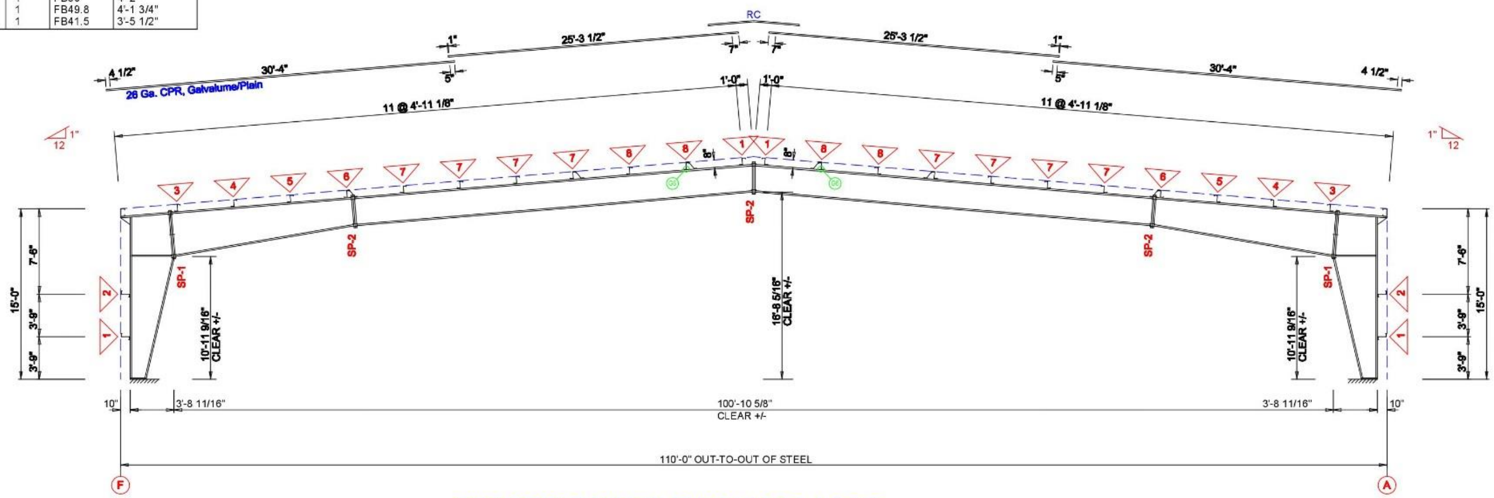

BOLT TABLE
FRAME LINE 1 & 8
LOCATION QUAN TYPE DIA LENGTH
ER-1/ER-2 4 A325T 1/2" 2"
ER-2/ER-2 4 A325T 1/2" 2"
Columns/Raf 8 A325T 1/2" 2"
FLANGE BRACE TABLE
FRAME LINE 1 & 8
ID MARK LENGTH
1 FB29.8 2'-5 3/4"
CONNECTION PLATES
FRAME LINE 1 & 8
ID MARK/PART
1 CL003
2 CL081
3 CL083
4 CL021
5 CL020
6 CL050
7 CL127
8 CL122
9 CL002
10 CL025
110'-0" OUT-TO-OUT OF STEEL
22'-0"
ER-1
ER-2
SA
G-1
G-2
G-3
CB-1
CB-2
DH-1
DJ-1
DJ-2
7'-2"
Field
3'-4"
TR340(TYP)
BC-
15'-0"
EC-1
EC-2
EC-3
EC-4
EC-5
ENDWALL FRAMING: FRAME LINE 1
ENDWALL FRAMING: FRAME LINE 8
CABLE NOTES:
FIELD SLOT GIRTS FOR
CABLE TO PASS-THRU.
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
City: STOUFFVILLE State: CN
Designer: X Date: 2/20/19
Drafter: X Date: 2/20/19
Detailer: X Date: 2/20/19
Checker: X Date: 2/20/19
Customer: SON LE
Location: CALGARY ,CA
Revision No: Date: Init.
Office: X
Office: X
Job No.: SonLe
ENDWALL FRAMING
Sht. of 10


TR101
TR080
TR080
TR001
ENDWALL SHEETING & TRIM: FRAME LINE 1
PANELS: 26 Ga. CGR - NEED COLOR
TR101
TR080
TR080
TR001
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
City: STOUFFVILLE
State: CN
Customer: SON LE
Location:
CALGARY ,CA
Designer: X
Date: 2/20/19
Drafter: X
Date: 2/20/19
Revision No:
Date:
Init.
Detailer: X
Date: 2/20/19
Office: X
Job No.:
Checker: X
Date: 2/20/19
Office: X
SonLe
ENDWALL FRAMING
Sht. of 10

SPLICE BOLT TABLE						
Mark	Qty Top	Bot	Int	Type	Dia	Length
SP-1	4	4	2	A325	0.875	3.00
SP-2	4	4	0	A325	0.625	2.25

FLANGE BRACE TABLE
FRAME LINE 2 3 4 5 6 7

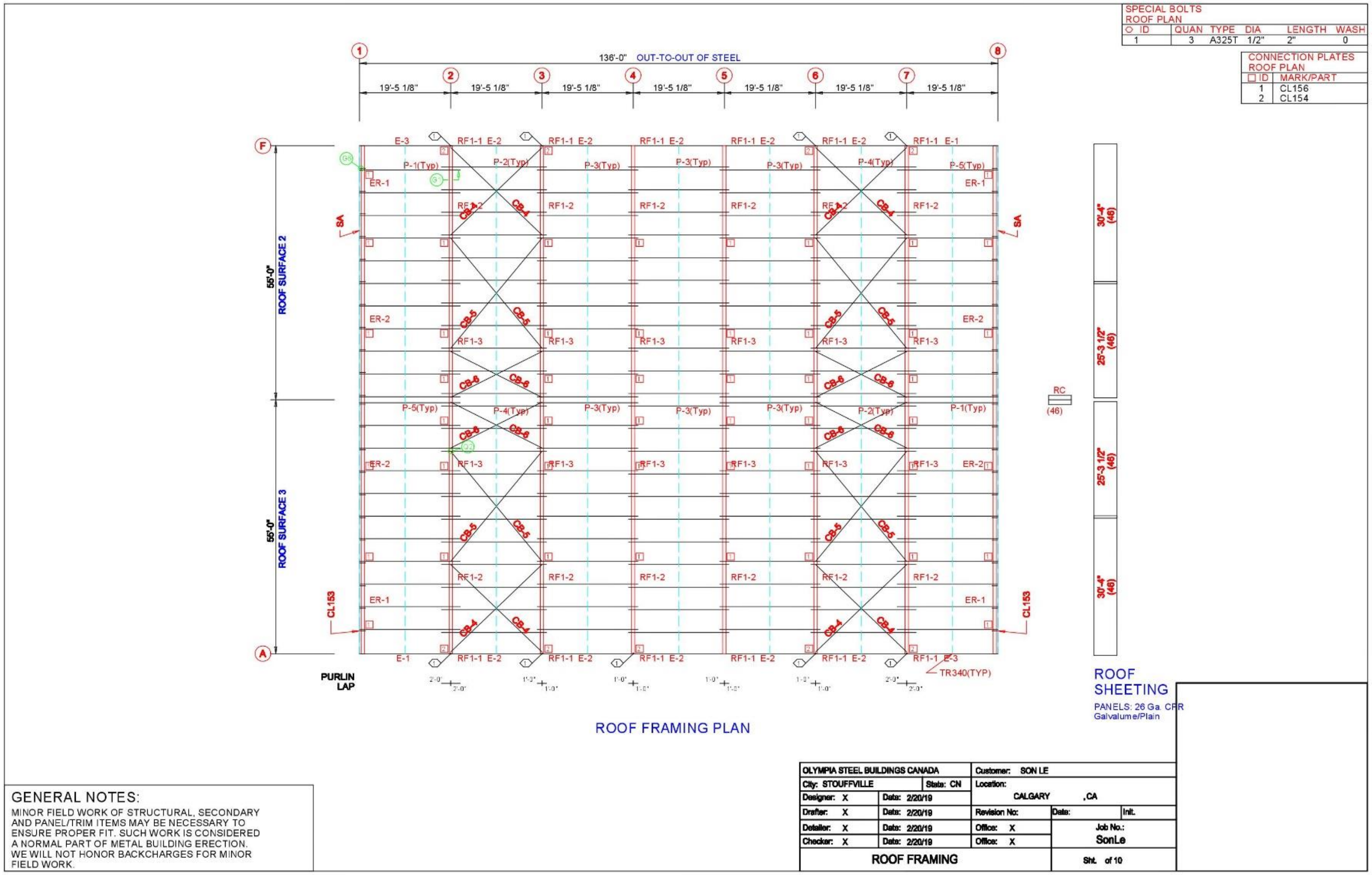
▽ ID	# SIDES	MARK	LENGTH
1	1	FB41.3	3'-5 1/4"
2	1	FB57	4'-9"
3	2	FB62	5'-2"
4	2	FB57.8	4'-9 3/4"
5	2	FB53.8	4'-5 3/4"
6	1	FB50	4'-2"
7	1	FB49.8	4'-1 3/4"
8	1	FB41.5	3'-5 1/2"

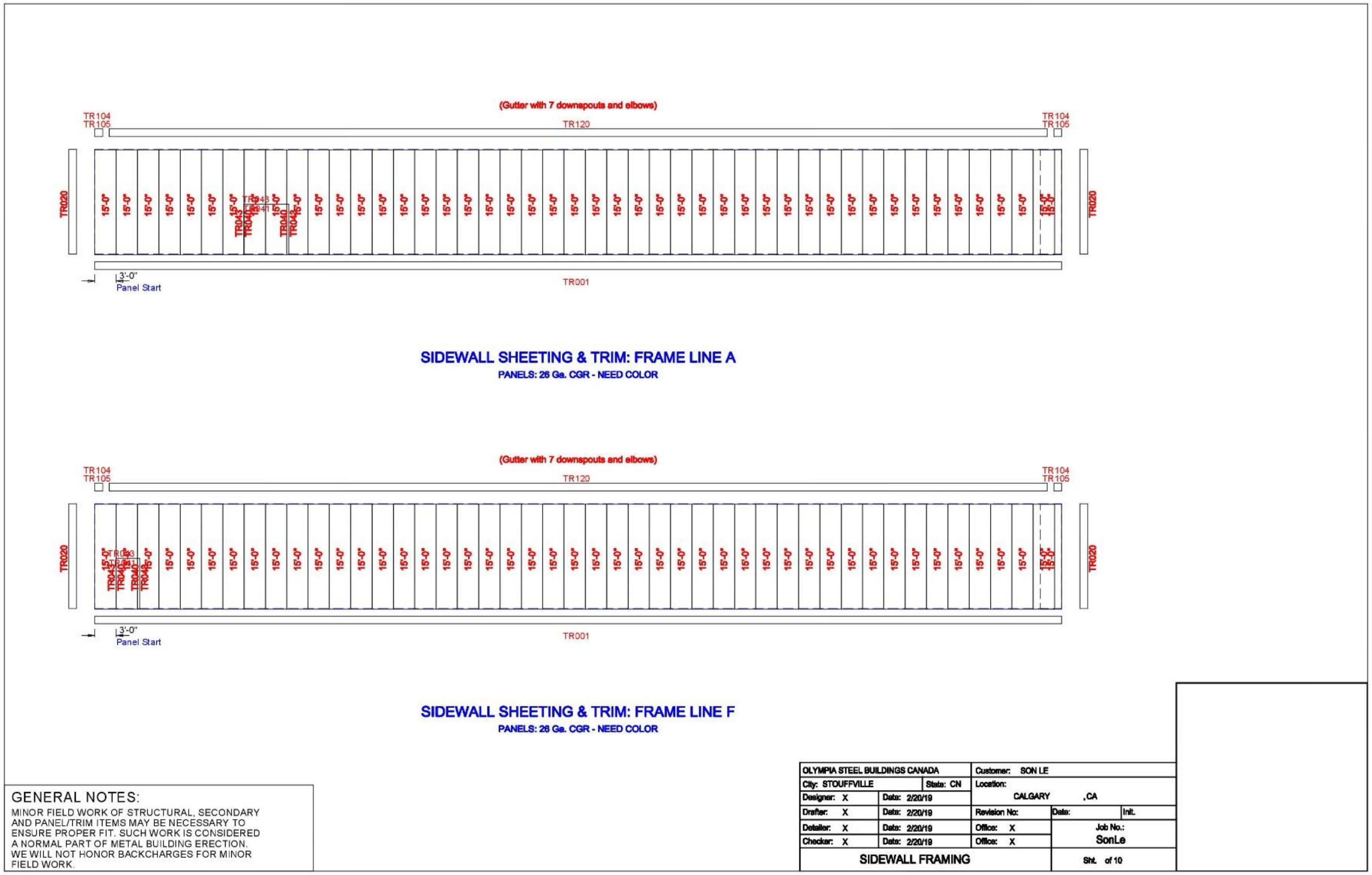


RIGID FRAME ELEVATION: FRAME LINE 2 3 4 5 6 7

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				
Drafter: X	Date: 2/20/19	Revision No:	Date:	Init.	
Detailer: X	Date: 2/20/19	Office: X	Job No.: SonLe		
Checker: X	Date: 2/20/19	Office: X			
RIGID FRAME ELEVATION			Sht. of 10		


SPECIAL BOLTS
ROOF PLAN
CONNECTION PLATES
ROOF PLAN
136'-0" OUT-TO-OUT OF STEEL
ROOF SURFACE 2
ROOF SURFACE 3
ROOF SHEETING
PANELS: 26 Ga. CPR Galvalume/Plain
ROOF FRAMING PLAN
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
City: STOUFFVILLE
State: CN
Customer: SON LE
Location: CALGARY ,CA
ROOF FRAMING
Job No.: SonLe


(Gutter with 7 downspouts and elbows)
TR104
TR105
TR120
TR020
TR001
3'-0"
Panel Start
SIDEWALL SHEETING & TRIM: FRAME LINE A
PANELS: 26 Ga. CGR - NEED COLOR
SIDEWALL SHEETING & TRIM: FRAME LINE F
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.
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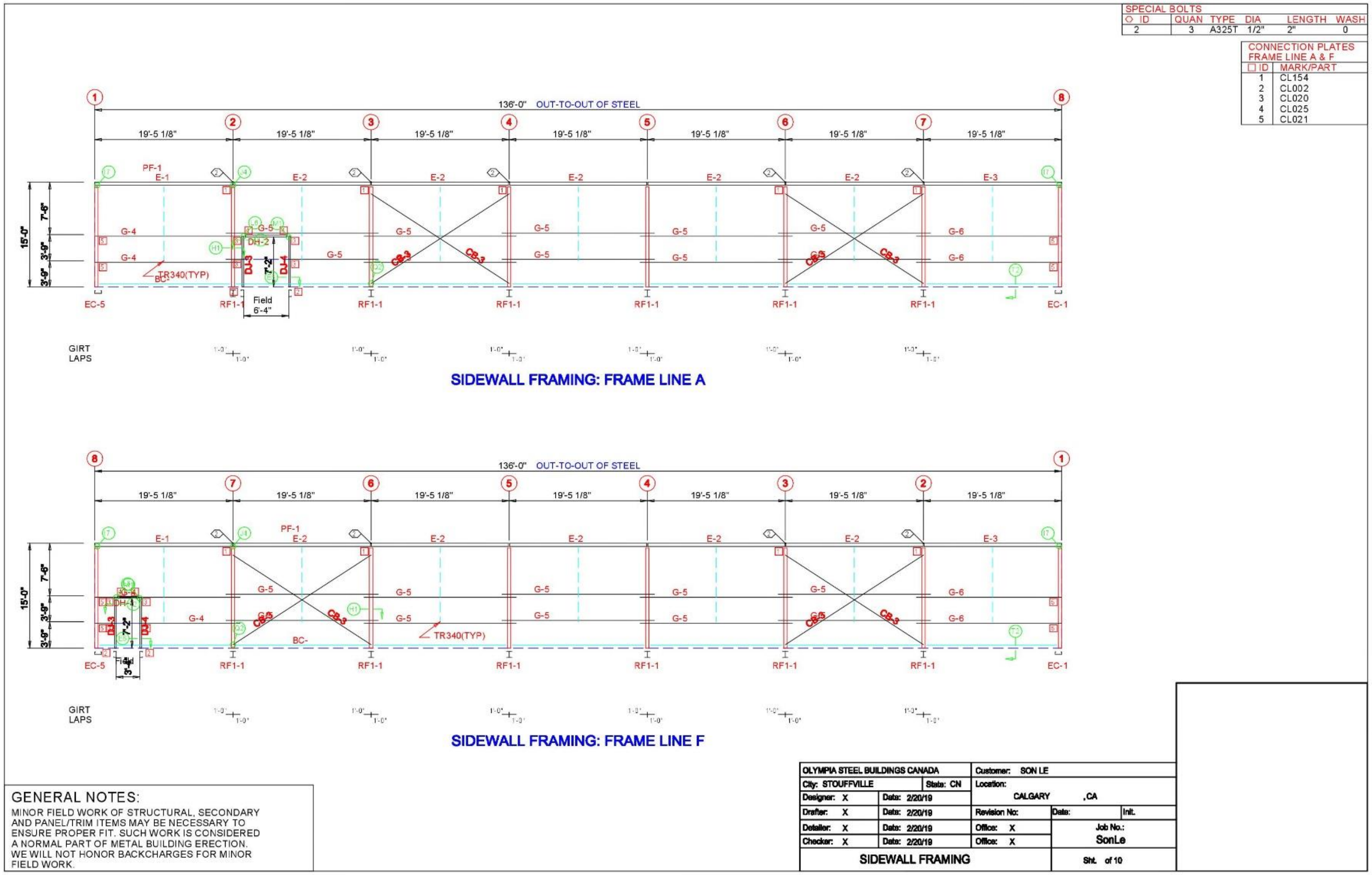
State: CN
Customer: SON LE
Location:
CALGARY ,CA
Designer: X
Date: 2/20/19
Drafter: X
Date: 2/20/19
Detailer: X
Date: 2/20/19
Checker: X
Date: 2/20/19
Revision No:
Date:
Init.
Office: X
Office: X
Job No.:
SonLe
SIDEWALL FRAMING
Sht. of 10


SPECIAL BOLTS
ID QUAN TYPE DIA LENGTH WASH
2 3 A325T 1/2" 2" 0
CONNECTION PLATES FRAME LINE A & F
ID MARK/PART
1 CL154
2 CL002
3 CL020
4 CL025
5 CL021
136'-0" OUT-TO-OUT OF STEEL
19'-5 1/8"
15'-0"
7'-6"
3'-9"
E-1
E-2
E-3
G-4
G-5
G-6
CB-3
DH-2
DJ-3
DJ-4
7'-2"
TR340(TYP)
Field 6'-4"
EC-5
RF1-1
EC-1
GIRT LAPS
SIDEWALL FRAMING: FRAME LINE A
SIDEWALL FRAMING: FRAME LINE F
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.
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Date: 2/20/19
Office: X
SIDEWALL FRAMING
Sht. of 10

Nectar Technologies Inc.
55 de Louvain Ouest, #360-04
Montreal (QC), H2N 1A4
Canada

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

Quote Details

Prepared by	Maximilian Cherney	Created Date	2/25/2019
Email	max@nectar.buzz	Shipping Period	Fall 2019
		Payment Terms	
		Hardware	100% upon purchase
		Software	100% upon purchase

Quote items

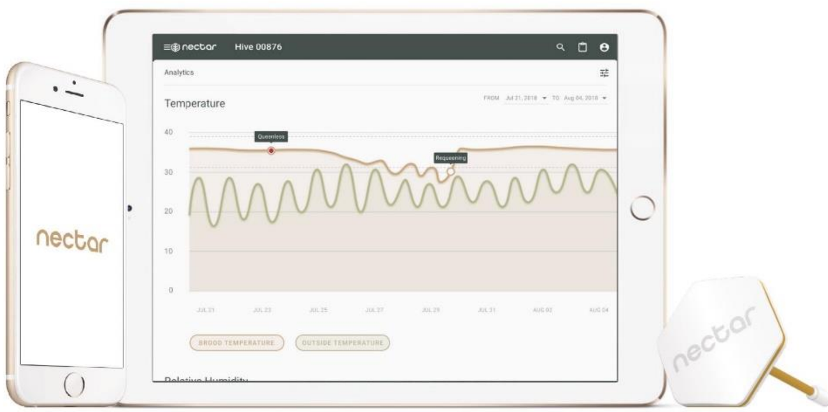
Product	Product Code	(CAD)	Quantity	Total Price
Beecons	BCN-AD	32.90 $	600	19,740.00 $
Software Subscription (6 months)*	YRD-SW	4,998.00 $	1	4,998.00 $

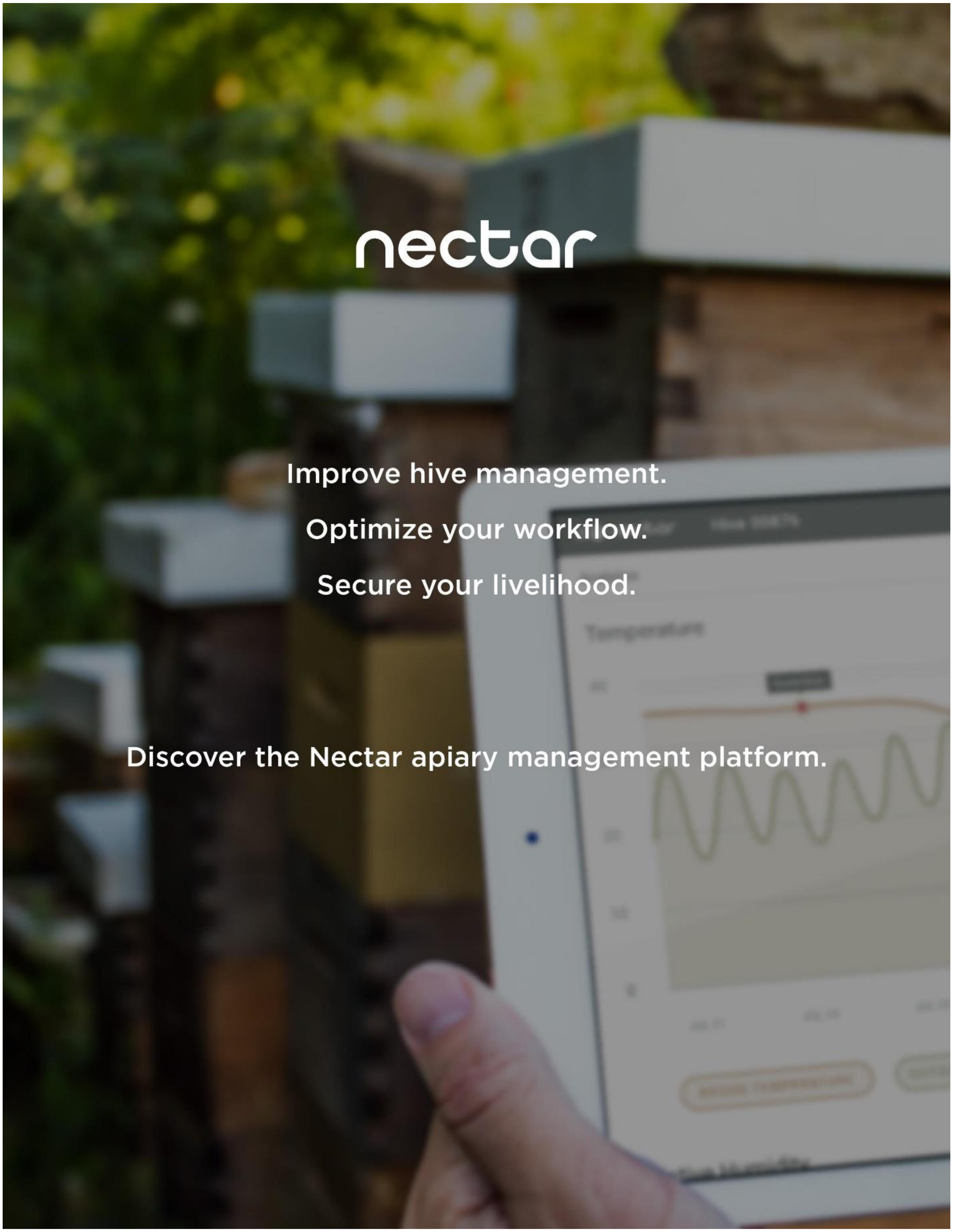
**Includes lease of sufficient quantity of BeeHubs to connect purchased Beecons.*

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
nectar

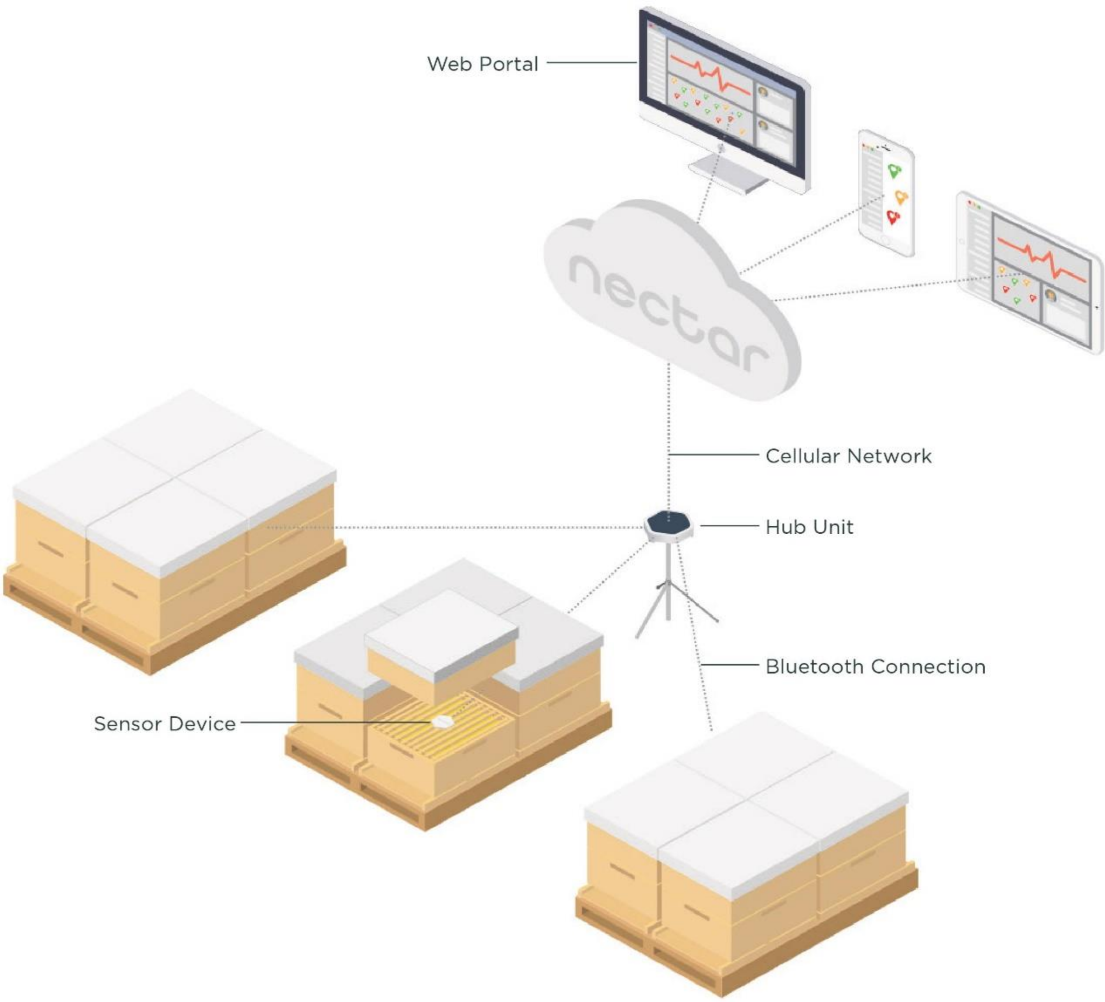

nectar
Hive 00876
Analytics
Temperature
nectar
nectar


nectar
Improve hive management.
Optimize your workflow.
Secure your livelihood.
Discover the Nectar apiary management platform.

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 recommandations.



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.

- Hive Temperature
- Hive Humidity
- Sound Frequencies
- Hive Movement
- 1+ Year Battery Life

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.

- Hives Geolocation
- Solar Powered
- Bluetooth Connected
- Cellular Connected
- Weather Proof

Secured Hives

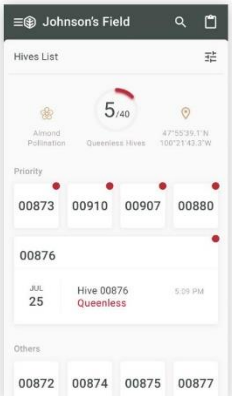
Protect your livelihood with Nectar's theft detection & alerts.

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.

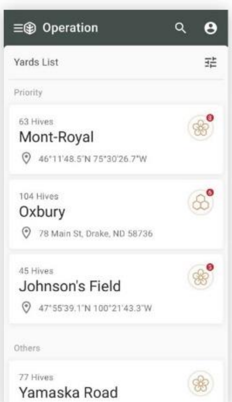


Real Time Queen Status

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

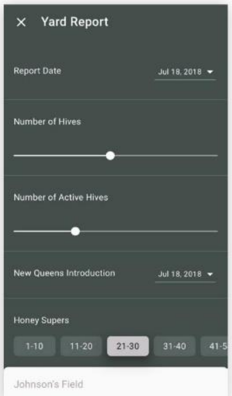


Yard Visits Prioritization

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

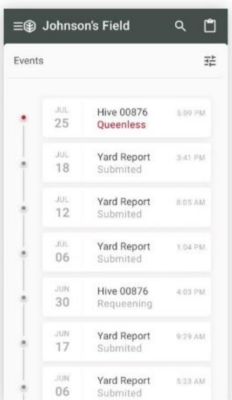
Optimized Workflow

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.

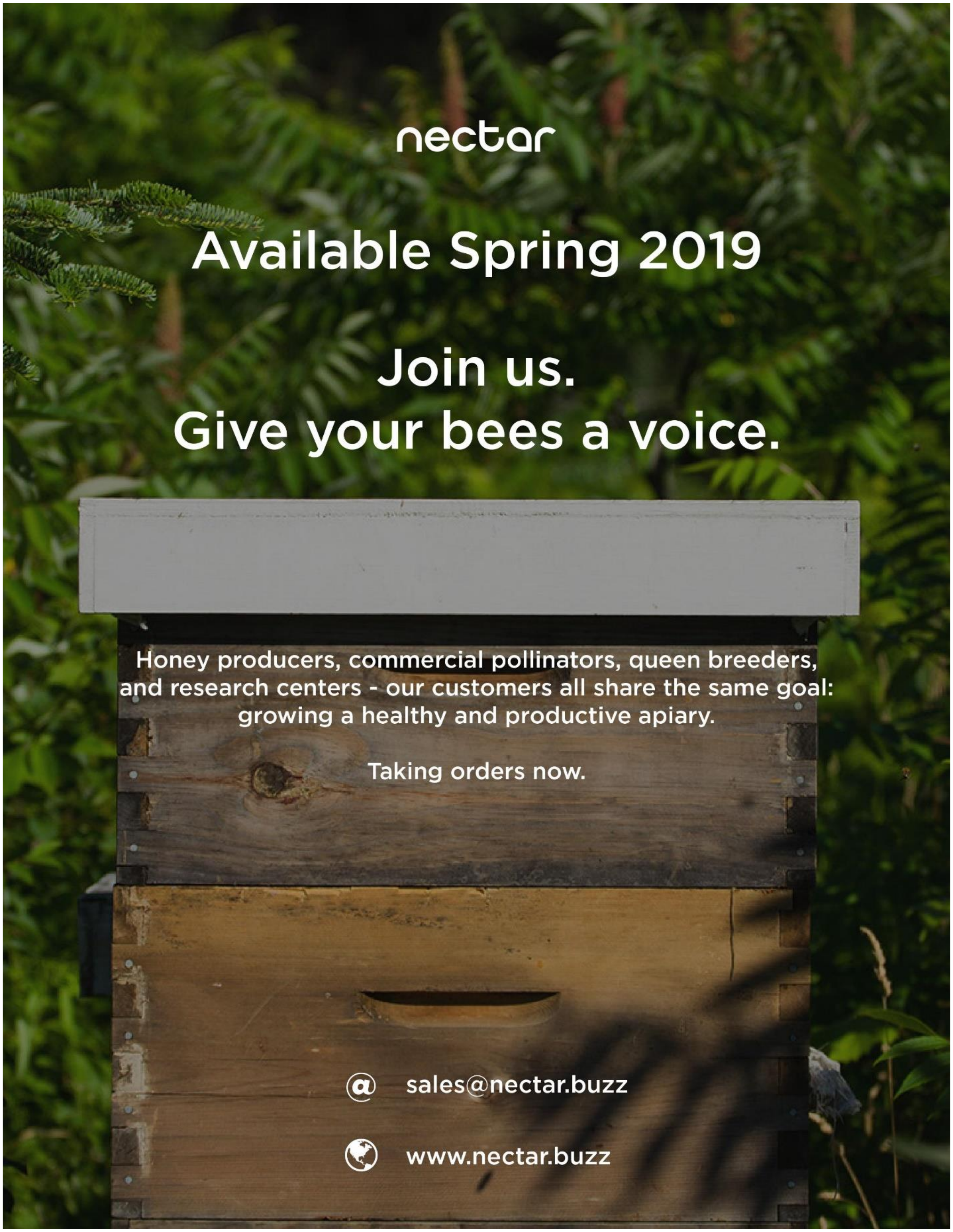


Online Field Reports

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.

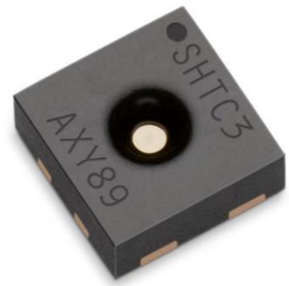

nectar
Available Spring 2019
Join us.
Give your bees a voice.
Honey producers, commercial pollinators, queen breeders, and research centers - our customers all share the same goal: growing a healthy and productive apiary.
Taking orders now.
sales@nectar.buzz
www.nectar.buzz

SENSIRION
THE SENSOR COMPANY

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 mm³
- 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 I²C Fast Mode Plus. The small 2 × 2 × 0.75 mm³ 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

Block diagram

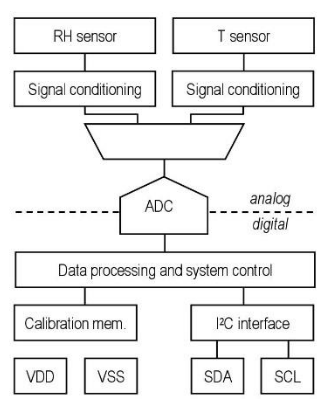


Figure 1 Functional block diagram of the SHTC3.

SENSIRION
THE SENSOR COMPANY

1 Humidity and Temperature Sensor Specifications

Relative Humidity

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

Table 1 Humidity sensor specifications.

Temperature

Parameter	Condition	Value	Unit
Accuracy tolerance[1]	Typ.	±0.2	°C
	Max.	see Figure 3	°C
Repeatability[2]	-	0.1	°C
Resolution[3]	-	0.01	°C
Specified range[4]	-	–40 to +125	°C
Response time[8]	τ 63%	<5 to 30	s
Long-term drift [9]	Typ.	<0.02	°C/y

Table 2 Temperature sensor specifications.

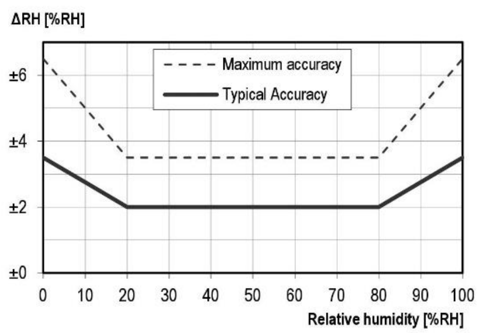


Figure 2 Typical and maximal tolerance for relative humidity in %RH at 25 °C.

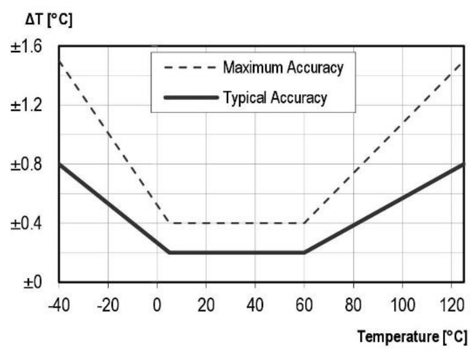


Figure 3 Typical and maximal tolerance for temperature sensor in °C.

[1] For definition of typ. and max. accuracy tolerance, please refer to the document "Sensirion Humidity Sensor Specification Statement". Specification applies to normal mode.
[2] 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.
[3] Resolution of A/D converter. Specification applies to normal mode.
[4] Specified range refers to the range for which the humidity or temperature sensor specification is guaranteed.
[5] For details about recommended humidity and temperature operating range, please refer to section 1.2.
[6] 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.
[7] 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.
[8] Temperature response time depends on heat conductivity of sensor substrate and design-in of sensor in application.
[9] 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.

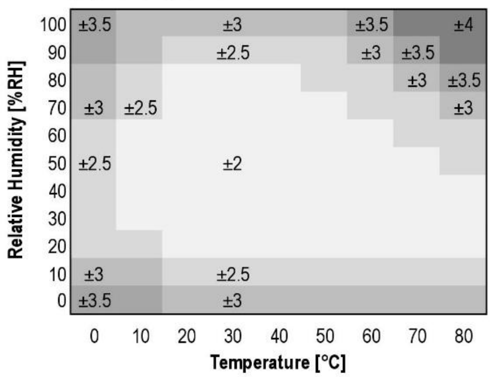


Figure 4 Typical accuracy of relative humidity measurements given in %RH for temperatures 0°C … 80°C.

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_{DD}			1.62	3.3	3.6	V	-
Power-up/down level	V_{POR}	Static power supply		1.28	1.4	1.55	V	-
Supply current	I_{DD}	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 I²C 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_{IL}	-		-	-	0.42 V_{DD}	V	-
High level input voltage	V_{IH}	-		0.7 V_{DD}	-	-	V	-
Low level output voltage	V_{OL}	3 mA sink current		-	-	0.2 V_{DD}	V	-

Table 3 Electrical specifications.

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THE SENSOR COMPANY

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[10]	-40 to +125 °C
ESD HBM (human body model)[11]	-2 to 2 kV
ESD CDM (change device model)[12]	-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	µs	Time between V_{DD} reaching V_{PU} and sensor entering the idle state
Soft reset time	t_{SR}	After soft reset.		-	180	240	µs	Time between ACK of soft reset command and sensor entering the idle state
Measurement duration	t_{MEAS}	Average	Normal Mode	-	10.8	12.1	ms	Duration for a humidity and temperature measurement
			Low Power M.	-	0.7	0.8		

Table 5 System timing specifications.

[10] The recommended storage temperature range is 10-50°C. Please consult the document "SHTxx Handling Instructions" for more information.
[11] According to ANSI/ESDA/JEDEC JS-001-2014; AEC-Q100-002.
[12] According to ANSI/ESD S5.3.1-2009; AEC-Q100-011.

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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	-	µs
LOW period of the SCL clock	t_{LOW}	-	4.7	-	1.3	-	0.5	-	µs
HIGH period of the SCL clock	t_{HIGH}	-	4.0	-	0.6	-	0.26	-	µs
Set-up time for a repeated START condition	$t_{SU;STA}$	-	4.7	-	0.6	-	0.26	-	µs
SDA hold time	$t_{HD;DAT}$	-	0	-	0	-	0	-	µs
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 x (V_{DD} / 5.5V)	300	20 x (V_{DD} / 5.5V	120	ns
SDA valid time	$t_{VD;DAT}$	-	-	3.45	-	0.9	-	0.45	µs
Set-up time for STOP condition	$t_{SU;STO}$	-	4.0	-	0.6	-	0.26	-	µs
Capacitive load on bus line	C_B	-	-	400	-	400	-	550	pF

Table 6 Communication timing specifications. The numbers above are values according to the I²C specification.

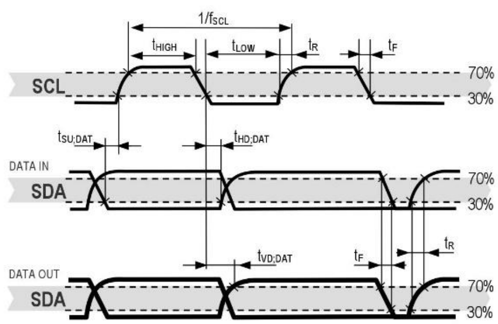

Figure 5 Timing diagram for digital input/output pads. SDA directions as seen from the sensor. Bold SDA lines are controlled by the sensor, plain SDA lines are controlled by the micro-controller. Note that SDA valid read time is triggered by falling edge of preceding toggle.

4 Interface Specifications

The SHTC3 supports I²C 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 I²C protocol, refer to NXP I²C-bus specification and user manual UM10204, Rev. 6, April 4th, 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

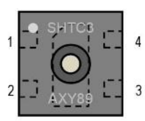

Table 7 SHTC3 pin assignment (top view). The center pad is internally connected to VSS.

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 I²C 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.

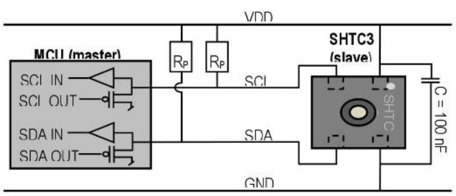

Figure 6 Typical application circuit, including pull-up resistors R_P and decoupling of VDD and VSS by a capacitor.

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 I²C protocol.

5.1 I2C Address

The I2C device address is given Table 8:

SHTC3	Hex. Code	Bin. Code
I²C address	0x70	111'0000

Table 8 SHTC3 I²C device address.

Each transmission sequence begins with START condition (S) and ends with an (optional) STOP condition (P) as described in the I2C-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[13].

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
Wakeup	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.

[13] 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.

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	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

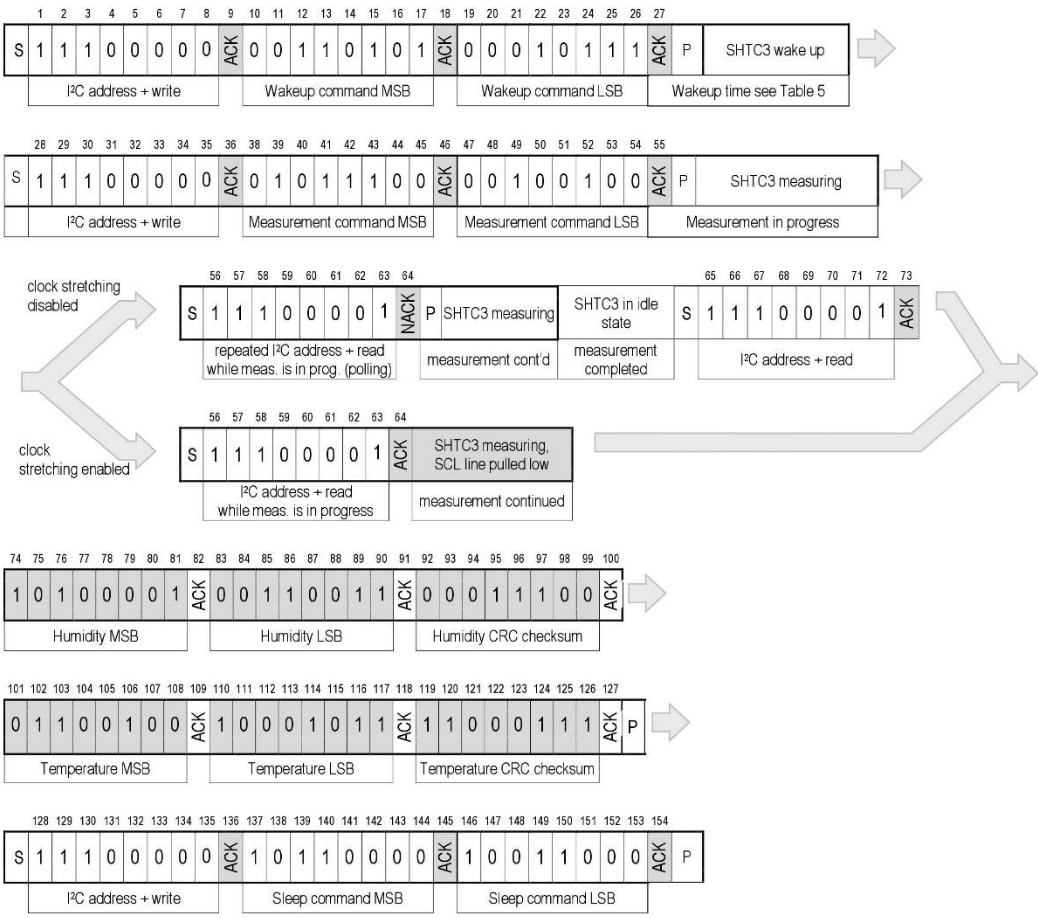

Figure 7 Communication sequence for waking up the sensor, starting a measurement and reading measurement results displaying both clock stretching options.

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 I²C activity during measurement, i.e. I²C 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 I2C bus while the SHTC3 is measuring. For more information, see the application note "Optimization of Repeatibility".

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 I²C 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 I²C 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 I2C-bus specification[14]. 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 I2C bus that support the general call mode will perform a reset. Additionally, this command only works when the sensor is able to process I2C 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

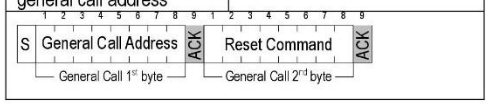

Table 13 Reset through the general call address (clear blocks are controlled by the microcontroller, grey blocks by the sensor)

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 I²C write header. Once the SHTC3 has acknowledged the proper reception of the command, the master can send an I²C 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.

[14] http://www.nxp.com/documents/user_manual/UM10204.pdf

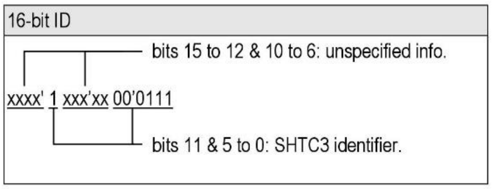

Table 15 Structure of the 16-bit ID. Bits 15:12 & 10:6 of the ID contain unspecified information (marked as "x"), which may vary from sensor to sensor, while bits 11 & 5:0 contain the SHTC3-specific product code.

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^2C 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 × 2 × 0.75 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.

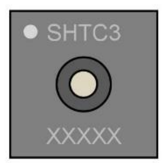

Figure 8 Laser marking on SHTC3, the top line with the pin-1 indicator and the sensor type, the bottom line with the 5-digit alphanumeric tracking code.

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.

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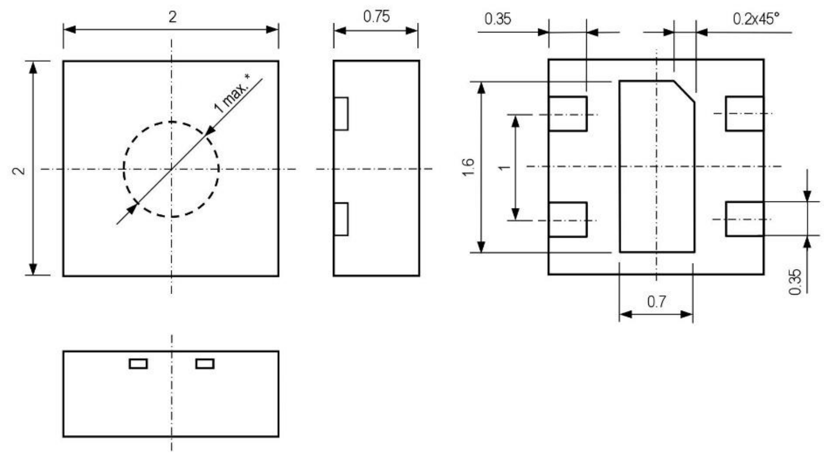
9 Technical Drawings

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

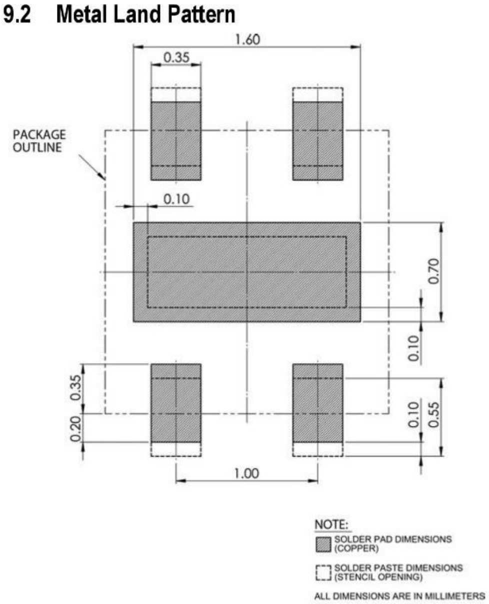


Figure 10 Recommended metal land pattern for SHTC3 (all dimensions are in mm). Recommended solder paste stencil thickness is 100µm, pads on PCB are recommended to be non solder mask defined (NSMD).

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9.3 Tape and Reel Package

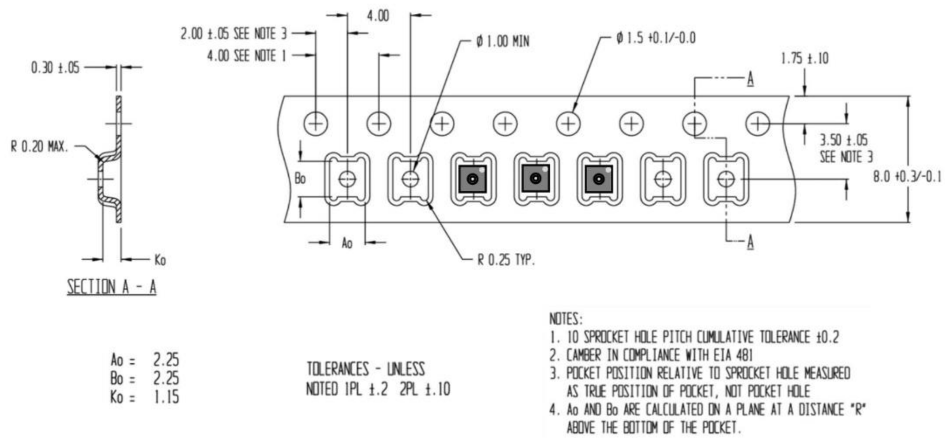

Figure 11 Technical drawing of the packaging tape with sensor orientation in tape. Header tape is to the right and trailer tape to the left on this drawing. Dimensions are given in millimeters.

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: www.sensirion.com/humidity-download
SHTxx Design Guide	Design guidelines for designing SHTxx humidity sensors into applications	Available for download at the Sensirion humidity sensors download center: www.sensirion.com/humidity-download
SHTxx Handling Instructions	Guidelines for proper handling of SHTxx humidity sensors	Available for download at the Sensirion humidity sensors download center: www.sensirion.com/humidity-download
Sensirion Humidity Sensor Specification Statement	Definition of sensor specifications.	Available for download at the Sensirion humidity sensors download center: www.sensirion.com/humidity-download

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^2C mode.

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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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SENSIRION reserves the right, without further notice, (i) to change the product specifications and/or the information in this document and (ii) to improve reliability, functions and design of this product.

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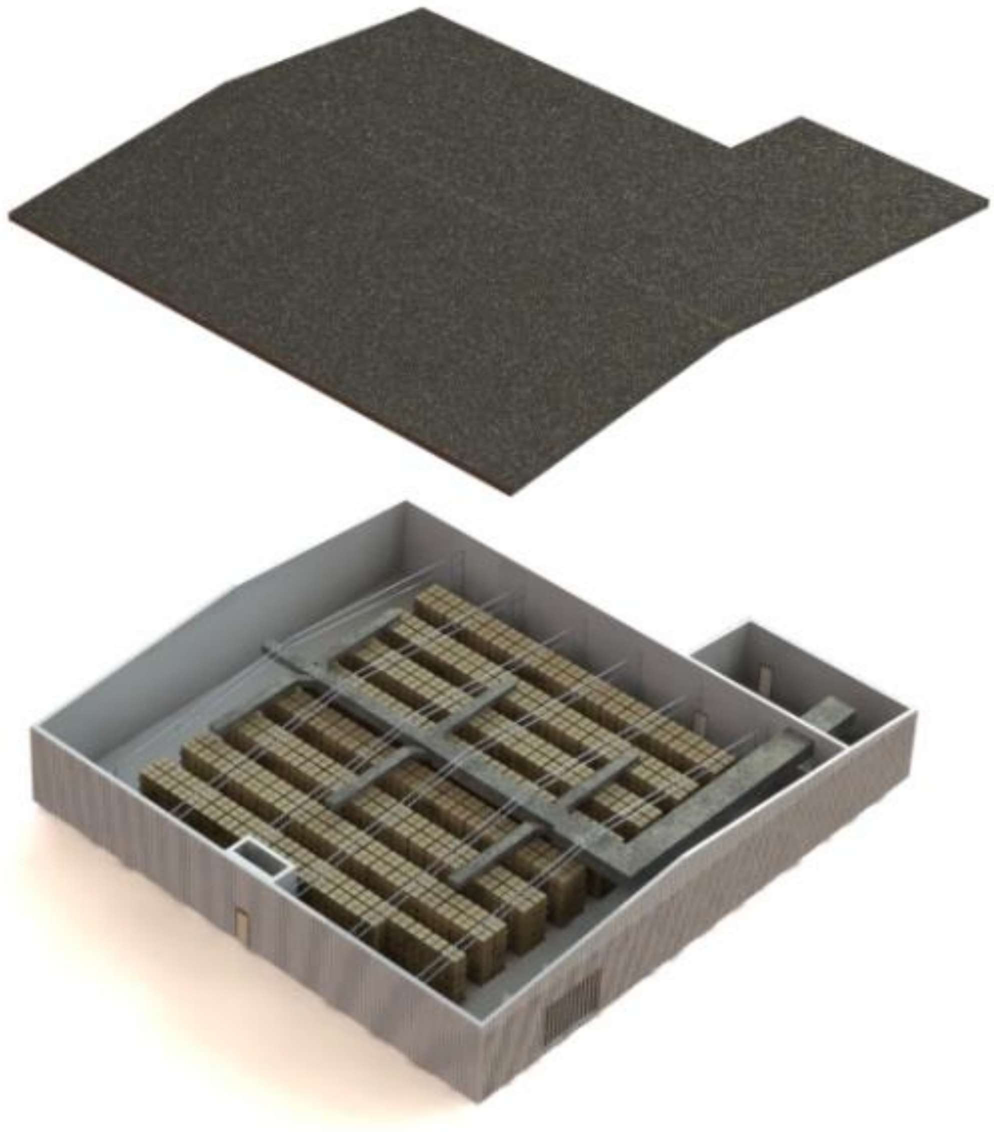
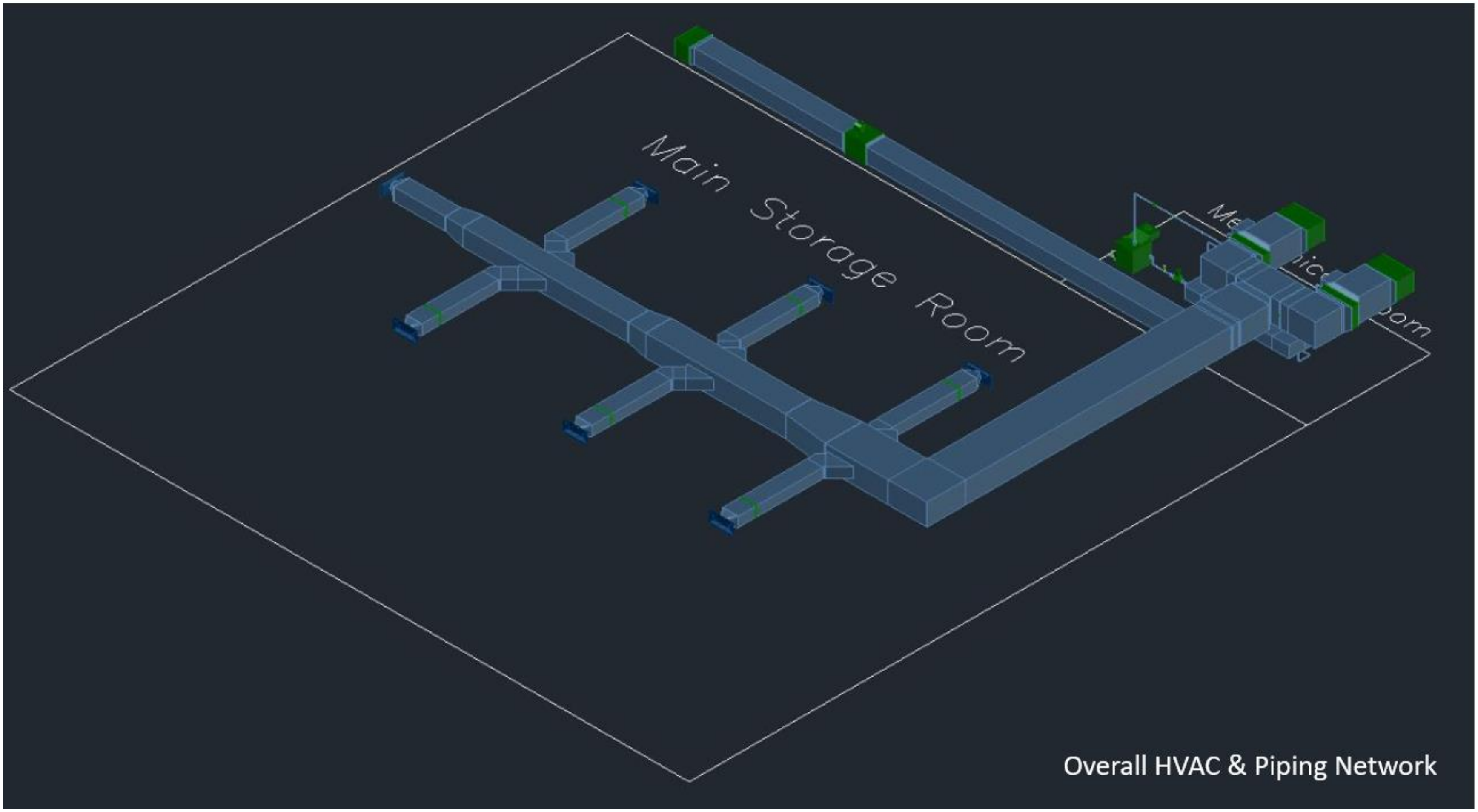
SHTC3 SHTC3-10k

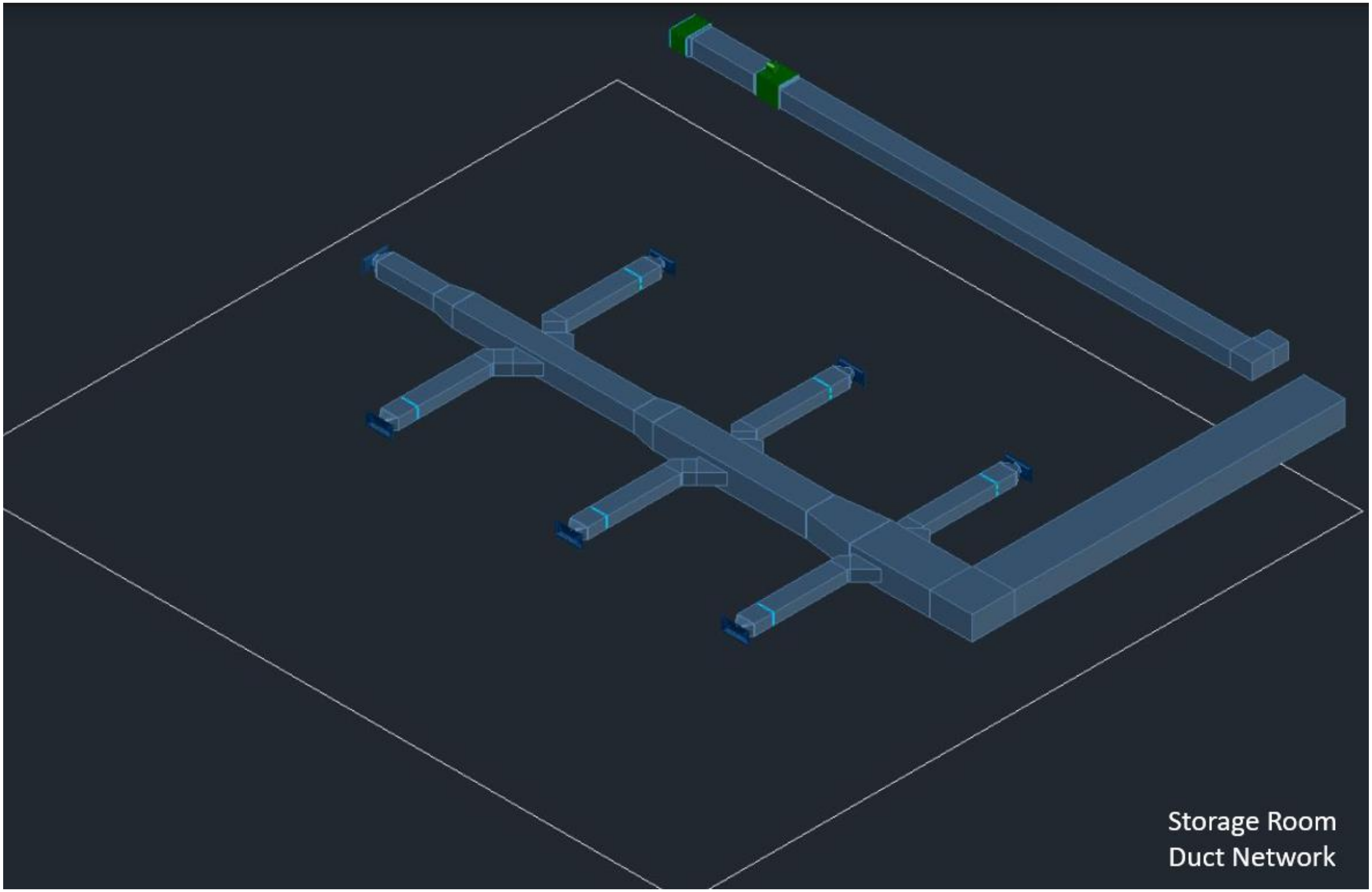
APPENDIX I: EQUIPMENT SCHEDULE

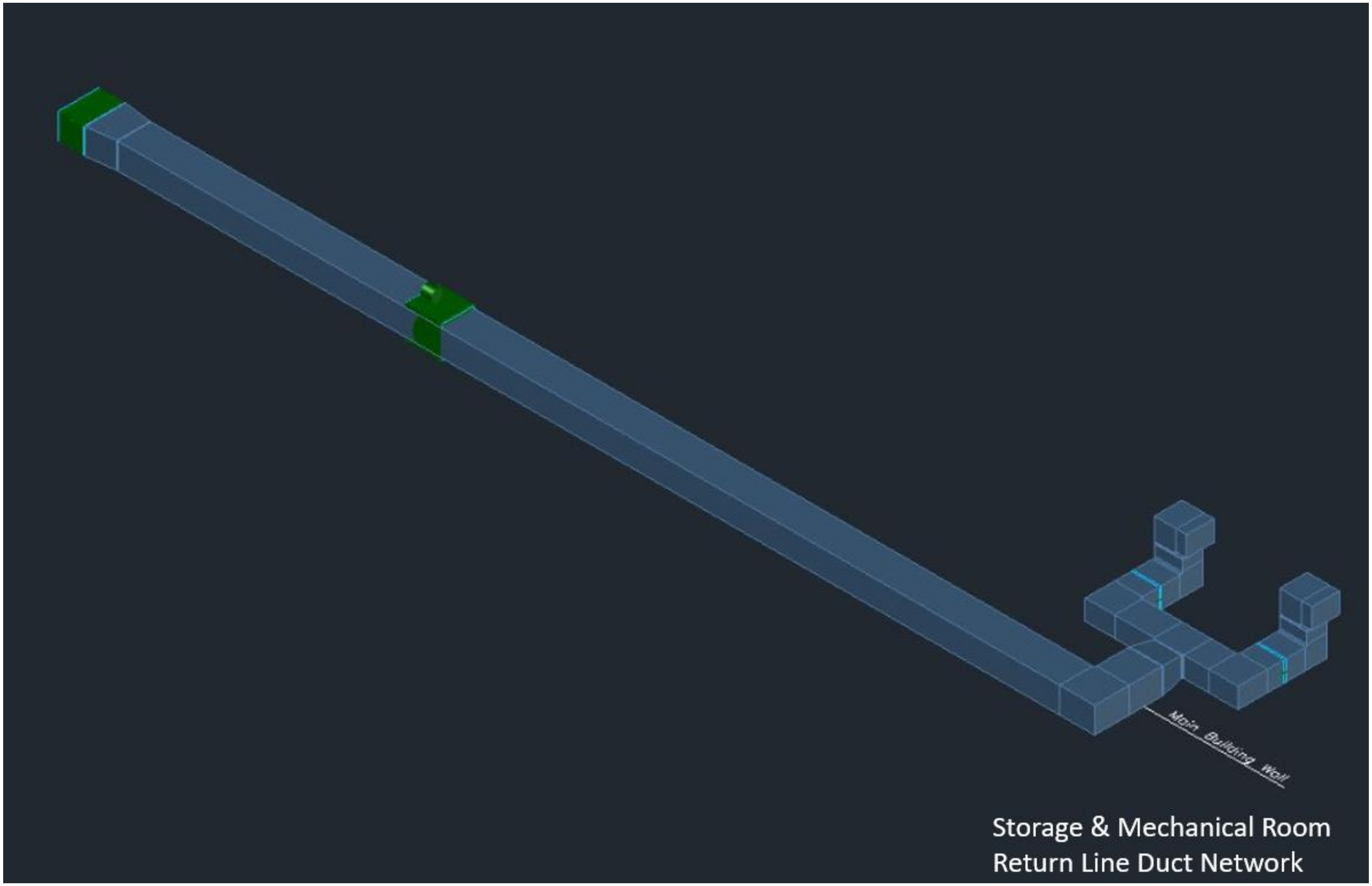
Equipment	Model	Quantity	Supplier	Function
Inlet line fan	TBI-CA-3H30	2	Greenheck	Bring in fresh air
Return line fan	AX-72-190-0618	1	Greenheck	Recycle air from building
Exhaust fan	SBE-1L24	4	Greenheck	Exhaust air to outside
Ceiling fan	DS-8	4	Greenheck	Circulate air in the building
Water Pump	2400-30S-3P	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.

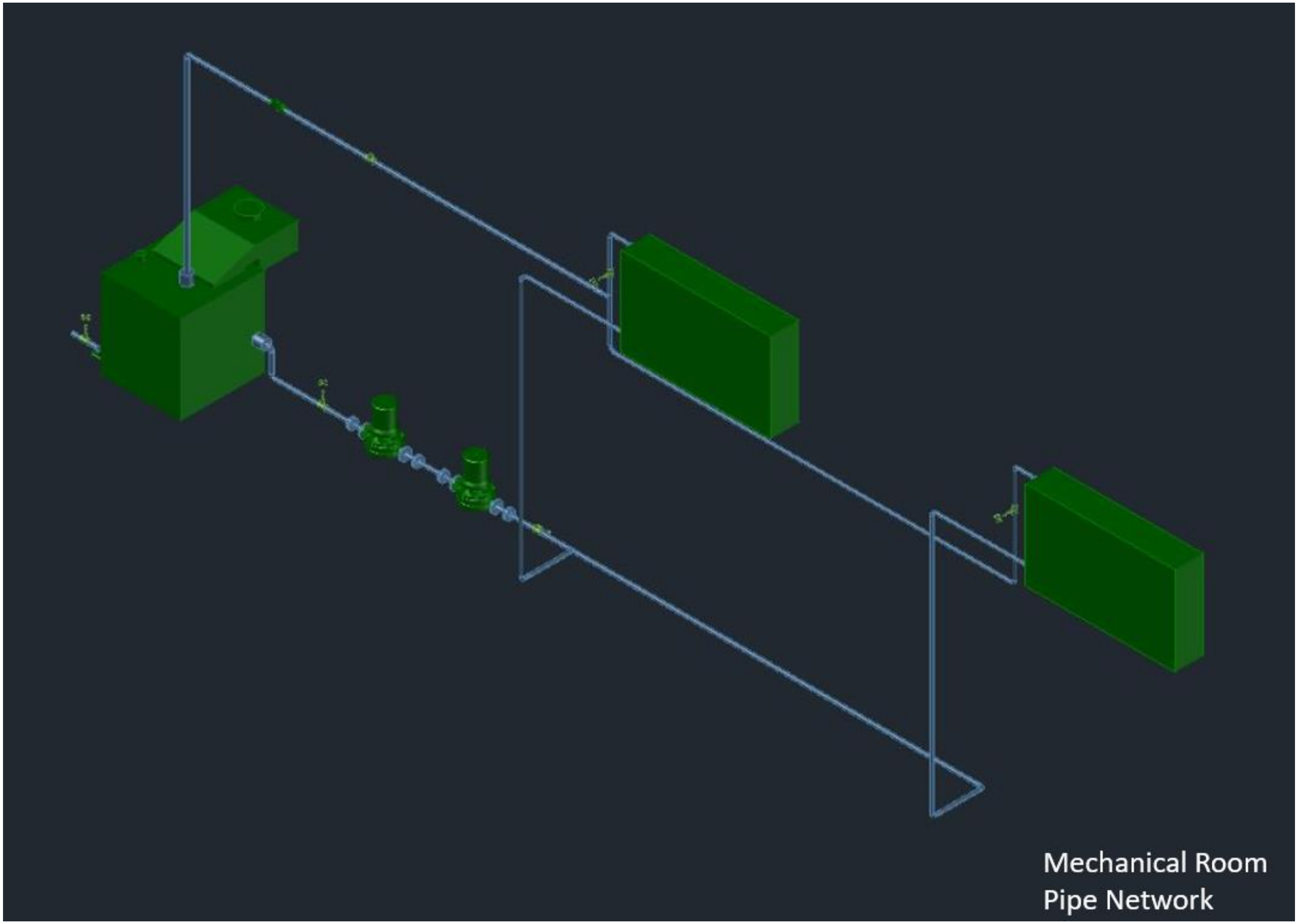
APPENDIX J: 3D BUILDING RENDERINGS



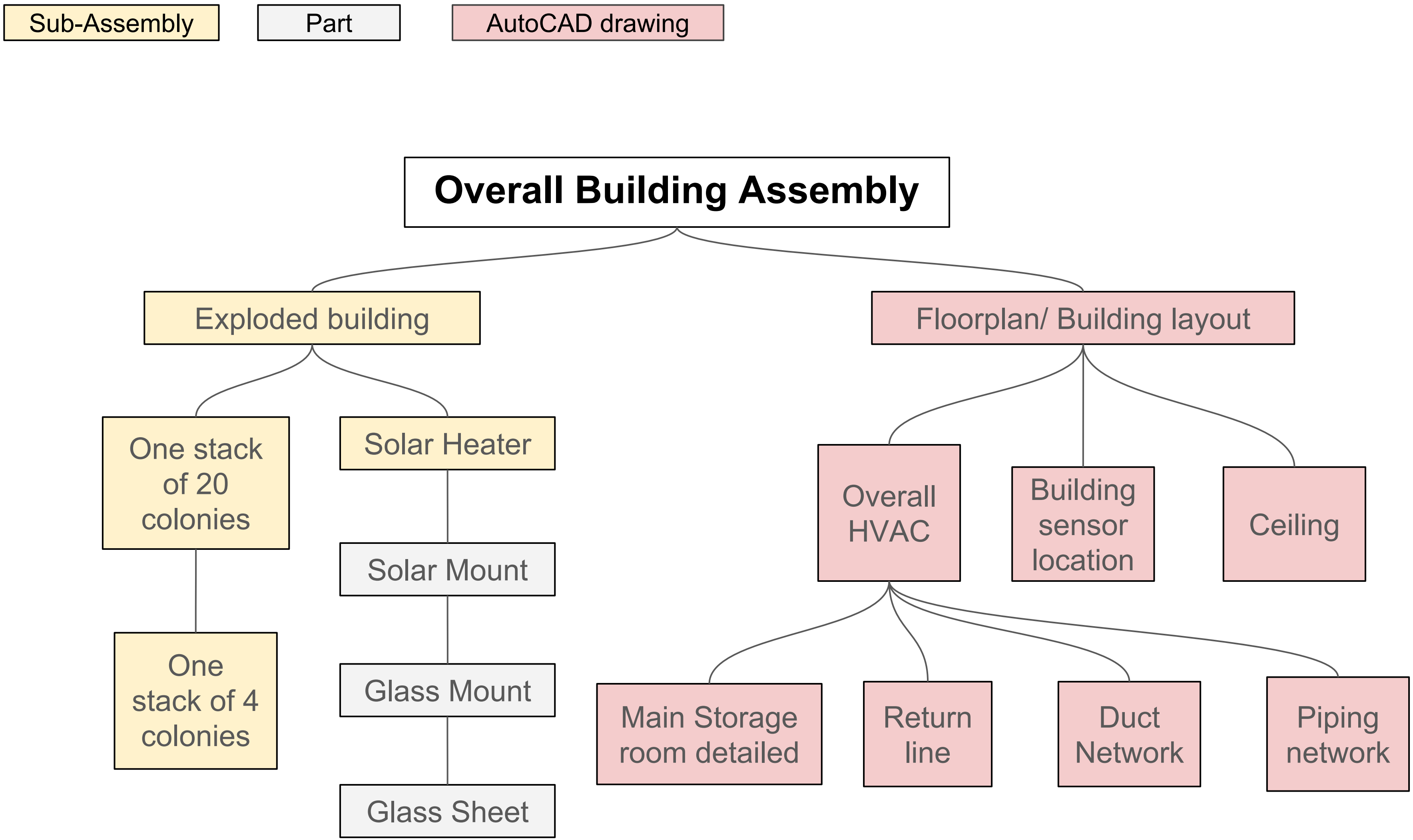

Main Storage Room
Overall HVAC & Piping Network

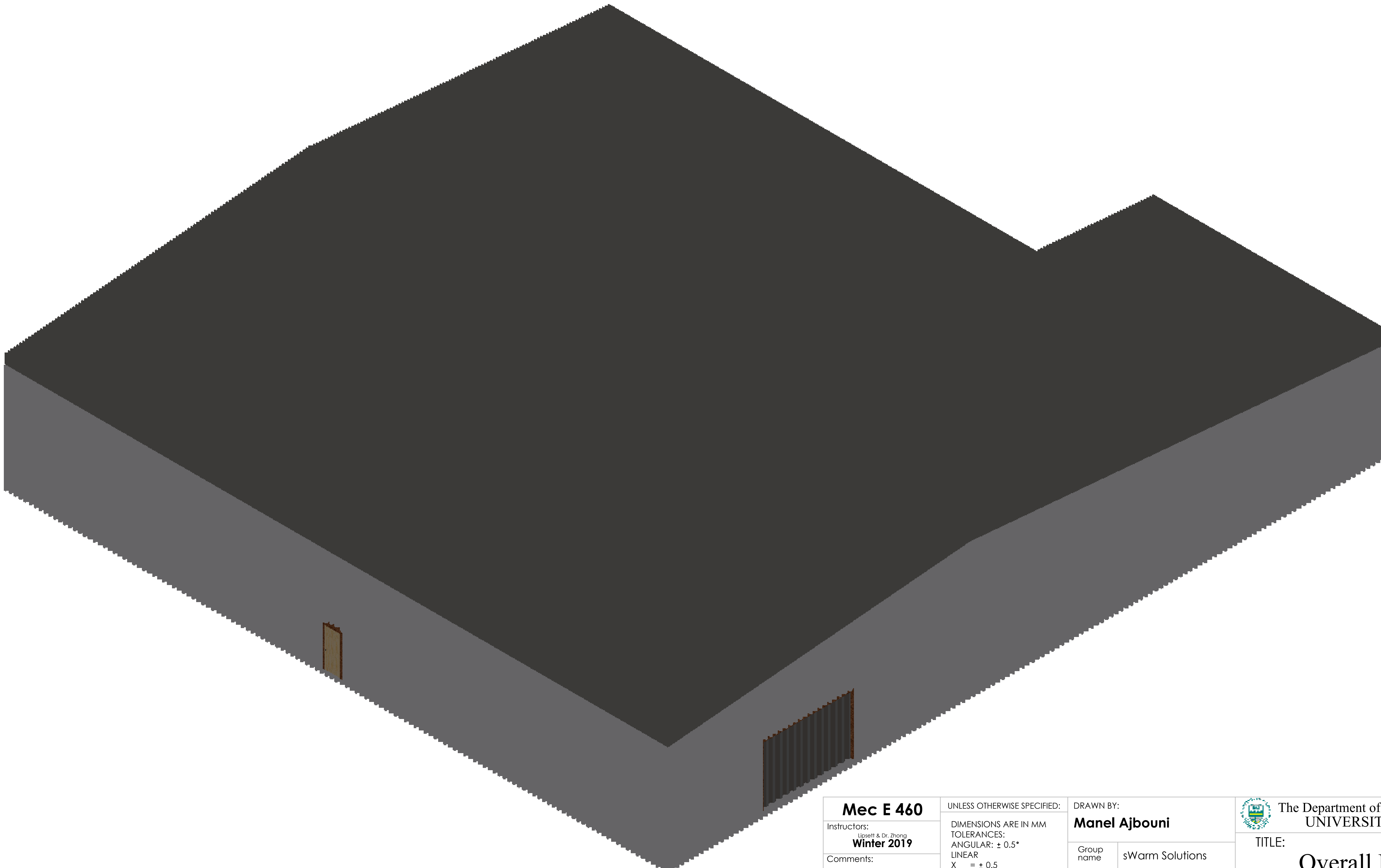

Storage Room
Duct Network


Main Building Wall
Storage & Mechanical Room
Return Line Duct Network


Mechanical Room
Pipe Network

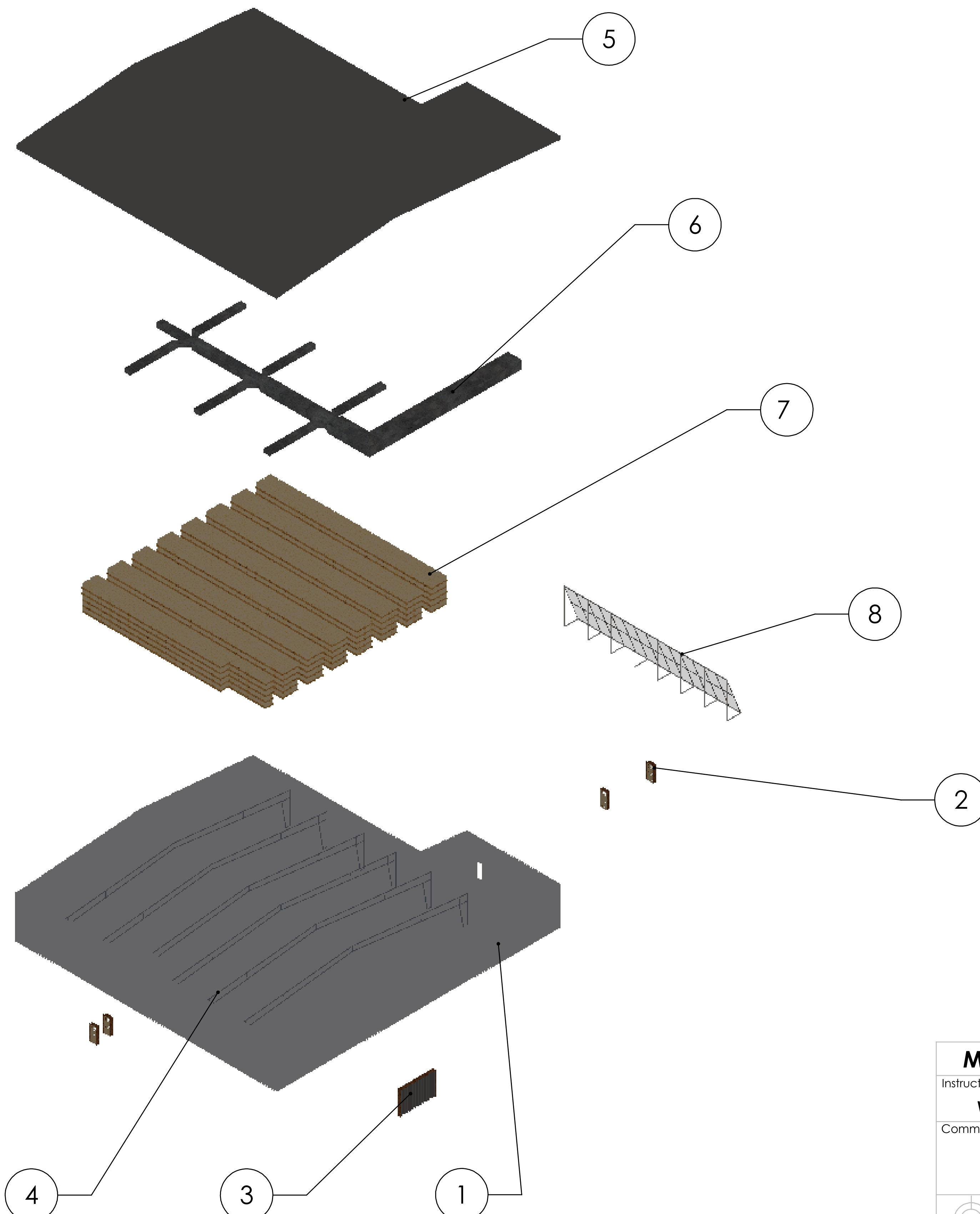
APPENDIX K: DRAWING PACKAGE


Sub-Assembly
Part
AutoCAD drawing
Overall Building Assembly
Exploded building
Floorplan/ Building layout
One stack of 20 colonies
Solar Heater
One stack of 4 colonies
Solar Mount
Glass Mount
Glass Sheet
Overall HVAC
Building sensor location
Ceiling
Main Storage room detailed
Return line
Duct Network
Piping network

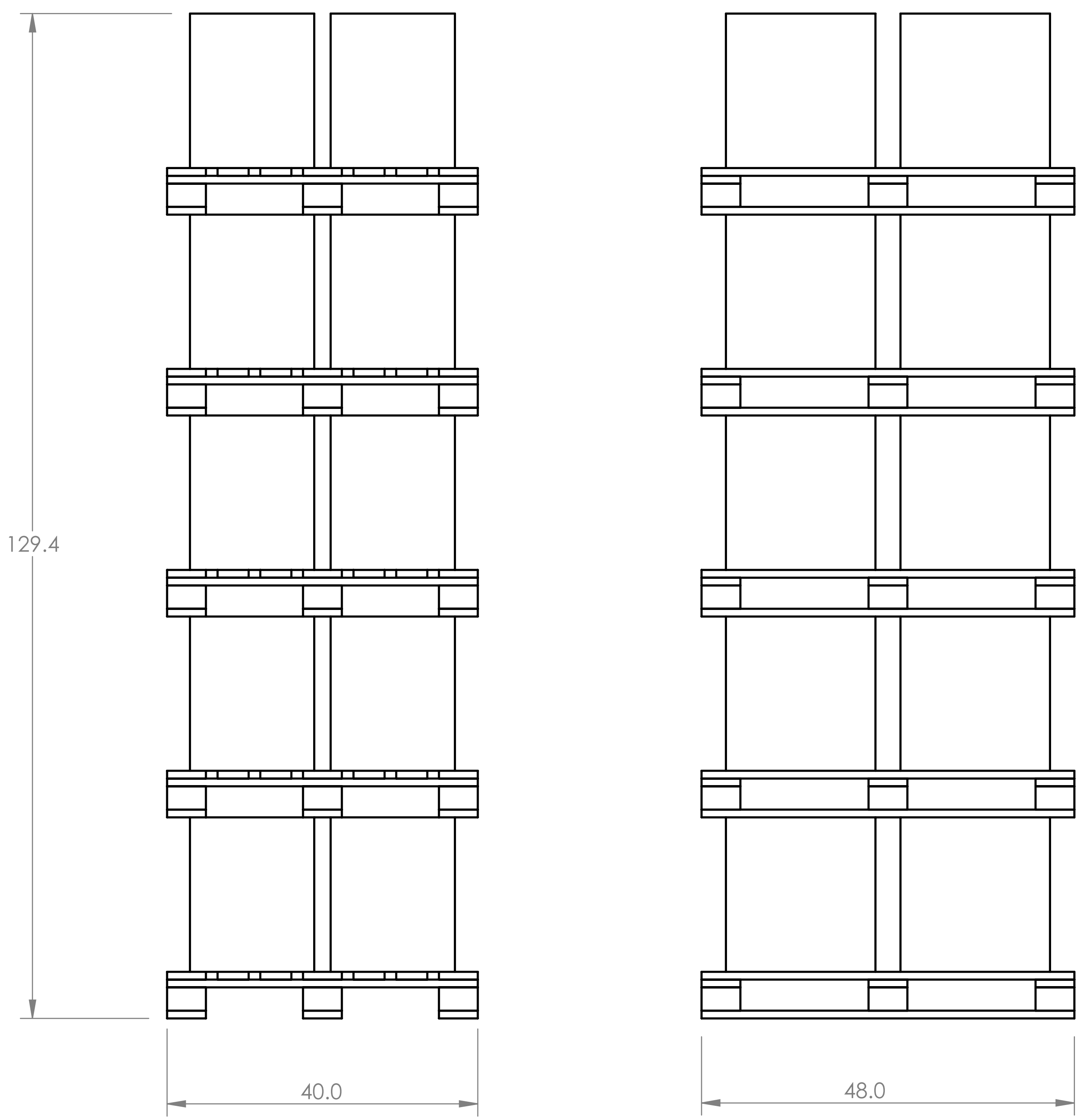


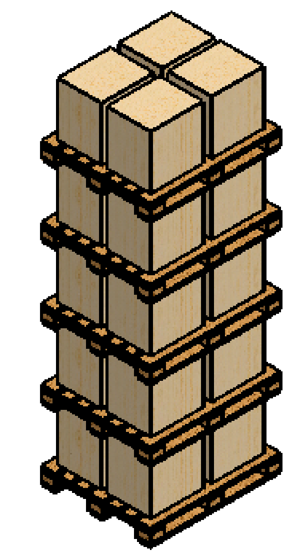
Mec E 460 Instructors: Lipsett & Dr. Zhong **Winter 2019** Comments:	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MM TOLERANCES: ANGULAR: ± 0.5° LINEAR X = ± 0.5 X.X = ± 0.1 X.XX = ± 0.025 SURFACE FINISH µm 0.6 DO NOT SCALE DRAWING	DRAWN BY: **Manel Ajbouni** Group name: sWarm Solutions Group number: 21 SM By: Manel Ajbouni Reviewed by: Yu Tim Leung Monday, April 8, 2019 6:09:57 PM Tuesday, March 26, 2019 2:58:46 PM	The Department of Mechanical Engineering UNIVERSITY OF ALBERTA TITLE: Overall Building SIZE **B** Part supplier/manufacturer REV SCALE: 1:500 Mass: SHEET 1 OF 4
MATERIAL:			
FILE NAME: Building assembly			

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

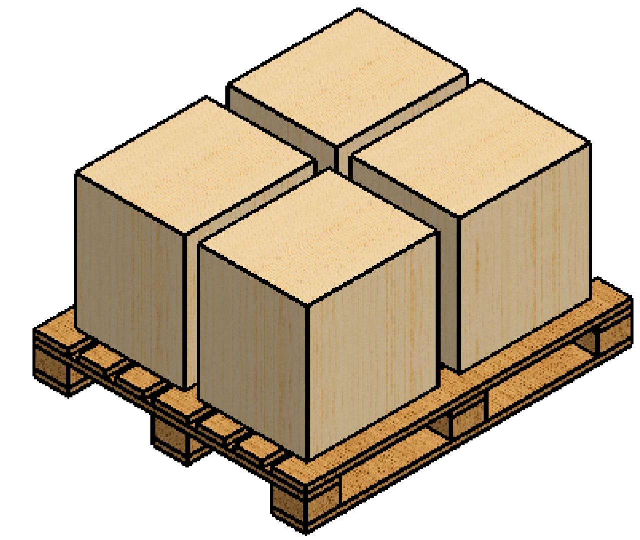


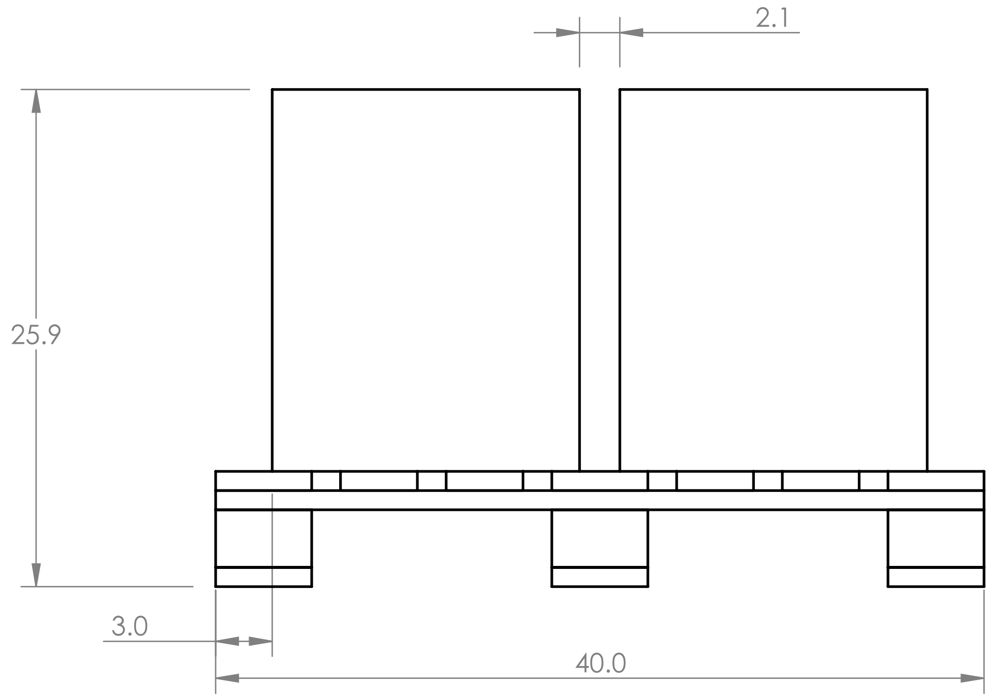
Mec E 460	UNLESS OTHERWISE SPECIFIED:	DRAWN BY: **Manel Ajbouni**	The Department of Mechanical Engineering UNIVERSITY OF ALBERTA
Instructors: Lipsett & Dr. Zhong **Winter 2019**	DIMENSIONS ARE IN MM TOLERANCES: ANGULAR: ± 0.5° LINEAR X = ± 0.5 X.X = ± 0.1 X.XX = ± 0.025	Group name: sWarm Solutions	TITLE: Exploded Overall Building
Comments:	SURFACE FINISH µm 0.6	Group number: 21	
	DO NOT SCALE DRAWING	SM By: Manel Ajbouni	SIZE **B** — Part supplier/manufacturer — REV
MATERIAL:		Reviewed by: Yu Tim Leung	
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 2 OF 4

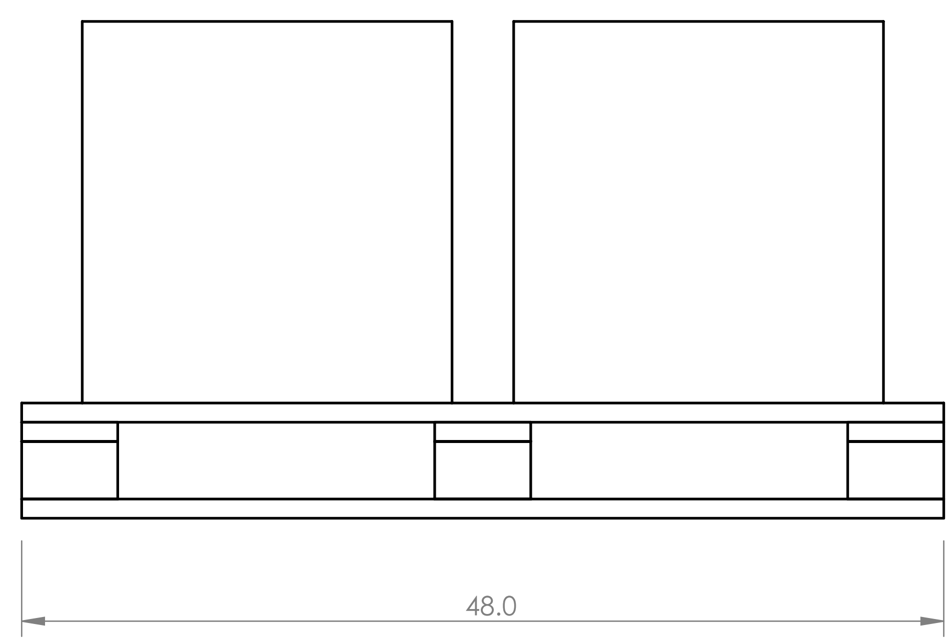




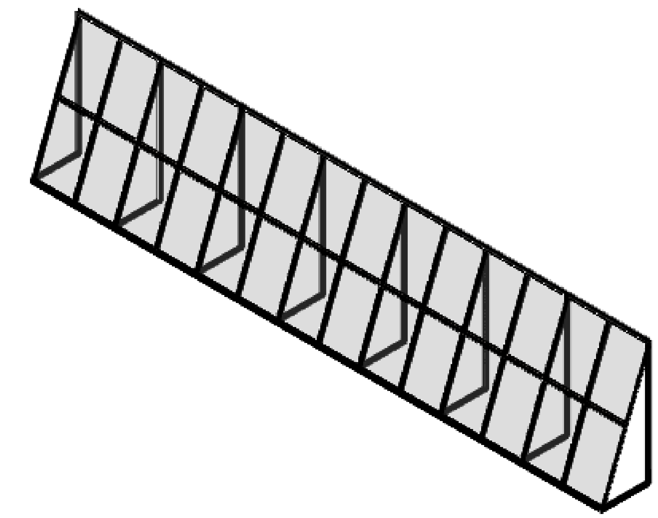
Mec E 460	UNLESS OTHERWISE SPECIFIED:	DRAWN BY: **Manel Ajbouni**	The Department of Mechanical Engineering UNIVERSITY OF ALBERTA
Instructors: Lipsett & Dr. Zhong **Winter 2019**	DIMENSIONS ARE IN MM TOLERANCES: ANGULAR: ± 0.5° LINEAR X = ± 0.5 X.X = ± 0.1 X.XX = ± 0.025	Group name: sWarm Solutions	TITLE: One stack of 20 colonies
Comments:	SURFACE FINISH µm 0.6	Group number: 21	
	DO NOT SCALE DRAWING	SM By: Manel Ajbouni	SIZE **B**
MATERIAL:		Reviewed by: Yu Tim Leung	Part supplier/manufacturer
FILE NAME: Stack		Monday, April 8, 2019 6:09:58 PM Saturday, March 9, 2019 8:19:26 PM	SCALE: 1:50 | Mass: | REV | SHEET 3 OF 4

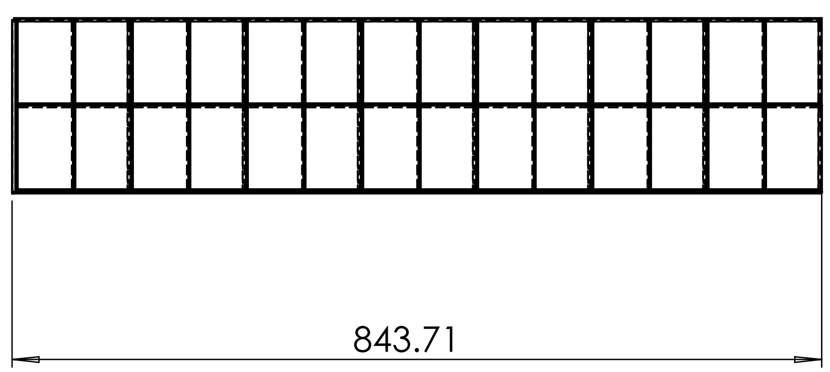


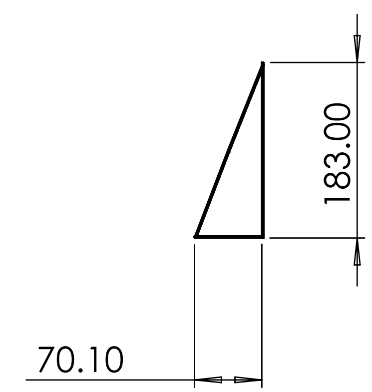




Mec E 460 Instructors: Lipsett & Dr. Zhong **Winter 2019** Comments:	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MM TOLERANCES: ANGULAR: ± 0.5° LINEAR X = ± 0.5 X.X = ± 0.1 X.XX = ± 0.025 SURFACE FINISH µm 0.6 DO NOT SCALE DRAWING	DRAWN BY: **Manel Ajbouni** Group name: sWarm Solutions Group number: 21 SM By: Manel Ajbouni Reviewed by: Yu Tim Leung Monday, April 8, 2019 6:09:57 PM Saturday, March 9, 2019 8:05:03 PM	The Department of Mechanical Engineering UNIVERSITY OF ALBERTA TITLE: One stack of 4 colonies
MATERIAL:			SIZE **B** | Part supplier/manufacturer | REV
FILE NAME: Pallet _ Hive			SCALE: 1:20 | Mass: | SHEET 4 OF 4







Mec E 460

Instructors: Lipsett & Dr. Zhong

Winter 2019

Comments:

MATERIAL:

FILE NAME: SolarHeater

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.02
X.X = ± 0.004
X.XX = ± 0.001

SURFACE FINISH µm 0.6

DO NOT SCALE DRAWING

DRAWN BY: **Manel Ajbouni**

Group name	sWarm Solutions
Group number	21
SM By	Alex Madsen
Reviewed by	Manel Ajbouni

Tuesday, April 9, 2019 10:49:26 AM
Wednesday, March 27, 2019 10:28:07 PM

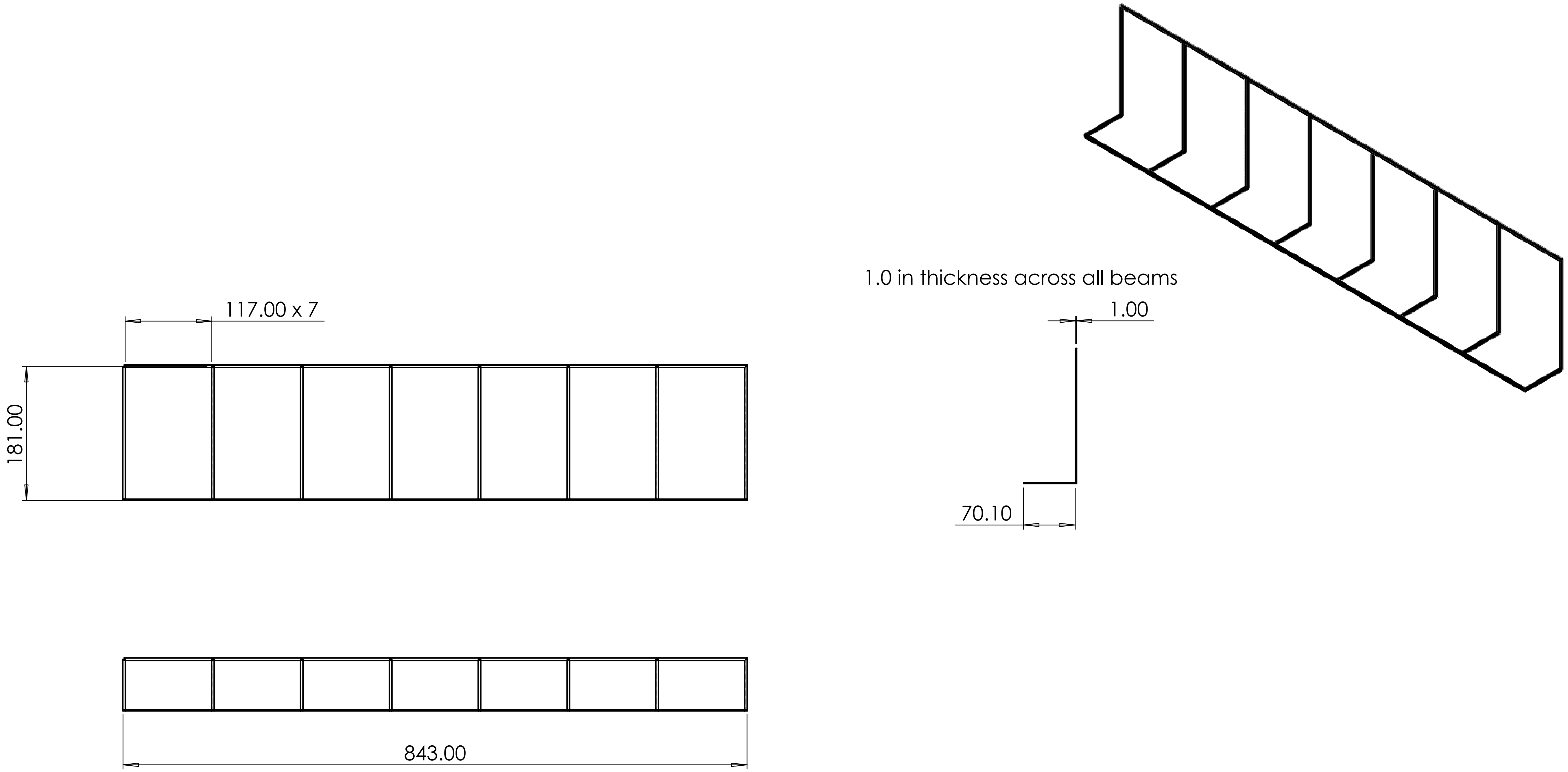
The Department of Mechanical Engineering
UNIVERSITY OF ALBERTA

TITLE:

Solar Heater

SIZE	Part supplier/manufacturer	REV
B		

SCALE: 1:200 | Mass: | SHEET 1 OF 4



Mec E 460

Instructors: Lipsett & Dr. Zhong

Winter 2019

Comments:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.02
X.X = ± 0.004
X.XX = ± 0.001

SURFACE FINISH µm 0.6

DO NOT SCALE DRAWING

MATERIAL:

FILE NAME: SolarHeater

DRAWN BY: **Manel Ajbouni**

Group name	sWarm Solutions
Group number	21
SM By	Alex Madsen
Reviewed by	Manel Ajbouni

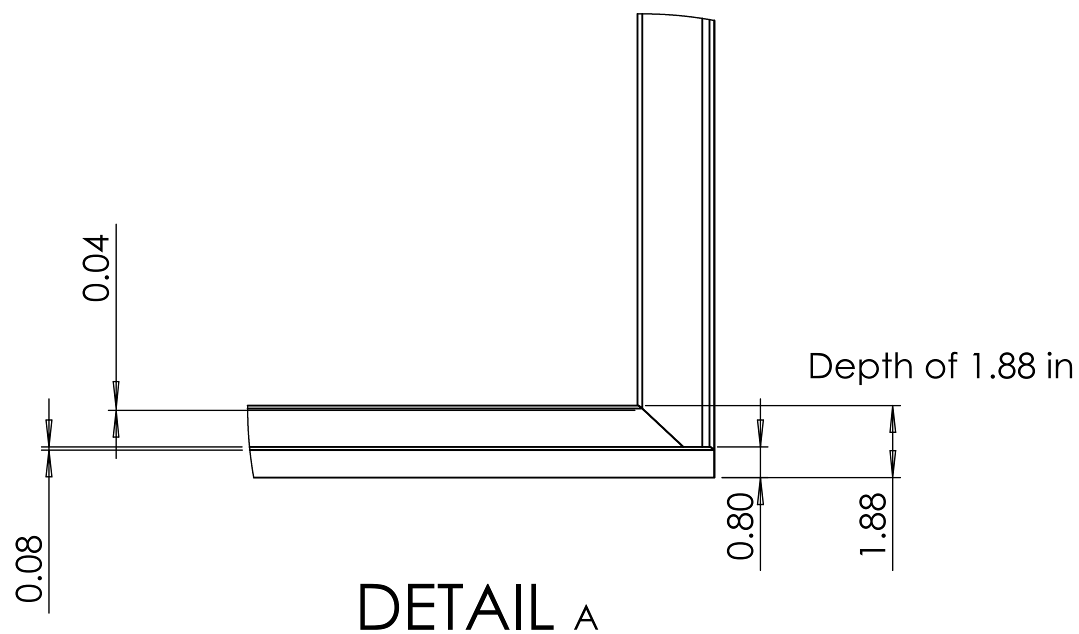
Tuesday, April 9, 2019 10:49:26 AM
Wednesday, March 27, 2019 10:28:07 PM

The Department of Mechanical Engineering
UNIVERSITY OF ALBERTA

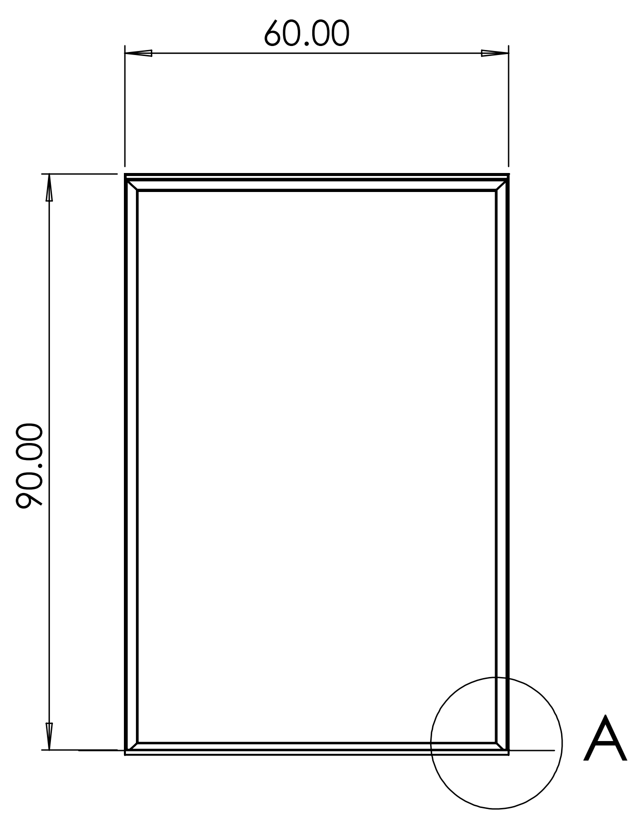
TITLE: **Solar Mount**

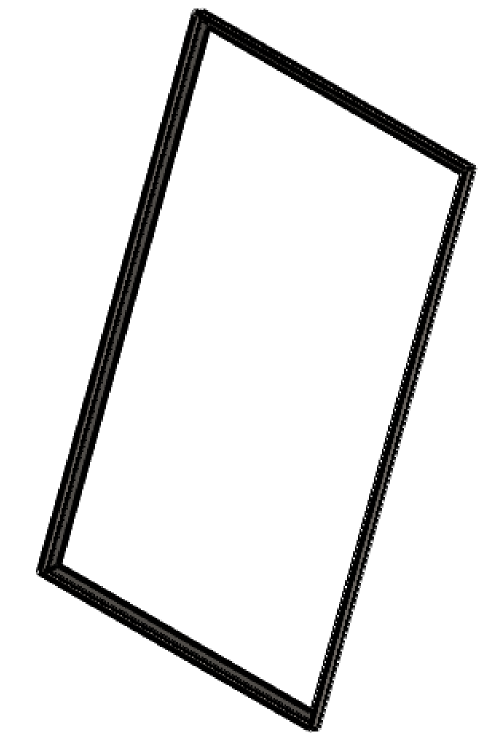
SIZE	Part supplier/manufacturer	REV
B		

SCALE: 1:100 | Mass: | SHEET 2 OF 4



DETAIL A
SCALE 1 : 5





Mec E 460
Instructors: Lipsett & Dr. Zhong
Winter 2019
Comments:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.02
X.X = ± 0.004
X.XX = ± 0.001
SURFACE FINISH µm 0.6
DO NOT SCALE DRAWING

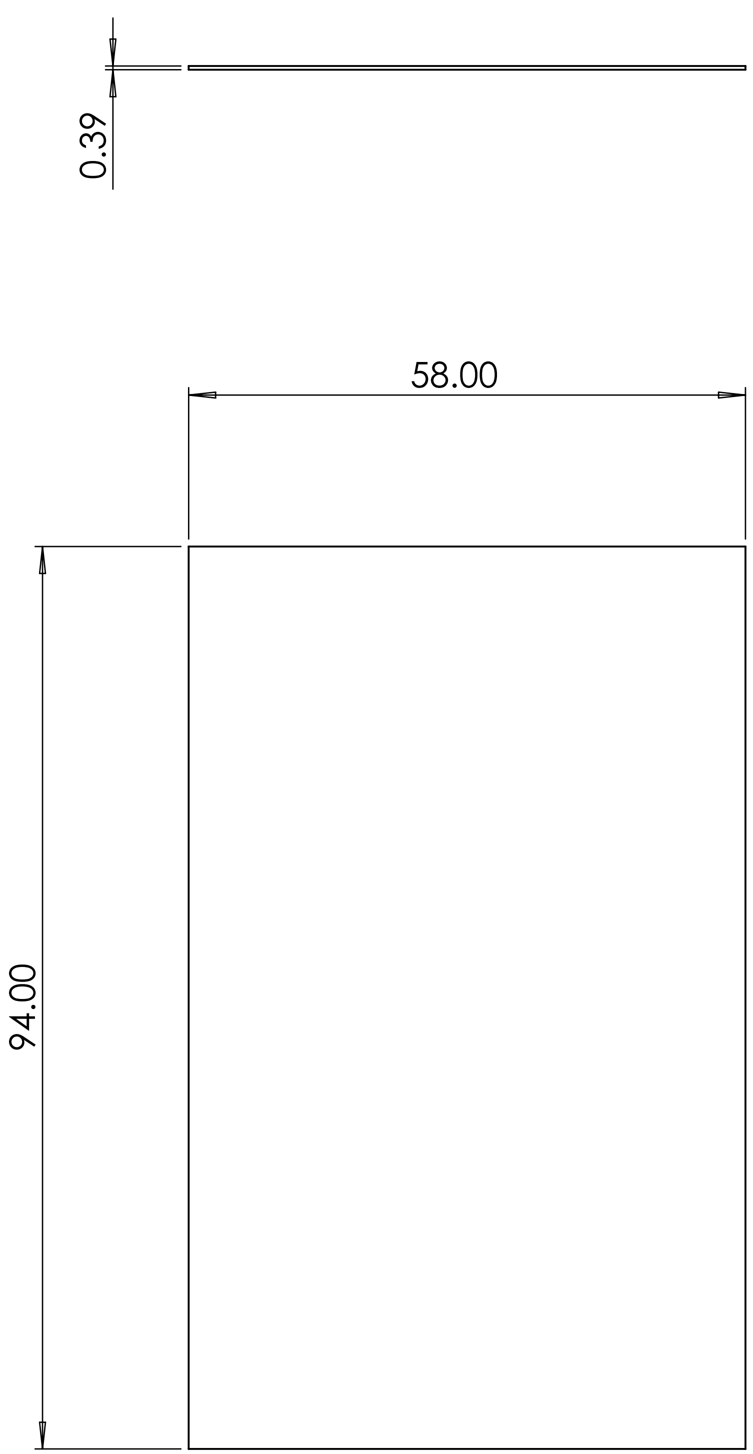
MATERIAL:
FILE NAME: SolarHeater

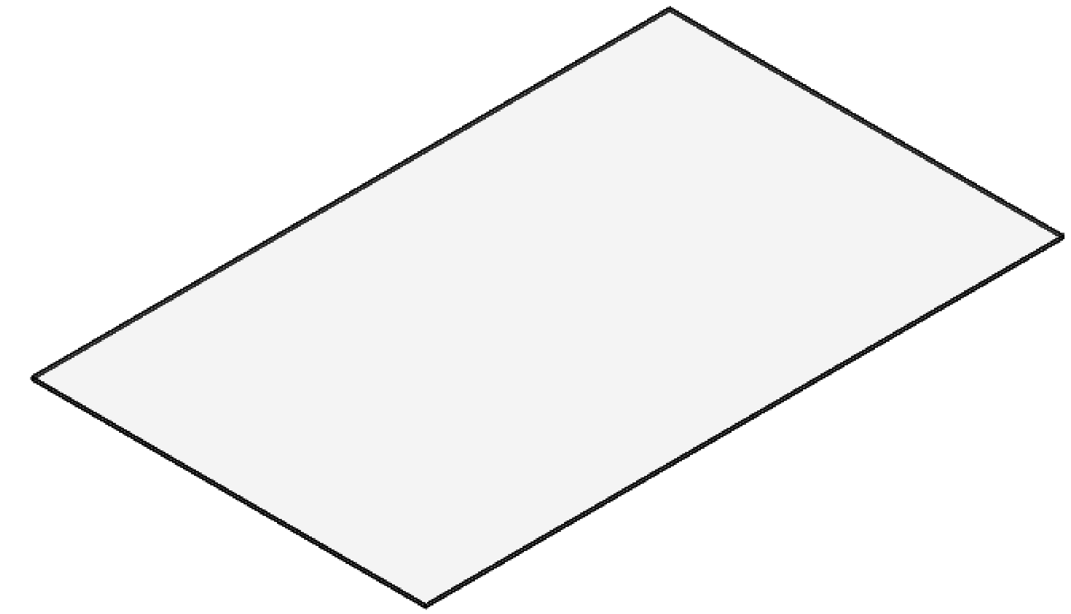
DRAWN BY: **Manel Ajbouni**
Group name: sWarm Solutions
Group number: 21
SM By: Alex Madsen
Reviewed by: Manel Ajbouni
Tuesday, April 9, 2019 10:49:26 AM
Wednesday, March 27, 2019 10:28:07 PM

The Department of Mechanical Engineering
UNIVERSITY OF ALBERTA

TITLE:
Glass Mount

SIZE **B** | Part supplier/manufacturer | REV
SCALE: 1:50 | Mass: | SHEET 3 OF 4





Mec E 460

Instructors: Lipsett & Dr. Zhong
Winter 2019

Comments:

MATERIAL:

FILE NAME: SolarHeater

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: ± 0.5°
LINEAR
X = ± 0.02
X.X = ± 0.004
X.XX = ± 0.001

SURFACE FINISH µm 0.6

DO NOT SCALE DRAWING

DRAWN BY: **Manel Ajbouni**

Group name	sWarm Solutions
Group number	21
SM By	Alex Madsen
Reviewed by	Manel Ajbouni

Tuesday, April 9, 2019 10:49:26 AM
Wednesday, March 27, 2019 10:28:07 PM

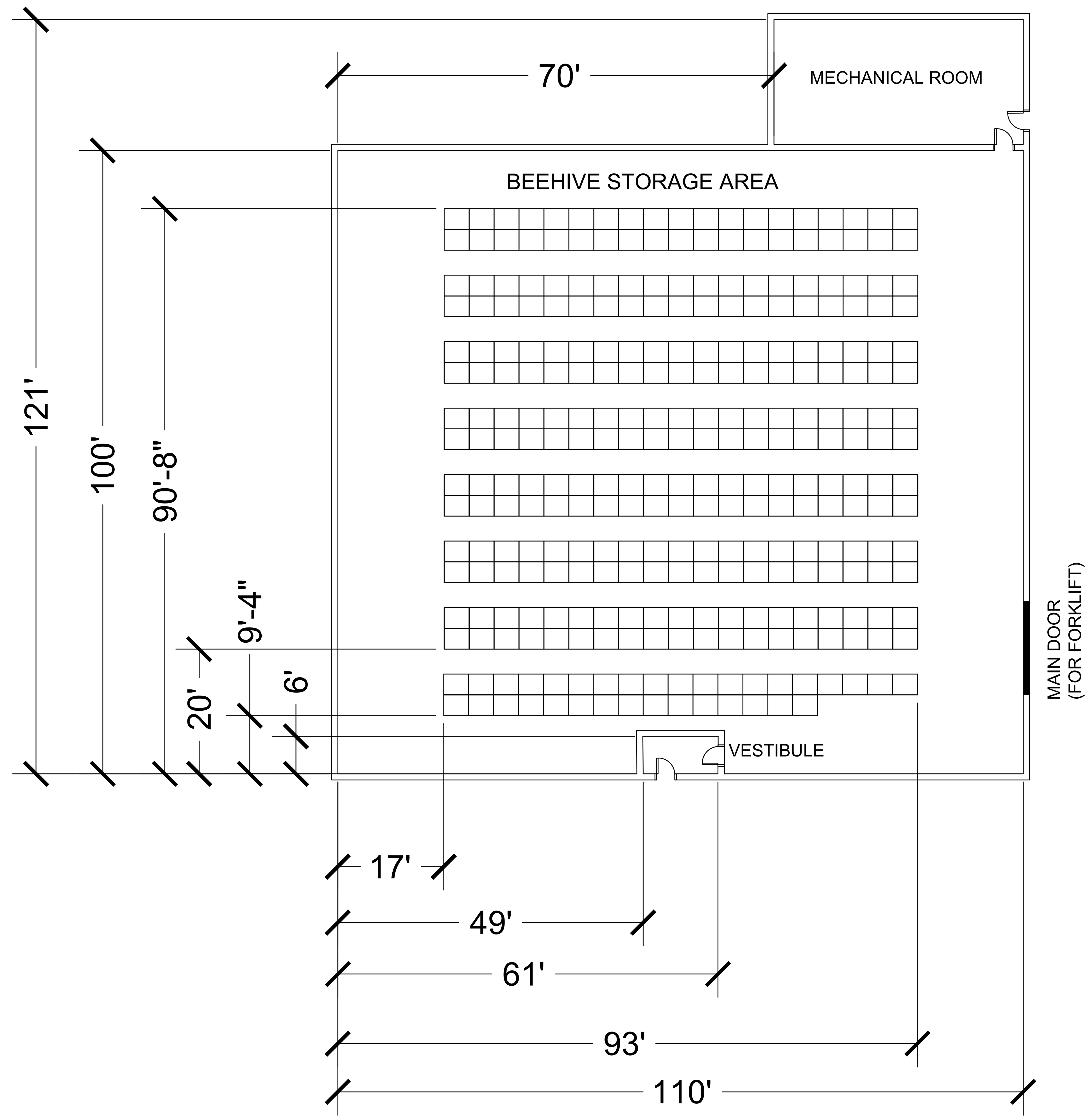
The Department of Mechanical Engineering
UNIVERSITY OF ALBERTA

TITLE:

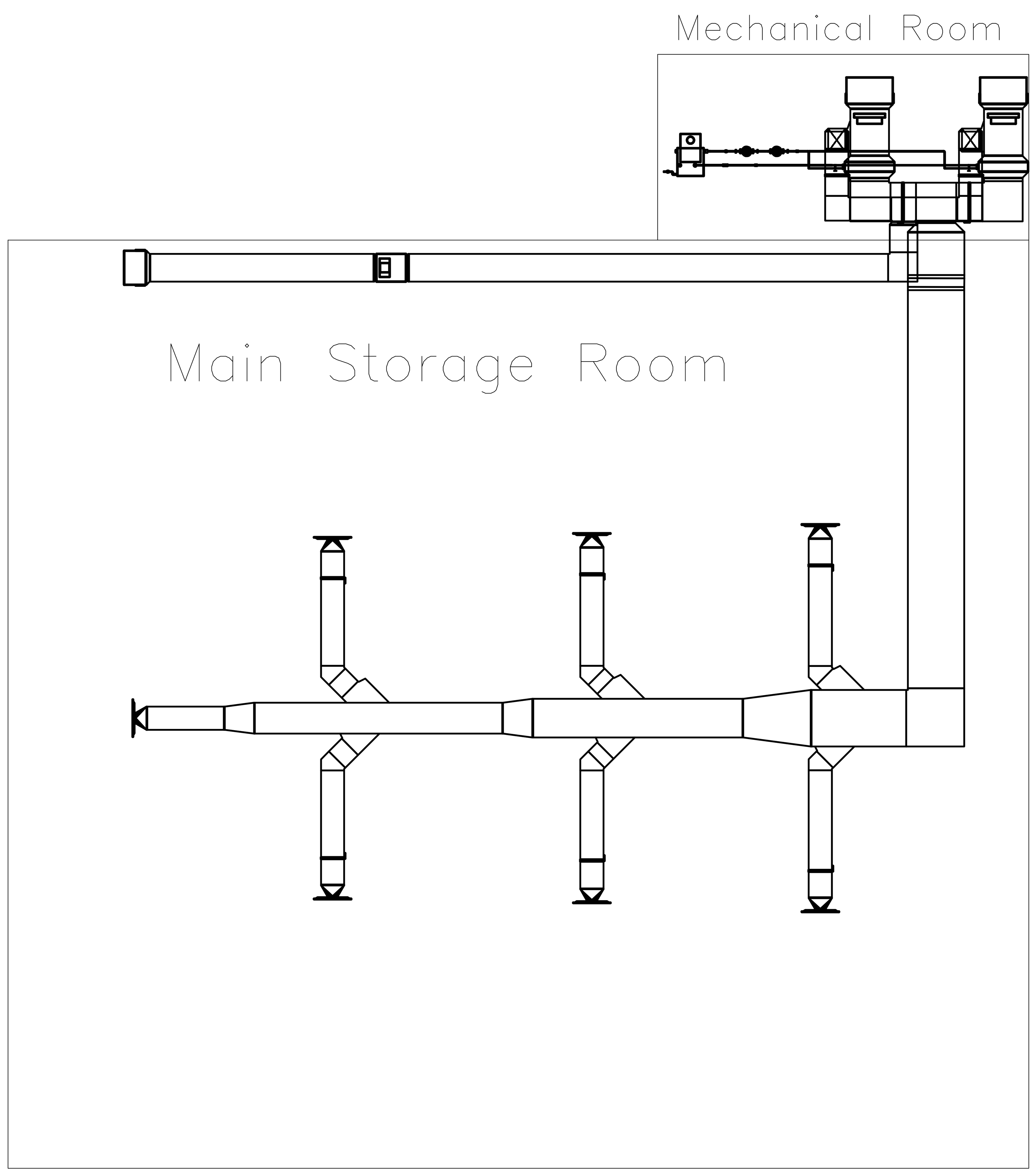
Glass Sheet

SIZE **B** | Part supplier/manufacturer | REV

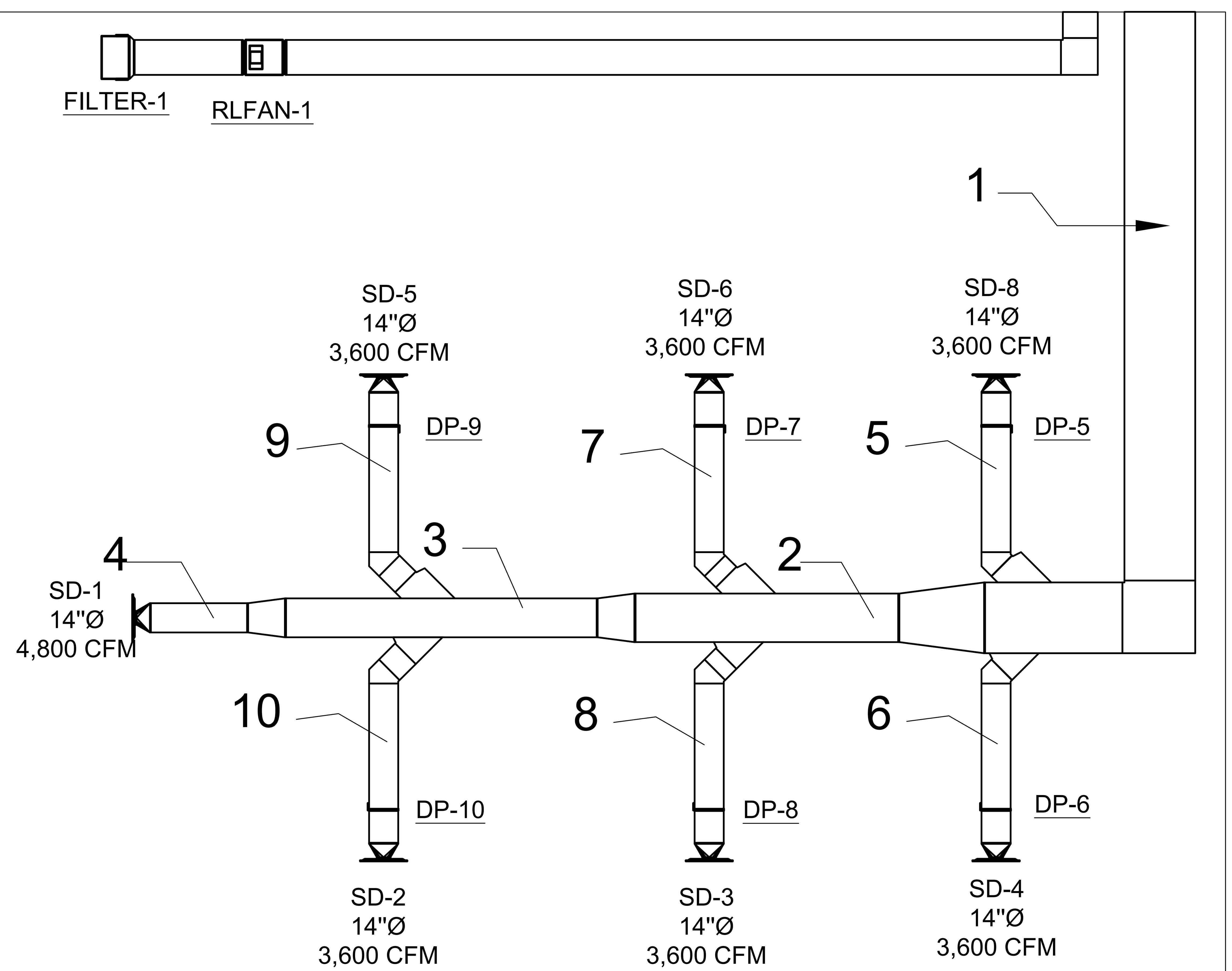
SCALE: 1:20 | Mass: | SHEET 4 OF 4



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	
		Group number	21	Date prepared: April 5th, 2019
Materials:		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	
		Group number	21	Date prepared: April 5th, 2019
Materials:		SM By	Son Le	File Name: HVAC+PIPING
		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
Group number	21
SM By	Son Le
Reviewed by	Alex Madsen

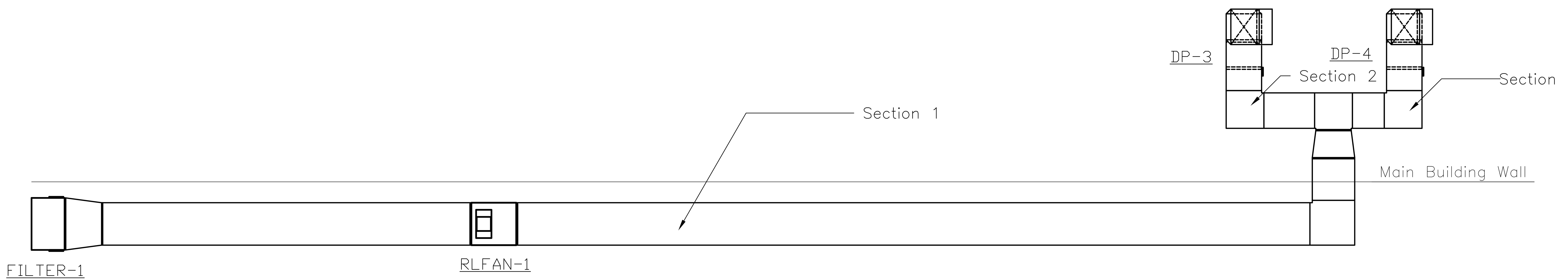
Date prepared:
April 5th, 2019

Materials:

File Name:
Building Duct

Prepared in AutoCAD MEP 2019 STUDENT VERSION

PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION

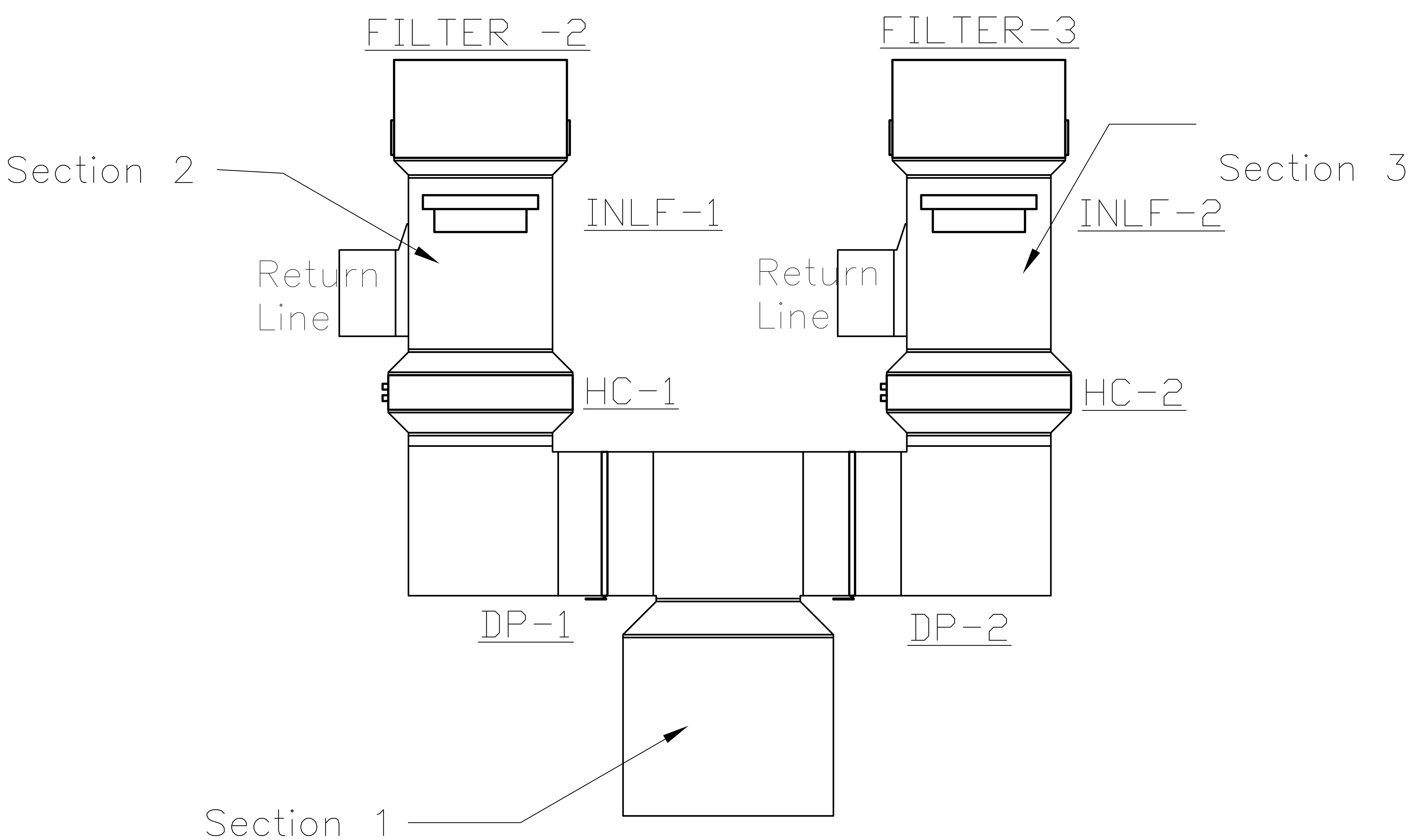


Duct Schedule					
Section	Size	Length (ft)	Air flow rate (cfm)	Velocity (fpm)	Friction loss (inwg/100ft)
1	38x28	85	7920	1149	0.0457
2, 3	30x22	16	3960	926	0.0406

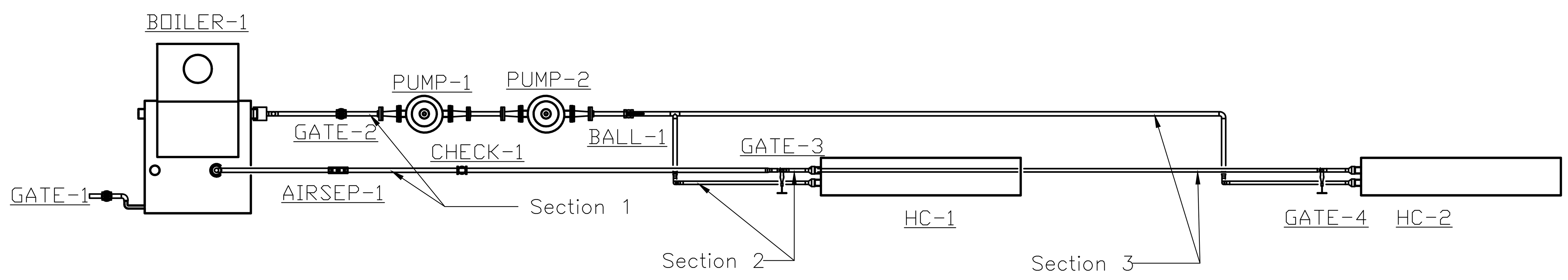
<table>
<tr><td>Mec E 460</td><td>UNLESS OTHERWISE SPECIFIED</td><td colspan="2" rowspan="2">DRAWN BY:
Son Le</td><td>The Department of Mechanical Engineering The University of Alberta</td></tr>
<tr><td>Instructors:
Lipsett & Zhong
Winter 2019</td><td rowspan="5">DIMENSIONS ARE IN Inches
Line Type: Engineering
Precision: 0'-0.00"
Angle Type: Degrees
Precision: 0.00

DP = DAMPER
RLFAN = Return Line Fan</td><td rowspan="2">Title: Return Line Duct Network</td></tr>
<tr><td rowspan="2">Comments:</td><td>Group name</td><td>sWarm Solutions</td></tr>
<tr><td>Group number</td><td>21</td><td>Date prepared:
April 5th, 2019</td></tr>
<tr><td rowspan="2">Materials:</td><td>SM By</td><td>Son Le</td><td>File name:
Return Line</td></tr>
<tr><td>Reviewed by</td><td>Shengnan Chen</td><td>Prepared in AutoCAD MEP 2019 STUDENT VERSION</td></tr>
</table>

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

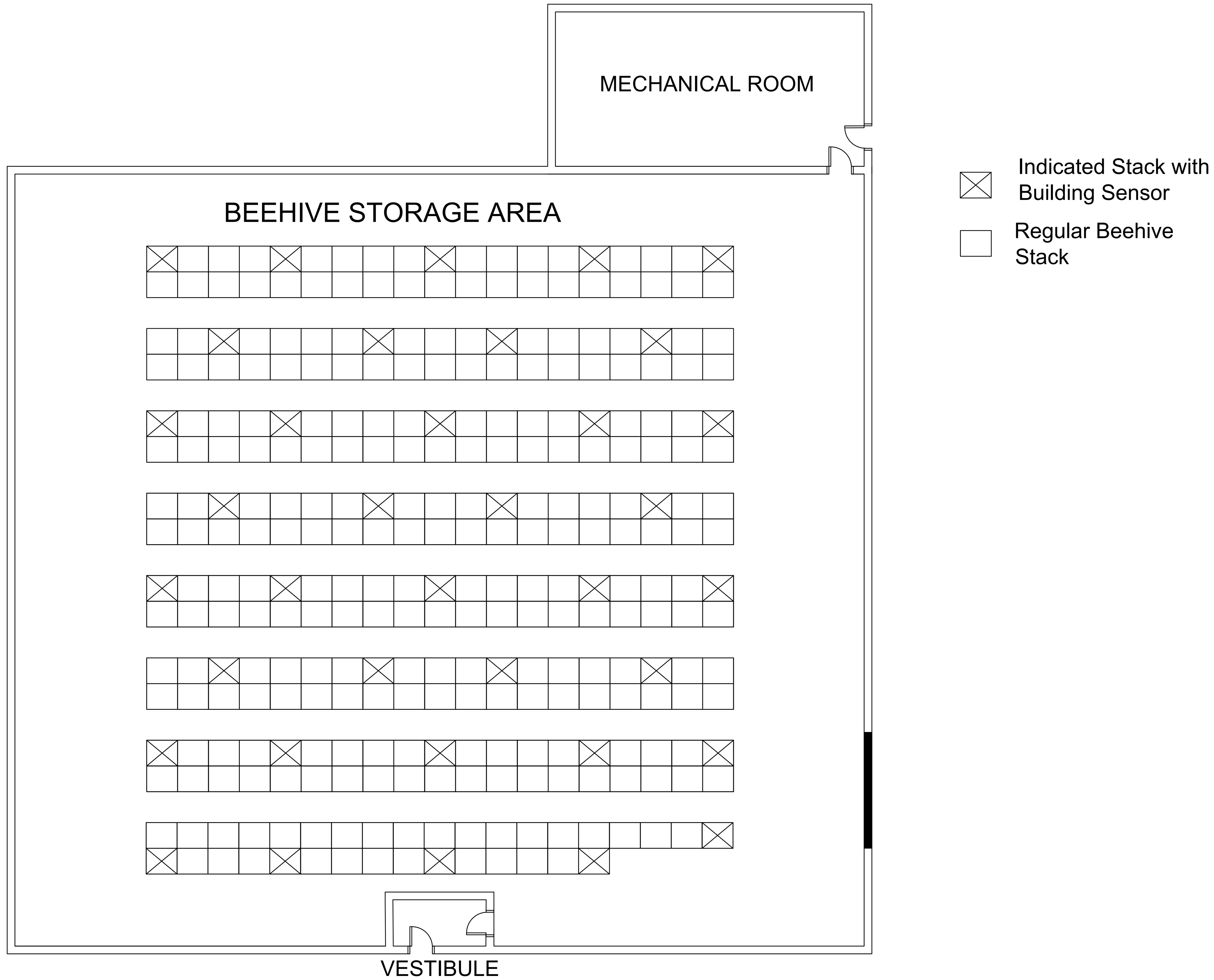


Mec E 460	UNLESS OTHERWISE SPECIFIED	DRAWN BY: Son Le		The Department of Mechanical Engineering The University of Alberta
Instructors: Lipsett & Zhong Winter 2019	DIMENSIONS ARE IN Inches Line Type: Engineering Precision: 0'-0.00" Angle Type: Degrees Precision: 0.00			Title: Intake Duct Network
Comments:	DP = Damper HC = Heating Coils INFL = Inline Fan	Group name	sWarm Solutions	
		Group number	21	Date prepared: April 5th, 2019
Materials:		SM By	Son Le	File name: Duct Network
		Reviewed by	Shengnan Chen	Prepared in AutoCAD MEP 2019 STUDENT VERSION



Pipe Schedule				
Section	Size	Length (ft)	Flow rate (gpm)	Friction loss (H20/100ft)
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



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

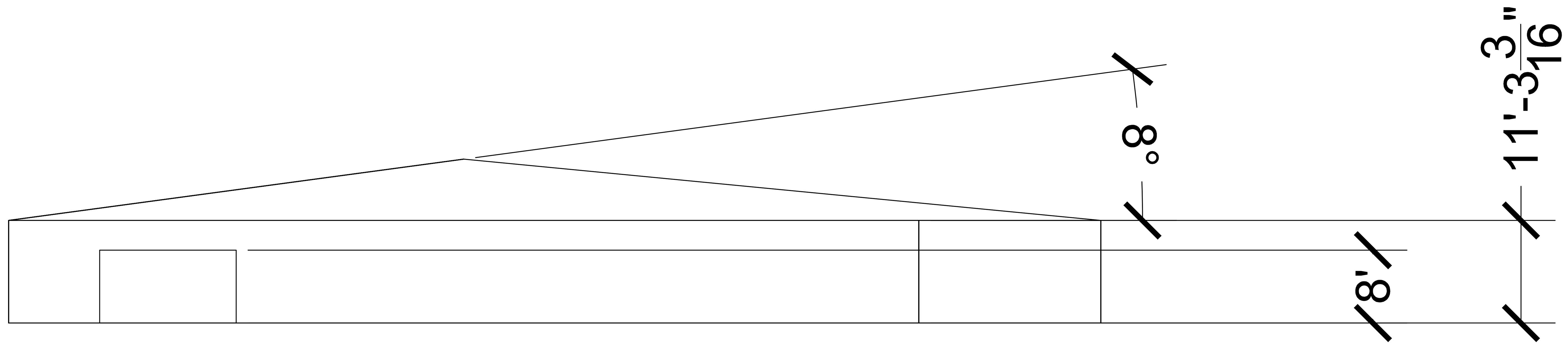
Group name	sWarm Solutions
Group number	21
SM By	Son Le
Reviewed by	Alex Madsen

Date prepared: April 5th, 2019

Materials:

File Name: Building Sensors

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
Materials:		SM By	Son Le	File Name: Building Final
		Reviewed by	Alex Madsen	Prepared in AutoCAD MEP 2019 STUDENT VERSION

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