HVAC System Design for the New Paint Facility at Sperling Industries Ltd.

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EXECUTIVE SUMMARY

Team 20 of MECH4860 was paired with Sterling Industries Ltd., a local steel fabrication company and tasked with designing the HVAC for Sperling Industries' anticipated 19,400 sq. ft. paint facility. Sperling Industries looks to take our design and estimated cost into consideration to see if their new paint facility is feasible.

Multiple concepts were brainstormed and put against each other in pair wise selection matrices to determine which design would be best suited for this application. Between three energy sources and three air handling equipment, Team 20 had to select a final design from nine generated conceptual designs. After collaboration with Sperling Industries, Team 20 chose to proceed into final design with the concept that included the use of a propane-burning make up air unit (MUA).

The final design incorporated calculations and finer design details that were overlooked in the concept selection phase. First, the exhaust requirement was determined for the building, which depended heavily on the lower flammability limit of the paints used in the paint area. Team 20 decided to implement two MUA's on the basis of system control; the flexibility to turn off one MUA during the periods while the paint booth was not running overweighed the increased capital cost of separate MUA's. Second, the MUA's were sized as per the air volume required by the exhaust and heating calculated by CAN-QUEST needed to keep a comfortable, 25°C within the building. Third, exhaust equipment was specified and duct sizes and diffuser layout was selected.

Team 20 chose to use two Engineered Air manufactured HE direct fire propane burning MUA's, complete with M-TRAC controls, two Price Industries manufactured CWB belt driven sidewall exhaust fans, and Standard Tools and Equipment Co.'s custom sized semi-down draft paint booth with separate Greenheck CUBE-480 explosion proof upblast exhaust fan. The remaining spaces in the building are to be exhausted by Greenheck CWB-240 and CWB-300 explosion proof exhaust fans. The building HVAC will connect with pneumatic controls for simple operation and cost. The total estimated equipment cost for the new paint facility is $127,683.

To conclude, the HVAC design was intended to be practical and minimize costs. Team 20 can confidently say the design is exactly that, while conforming to all Industrial Ventilation and National Fire Protection standards. Sperling Industries was presented with one 18x24" AutoCAD engineering drawing that convey the design to contractors and stakeholders.

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1.0 INTRODUCTION

Our team, Team 20, is working directly with Sperling Industries Ltd. to design the HVAC system for Sperling Industries' new paint facility. Sperling Industries Ltd. provides services in steel fabrication and installation for various mechanical equipment and buildings. Once the parts have been fabricated per customers' specifications, the products are painted and finished at the painting facility. This report will build on the progress made in the Problem Definition Report (PDR) and the Concept Definition Report (CDR) and finalize the HVAC design for the new paint facility. A brief recap of PDR and CDR are utilized to ensure continuity from our previous reports.

1.1 PROJECT OBJECTIVES

Defining clear outcomes for this project is essential to satisfy the client at the end of the project. As a team, the objectives of the project are to deliver complete mechanical AutoCAD drawings for Sperling Industries' new paint facility. The drawings will include mechanical equipment layout and specifications, air volume calculations, and overall system integrations. In order to meet our deliverables, we must calculate all net heating loads and outdoor air requirements. Most importantly, we must design the most economical HVAC design for Sperling Industries' new paint facility, while minimizing the overall cost and adhere to all local and national building codes.

1.2 TARGET SPECIFICATIONS

The process of establishing target specifications consists of identifying customer needs and metrics for evaluating these customer needs. Properly identifying customer needs in the beginning of the project is one of the most crucial tasks to be successful. First, we address the process of establishing customer needs and the results of the process along with importance rating assigned to them are tabulated. After the customer needs are identified, we determine the required metrics for each needs. These metrics allow us to learn more about the effect that each of the needs has on the overall project. Once we have a clear understanding of the customer needs and their metrics, target values can be determined to help guide the project on the path to success.

1.3 CUSTOMER NEEDS

Our team began the project by identifying and prioritizing the customer's needs to clearly establish the goals for the project. Needs breakdown consists of two high level categories: customer defined needs and health and safety needs.

In the process of establishing customer needs, we considered all the requirements and expectations that were provided to us by Adam Nicolajsen, Project Manager at Sperling Industries. The customer defined needs are created based on the customer's expectations on the design of HVAC system in relation to the cost, code compliance, and mechanical performance characteristics such as air temperature and airflow controls. Our team identified health and safety needs in order to address any potential issues related to protection of the public and specifically the paint shop workers who will be relying on the safe design of our system.

In the process of establishing the needs for the project, we first gathered information via interview with Adam Nicolajsen, focusing on the desired outcomes rather than potential solutions. Second, we interpreted the gathered information into high level need statements. Third, we subdivided the needs into smaller areas of the project aiming to provide clarity to each aspect. Finally, we prioritized them according to the importance that was placed on the different aspects of the design during the customer interview. The needs breakdown can be seen in TABLE I.

TABLE I: CUSTOMER NEEDS BREAKDOWN

Category	Need Description	Priority
1.	Customer defined needs	5
1.1.	Lower cost of overall design	5
1.1.1.	Acceptable initial investment	5
1.1.1.1.	Affordable equipment	4
1.1.1.2.	Prompt installation	2
1.1.2.	Acceptable long term cost	3
1.1.2.1.	Long service life	4
1.1.2.2.	Good warranty	2
1.1.2.3.	Low maintenance	3
1.2.	Proper heating of the space	5
1.2.1.	Reliable temperature control	4
1.2.2.	Sufficient heating capacity	5
1.3.	Visually unnoticeable	1
1.4.	Equipment serviceability	3
1.5.	Code compliancy	5
2.	Health and safety	5
2.1.	Proper air quality	5
2.1.1.	Proper air filtration	5
2.1.2.	Sufficient fresh air	4
2.2.	Low noise and vibrations	3
2.3.	Safe layout (obstructions)	4
2.4.	Reliable fire protection	5

As a result of breaking down main need categories, we defined a number of needs on which we should focus our direct attention. Lower cost of overall design need can be satisfied mainly through finding affordable equipment with long service life and low maintenance requirements. This analysis is represented through indicated priority rating. Proper heating of space, a higher level need, can be satisfied through reliable temperature control and sufficient heating capacity of the HVAC system. We gave the highest priority rating to code compliancy need since it must be met for the design to be accepted.

1.4 PROJECT METRICS

In order to establish target specifications, we identified the metrics that can be used to evaluate the level of accomplishment for all customer needs identified previously. Where possible, the metrics were assigned defined units of measurement such as $CAD for cost, cubic feet per hour (CFH) for number of air changes, and where the metric was relying on the judgment call, we used subjective (subj.) as a unit. As the project progressed some of the metrics fell out of the scope due to time limit on the completion of the project and we identified them as OS. The metrics are listed in TABLE II.

TABLE II: METRICS LIST

Metric #	Need	Metric	Priority	Units	Marginal Value	Ideal Value
1.	1.	Customer satisfaction	High	Grade awarded	B	A+
2.	1.1.	Present total cost	High	$CAD	TBD	TBD
3.	1.1.1.	Total initial cost	High	$CAD	TBD	TBD
4.	1.1.1.1.	Cost of equipment	High	$CAD	TBD	TBD
5.	1.1.1.2.	Installation time	Moderate	Days	OS	OS
6.	1.1.2.	Monthly cost	High	$ CAD/month	TBD	TBD

Metric #	Need	Metric	Priority	Units	Marginal Value	Ideal Value
7.	1.1.2.1.	Time to replacement	Moderate	Years	OS	OS
8.	1.1.2.2.	Duration of warranty	Moderate	Years	TBD	TBD
9.	1.1.2.3.	Yearly cost	Moderate	$CAD/year	Varies on the temperature setting	Varies on the temperature setting
10.	1.2.	Maintained temperature	High	°C	20-25	24
11.	1.2.1.	Reliability/Precision	High	Y/N	Yes	Yes
12.	1.2.2.	Energy transfer rate	High	Btu/hr	Varies on the climate	Varies on the climate
13.	1.3.	Concealment	Low	subj.	Typical for industrial applications	Similar to U of M room ventilation
14.	1.4.	Ease of access	Moderate	subj.	Comfortable for 1 worker	Comfortable for 2 workers
15.	1.5.	Meeting codes	High	Y/N	Yes	Yes
16.	2.	Safety rating	High	# of hazards	Some with mitigation	0
17.	2.1.	Air quality rating	High	Grade	NFPA91	NFPA91
18.	2.1.1.	Aerosols concentration	High	PPM	No recirculation PPE used	No recirculation PPE used
19.	2.1.2.	# of air changes	Moderate	CFH	NFPA33	NFPA33
20.	2.2.	Noise level	Moderate	dB	OS	OS
21.	2.3.	Worker movement safety	High	subj.	Engineering Controls	All hazards eliminated
22.	2.4.	Fire protection rating	High	Grade	NFPA33	NFPA33

In the table above, each need we identified previously is linked to one metric with a corresponding unit which best represents that need. However, we are not be able to determine target values for most of the metrics due to lack of technical knowledge in the HVAC industry.

1.5 Constraints

In the concept generation for the HVAC design of Sperling Industries new paint facility, our team is constrained by information given to us by Adam Nicolajsen, Project Manager at

Sperling Industries. In Sperling, MB, the new paint facility already has a building envelope that we must design around. The size and wall construction will directly affect the heating loads, and ultimately, the size of our heating equipment. Also, Sperling does not have access to a natural gas service, which limits the equipment we can select, eliminating any equipment that use natural gas in the heating section. The HVAC design must also be able to handle the current paint process, which includes many extremely volatile paints. For us, this will introduce explosion proof materials and extra codes on minimum air change requirements. Finally, the project, and all its deliverables, must be submitted by December 9, 2016.

1.6 LIMITATIONS

In addition to the constraints provided in the above section, our HVAC design is also limited by our access to the most up-to-date codes, including National Building Code, ASHRAE, Industrial Ventilation, and National Fire Protection Code (NFPA). Sperling Industries does not have any codes related to paint facility. Therefore, with the $400 budget provided by the University of Manitoba, our group was able to purchase two NFPA documents: NFPA 33 and 91. These two documents will be further elaborated in future sections. These two NFPAs are crucial for designing air handing system for the paint facility.

1.7 ITEMS NOT IN SCOPE

To better define the project requirements, a list of items that are not to be handled by our group have been included. The following items are not in the scope of the project and therefore, not our responsibility:

- Design of the paint-shop, material handling equipment, and electrical system

- HVAC cooling and humidity control
- Plumbing system
- Architectural layout and building envelope

1.8 DESIGN EXPECTATIONS

The final design that our team will present must comply with all applicable codes. In doing so, the design will maintain acceptable air quality, temperature control, and ventilation requirements. Our design will be simple, cost effective, and easy to maintain. Overall, we plan to be successful in completing our design by staying on track with our Gantt Chart is found in Appendix A.

2.0 Concept Generation

To brainstorm the concept generation for Sperling Industries' new paint facility, it is recommended to look into both external and internal research. This helps us to establish concept analysis for Sperling Industries' air handling system.

2.1 External Research

In order to establish our understanding of the HVAC industry, we decided to perform external research in the following areas: heat distribution system, energy resources, and types of supply air system.

2.1.1 Heat Distribution System

Heat can be delivered to rooms in two common ways, through convection or radiation. Many designs will incorporate one of the two, or sometimes a combination of the two. Both forced air convection and radiation are elaborated in this section.

2.1.1.1 Forced Air Convection Heating system

Convection can simply be defined as the heat transfer from one place to another by the movement of a surrounding fluid, commonly water or gas. There are two types of convection: natural and forced. Forced convection can be obtained by moving the fluid by means of an external source, such as fan or a pump [1].

We can utilize forced air convection to heat the rooms of Sperling Industries' new paint facility by using a centralized fan forcing the air to pass through a heat source and then circulate the warm air through the building by means of strategically designed duct work. Forced air convection can be shown in Figure 1.

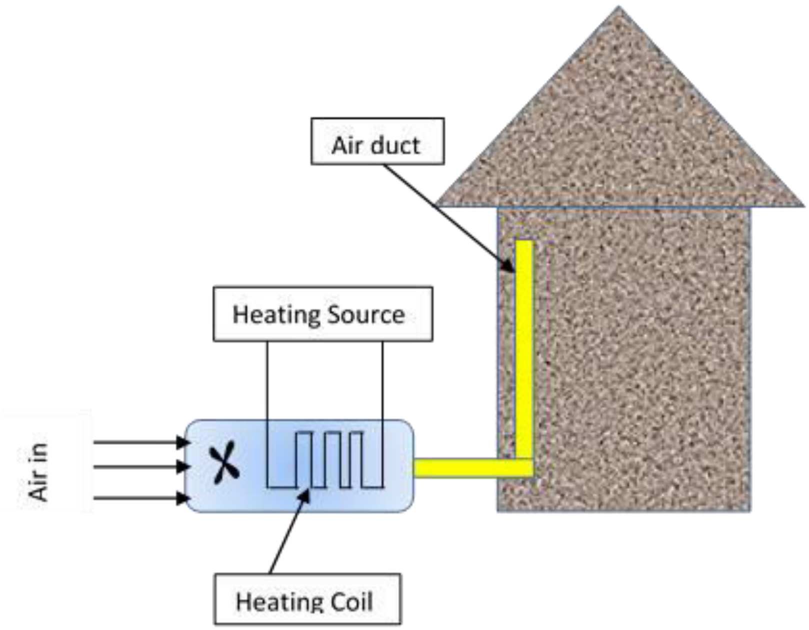

Figure 1: Forced Air Convection Heating System using a Centralized Fan [2].

Air is drawn in by a fan, which passes over a heat source, often a heating coil or gas burner, and then distributed through the ductwork to the spaces in the building.

2.1.1.2 Hydronic Radiant Heating System

Radiant heat can be described as the heat transferred from one place to another in the form of electromagnetic radiation [3]. In a radiant heating system, the heat energy is emitted from a heat source either embedded in the floor or installed in the wall in the form of baseboards or standalone radiators. The emitted heat energy in turn warms up the occupants and the objects in the building instead of warming up the air directly [4].

In radiant heating systems, either hot water, team pipes (hydronic) or electric resistance creates heat coils. For hydronic systems, a boiler, pump, and accompanying pipe network would be required to create the hot water loop. The figure below shows the fundamental working of a hydronic radiant heating system. The water is circulated through the whole system through a water pump. The cycle starts by heating the water in the boiler and then the water is passed through a series of a pipe network running through floor of the required space. The radiant heating system provides even temperature throughout the space in which in-floor heating is provided.

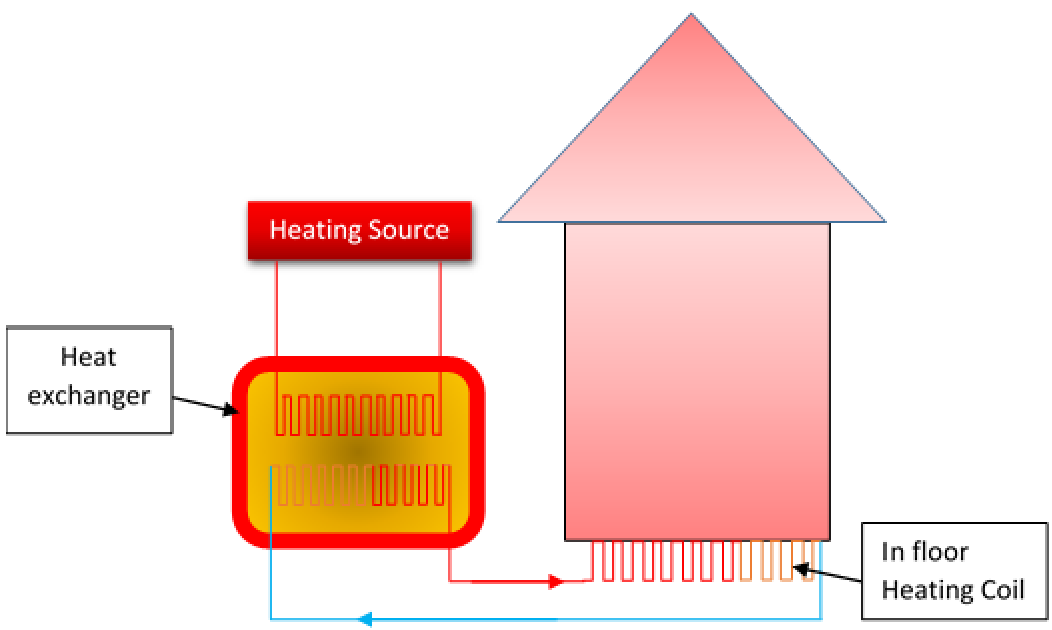

Figure 2: Hydronic Radiant Heating System using Water [5].

2.1.2 ENERGY SOURCES

There are three different types of energy sources that are commonly used in HVAC industry: geothermal, electricity, and propane.

2.1.2.1 GEOTHERMAL ENERGY

Geothermal energy is commonly used around the world as it is available everywhere. The energy is extracted from the Earth. Geothermal energy is a clean and renewable source of energy. Heat from the earth can be extracted 24-hours a day. Geothermal energy can be used either to create electricity or it can be used directly for heating. For heating a building efficiently, geothermal heat pumps have to be used [6].

Figure 3: Schematic View of Geothermal Energy in Operation [7].

The figure above shows how the building can be heated using the heat from the ground and a forced air circulation duct system. The ground loop runs water through the loop and the water absorbs heat from the earth and takes it back to the heat exchanger (Figure 3 shown in blue). The water is circulated in the loop by using a geothermal pump. The cold refrigerant absorbs the heat from the water in the heat exchanger and the compressor pumps the hot refrigerant in the second heat exchanger (Figure 3 shown in red). In the second heat exchanger air, which is forced through the coils by a fan, the heat exchanger absorbs the warmth from the refrigerant and is then circulated through the different parts of the building by using the duct work.

2.1.2.2 ELECTRICITY

Another source of energy considered is electricity. The equipment used to convert electricity to heat involves no moving parts and they are very economical and easy to find. Electricity in Manitoba is produced by hydro dams and it is available in Sperling Manitoba. It can be used to heat the buildings. Figure 4 explains how the electric heating coils can be used to warm up the in a forced air convection system. The electric heating systems are easy to install and easy to maintain as well.

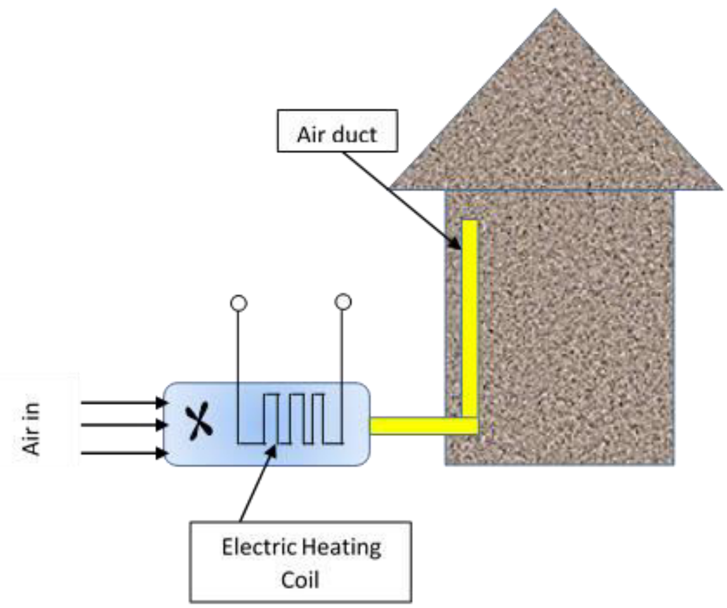

Figure 4: Schematic View of the Heating Coil Heating Source using Electricity [8].

2.1.2.3 PROPANE

Finally, we looked at propane as our third energy source. Propane is also one of the common energy sources used for heating a building. One litre of propane contains approximately 25.3MJ of energy [9].

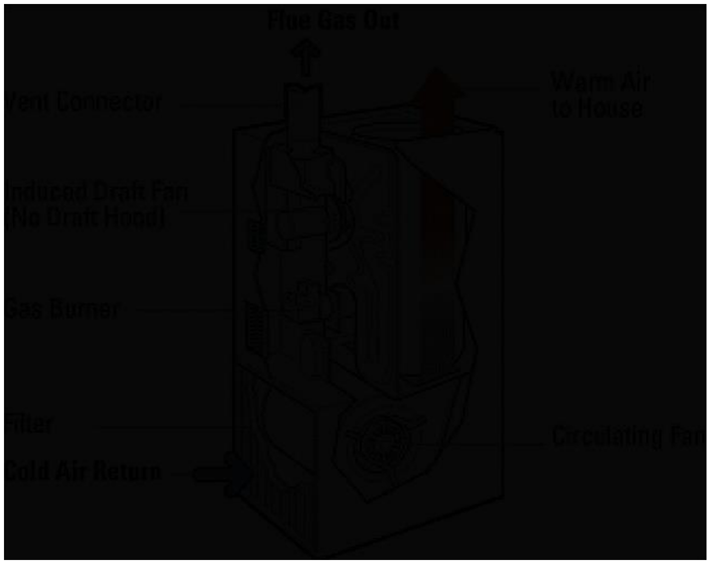

Figure 5: Schematic View of Propane System using Forced Air System [10].

Figure 5 shows a forced air circulation system propane furnace. The cold air forced in the furnace using a circulating fan. Propane is burnt using the gas burner and the cold air gets heated. The heated air is circulated in the building through the ducts.

2.1.3 Supply Air System

There are three different supply air systems that are commonly used in the HVAC system: Heat Recovery Ventilation (HRV), Air Handling Unit (AHU), and Makeup Air Unit (MUA).

2.1.3.1 Heat Recovery Ventilation

A Heat Recovery Ventilator (HRV) is a piece of HVAC equipment that recovers heat from return air and transfers it to fresh, outdoor air supplied to the building. A HRV acts similar to a regular air-handling unit, while also being more energy efficient [11].

HRV’s can be added to a system that already has an air handler, or can be a standalone piece of equipment. For the Sperling Industries paint facility, the HRV would be a standalone unit. In a standalone unit, the HRV would have a supply and return fan, heat exchanger, filter section, and heating section. In the heating section, we could have hydronic coils, electric resistance coils, and direct or indirect gas burner [11].

As seen in Figure 6, the fresh outdoor air enters the HRV, passes through a heat-exchange core, where it gains heat from the previously heated, the blower, and is then sent into the rooms as warm fresh air.

Figure 6: Schematic View of the HRV System with Air Movement Shown [12].

The energy that is transferred from the stale, warm return air is essentially free energy. The incoming air gains heat from air being exhausted from the building. The pre-conditioned air will rise in temperature, leaving a smaller job for the heating section to handle, ultimately reducing the total energy required to heat the air in the cold winter months. The same principle works in the summer, but the biggest benefits are seen in cold, dry climates.

The advantages of introducing an HRV into an HVAC design is the ability to recover energy form the exhaust air and pre-condition the outdoor air. HRVs have developed into efficient pieces of equipment that can greatly reduce heating costs. The disadvantages of adding an HRV include an increase in initial costs and complexity of the ductwork in the mechanical room. More space is often required to install an HRV. As well, typical HRVs require condensate drain and/or pump.

2.1.3.2 Air Handling

In an HVAC system, an Air Handling Unit (AHU) is a main component, which can contain heat exchangers, blower, filters, and dampers. The AHU serves the purpose of heating, cooling, filtering air, controlling humidity of the supplied air, and setting the amount of the fresh air in the supply to the conditioned zones by mixing the outdoors air with recirculated air. The following is a diagram of a typical AHU.

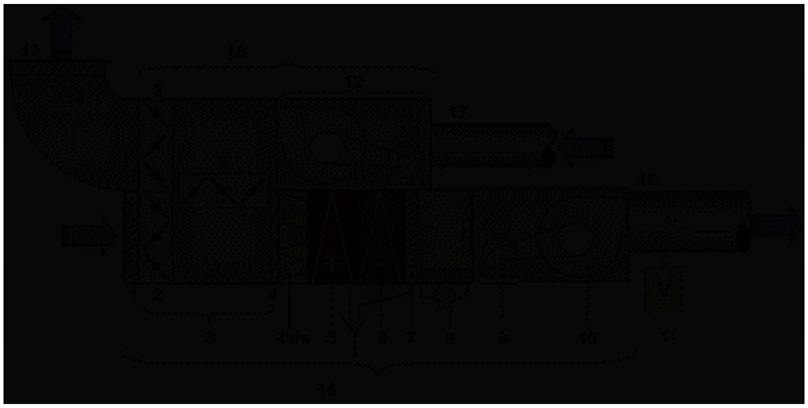

Figure 7: Typical AHU [13].

The main components shown in Figure 7 that are common to most AHUs are summarized in TABLE III.

TABLE III: KEY COMPONENETS FOUND IN AHU SYSTEM

Component	**Part # (Based on Figure 7)**
Air Inlet	1
Mixing Chamber	3
Heat Supply	5
Heat Sink	6
Humidifier	8
Blower Motor	9
Blower Fan	10
Supply Air Duct	16
Return Air Duct	17
Exhaust Duct	18

Air-handlers come in various types and sizes ranging from typical residential furnace which fits in a small room to meters long and high industrial units, see images below.

Figure 8: Residential Furnace commonly found in Home [14].

Figure 9: Industrial Air-handling Unit commonly found in Buildings [15].

There are several different types of AHUs that can be categorized based on their functionality. The most basic type is fan coils/blower coils. This type consists of a fan, a heat exchanger, and a filter and it is intended to serve one zone with simple controls while having lower efficiency than other types. Typical residential furnace represents this type. Next type is Packaged AHU which is a preferred type for commercial applications due to its smaller size and lower cost. As the name implies, this type includes all the necessary components of a complete system such as fans, filters, dampers, heat exchangers, compressors and heat sources all in one unit. However, these AHUs are less efficient and require more maintenance than the next types.

The next type is modular AHUs, which allow selection of individual components. Each stage of the AHU can be picked from a selection to match the particular requirements and easily added to the complete AHU system.

The final type is custom AHUs which can be made to suit the particular task to the highest degree. Usually, this type is used where there exist special requirements for size, shape, and performance. Custom AHU is the most expensive out all types [16]. Furthermore, AHUs can be further distinguished according to their configuration types.

Inline AHU has all of the replacement air coming from outdoors.

Figure 10: Inline AHU Configuration with 100% Outdoor Air Supply [17].

Inline Supply Mixed Air AHU has part of the replacement air coming from outdoors and part being reused from indoors.

Figure 11: The Inline AHU Configuration with Mixed Air Supply [17].

The Inline Double Flux AHU has replacement air as a mixture of indoors and outdoors air with the greater control of the supply air mixture as shown in Figure 12.

Figure 12: Inline Double Flux AHU Configuration with Mixed Air Supply [17].

The Double-Deck AHU has replacement air entirely coming from outdoors and it allows additional treatment of the exhaust air as shown in Figure 13.

Figure 13: Double-deck AHU Configuration with 100% Outdoor Air Supply [17].

The Double-Deck AHU has mixed indoor and outdoor air used as a replacement air with the ability to control the air flows with dampers as shown in Figure 14.

Figure 14: Double-deck AHU Configuration with Mixed Air Supply [17].

U-Shape AHU has 100% of the replacement air coming from the outdoors and can be used where length of the AHU is a factor as shown in Figure 15.

Figure 15: U-shape AHU Configuration with 100% Outdoor Air Supply [17].

L-Shape AHU has 100% of the replacement air coming from the outdoors and can be used where an L shape better suits the location as shown in Figure 16.

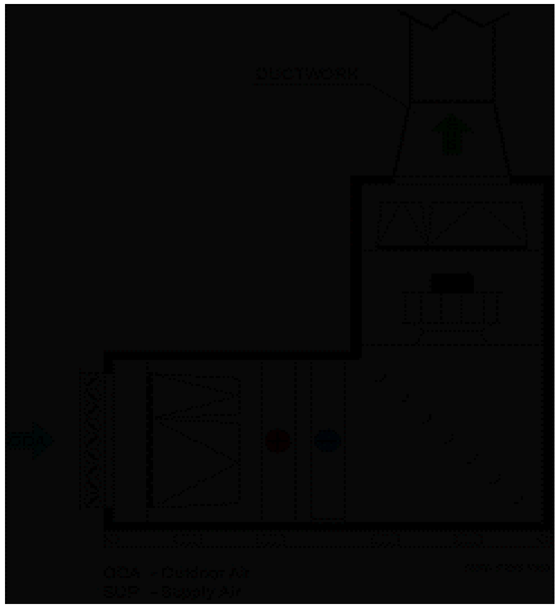

Figure 16*:* L-shape AHU Configuration with 100% Outdoor Air Supply [17].

There are several aspects that need to be considered when choosing AHU. The casing should be double walled construction with foam insulation and no thermal bridging between outside and inside walls of the unit [16]. Filters play an important role not only in removing aerosols from the air, but also in establishing the overall efficiency of the unit. In addition, direct-drive fans allow to eliminate energy losses of a typical belt-drive system. Fan arrays is another consideration, where instead of a single large fan several smaller fans are used to move air. This fan set-up provides greater reliability for the AHU. Energy recovery can be utilized by AHU to precondition the incoming outdoors air with the exhausted indoors air [16].

2.1.3.3 MAKEUP AIR UNIT

Another alternative air handling system is called Makeup Air Unit (MUA) as shown in Figure 17. MUA is commonly found on the rooftop or in a mechanical room which supplies

100% outdoor air to its desired location and the inside air gets removed by an exhaust unit [18]. MUA is commonly implemented in areas, such as hospitals, construction structures, or painting facilities that cannot recycle the existing indoor air. These places must be able to maintain indoor air quality to prevent any contaminations.

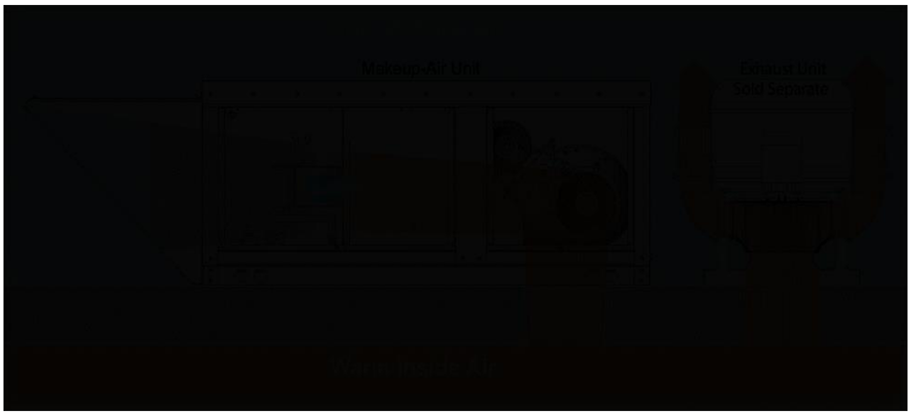

Figure 17: Direct Makeup Air Unit Extracting Outdoor Air into Warm Air [18].

As seen in Figure 18, MUA mainly consists of the following components: fan, heating (or cooling) element, filter, heat exchanger, and electromechanical controls. The MUA system is typically powered by electricity, natural gas, or propane [18, 19]. First, the outdoor air enters the filtered hood which provide debris-free air to the downstream of the MUA components. The filtered air then gets drawn into dampers, which control the flow of outdoor air that enters the building. Next, the air enters the heat exchanger.

There are two types of heat exchangers in MUA: direct fired and indirect fired [20]. Direct fired system occurs when the products of combustion are directly sent to the building. Direct fired system is commonly used in a large space where a great amount of air gets exhausted. Due to large volume of air being exhausted, air contaminants such as carbon monoxide or water-vapor build up is not a big concern. Indirect fire system on the other hand, the combustion products are vented out of the MUA prior to entering the building. Finally, the fan will allow the heated air to enter the building.

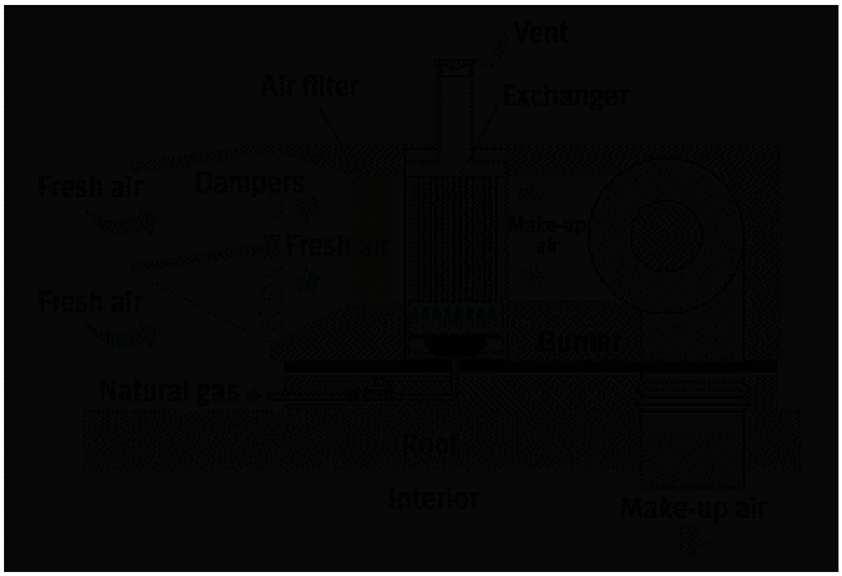

Figure 18: Cross Sectional View of Indirect MUA where Combustion Products are Disposed to the Atmosphere [21].

The main advantage of MUA is its ability to provide fresh outdoor air at all times. Due to continuous air supply, MUA can help prevent the risk of negative pressure inside the building. MUA is also known for its efficiency as a basic indirect MUA must meet 80% combustion efficiency [21]. Additionally, a direct MUA has a combustion efficiency of 100% with an overall efficiency of 92% [22].

It is crucial to have make up air at all times in order for an exhaust system to work properly. Ideally, fresh outdoor air should be introduced to the building at the same rate as the contaminated air is removed. If the exhaust system does not work properly, a negative air pressure could become an issue. A negative pressure occurs when the building has a lower pressure than the outside air. This will cause the air to flow into room, but cannot escape the building, as the air naturally flows from high to low pressure. [23]. As a result, this can be a costly situation where not only does the exhaust system must work hard to remove the contaminated air, the MUA also needs to work excessively to push the fresh air into the building.

2.1.4 Codes Used in Paint Facility

Painting or spray coating is a process that poses risks of fire and explosion; in addition, physical over-exposure to chemicals during spray coating can cause severe health problems. Therefore, any processes that involve spray coating must be properly controlled. Since our project deals with designing an appropriate HVAC system for the paint shop and curing facility, we must incorporate engineering controls to reduce the risks.

One of our main goals was to determine the appropriate codes that would establish the requirements for the equipment to be used, rate of exhausting contaminated air, make-up air, allowed aerosols concentrations and the ventilation maintenance procedures. We conducted research to determine various relevant agencies and their publications in order to establish where to find the codes that we would use for the final HVAC design. Since we have to design the system for Sperling Industries' new paint facility, we determined that Manitoba Office of the Fire Commissioner would be a suitable agency.

Based on further research we found out that National Fire Code of Canada is the document that we should consult; however, the code referred us to National Fire Protection Association (NFPA) for the actual design requirements for spray painting facility HVAC systems. The National Fire Protection Association (NFPA) is a global nonprofit organization, established in 1896, devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards [24].

We identified two standards that establish guidelines for the design of spray painting facilities and their ventilation requirements. NFPA 33 is Standard for Spray Application Using Flammable or Combustible Materials and NFPA 91 is Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids. Both of these standards are described in greater detail in the following sections and the relevant to our design guidelines from these standards are outlined in the corresponding tables.

2.1.4.1 NFPA 33

NFPA 33 standard outlines requirements for various areas of building systems, design, and procedures which are meant to prevent hazardous situations in facilities where spray applications of flammable and combustible materials are performed. The standard provides guidelines for various spray applications such as conventional spray painting, electrostatic spray painting, powder coating and others. These guidelines address location, construction, potential sources of ignition, ventilation, storage and handling of combustible liquids, protection and several other areas related to spray applications. For this project we are only interested in the requirements related to the ventilation systems design for spray areas dedicated to manual spray painting operations. Appendix B.1 includes a table with all the relevant to our design standards from NFPA33 standard [25].

2.1.4.2 NFPA 91

NFPA 91 provides the technical requirements for the exhaust systems which have to be fulfilled to pass the standards of National Fire Codes of Canada. NFPA 91 covers the design, construction, operation, maintenance, testing and installation of exhaust systems which carry flammable gases, mists vapors and particulate solids. [26]. Some codes from NFPA 91 considered for Sperling Industries' new paint facility are presented in Appendix B.2

2.2 INTERNAL RESEARCH

For internal research, we chose morphological chart, a method to generate ideas in an analytical and systematic manner [27].

In order to make the chart we identified the five aspects of our HVAC design. Against each aspect we tried to brainstorm at the most seven different alternatives, even though some had less than seven alternatives. The chart that our team formulated is displayed in TABLE IV.

TABLE IV: MORPHOLOGICAL CHART

Alternatives	1	2	3	4	5	6	7
Energy sources	Grid electricity	Gas powered generator electricity	Solar panel generated electricity	Natural gas	Solar tubes for heating water	Propane	Geothermal

Alternatives	1	2	3	4	5	6	7
HVAC system	HRV	Air handling	MUA				
Distribution system	Centralized heating system	Individual zone heating system					
Heat Carrying medium	All water system	All-air system	Air and water system				
Space heating system	In floor water tubes	Baseboard tubes	Electric baseboard heating	Indoor water radiator heating	Duct distribution		

The morphological chart above was used to brainstorm and systematically compile all the possible alternatives for each possible sections of our project design. Based on our discussion with team members and our client, we prepared seven criteria to evaluate the all possible alternatives against each other as explained in Section 3.0 Concept Analysis.

3.0 CONCEPT ANALYSIS

To avoid arbitrarily assigning values to the criteria used for our selection matrices, our team created a weighting matrix to mathematically address weights to individual criterion. Our team's selection criteria weighting matrix can be seen below.

3.1 SELECTION CRITERIA DESCRIPTION

This section will provide a description of each criteria used to create a weighted matrix.

- *Initial Cost* includes the consulting fee, equipment purchase, and installation fee. The initial cost may vary with respect to complexity of the conceptual design. This is an important factor as the client wants to minimize the upfront expenditure.
- *Maintenance Cost* includes the cost of periodic general cleaning, change of filters, periodic greasing/oiling of the moving parts, replacement of parts over time (if required), and man hours required to perform the maintenance activities.
- *Equipment Size* refers to the amount of physical space the mechanical equipment will acquire. The size and length of the ducts are not evaluated under this criterion as they will be comparable between different conceptual designs.
- *Air Quality* is dictated by the ability of the HVAC equipment to remove particulates from the air, maintain comfort, and temperature control.
- *Operation Cost* includes the cost of the selected energy source, whether that be propane or electricity to run the HVAC equipment, and any man hours involved in the operation of the HVAC system.

- *Ease of Maintenance* is rated based on the complexity of the equipment and the availability of the service technician in the local market.
- *Accessibility of Resource and/or parts*, is the local market availability of the parts and the filters which will be required for initial setup and repair.

3.2 Selection Criteria Weighting

This section determines the weight for each criterion where TABLE IV is used to determine the ideal concept.

TABLE V: SELECTION CRITERIA WEIGHTING MATRIX

	Selection Criterion		A	B	C	D	E	F	G
1	Initial Cost	A		A	A	D	A	A	A
2	Maintenance Cost	B			B	D	E	B	B
3	Equipment Size	C				D	E	F	C
4	Air Quality	D					D	D	D
5	Operation Cost	E						E	E
6	Ease of Maintenance	F							F
7	Accessibility of Resources	G							
Total Hits			5	3	1	6	4	2	0
Weighting			0.18	0.11	0.04	0.21	0.14	0.07	0.00

The previous matrix provides calculated weights for each design criterion. The results show criterion D with the max number of head-to-head wins with 6. The number of head-to-head wins indicates the importance, and ultimately, gives the relative weighting. In our case, criterion D receives the highest weight, while criterion G received a zero. To elaborate, criterion G: "Accessibility of Resources" was deemed to be the least important criterion. Since criterion G did receive a weight of zero, it will be eliminated from future selection matrices.

4.0 Concept Selection

This section outlines the methodology to selection both the energy source, and air handling equipment to use for the HVAC design in Sperling Industries' new paint facility.

4.1 Energy Source Selection

To determine which energy source our HVAC design would use, we performed a selection matrix, as seen below in TABLE VI.

TABLE VI: SELECTION SCORING MATRIX FOR ENERGY SOURCES

Item	Selection Criterion	Weight	Geothermal		Electric		**Propane**	
			Rank	Score	Rank	Score	**Rank**	**Score**
1	Initial Cost	0.18	4	0.72	7	1.26	**9**	**1.62**
2	Maintenance Cost	0.11	4	0.44	7	0.77	**7**	**0.77**
3	Size of the equipment	0.04	5	0.2	8	0.32	**6**	**0.24**
4	Operation Cost	0.14	9	1.26	7	0.98	**7**	**0.98**
5	Ease of Maintenance	0.07	6	0.42	8	0.56	**8**	**0.56**
6	Accessibility of Resources	0	5	0	8	0	**8**	**0**
Total Weighted Score rank			3.04		3.89		**4.17**	

As bolded, the third column shows the highest score being awarded to propane. The main attributes of propane are that it is easy to set up and install. As well, Sperling Industries already brings in propane for their current paint shop and they are satisfied with that shop. Propane's lowest rank is for the equipment size, as it requires a large holding tank outside the mechanical room. Overall, our client hinted that propane would be their suggested approach, but we have concluded that it would be the best energy source for this specific use.

4.2 SUPPLY AIR SYSTEM SELECTION

To determine which air handling system our HVAC design would use, we performed a selection matrix, as seen below in TABLE VII.

TABLE VII: SELECTION SCORING MATRIX FOR SUPPLY AIR SYSTEM

Item	Selection Criterion	Weight	HRV		AHU		**MUA**	
			Rank	Score	Rank	Score	**Rank**	**Score**
1	Initial Cost	0.18	6	1.08	8	1.44	**8**	**1.44**
2	Maintenance Cost	0.11	7	0.77	7	0.77	**8**	**0.88**
3	Size of the equipment	0.04	7	0.28	8	0.32	**8**	**0.32**
4	Air Quality	0.21	8	1.68	8	1.68	**10**	**2.1**
5	Operation Cost	0.14	10	1.4	7	0.98	**5**	**0.7**
6	Ease of Maintenance	0.07	7	0.49	8	0.56	**9**	**0.63**
7	Accessibility of Resources	0	8	0	9	0	**9**	**0**
Total Weighted Score rank			5.7		5.75		**6.07**	

Again, the third column shows the highest score goes to MUA. The MUA provides the greatest score in the most heavily weighted category, air quality. MUA units are known for ideal air quality as they provide 100% outdoor air. While heating 100% outdoor air in the winter causes higher operating costs, the codes do not allow for any air re-circulation in the paint booth or curing areas.

4.3 CONCEPTUAL DESIGN SUMMARY

To summarize, the conceptual design we will take further into calculations will include an MUA with propane burning heating section. The burner can be either direct or indirect, and will be selected while specifying the mechanical equipment. A propane holding tank must be within acceptable limits to the MUA, located in the mechanical room of the paint facility. To accompany the propane burning MUA, we will size ductwork and diffusers to deliver fresh outdoor air to each space in Sperling Industries new paint facility.

5.0 DETAILED DESIGN

In this section of this report the qualified concepts in the concept generation section are selected together to design the final HVAC system for the new paint shop of Sperling Industries. As explained in Concept generation based on external and internal research we have finalized a forced air heat distribution system, propane for the energy source and make-up air unit for air supply system. In this section we have a detailed design of the exhaust of the paint booth, CAN-QUEST design of the building with the energy requirement of the building. Using the energy values and the required exhaust the size of the ducts, exhaust fan and motor is determined.

5.1 EXHAUST SELECTION

Exhaust system selection for the paint booth is very important and the calculations for the required volume to be exhausted is governed by the regulatory as seen in Section 2.1.4.. The design of the air exhaust is selected based on the products which will be painted in the paint booth. The biggest product which will be painted is a large iron beam which is used in construction. The section steps are explained as follows.

5.1.1 TYPES OF EXHAUST SYSTEMS

The purpose of an exhaust system is to remove sufficient amount of air-vapor mixture from a spray painting area to maintain concentration of flammable vapors below their lower flammable limit. In addition, exhaust system removes paint particulates from the working area and filters them before releasing the air into the outdoor environment.

One of the main distinctions between the exhaust systems is the type of draft that they produce. There are three types of drafts which are classified based on the direction of the air movement within the spray area. The first type is cross draft. In cross draft configuration, the air is pulled horizontally from one side of the room with air inlet to the other side picking up paint particulates. The particulates are filtered with one of the filtering methods and the air is exhausted in to the atmosphere. See the image below. This type of draft system is easier to build and modify than other types; however, the resultant finish is not as good [28].

Figure 19: In crossdraft configuration, the air moves parallel to the floor [29].

The second type of draft is semi-downdraft. In this draft configuration make-up air is supplied from the ceiling then changes direction and is exhausted through the side. See the image below.

Figure 20: In semi-downdraft configuration, the air enters from ceiling changes direction to horizontal and exits at the floor level [30].

There is another type similar to semi-downdraft which is side-downdraft where air enters through the ceiling inlet and is exhausted through more than one side along the walls of the spray area. The detailed concept drawing is shown in the figure below:

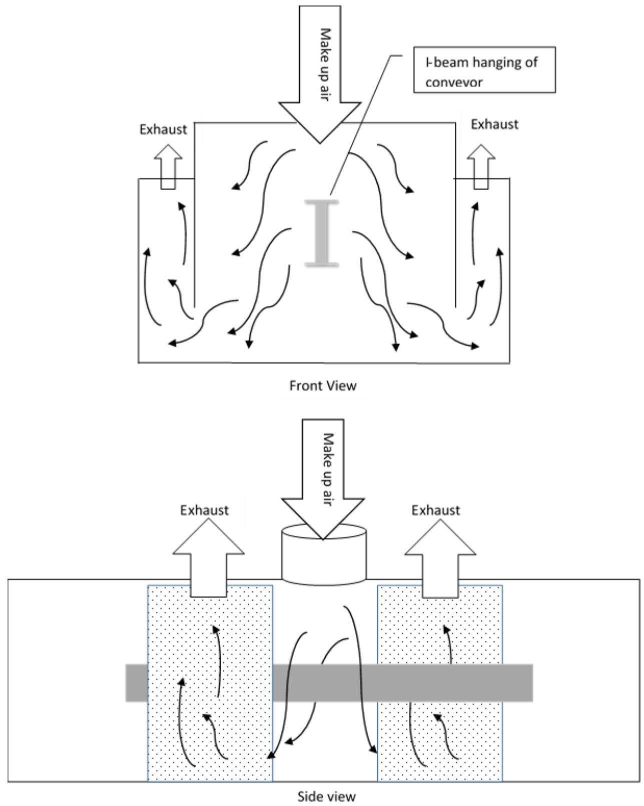

Figure 21: Semi-side downdraft showing the air exhausted from the bottom of the side walls [56].

The third type of draft is downdraft. In this draft configuration air flows from the ceiling to the floor. See the image below. In order to accommodate the exhaust plenums with filters, a pit is required for a spray room or booth, or a booth can be raised over ground to provide the necessary clearance. The main advantage of a downdraft design is that it removes paint particulates from the working environment faster than other configurations. In addition, it produces the best painted finish [28].

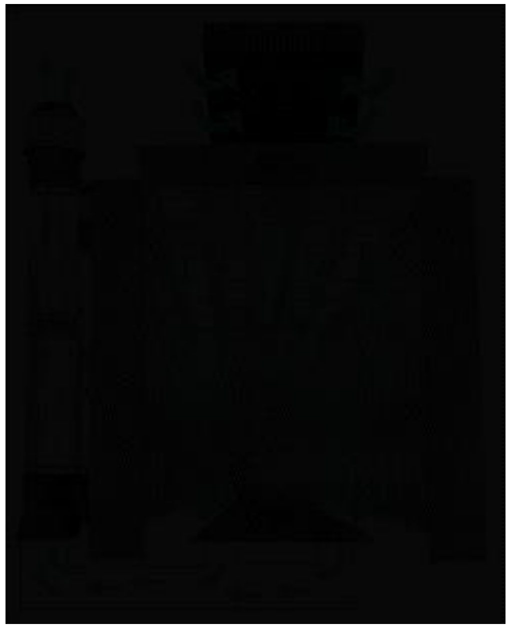

Figure 22: In downdraft configuration air enters from changes direction and exits at the floor level [31].

Since we are designing the ventilation system for spray painting facility which is intended to spray coat structural beams, finish quality is not very important. Therefore, semi-downdraft configuration is more appropriate configuration which in addition to being cheaper and easier to install, reduces workers' exposure due to having paint fumes and particles moving in downward direction.

The following drawings demonstrate the how semi-downdraft spray booth configuration with the corresponding air make-up and exhaust systems would fit into the layout of the new spray painting facility. Figure 23 contains the top view of the facility. For the spray painting room, make-up air supply is divided into two separate systems. One of the air supply lines feeds into the room itself while the other line comes from a dedicated make-up air unit and feeds into the spray booth. The air supplied to the spray booth comes at a significantly greater rate than the air that is supplied to the room. As air enters the booth at the ceiling and is filtered, it flows past the area of spray paint application picking up paint overspray and carrying it downward away from workers and then along the floor into the exhaust plenums. See Figure 24. The exhaust plenums contain filters and a fan which exhaust the filtered air-vapor mixture outdoors. The fan has to be constructed out of non-ferrous material such as aluminum. In addition, it is critical to balance the air flow rate of the make-up supply and exhaust in order to maintain atmospheric pressure so that contaminants cannot enter the paint room if the room is negatively pressurized or paint vapors and spray escape if the room is positively pressurized. The rest of the room is ventilated by a shared air supply line which also supplies air to the staging, surface preparation and curing areas of the facility from the second make-up air unit.

In the curing area, make-up air supply is located in one end of the room while the exhaust is located in the opposite end. For the curing room, it is not as crucial to establish downdraft since there is no paint overspray to deal with. Therefore, we can either have side draft or semi-downdraft system. Provided that side draft design is cheaper to implement it is more practical approach for the curing area. The top view of the facility, also, shows potential location for the mechanical room which would contain two air make-up units which draw the outside air, filter it and heat it up as needed. In our design, one of the make-up units would be supplying air to all of the areas but not booth. The staging, surface preparation, and paint room do not require special considerations; therefore, only one exhaust fan and plenum would be sized for these three rooms. In order to regulate the make-up air supply for each of the areas individually we consider installing dampers inside the ducts leading to each of the areas. The dampers would be controlled automatically to maintain the desired pressure in those areas.

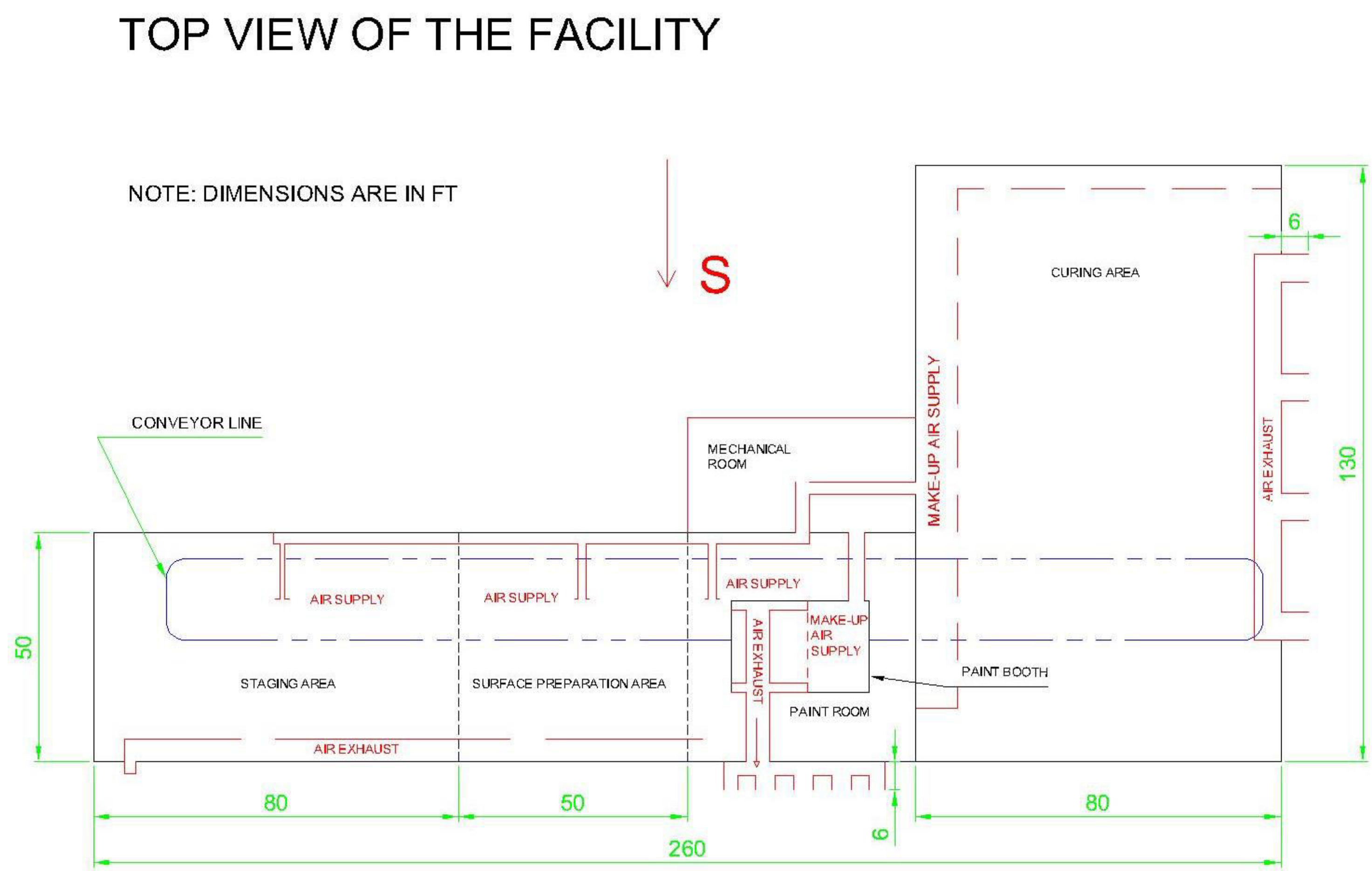

Figure 23:The location of the exhaust system is shown in the top view of the facility.

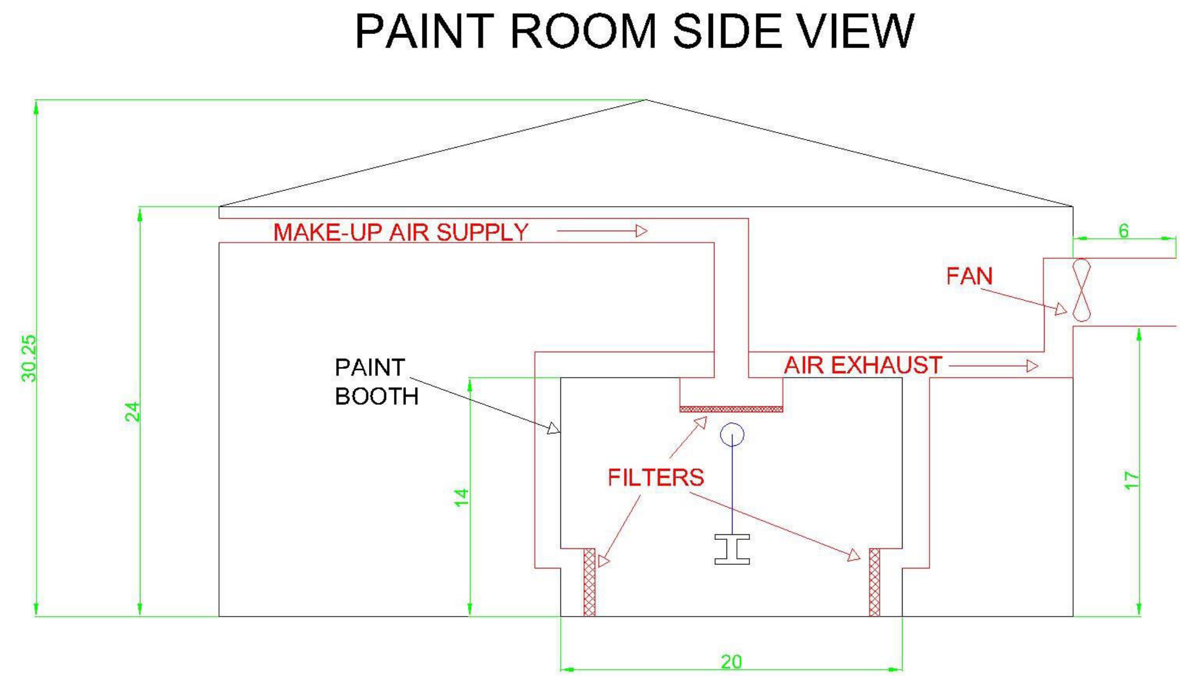

Figure 24: Side view of the paint room shows relative locations of the paint booth with its air make-up and exhaust systems.

5.1.2 DETERMINING THE LOWEST LFL

In order to determine the needed exhaust air flow rate, we had to investigate the types of paints that have been used by Sperling Industries in their current painting facility. This was needed to establish which of the paints had the lowest Lower Flammability Limit (LFL). LFL for a given flammable substance indicates the minimum concentration of its flammable vapors in the air at which the air-vapor mixture can ignite. LFL is also referred to as Lower Explosive Limit (LEL) depending on the source.

The list of the various paints with references to their corresponding companies' online Material Safety Data Sheets (MSDS) catalogs was provided by Sperling Industries and the table below was created based on that list. In MSDS documentation the LFL values are typically reported in percent by volume or % vol. at room temperature (20°C - 25°C) and standard pressure.

As a result of the research we determined several substances which had LFL of 0.19 % which is the lowest value that we found. Refer to Appendix C for the complete list of paints and their LFL values. However, we were not able to identify LFL values for a number of paints due to various reasons such as absence from the corresponding company's online MSDS data base or LFL value was not available. Although some of the LFL values are missing, 0.19 % is a very low LFL value in comparison to the typical value of 1%. NFPA 33 identifies 1% LFL as a conservative value meaning that majority of the solvents have LFL greater than 1% [32]. Therefore, 0.19% LFL would probably capture the most demanding requirement for exhaust air flow rate but it would, also, drive the price of the HVAC system significantly up. In order to make sure that the system would not be overdesigned for the actual usage of the paints, we needed to confirm with Sperling Industries how often and in what quantities the paints with this LFL would be used.

One more point that is worth noting is that a LFL value of 0.008 was found for substance number (S.N) 175, Rust Coat Red Oxide from Home Hardware. Since the value appeared unusually low, paint lab which prepared the corresponding MSDS sheet was contacted. The lab confirmed that the value was in % vol.; however, our further investigation of LFL values for the individual ingredients of the paint revealed that none of the ingredients had 0.008% LFL. The lowest LFL value for the individual ingredients was 0.8%; as a result, it is likely that the lab made a mistake of not converting their result from fraction to %. Based on this conclusion, we did not include this paint into the design considerations.

5.1.3 Exhaust Air Flow Calculation Based on the Lowest LFL

After researching Lower Flammable Limit for all the paints used in Sperling Industries paint shop we found that our exhaust design would have to be rated based on the lowest value of 0.19% LFL. However, after performing calculations based on this LFL we obtained very high requirement of 250664 cfm for the exhaust air flow rate. This flow rate would require about three air make-up units. Since cost of the final design is of the major importance, we met with the client and discussed this value. As a result of the conversation, we learned that the paints with 0.19% LFL are being used rarely and in smaller quantities. Therefore, the client approved us designing the system based on the more frequently used paint with the next highest LFL of 0.5%. I addition, the initial parameter for the paint spraying rate was reduced from 1.6 US gallons to 1 US gallon per minute per gun and the number of spray guns that would be used at one time was reduced to two guns from three. Using the above specifications, we needed to calculate the exhaust air flow rate requirement for the two areas, spray booth and curing area.

5.1.3.1 SPRAY BOOTH EXHAUST REQUIREMENT CALCULATIONS

As a basis for the calculations below we used the following starting point: 1 US gallon (3.79 L) average solvent occupies approximately 0.7 m^3 once evaporated [33]. After that, we calculated that 36.9 m^3/L_{paint} of air would be required to maintain concentration of fully evaporated 1L of a liquid solvent at 0.5% LFL. Next we applied safety factor of 4 which satisfies NFPA requirement of maintaining concentration of solvent vapor in the air below 25% of LFL resulting in 148 m^3/L_{paint}. For the two spray guns with 1 US gallon/min, the rate of air that needs to be replaced results in 1122 m^3/min or 39623 ft^3/min or 39623 cfm. Note that for this analysis we assumed that the paint consists entirely of solvents. This assumption is not that farfetched considering that concentrations of volatile organic compounds VOCs in paints considered can be > 60% and considering that paint aerosol particles can act as combustible solids and propagate the flame with high rate due to greater overall surface area. The equations below show the calculations that were described above.

Air requirement for 0.5% LFL:

$$0.7\ m^3 * \frac{1}{0.005} = 36.9\ \frac{m^3}{L_{paint}}$$

Applying safety factor of 4:

$$36.9 \frac{m^3}{L_{paint}} * 4 = 148 \frac{m^3}{L_{paint}}$$

Accounting for 2 spray guns with 3.79 L/min (1 US gallon) flow rate:

$$148 \frac{m^3}{L_{paint}} * 2 * 3.79 \frac{L_{paint}}{min} = 1122 \frac{m^3}{min} \text{ or } 39623 \ cfm$$

5.1.3.2 CURING ROOM EXHAUST REQUIREMENT CALCULATIONS

Once the parts were coated with paint they would go into curing room where the rate of evaporation of solvents in the paint would be a determining factor in the exhaust air flow rate requirements. For the curing room we used the paint with 0.5% LFL, Armour Shield White from Cloverdale, as the worst case and based our calculations on its VOCs evaporation rate, rate of the painted parts coming into the curing room, and a greatest concentration of VOCs in a paint from the list provided. First, we determined the rate of evaporation by choosing one of the paint components with medium evaporation rate, Ethyl Alcohol (Ethanol), based on its boiling point of 173.3° F [34]. All other compounds are assumed to evaporate with this rate. Refer to Appendix D for partial MSDS and TDS. The complete versions are available from the Cloverdale website. The evaporation rate of Ethanol was 7.80 mmol/m^2/s and it was taken as the greatest experimental value from a study [35]. After converting the evaporation rate to cfm per ft^2 of painted surface area we obtained $9.0*10^{-5}$ cfm/ft^2. Next, the TDS for the paint provided minimum hard drying time of 3hrs or 180 mins and we assumed that most of the

VOCs would have evaporated within this time. Therefore, the goal was to determine the amount of paint that would enter the curing area within a 180 mins window and to calculate what the combined evaporation rate of the paint would be. The calculations below outline this procedure.

Converting 7.80 mmol/m^2/s to cfm/ft^2:

$$\frac{7.8}{1000} * \frac{\frac{46.07}{1000}}{0.79} * \frac{0.0353}{10.76} * 60 = 9.0 * 10^{-5} \frac{cfm}{ft^2}$$

Where, 46.07 is molecular weight of Ethanol in g/mol; 0.79 is density of Ethanol in kg/L based on its specific gravity; 10.76 is conversion factor from m^2 to ft^2; 0.00353 is conversion factor from L to ft^3; and 60 is conversion factor from s to mins[34].

Calculating the total evaporation rate in curing room, requires us to know the number of ft^2 painted areas that enter the room in 180 mins and multiplying it by the evaporation rate per ft^2.

$$9.0 * 10^{-5} \frac{cfm}{ft^2} * \frac{0.27cfm * 0.7}{(\frac{0.003}{12} ft^3)/ft^2} * 180\ mins = 12.33\ cfm$$

Where, 0.27 cfm is volume flow rate of paint that is being sprayed; 0.003 is the thickness of paint applied to the beam in inches; 0.7 is the higher end of the possible concentration of VOCs in a paint.

Accounting for 0.5% LFL and safety factor of 4:

$$12.33 * \frac{1}{0.005} * 4 = 9870\ cfm$$

Therefore, the curing room requires 9870 cfm.

5.1.4 Paint Booth Selection

Based on the customer requirement and the available budget team has decided to select a semi-side downdraft paint booth. The company selected for the purchase of the paint booth is Standard Tools and Equipment Co. based in North Carolina, US. The company sells a similar paint booth with interior dimension of 14' W X 9' H X 26' ½" L. The entrance doors' size is 10' W X 9' H. The cost to purchase this paint booth is U.S. $ 8,549. [36]

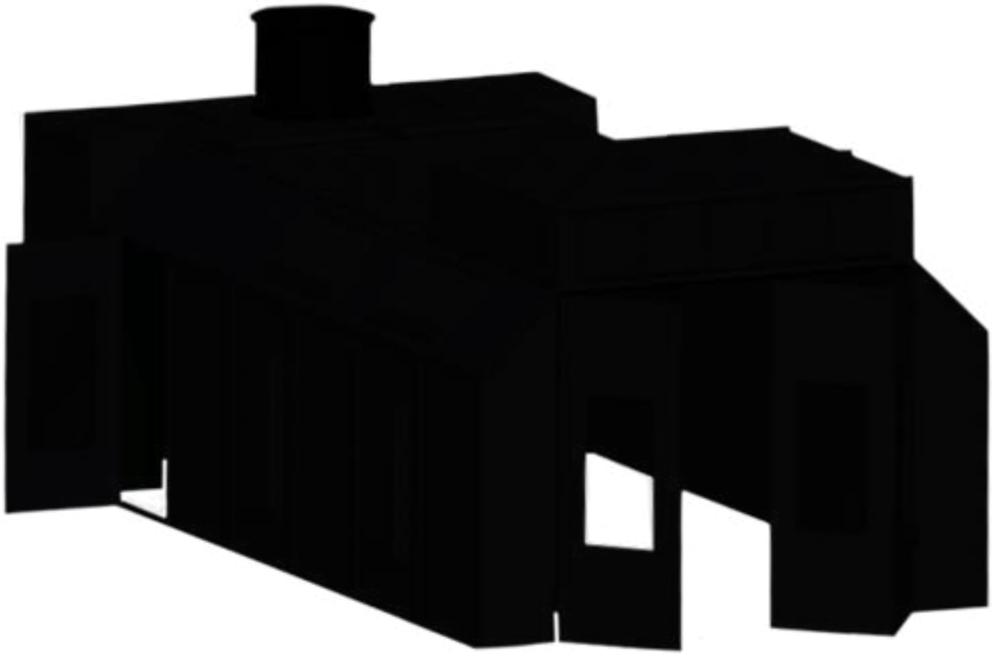

Figure 25 Semi Downdraft paint booth sold by Standard Tools and Equipment Co. [36]

Standard Tool and Equipment Co. provides the flexibility to work with their design engineer and customize the size of the required paint booth. The suggested design uses air curtain instead of entrance door in the paint booth. The dimensions of the required paint booth are 20’ W X 14’ H X 30’ L and the entrance size of 20’ W X 14’ H. Being a custom design the cost to purchase the paint booth will increase. For the final cost estimation of the project the cost of purchasing the customized paint booth will be approximated to the double the posted amount i.e. U.S. $ 17,098.

5.1.5 Fans Selection

In the HVAC industry, it is common to find favored manufacturers and continue to use them because you enjoy their customer service, performance, and reliability. From previous experience and customer reviews, we will select all fans from Greenheck. Greenheck is known for their high quality fans with superior reliability. For this, we will use their website to select our exhaust fans. The performance data and fan curves for the selected Greenheck exhaust fans can be found in Appendix E.

5.1.5.1 Paint Booth

The paint booth will get a dedicated exhaust to removed used air from the painting process. Finding a sidewall exhaust fan that can remove nearly 40,000 CFM was difficult. To aid the process of selecting a fan, we switched from sidewall exhaust to a high capacity updraft exhaust fan. The updraft exhaust design actually reduces total pressure loss. In order to remove the air volume needed to remain under 25% of the LEL, we must use two exhaust fans. After consulting the performance data, two CUBE-480 belt driven exhaust fans were chosen for our applications. These two fans are rated each for 20,222 CFM @ 0.25" w.g, with a 3 hp motor at 360 rpm, creating 16.1 sonnes.

5.1.5.2 Curing Area

The curing area needs to exhaust nearly 10,000 CFM. For this, we will choose a fan that is capable of pulling that much air, while trying to remain efficient on the fan curve. Also, minimizing noise is key. Note, we cannot combine the curing room exhaust with another other exhaust, as per NFPA 33.

We will choose to select sidewall exhaust fans rather than roof due the probability of roof leaks. Although contractors use roof curbs to seal the void between the equipment and roof structure, there can be malfunctions in the process. It is good practice to not pierce the roof unless absolutely necessary.

Greenhecks CWB-400 sidewall, belt driven exhaust is more than capable to remove 9,870 CFM from the curing area. This exhaust fan is rated for 10,508 CFM @ 0.25 “ w.g., using 2 hp motor @ 665 rpm, creating 19.7 sonnes of noise. Note, 19.7 sonnes is on the high side, but since it will be used in an industrial setting, located 24 ft. off the ground, 19.7 sonnes will not be an issue.

5.1.5.3 Paint, Shot Blasting, and Staging Area

The paint room less the volume occupied by the paint booth, shot blasting, and staging areas will be exhausted by one exhaust fan. There will be no walls to divide these areas, allowing for easy transfer of air back to the exhaust fan. Similarly to the curing area, the remaining rooms will use a Greenheck exhaust fan. After consulting the performance data, the CWB-240 belt driven sidewall exhaust fan was chosen. This fan is capable of pulling 4540 CFM @ 0.25” w.g., using a 1/2 hp motor @ 580 rpm, creating 9.5 sonnes. This fan is will be quieter than the curing area exhaust fan

5.2 HEATING LOADS

In order to determine suitable heating equipment for the Sperling Industries' paint facility, the total heating load should be defined. Consequently, we used a building energy modeling software program recognized by Natural Resources Canada called CAN-QUEST [37]. CAN-QUEST is a Canadian version of eQUEST, a commonly used energy simulation software in the U.S.. The latest version of CAN-QUEST is compliant with the National Energy Code for Canada for Buildings (NECB) 2011. The software is designed to analyze a building based on a given data. It then provides a 2D and 3D representation of the building geometry and an annual building performance report.

5.2.1 ASSUMPTIONS

When creating the building layout using CAN-QUEST, some assumptions have been made as follows:

- No changes will be made to the layout and the exterior design of the facility
- Standard doors and windows are assumed to be installed
- Typical zone temperatures considered for heating
- Typical operating schedule for the paint facility
- One zone is considered as per client's request
- Usual Winnipeg weather throughout the year is considered
- Propane should be used as a source of heating

5.2.2 BUILDING LAYOUT

Sperling Industries has provided us with the layout of the paint facility as shown in Figure 26. Given dimensions are in feet.

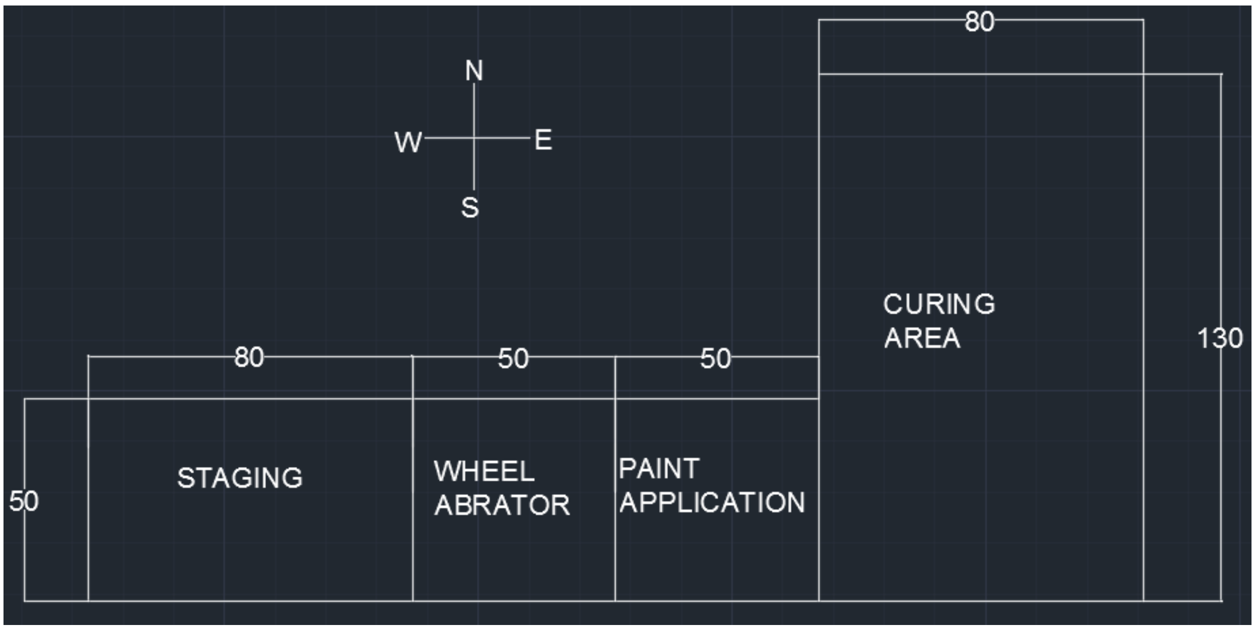

Figure 26: Paint Facility Layout for Sperling Industries Ltd.

Additionally, other critical dimensions and information that are required for the building are presented in TABLE VIII as shown below. These values were also provided by the client.

TABLE VIII: CRITICAL DIMENSIONS AND INFORMATION FOR THE PAINT FACILITY

Critical Dimensions and Information	**Measurement**
Ceiling Height	24 ft.
Roof Slope	3 rise per 12 run (14°)
R-value for the Wall	28
R-value for the Roof	35
Man Doors Spacing	~ Every 60 ft.
Overhead Doors	30 ft. wide, 20 ft. tall

With given building information, we were able to design the building layout using CAN-QUEST as shown in Figure 27.

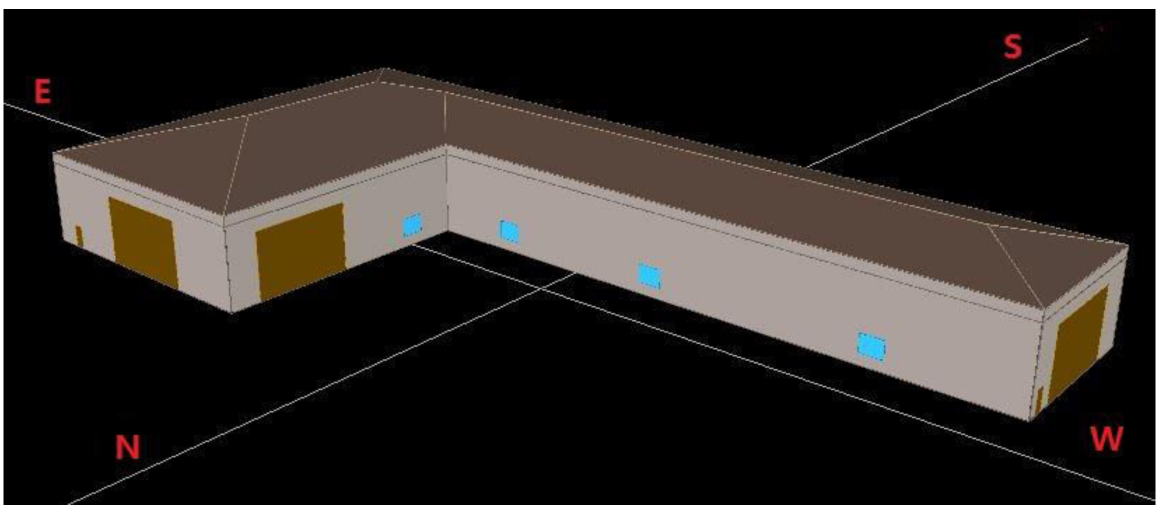

Figure 27: Isometric View of the Paint Facility Layout using CAN-QUEST.

5.2.3 Total Heating Load

Once the building layout of the paint facility was created using CAN-QUEST, we were then able to determine the total heating load that is required for the building. Figure 28 contains space name for the building and TABLE IX describes the heating load for each space.

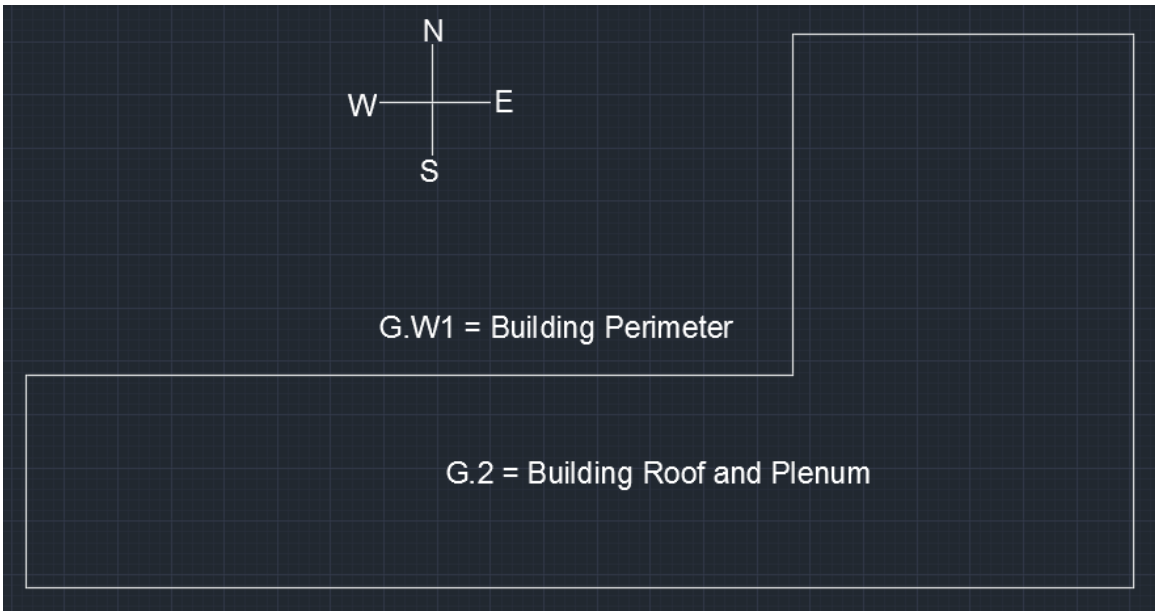

Figure 28: Space Name for the Paint Facility

TABLE IX: HEATING LOAD AT VARIOUS SPACE FOR THE PAINT FACILITY

Space Name	Total Heating Load (KBTU/hr)
West Perim Spc (G.W1)	397.458
Plnm (G.2)	19.417
Under Roof (G.2)	51.097
Total Load	467.972 ≈ 468

5.2.4 ENERGY CONSUMPTION

Additionally, we were able to determine the annual building performance in terms of electric consumption and natural gas consumption using CAN-QUEST. As mentioned in Section 5.2.1, the heating should be completed using propane. Unfortunately, CAN-QUEST does not have propane as one of their energy sources. After consulting such issue with Sperling Industries, they have allowed us to use natural gas as the energy source. As clearly shown in Figure 29 the gas consumption during summer (May – September) was a lot lower due to warmer weather. Figure 30 contains the numerical values of energy consumption for each month.

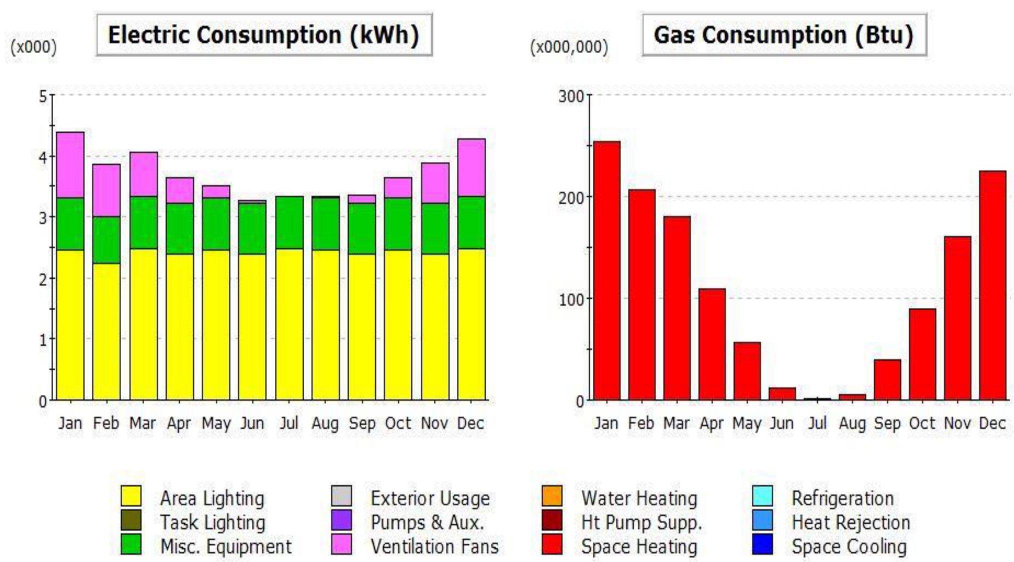

Figure 29: Bar Graph of Monthly Electric and Natural Gas Consumption for Sperling Industries' New Paint Facility.

Electric Consumption (kWh x000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	1.08	0.87	0.74	0.43	0.21	0.04	0.00	0.02	0.14	0.34	0.65	0.94	5.46
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.84	0.77	0.85	0.82	0.84	0.82	0.85	0.84	0.82	0.84	0.82	0.85	9.98
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	2.46	2.23	2.48	2.40	2.46	2.40	2.48	2.46	2.40	2.46	2.40	2.48	29.12
Total	4.38	3.87	4.07	3.65	3.52	3.26	3.33	3.33	3.36	3.65	3.87	4.27	44.55

Gas Consumption (Btu x000,000)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	254.6	207.0	180.4	108.9	56.6	11.9	0.8	5.5	39.5	88.9	160.9	225.6	1,340.6
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	254.6	207.0	180.4	108.9	56.6	11.9	0.8	5.5	39.5	88.9	160.9	225.6	1,340.6

Figure 30: Numerical Data of Monthly Electrical and Natural Gas Consumption for Sperling Industries' New Paint Facility.

5.3 Makeup Air Unit Selection

In order to select an adequate MUA for our application, we must determine the following criteria: direct or indirect burner, size of burner, size of blower and motor, and filter. The following subsections will explain the methodology and calculations in determining the necessary criteria.

5.3.1 Direct vs. Indirect Heating

From the concept selection phase, it is noted that the MUA will use propane for the energy source. Propane can be burned in two methods, direct or indirect. Both strategies have their pros and cons, as seen below in TABLE X.

TABLE X: DIRECT VS. INDIRECT MUA [38]

Direct Fired		**Indirect Fired**	
Advantages	Disadvantages	Advantages	Disadvantages
100% theoretical efficiency	Byproducts of combustion in air	No byproducts of combustion in air	Heavier in weight
Lighter in weight	Limited turndown ratio	Does not require large amounts of air	More expensive
Cheaper	-	-	Less efficient, approx. 80%

For our application, we will have large volumes of air and value lower price and weight of the direct fire burner. For this, we will select a MUA with a direct fire burner.

5.3.2 Sizing the Direct Fire Burner

There are two major calculations that must be accounted for when sizing a MUA burner. One, the amount of heat required heating the space due to infiltration in peak climate conditions. Two, the amount of heat required heating up outdoor air from the outside temperature to a comfortable room temperature.

The amount of heat required to keep the space at a comfortable room temperature is calculated by CAN-QUEST, which takes into many factors, including solar gain, infiltration, building usage, and building construction. The total amount of space heating required as per CAN-QUEST is 468 MBH.

Since we are incorporating a MUA unit into our HVAC design, 100% of our supply will be comprised of outdoor air. In our worst condition, the outdoor air will be cold winter air. Our MUA must be able to deliver air at room temperature, which requires raising the temperature of the air from a potential -33^{o}C to 25^{o}C, a range of 58^{o}C.

The ventilation heating load can be calculated using simple heat transfer fundamentals, as seen below:

$$q = \dot{m} c_p \Delta T$$

Where q is the heat transfer in watts, $\dot{m}$ is the mass flow rate in kg/s, c_p is the specific heat in kJ/kg s, and ΔT is the total temperature difference in Kelvin. Mass flow rate can be rewritten as the following:

$$\dot{m} = \rho Q$$

This allows up to write the equation for heat transfer in terms of air properties, taken from Principles of Heat and Mass Transfer, 7th Ed [39]. The air properties used in the ventilation heating load are taken to maximum q – in other words, to simulate the worst-case condition. TABLE XI shows the air properties used.

TABLE XI: AIR PROPERTIES IN DETERMINING VENTILATION HEATING LOAD [39]

C_p	1.007 kJ/Kg s
$\boldsymbol{\rho}$	1.7458 kg/m^3

Plugging in all values, and converting from kW to MBH using 1 kW = 3.412 MBH, the ventilation heating load can be calculated for MUA-1 and MUA-1 to be:

$$q_{vent,MUA-1} = 6506\ MBH$$

$$q_{vent,MUA-2} = 2327\ MBH$$

The total heating load required by the direct burner for MUA-2 is must also include the space heating load calculated previously by CAN-QUEST, while the total heating load for MUA-1 is simply the ventilation load as the paint booth in situated inside the building envelope. The total heating load required for MUA-2 can be seen below

$$q_{total} = q_{space} + q_{vent}$$

The total heat transfer required by the burner can calculated to be $q_{total,\ MUA-2}$ = 2795 MBH.

5.3.3 Sizing Blowers and Motors

The size of the blower and motors depends primarily on the amount of air being moved by the MUA and the external static pressure (ESP) within the system.

The amount of air moved by the MUA will be determined by the bigger of either the CFM exhausted in order to satisfy NFPA 33 requirements, or, the CFM required to heat the building. Theoretically, the MUA will supply as much as much air as the exhaust removes. In fact, the exhaust requirements will not match exactly the supply requirements. For this reason, the greater of the two will determine the amount of air the MUA will deliver to the building. Note, it is common practice to deliver slightly more, or slightly less to add a pressure difference to either keep contaminants in, or push them out.

ESP can be calculated with the longest duct run and the amount of and severity of fittings. The longest duct run can be calculated using a rough AutoCad drawing of the initial duct layout. Using intuition and past experience, the longest duct run will be connecting the MUA and staging area, which measures to be approximately 180 ft. Common fittings will include round 90 degree bends, size transitions, duct connections, and dampers. Fittings can be converted into effective length, as seen as a straight section. The ESP can be determined by using the total length, which is comprised of the total duct length plus the effect length from fittings, to look up on a Total Pressure Drop table, or also known as Ductulator. An approximated number of fittings can be translated into a conservative guess of 150 ft. The total pressure drop, based on 0.1” wg. per 100 feet, can be looked up to be 0.25” wg. We will size both MUA’s to overcome 0.25” wg. of external static pressure.

5.3.4 MUA SELECTION

Based on the above criteria, we will select a MUA from Engineered Air. Engineered Air is North America’s leading manufacturer of custom built heat, ventilating, air condition, refrigeration, and energy recovery equipment [40].

We will select the HE Direct Fire MUA. This series comes standard with 18 gauge steel construction, hinged doors, acoustic lining, forward curved fan blades and high velocity filters. The HE series is a reliable, heavy duty, industrial unit with lots of experience in the field. Capable of up to 11,000 MBH and 100,000 CFM, the HE direct-fire MUA is perfect for our application. We will accompany the HE direct fire MUA with a M-Trac MUA controller [41]

We reached out to Engineered Air Winnipeg to size and quote our MUA's. Engineered Air provided us with MUA selection, with MUA-1 and MUA-2 being the HE 171 and HE 401 MUA units, respectively. The cost can be seen in Section 6.8 and the cut sheets for these units can be found in Appendix F.

5.4 CONTROL SYSTEM

In order to operate the HVAC system smoothly, the control system must be implemented for the paint facility. The main purpose of the control system is to regulate the HVAC system. Such that it allows us to collect the HVAC data for the building, process such data with other information, and create a control plan to satisfy the building condition. The control system for the paint facility will be installed in the mechanical room adjacent to the west and south wall of the building.

Control system is comprised of several steps. The first step is the sensor, which measures the controlled variable such as temperature, pressure, flow rate, and relative humidity. Secondly, the controller receives data from the sensor. Based on the information given, the controller will create an “action plan” for the controlled device. The controlled device include valve operators, dampers, fans, and pumps. Lastly the controlled device will make modifications to the controlled variable as instructed by the controller [42]. Following control systems were considered for Sperling Industries’ paint facility: DDC and pneumatic system.

5.4.1 PNEUMATIC SYSTEM

A pneumatic system uses compressed air to control the HVAC system. The thermostat with a pneumatic system has one or more air lines which compressed air is delivered to the controlled variable, such as valve actuators [43]. Valve actuators usually contain diaphragms and spring to respond directly to the air pressure. Compressed air is generally transferred using the copper or plastic tubing and the air must be dirt free or any other residues that could affect the system operation. The pneumatic system is ideal for hazardous areas as it does not use electric signals, so it can prevent electrical sparks. Also, the pneumatic system is relatively cheaper than electrical based system which will be discussed in the following section.

One of main disadvantages of the pneumatic system include the potential leakage of pressured air. Air leakage can lead to inaccurate measurement thus potentially result in energy loss. Another disadvantage is noise. Compressed air that has been used needs to be removed from the pipe thru dump line and the removal process can be irritating acoustically. Therefore, implanting a silencer on each dump line is recommended. [44]

5.4.2 DDC SYSTEM

DDC, or Direct Digital Control is an electronic system which is commonly used control system in modern buildings. DDC first receives input condition, such as temperature and humidity level and once the system has been analyzed, DDC provides an output that control heating system and outdoor air. Some advantages of DDC are that it has one central monitoring system where the operators can change immediately change the building condition from one location as shown in Figure 31[45]. Also DDC uses electronic system, rather than pneumatic sensors, which allows for higher degree of accuracy and ease of system modifications. Changing a DDC simply requires a change in computer program whereas a pneumatic or analog electronic system may require major replacement and wiring rearrangement [46]. With an accurate control system, DDC can help reduce the energy costs.

Figure 31: Schematics of Digital Data Control from the Sensor Level to the Management Level [47]

5.4.3 Control System Selection

After considering two types of control system, we have decided to choose the pneumatic system over DDC. This is mainly because the pneumatic system is more cost friendly. Due to its complexity, the DDC tends to be more expensive than pneumatic and analog electronic system. Additionally, DDC software interfaces are not user friendly as compared to physical switches. Most buildings are still in favor of using conventional pneumatic system due to the simplicity. It is easier to understand and most importantly, easy to operate [46].

5.5 AIR FILTRATION

Air cleaning is a process that removes particulates from air stream. There are a number of parameters that need to be considered for selecting an appropriate type of air cleaning filter or process. We need to consider the amount of contaminants that need to be removed, nature of those contaminants, and a type of process that the ventilation system services. In our design we need to consider three types of air cleaning processes, one for the air make-up units, one for the spray booth, and one for the curing room.

5.5.1 AIR MAKE-UP FILTER SELECTION

The air make-up units would require air filters that only need to deal with the contaminants that are present in outside air. However, since the filtration system is required for spray painting operation air supply, a secondary filtration is needed to remove finer particulates.

Our design of HVAC system calls for two air make-up units. One of the units is needed for the curing room, which would also service staging, surface preparation and paint room. For this air supply system, we need one general coarser filtration for all the rooms and one additional finer filtration for the curing room to prevent contamination of the freshly painted parts. The other air make-up unit is needed solely for the spray booth; and therefore, this air supply system will require the two filtration systems as well.
For the general coarser filtration, we can select a low cost polyester pad with scrim backing as prefilter which provides low initial pressure drop good dust holding. This

filter would be located in the air make-up unit and it provides cheaper way to remove coarser contaminants from the air supply for both air make-up systems.

The prefilter that we would choose for both MUAs is from BoothFilterStore.com, LLC: Pad prefilter which costs about $1 USD/sq.ft [48].

For the finer filtration in our semi downdraft spray booth and curing room air supply we can select the following downdraft ceiling filters from BoothFilterStore.com, LLC: DS-560 Cut pads which costs $1.55 USD/sq.ft. [49].

5.5.2 PAINT BOOTH EXHAUST AND CURING ROOM EXHAUST FILTERS SELECTION

One of the main requirements for the paint booth and curing room exhaust filtration system is that it does not contain combustible components. Therefore, fibreglass filters would be appropriate choice for the overspray collection. For the spray paint booth, we can select the following paint arrestor from BoothFilterStore.com, LLC: XD-22F Extra Density Fiberglass Paint Arrestor which costs $0.14 USD/sq.ft.[50]. Since there is no particulate matter being generated in the curing room, there is no need for the filtration.

5.5.3 Filter Sizing Considerations

After determining the types of filters we would need to use for each of the HVAC systems, we had to estimate the filtrations areas for these systems. Generally, we aimed at increasing the filtration areas in order to minimize air resistance through the filters. Also, some specific requirements were considered for the spray booth. In addition, the following considerations are based on the requirement to have a balanced ventilation so that the rate of air supplied into a room equals the amount of air being exhausted per given amount of time.

5.5.3.1 Paint Booth Air Exhaust and Make-up Supply

The exhaust requirement of 39623 cfm requires a large air intake area in order to reduce the velocity of the air flow so that the spray painting process is not negatively affected by fast moving air. Due to this reason we decided to create a 240 ft^2 exhaust filtration zone which would result into 165 FPM or 3 km/h air velocity. For the air make-up filtration area, we decided to use the same 240 ft^2 zone in order to maintain uniform air velocity throughout the booth.

5.5.3.2 Make-Up Air Supply for the Paint Booth

For the make-up air unit that supplies air to the paint booth, we decided to use 100 ft^2 since the velocity of the air at the outside air intake is not that important. This filtration area results in 396 FPM or 7.2 km/h air velocity at the outside intake. The calculation is based on the same requirement of 39623 cfm.

5.5.3.3 Make-Up Air Supply for the Rest of the Facility

The exhaust requirement for the rest of the facility all together is 14170 cfm. Therefore, filtration area for this make-up air unit outside intake can be about 50 ft^2. This translates into 283 FPM or 5.2 km/h air velocity.

5.5.3.4 Curing Make-Up Air Supply:

The exhaust requirement for the curing area is 9870 cfm. Therefore, filtration area for the curing air supply can be about 60 ft^2 which would result into 164 FPM or 3 km/h air velocity.

6.0 FINAL DESIGN

This section includes details needed to complete the design, including duct sizing, layout of ducts and diffusers, mechanical room, cost analysis, and any other miscellaneous details pertaining to the final design and AutoCAD drawings.

6.1 DUCT RUNS AND DIFFUSER LAYOUT

In order to select the location of the duct, they must first be sized based on the air volume passing through them. As determined previously, MUA-1 that serves the paint booth is required to pass nearly 40,000 CFM and MUA-2 that serves the remaining spaces requires nearly 15,000 CFM. To size the ducts, our team will use E.H Price's well-known 'ductulator'. This ducting calculator is a simple to use, accurate, and it is actually an industry standard method to size ductwork.

To use the ductulator, we must know the air volume, desired duct velocity, and friction loss per 100 ft. of duct, and with this, the ductulator spits out the duct sizes – in both round and rectangular geometry. For both MUA's, we will use 0.1 " w.g per 100 ft. of duct – an industry standard for smooth steel ductwork. Air velocity is debated what is a safe value. We will shoot for 1200-1700 fpm as noise is not a huge issues and the faster the air moves, the smaller the ducts can be. Both MUA's are pushing a large amount of air and the ducts are going to be very large. Anything we can do to reduce the size is recommended.

With the ducts sized, we can determine where the ducts will run. Since the ductwork is quite large, and Sperling Industries wants to have an overhead crane in their building for part movement, we will try to keep our duct runs near exterior walls. This is easy to do, but with duct runs being on exteriors, we must find diffusers that are capable of shooting the air far distances to get proper air circulation.

E.H Price is the leader in HVAC diffusers, so it is easy to use their website to help find diffusers. Also, E.H Price provides all performance data and sizing on their website, making it extremely easy to find the exact model we need for our application. Looking into diffusers, we found the high capacity drum (HCD) louver diffusers that are designed to throw air in industrial applications were duct layout is limited. Before we can select the size of the diffusers, we must determine how much air will be supplied at each location.

Typically, supply air and outdoor air requirements are governed by ASHRAE 62.1, which depends on the room usage, floor area, and number of people. Sometimes, like in our application, ASHRAE 62.1 refers air calculations to other standards, such as Industrial Ventilation and NFPA 33/91. For the paint facility, the supply air requirements are governed by the exhaust requirements. MUA-1 is easy, because there is only one duct run between the MUA and the paint booth. Although in the case of MUA-2, there is a division where separate duct runs will have different air volume and diffusers that supply air to the rooms. In this case, we know the curing area needs to exhaust 9870 CFM based on NFPA 33. For the remaining rooms, we use exhaust requirements governed by Table 6.4 in ASHRAE 62.1. We chose a conservative category of Woodshop, where exhaust is calculated at 0.5 CFM/sq. ft. The air exhausted in the remaining space is calculated to be 4300 CFM.

Based off the duct sizing and air volumes, the diffusers can be sized. For simplicity, we chose the same size diffusers for all spaces. This allows bulk ordering to reduce cost and eliminated chance of improper installation by contractors. Making common parts in large jobs is a good way to reduce error and overall, extra time and cost. The diffusers we selected was the E.H Price HCD 15/36" diffuser, rated for 2250 CFM, with pressure drop of 0.048 " w.g and a noise control (NC) = 31.

6.2 MECHANICAL ROOM LAYOUT

The mechanical room must be large enough to fit both MUA's. As for the orientation of both MUA's, we placed them with the top discharge side closest to the paint room (indicated by an X) and the intake facing the North wall of the mechanical room. The top discharge MUA's allow for easy discharge of air. The ducts will directly run up to high level where it will enter the paint facility as high as possible, dictated b the crane locations (to be determined by Sperling Industries). While we do not care about the exact dimensions of the mechanical room, the room must be large enough to pull out any filters and perform any needed maintenance.

The North wall of the mechanical room will have to be dedicated for air intake for both MUA's. Typically, ducted louvers are connected to the MUA's to allow fresh, outdoor air to get to the equipment.

MUA's should be placed on vibration insulators, such as rubber pads, and connected to ductwork using flexible connections. Vibrations from equipment can resonate through the ductwork and create annoying and unwanted noise.

6.3 PROPANE TANK SELECTION

To determine the adequate propane tank size for the new paint facility, we look at the monthly propane usage strictly based on heating.

First, we need to convert the monthly energy usage from natural gas to propane. Per Figure 30, the average natural gas consumption is 111,716,666.67 BTU/month. TABLE XII shows the energy content for both natural gas and propane.

TABLE XII: ENERGY CONTENT FOR NATURAL GAS AND PROPANE [51].

Energy Type	**BTU/ft^3**
Natural Gas	1030
Propane	2516

As seen in TABLE XII, propane contains 2.44 times more energy than propane. We can apply this ratio to determine the monthly gas consumption for propane.

$$\frac{111{,}716{,}666.67\ \frac{BTU}{month} natural\ gas}{2.44} = 45{,}785{,}519.13 \frac{BTU}{month} propane$$

Next, we can convert BTU of propane to litre (or gallon) using TABLE XIII.

TABLE XIII: NATURAL GAS CONVERSION FROM BTU TO LITRE OR GALLON [52].

Natural Gas	24,127 BTU/L
	91,333 BTU/gal

$$\frac{45{,}785{,}519.13\ \dfrac{BTU}{month}propane}{24{,}127\dfrac{BTU}{L}} = 1897.69\ \frac{L}{month}propane$$

$$\frac{45{,}785{,}519.13\ \dfrac{BTU}{month}propane}{91{,}333\ \dfrac{BTU}{gal}} = 501.30\ \frac{gal}{month}propane$$

Finally, we can determine a suitable propane tank size based on the above calculations. From Superior Propane, one 1000 gallon tank (3028 L capacity) is more than enough to heat Sperling Industries' new paint facility as shown in Figure 32 [53]. The 1000 gal tank is suitable for a residential application, especially for those that require high BTU loads. The tank must be installed at least 25 ft. from the building and at least 10 ft. from any property line [53]. The critical dimensions of the tank are shown in TABLE XIV.

Figure 32: Superior Propane's 1000 gal Propane Tank [53].

TABLE XIV: CRITICAL DIMENSIONS FOR THE 1000 GALLON TANK FROM SUPERIOR PROPANE [53].

Height	4 ft. 4 in.
Length	15 ft. 11 in.
Diameter	41 in.

6.4 Exhaust Grilles

The exhaust grilles used to cover duct openings in the curing paint, shot blast, and staging areas were selected from the E.H Price website. Refer to Appendix G. This application requires high air volume requirements and low-pressure loss. For this reason, the 80 series egg crate exhaust grill was chosen.

In the curing area, we will implement five, 30x22" exhaust grilles, rated for 2574 CFM at a NC of 37. For the remaining spaces, we will have three, 30x18" exhaust grilles, rated for 1805 CFM and a NC of 31. Overall, these exhaust grilles are sleek, easy to install, cheap, and most importantly, and perform the job well.

6.5 LEL Sensor

In our paint booth exhaust calculations, we have determined the volume of air which has to be replaced from the paint booth to maintain a safe work environment inside the booth. To make the system fool proof and alarm the operators of any kind of malfunction in the air circulation system which may result in increased VOC level in the booth. We have installing a LEL sensor after the scrub filter in the exhaust. This sensor can detect the presence of combustible gases and produces audible and visual alarm for the operators.

The LEL sensor reduces the risk of any fire hazard. It also alerts the staff to take the precautionary actions in time. A paint booth needs a combustible gas detector and a flame detector as well. The following are the possible sensors which can be used.

6.5.1 FLAME GUARD 5 MSIR FLAME DETECTOR

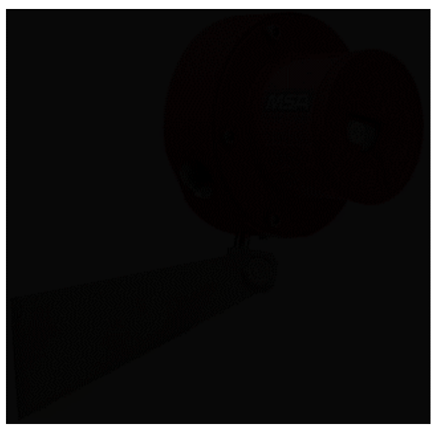

Figure 33 Flame detector sensor [54]

The flame detector as shown in Figure 33 uses a Multi Spectrum Infrared sensor to detect the possible flames in the monitored area. This sensor is available in the market for approximately $5,000 CAD. [54]

6.5.2 GasTrex Toxic or Flammable Gas Detector with Display and Alarm Outputs

Figure 34 Combustible gas detection sensor [55]

The combustible gas detector as shown in Figure 34 uses catalytic, electrochemical, PID and infra-red sensor types to detect the level of combustible gas levels in the monitored area. This sensor is available in the market for approximately $400 CAD. [55]

6.6 Miscellaneous Design Details

All numbers on drawings M-1 and M-2 are in imperial units because that is the industry standard, unless told otherwise. Metric units are common for government jobs. Typically, the architect chooses whether the job will be done in metric or imperial. Some abbreviations used on the drawing include ‘NTS’ and ‘C/W’, which refer to ‘not-to-scale’ and ‘complete with’.

Other dampers such as fire dampers and backdraft dampers are required in the system. Fire dampers are needed any time a duct crosses through a fire separation. The mechanical room is surrounded by wall that is deemed as fire separation and each duct crossing that boundary must have a fire damper inside it. The fire damper only closes if the fire alarm is tripped. The main purpose is to close the duct, shutting off the transfer of air from zone to zone and eliminating any more oxygen to the fire, as well as spreading smoke from zone to zone.

For the paint facility, each MUA gets it's own temperature control, set by a strategically placed thermostat. The thermostat must be far enough away from any windows to prevent false temperature readings from solar radiation. Also, the thermostat must be located in a convenient location.

The two ends of the building have large overhead doors and will have to open frequently even during the winter months to allow for new parts to enter the building. For this reason, we added two Ouellette 8kW electric force flow heaters at each end, for a total of four force flow heaters. To combat cold drafts, an easy solution, and an industry standard, are to add force flow heaters. Force flow heaters do not condition the air, nor add outdoor air, but they simply heat and recirculate the air. The outdoor air comes from the door to the outside that opens quite frequently. The cut sheets for the Quellette 8 kW force flow heaters can be found in Appendix H.

To reduce on energy costs, MUA-1 will be able to turn off when the paint booth is not in operation. Also, during the nights and weekends when the building in unoccupied, MUA-2 will want to reduce its load. For this reason, we have opted to include a variable-frequency-drive (VFD) motor is needed to create a variable speed supply fan. VFD's are added capital, but will reduce wear on the fan motor, as well as reduce operating costs and provide better comfort to the client.

The two high-efficiency direct fire MUA's must be connected to the propane tank via piping. When the piping reaches the mechanical room, a pressure regulator will knock down the pressure, causing the piping to get bigger, where the pressure will match the input operating pressure of the two MUA's.

A byproduct of combustion is carbon monoxide, which is a colorless and odorless gas, making it good practice to provide a carbon monoxide sensor. If a leak is going to occur, it will occur first in the mechanical room, and thus, the carbon monoxide sensor will be located in the mechanical room, near the two MUA's. Also, each MUA will require a 6" diameter intake and 6" diameter flue vent, as seen in drawing M-1.

On drawing M-1, there are supply ducts that cross in the ceiling space. The wall ceiling height is 24', so we are not worried of a lack of space for crossing ducts. Where large ducts were equipped with square elbows, turning vanes were added to help flow take corners and reduce space. Ceiling space can get very crowded in buildings and it is good practice to leave a little extra room for unexpected equipment, such as electrical cable trays or domestic water piping.

The mechanical room is equipped with a transfer air duct, which allows for the transfer of air from the supplied area to the mechanical. The air circulates into the mechanical room each time the door is opened and natural pressure difference between the rooms. The transfer air duct will be located above the door but below any ducts leaving the mechanical room.

6.7 REQUIREMENTS TO BECOME OPERATIONAL

Once the construction has finished, and before the owner receives the Occupancy Permit, the building must undergo a final test. Before the final test can be performed, all the equipment must be run to ensure the system works as designed. After the equipment is installed, ‘Air balancing’ contractors must balance the system. These contractors take the airflow numbers that come out of each diffuser and try to replicate it. For this to possible, manual dampers must be provided at all diffusers. For this report, and more specifically the drawings, all diffusers are assumed to come with manual dampers as far away from the diffuser itself as the damper can create unwanted noise.

It is assumed a professional contractor will be hired to perform all installations. In doing this, Sperling Industries will not have to worry about selecting metal gauges for ductwork, straps, and other code compliant issues.

6.8 Equipment Summary

This section outlines the equipment specified in the final design for easy reference. The table below will out display the equipment tag, as seen on M-1, and other pertinent details, such as manufacturer, model, size, and performance data, if applicable.

TABLE XV: EQUIPMENT SUMMARY

Equipment Tag	Manufacturer	Model	Notes
Paint booth	Standard Tools and Equipment Co.	Custom	Semi-down draft, fans sold separately
EF-1, paint booth	Greenheck	CUBE-480	Beltdriven, 3hp, 20,222 CFM, 360 rpm, 16.1 sonnes
EF-2, curing room	Greenheck	CWB-300	Belt driven, ½ hp, 4540 CFM, 580 rpm, 9.5 sonnes
EF-3, common rooms	Greenheck	CWB-240	Belt driven, 2 hp, 10,508 CFM, 665 rpm, 19.7 sonnes
Eggcrate Exhaust grille	E.H Price	80 Series	Sizes specified on M-1
MUA-1	Engineered Air	HE 401	39,623 CFM, 40 hp, 0.5” wg, 6442 MBH, 208V/3/60
MUA-2	Engineered Air	HE 171	14,170 CFM, 15 hp, 0.5” wg, 1839 MBH, 208V/3/60
Louver Supply Diffuser	E.H Price	HCD	Sizes specified on M-1
FF-1, Force Flow Heater	Quellette	OAC	8 kW, recessed, wall mounted
Propane tank	Superior	1000 gallon	1000 gallon, exterior purpose

6.9 Cost Analysis

In this section our team tried to research the cost to purchase the equipment which are included in the design of this HVAC system. All the prices in TABLE XV are in Canadian dollars. If the required equipment is not available in Canada, then the cost is converted to CAD using the online Google Currency Exchange rate calculator. The import cost, required labor cost and government documentation charges are not part of this cost analysis.

TABLE XVI: FINAL COST FOR SPERLING INDUSTRIES' PAINT FACILITY

Equipment name	Qty	Approximate Market Price	Total Market Price
Paint booth	1	$ 22,800	$ 22,800
EF-1, paint booth	2	$ 8,685	$ 17,370
EF-2, curing room	1	$ 6,070	$ 6,070
EF-3, common rooms	1	$ 2,480	$ 2,480
80 series Eggcrate Exhaust grille	7	$ 70	$ 490
MUA-1	1	$ 40,000	$ 40,000
MUA-2	1	$ 20,000	$ 20,000
HCD Louver Supply Diffuser	9	$ 240	$ 2,160
8 kW Quellette Force Flow Heater	5	$ 1,247	$ 6,235
Air filters	5	$136	$678
Flame detector sensor	1	$ 5,000	$ 5,000
Combustible gas sensor	1	$ 400	$ 400
Propane tank	1	$ 4,000	$ 4,000
Total Cost:			**$ 127,683**

The total cost can be seen to be $127,683, which only includes the equipment cost. In reality, there will be consulting fees and installation fees, too. A general rule of thumb for estimating contingency and installation is a factor of 2. With this, our projected overall cost for this project is $255,366.

7.0 CONCLUSION

Team 20 accepted to design the HVAC system for Sperling Industries' new 19,400 sq. ft. paint facility. Our team clearly outlined the problem statement, target specifications, customer needs, constraints, limitations, and design expectations for the paint facility.

Our team then conducted concept generation to brainstorm the following topics: heat distribution systems, energy sources, and supply air systems. Based on the selection criteria and weighting matrices, we decided the propane make-up air unit was the best choice for Sperling Industries.

Once we finalized our concept design, we were able to move forward by calculating heating loads using CAN-QUEST energy software, determining the exhaust requirements based off of the 0.25% LFL of the paint, and sizing the MUA. After the calculations were made, we were able to proceed with final design and equipment selection.

The paint booth is a semi-down draft paint booth from Standard Tools and Equipment. From Engineered Air, we specified two direct fire HE series MUA's, complete with M-Trac integrated controls. MUA-1 is dedicated to serve the paint booth, while MUA-2 serves both the curing area and remaining spaces. To exhaust the required air volume for the paint facility, we reached out to E. H Price for Greenheck exhaust fans.

We were able to determine the fan models based off performance data and availability. The curing room and common rooms were able to use CWB-240 and CWB-300 belt driven sidewall exhaust fans, respectively. Due to the high air volume, the paint booth required two high capacity CUBE-480 up-blast exhaust fans. Also from E.H Price, all supply diffusers and exhaust grilles were specified as HCD Louver style diffusers and 80 Series Eggcrate grilles, respectively.

Overall, our design encompasses the details needed to fulfill Sperling Industries needs, while conforming to applicable codes, standards, and typical practices. The total equipment cost for the paint facility is estimated to be $127,683.00.

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Appendix

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APPENDIX A : SCHEDULING

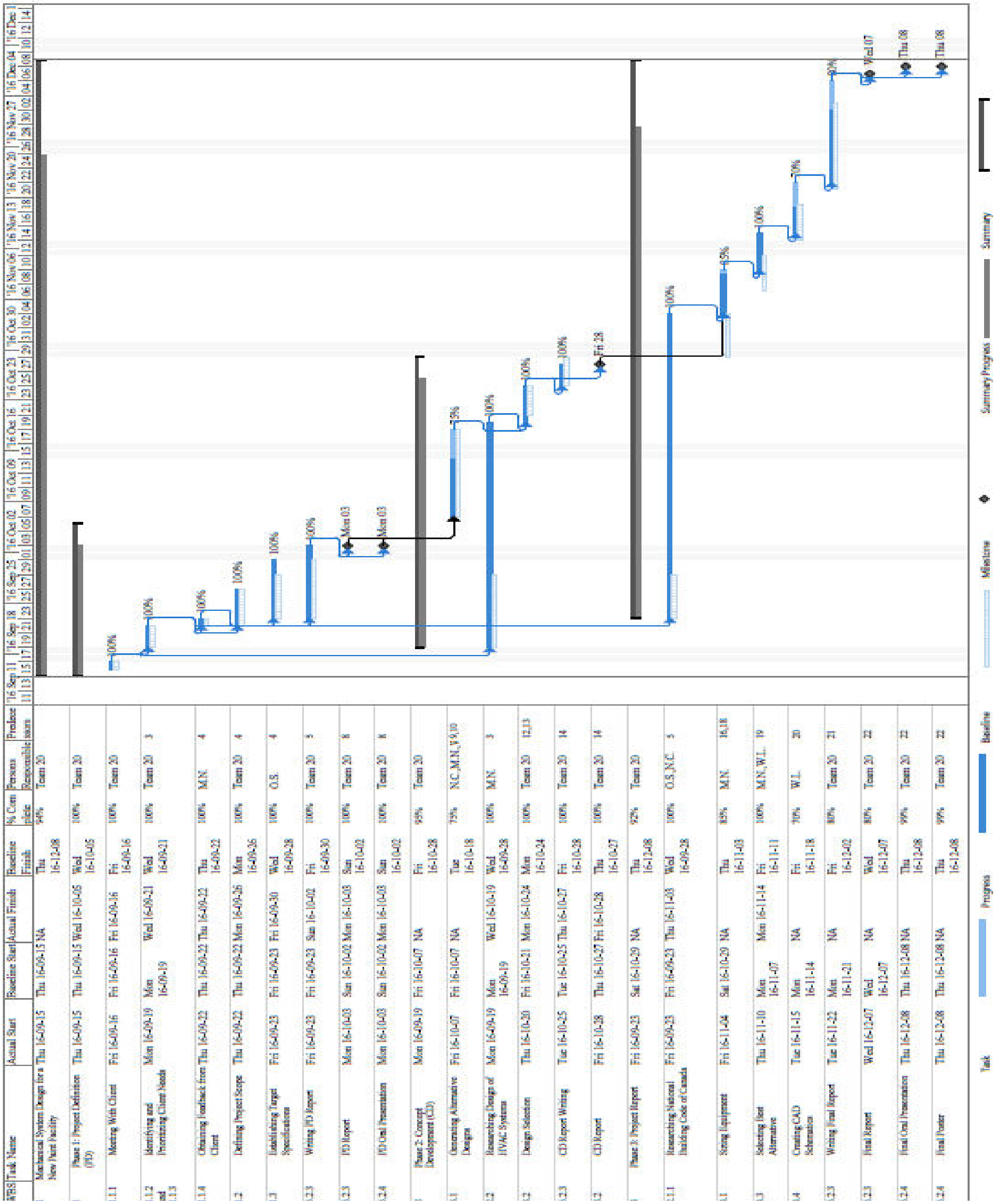


Figure 1: Final Gantt Chart for Team 20

APPENDIX B : NFPA CODES

Following two NFPA codes are considered for this project: NFPA 33 and 91.

APPENDIX B.1: NFPA 33

The following are the codes and standards which are taken from NFPA 33, 2015 Edition which directly apply to the new paint facility of Sperling industries:

TABLE I: RELEVANT GUIDELINES FROM NFPA 33

Section #	Description
5.5.1	[redacted]
5.5.2	[redacted]
5.5.3	[redacted]
5.5.4	[redacted]
5.5.5	[redacted]
7.1	[redacted]
7.2	[redacted]
7.2.1	[redacted]
7.2.3	[redacted]

Section #	Description
7.3	[redacted]
7.4	[redacted]
7.5	[redacted]
7.6	[redacted]
7.7	[redacted]
7.9	[redacted]
7.10.1	[redacted]
7.10.2	[redacted]

Section #	Description
7.10.3	[redacted]
7.11	[redacted]

APPENDIX B.2: NFPA 91

The following are the codes and standards which are taken from NFPA 91, 2015 Edition which directly apply to the new paint facility of Sperling industries:

TABLE II: RELEVANT GUIDELINES FROM NFPA 91

Section #	Description
4.2.5	[redacted]
4.2.6	
4.2.9	
4.2.10	
4.2.11	
4.3.1	
4.3.2	

Section #	Description
4.3.3	[redacted]
4.3.6.1	[redacted]
4.3.6.2	[redacted]
4.4.3.1	[redacted]
4.4.3.2	[redacted]
4.4.4	[redacted]
4.4.5	[redacted]
4.5.2	[redacted]
4.5.7	[redacted]
4.5.8	[redacted]
4.5.9	[redacted]
4.7.2	[redacted]
4.7.5.1	[redacted]
6.2	[redacted]
6.3.1	[redacted]
6.3.2	[redacted]
6.4	[redacted]
6.5.1	[redacted]
6.5.2	[redacted]

Section #	Description
6.6	[redacted]
8.1	[redacted]
8.2.1	[redacted]
8.2.2	[redacted]
8.2.4	[redacted]
8.6	[redacted]
8.7.1	[redacted]
8.7.2	[redacted]

APPENDIX C : VARIOUS PAINTS USED AT SPERLING INDUSTRIES LTD.

Following table shows the list of tables used at Sperling Industries Ltd.

TABLE III: PAINTS USED AT SPERLING INDUSTRIES AND THEIR LFL VALUES

S.N	PRODUCT NAME	COMPANY	PRODUCT #	LFL % vol.
2	2C ACRYCOTE GEN3 WHITE 4.1	PPG	604100	1.10%
3	THINNER ENAMEL	PPG	106(0819)	N/A
6	AD ENAMEL WHITE	PPG	549100 (0819)	N/A
8	FD ENAMEL HI SAG NEUTRA	PPG	549004	1.10%
10	AD ENAMEL WHITE TINT BASE	PPG	549002 (0819)	N/A
11	ACRYCOTE ACTIVATOR	PPG	794002	1.20%
12	2C ACRYCOTE N T B 4.1	PPG	694004	1.10%
13	WASH PRIMER BASE COMPONENT	PPG	ADS225	1.00%
14	FD PRIMER NON LIFT GREY	PPG	591609A	1.00%
15	URETHANE HARDENER	PPG	GXH1080	1.10%
16	FD ENAMEL YELLOW	PPG	CPC-207	N/A
17	Epoxy Thinner #2	PPG	97-737	1.10%
19	FD PRIMER NON LIFT RED OXIDE	PPG	591357A	N/A
21	ACRYCOTE ACCELERATOR	PPG	RX7055	N/A
22	MEDIUM REDUCER	PPG	MR186	1.20%
23	7199 SAFETY YELLOW ALKYD EN	PPG	549Q1140 (549T7199)	N/A

S.N	PRODUCT NAME	COMPANY	PRODUCT #	LFL % vol.
24	SLOW COMPLIANT CLEAR HARDENER	PPG	MH778	1.10%
25	4186 GREEN HB ALKYD	PPG	549Q1273	N/A
26	5139 UGG BLUE HB ALKYD	PPG	549Q1184	N/A
27	T5286 BLUE HB ALKYD	PPG	549C1210	N/A
28	204 SILVER MIST HB ALKYD	PPG	549Q1253	N/A
29	4209 AG PRO GREEN HB ALKYD	PPG	549Q1193	N/A
30	SPECTRACRON FLEETPRIME EPOXY GREY	PPG	634HB6315	N/A
31	CLOVA THINNER #11: XYLENE	Cloverdale	78011	N/A
33	CLOVATHANE ACRYL. URETH.EN.	Cloverdale	83400B	N/A
34	CLOVAMASTIC LOW TEMP CURE ACT	Cloverdale	83110B	1.00%
35	CLOVAMASTIC LOW TEMP CURE EPOX	Cloverdale	83110A	1.00%
36	DURAPRIME POLYAMIDE EPOXY PRIMER - GREY	Cloverdale	86850A	1.00%
37	DURAPRIME EPOXY PRIMER - ACTIVATOR	Cloverdale	86850B	1.00%
38	PREPTECH EPOXY PENETRATING SEALER	Cloverdale	83020A	N/A
39	ARMOUR SHEILD WHITE	Cloverdale	83900A	0.50%
41	CROWN 7008BRITE GALVANIZE COATING	AERVOE	7008	0.70%
42	CRYSTALLINE SILICA IN THE FORM OF QUARTZ	UNIMIN CORPORATION	011-U	N/A
43	EPOXY VINYL ESTER RESIN	ASHLAND	120327	N/A
44	GUNWASH, REGULAR	UNITED CHEMICALS		N/A
45	Armashell Blue Diamond Liquid Wax	Kleen-flo	300	N/A
46	INTERSEAL 670HS LIGHT BASE	INTERNATIONAL	EGA011	0.60%
47	INTERTHANE 990/990 PART B	INTERNATIONAL	PHA046	1.00%

S.N	PRODUCT NAME	COMPANY	PRODUCT #	LFL % vol.
49	INTERSEAL 670HS LIGHT BASE	INTERNATIONAL	EGA055	0.60%
50	INTERSEAL LOW TEMP CONVERTER	INTERNATIONAL	EGA056	N/A
51	INTERTHANE FD PART B	INTERNATIONAL	PHA046	1.00%
52	INTERTHANE 990 LIGHT BASE	INTERNATIONAL	PHA011	0.19%
53	INTERGARD 345 BASE LIGHT PART A	INTERNATIONAL	AAA130/5GL	1.00%
54	INTERGARD 345 PART B	INTERNATIONAL	AAA046/1GL	1.00%
55	INTERNATIONAL Thinner/Eqpt Cleaner (formerly GTA415 REDUTOR)	INTERNATIONAL	GTA415/5GL	1.30%
56	INTERZINC 52 PART B LOW TEMP	INTERNATIONAL	EPA176/1GL/SF	1.00%
57	INTERLAC 665FD BASE YELLOW	INTERNATIONAL	66555	1.00%
60	Fast Action Spray Wax	Napa Body Pro	32151	N/A
67	HS MASTIC URETHANE SCHULTE BLACK	PPG INDUSTRIES. INC.	Q3790-8501	N/A
68	4231 CARGILL DARK GREEN	PPG INDUSTRIES. INC.	549Q1227	N/A
69	INTERCHAR 1120 WHITE	INTERNATIONAL PAINT LLC	HFA124_A2	0.62%
70	INTERTHANE 990 BASE YELLOW PART A	INTERNATIONAL PAINT LLC	PHA150	0.19%
72	PHILLIPS 4286/356U GREEN	PPG	549Q1643	N/A
73	Graymont Gray HB ALKYD	PPG	549Q1401	1.10%
82	High Heat Black Enamel	PPG	HHB-900	1.00%
83	ARMOUR SHILED B COMPONENT	CLOVERDALE	83ARMB	N/A
85	Interprime 198 White	INTERNATIONAL	CPA097	0.90%
86	Intergard 251 Converter	INTERNATIONAL	251B	1.00%
87	Interlac 573 Grey	INTERNATIONAL	57398	0.90%

S.N	PRODUCT NAME	COMPANY	PRODUCT #	LFL % vol.
88	Interlac 665FD Base Ultra Deep	INTERNATIONAL	CGA044	1.00%
89	Interlac 665FD Base Yellow	INTERNATIONAL	CGA055	1.00%
90	Interseal 670HS Base Light Part A	INTERNATIONAL	EGA130	0.60%
91	Interseal 670HS Part B	INTERNATIONAL	EGA247	1.00%
92	Interseal 670HS White Part A	INTERNATIONAL	EGA010	0.60%
93	Interthane 870 Base Light Part A	INTERNATIONAL	QGA011	0.19%
94	Interthane 870 Base Yellow Part A	INTERNATIONAL	QGA055	0.19%
95	Interthane 870	INTERNATIONAL	QGA046	1.00%
96	Interthane 990 Base Metallic Part A	INTERNATIONAL	PHA077	0.19%
97	Interthane 990 Base Ultra Deep Part A	INTERNATIONAL	PHA044	0.19%
98	Interthane 990 Base Ultra Deep Part A	INTERNATIONAL	PHA100	0.19%
99	Interthane 990HS/870HS Part B	INTERNATIONAL	990B	1.00%
100	Interthane 990HS Base Deep Part A	INTERNATIONAL	99033A	1.05%
101	Interthane 990HS Base Ultra Deep Part A	INTERNATIONAL	99044A	1.05%
102	Interlac 665FD Base Light	INTERNATIONAL	CGA011	1.00%
103	Interthane 990HS Base Light Part A	INTERNATIONAL	99011A	1.00%
104	Intertherm 50 Aluminum	INTERNATIONAL	HTA097	0.90%
105	Intertherm 891 Aluminum	INTERNATIONAL	HTA002	0.90%
106	Interzinc 52 Esverdeado Base	INTERNATIONAL	EPA175	1.00%
107	Interlac 665FD Red Base	INTERNATIONAL	66566	1.00%
108	Interlac 789 Base Ultra Deep	INTERNATIONAL	RSA044	1.00%
109	Black Anti-Slip Aerosol	Rust-Oleum Corp	AS2178838	0.80%

S.N	PRODUCT NAME	COMPANY	PRODUCT #	LFL % vol.
110	Flat Grey Enamel Primer	Rust-Oleum Corp	V2182838	1.00%
111	Cold Galvanizing Compound	Rust-Oleum Corp	V2185838	0.80%
112	Deep Blue Enamel	Rust-Oleum Corp	V2125838	1.00%
113	Gloss Safety Blue	Rust-Oleum Corp	925402	1.00%
114	Heat Resistant Coating Grey	Rust-Oleum Corp	4286402	1.00%
115	Thinner	Rust-Oleum Corp	333402	2.00%
116	V7400 Silver Grey	Rust-Oleum Corp	245484	0.90%
117	V8400 Dairy White	Rust-Oleum Corp	259158	N/A
118	Flat White Clean Metal Primer	Rust-Oleum Corp	7780402	1.00%
119	Safety Blue Enamel	Rust-Oleum Corp	V2124838	1.00%
120	Safety Red	Rust-Oleum Corp	V2163838	1.00%
121	Old Caterpillar Yellow	Rust-Oleum Corp	245500	0.70%
122	Silver Aluminum Specialty Finish	Rust-Oleum Corp	V2115838	0.90%
123	White Multi-purpose Primer	Rust-Oleum Corp	1681830	0.90%
124	Flat Black Enamel	Rust-Oleum Corp	V2178838	1.00%
125	Thinner/reducer	Cloverdale	C-300	2.00%
126	Derakane 8084 Epoxy Vinyl Ester Resin 40214	Ashland	8084	N/A
127	Sure Grip 404	Carlisle	302014	1.00%
128	Sequoia Safe Yellow	Superior Finishes	243-435	N/A
129	Sequoia Xylol Fast Reducer	Superior Finishes	480007	N/A
130	Bar Rust 235 Base Tint Pt A	Devoe International	D235B9500	N/A
131	Bar Rust 235 Pt B	Devoe International	DC235C0980	1.00%

S.N	PRODUCT NAME	COMPANY	PRODUCT #	LFL % vol.
132	Super Spec HP Urethane Alkyd Glose Enamel Ultra Base	Benjamin Moore	KP224B	N/A
133	Super Spec Interior Latex Pearl Finish Pastel Base	Benjamin Moore	K2771B	N/A
134	Clear Gloss Base	Allcolour	AF01	N/A
135	Heat Resistant Black	Allcolour	299004	N/A
136	Aluminum Lacquer	Allcolour	041034	N/A
137	KEM BOND Primer Grey	Sherwin Williams	B50AZ8	N/A
138	Coraflon ADS Component B Curing Agent	PPG	ADS1B	1.10%
139	Coraflon ADS Silver Gray Peab. Ess	PPG	ADS9361030	0.90%
140	AD8702 Coraflon Epoxy Thinner 00411388	PPG	ADS702	1.30%
141	2C Epoxy Primer HB Grey 1:1	PPG	6376042	N/A
142	2C Epoxy Primer ACT Yellow 1:1	PPG	737700	N/A
143	Polyclutch Wash Primer Acid	PPG	97-688	2.30%
144	5338 Viterra Blue HB Alkyd	PPG	549Q1063	N/A
145	ACE058 OSHA Safety Red HB Alkyd	PPG	549Q1069	N/A
146	311 Red HB Alkyd	PPG	549Q1389	N/A
147	FD Enamel Neutral Tint B Pool Yellow	PPG	544004	N/A
148	FD Enamel S/G Neutral Tint Base Silver Grey Metallic	PPG	548004	N/A
149	2C Flake Fill Epoxy Act	PPG	780700	N/A
150	2C Herculon Epoxy Activator	PPG	784000	N/A
151	Spectracron Fleetprime 2C Epoxy Act	PPG	TX7068	N/A
152	Industrial Alkyd Enamel Bright Yellow	PPG	ALK110	N/A
153	Light Weight Body Filler	Autobody Master	4404	1.10%

S.N	PRODUCT NAME	COMPANY	PRODUCT #	LFL % vol.
154	Marine Fiber Glass Repair	Evercoat	100637	1.10%
155	Extra Solid Activator	Transtar	6894	0.90%
156	Low VOC clearcoat	Transtar	6531	0.90%
157	Grey Surface Primer	Kleen-Flo	4402	1.00%
158	John Deer Yellow	Valspar	TY25823	N/A
159	Armaflex WB Finish	Armacell	301412368	N/A
160	Oil Based semi gloss white	Behr	3800	0.80%
161	XO-1 Oil Base White	XO Rust	XO-1	N/A
162	Varathane (formerly Flecto) 1000 Semi Gloss	Rustoleum	Y100041	0.90%
163	Grey Primer	Tremclad	274103155	1.00%
164	Clear Tint Base	Cloverdale	74002	1.00%
165	Acrylic Eggshell Enamel Medium Base	Benjamin Moore	F3192B	N/A
166	Dem-Kote New Caterpillar Yellow	Rustoleum	70251F	0.90%
167	Dem-Kote White Enamel	Rustoleum	70100F	0.90%
168	Massey Ferguson Red	Valspar	M1041	N/A
169	Gloss Black Super Enamel	Kleen-Flo	4001	0.90%
170	Stove Paint	Thurmalox	279-26	N/A
171	Drywall Primer	Co-op	C5053	N/A
172	Super Primer Interior Latex	Co-op	C3053	N/A
173	Titan Red	Co-op	3714-001	N/A
174	Semi Gloss White General Paint	Co-op	C5100	N/A
175	Rust Coat Red Oxide Primer	Home Hardware	64-18	0.008%

APPENDIX D : PARTIAL MSDS AND TDS FOR GEMINI ARMOUR SHIELD WHITE

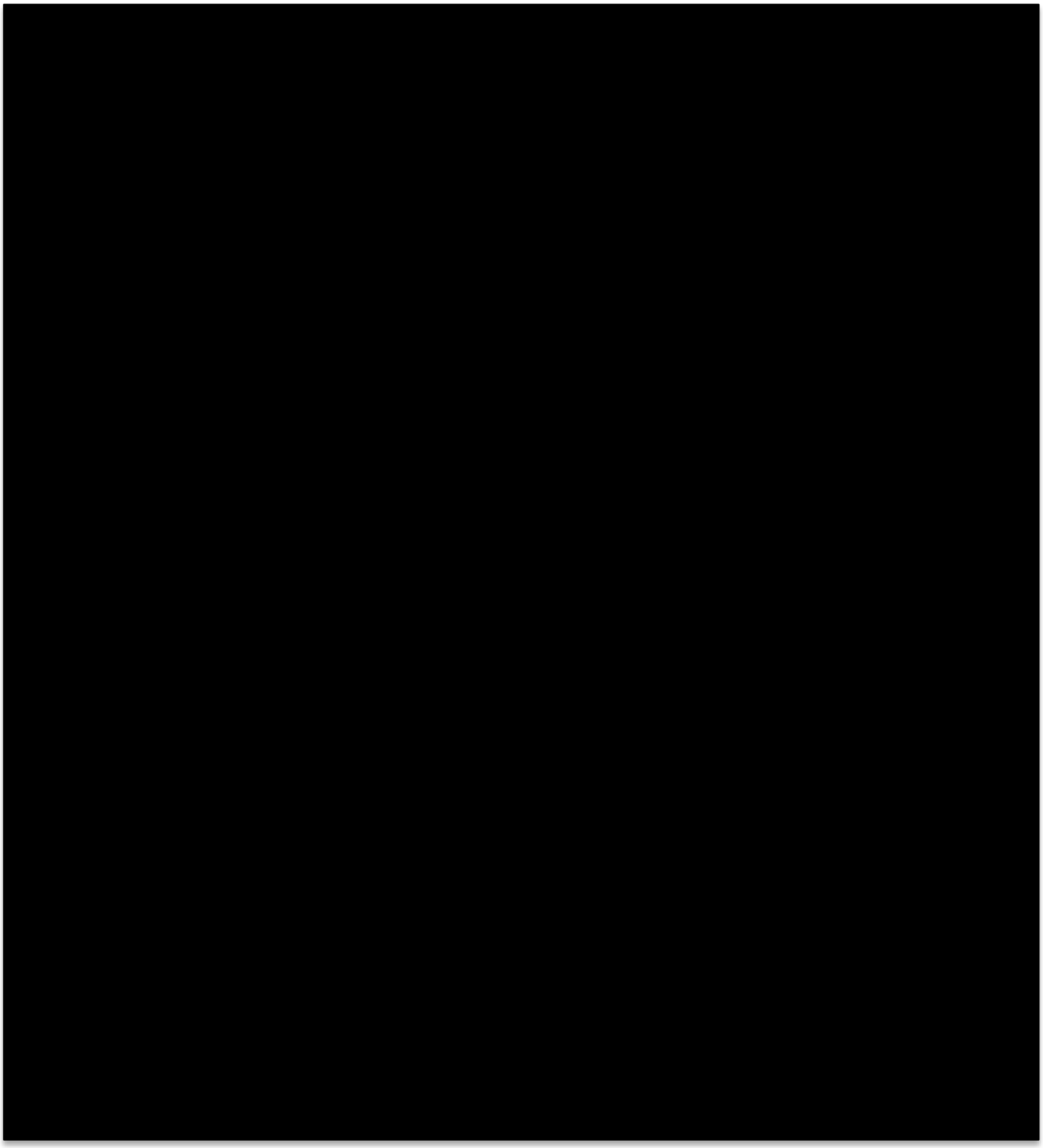


Figure 2: MSDS for Gemini Armour Shield White (Part 1)

[redacted]

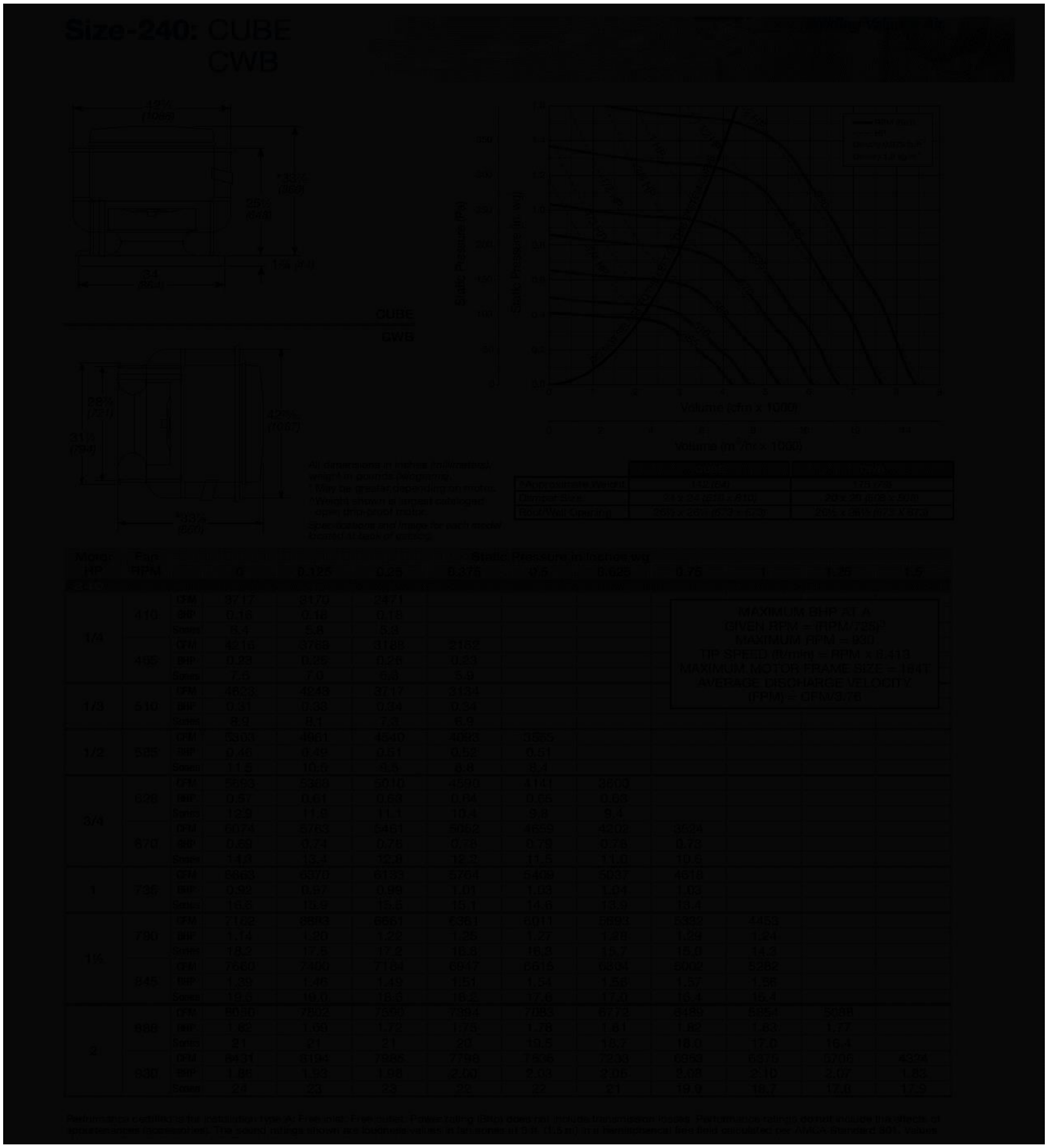
Figure 3: MSDS for Gemini Armour Shield White (Part 2)

[redacted]

Figure 4: Technical Data Sheet for Gemini Armour Shield

APPENDIX E : EXHAUST FAN SELECTION

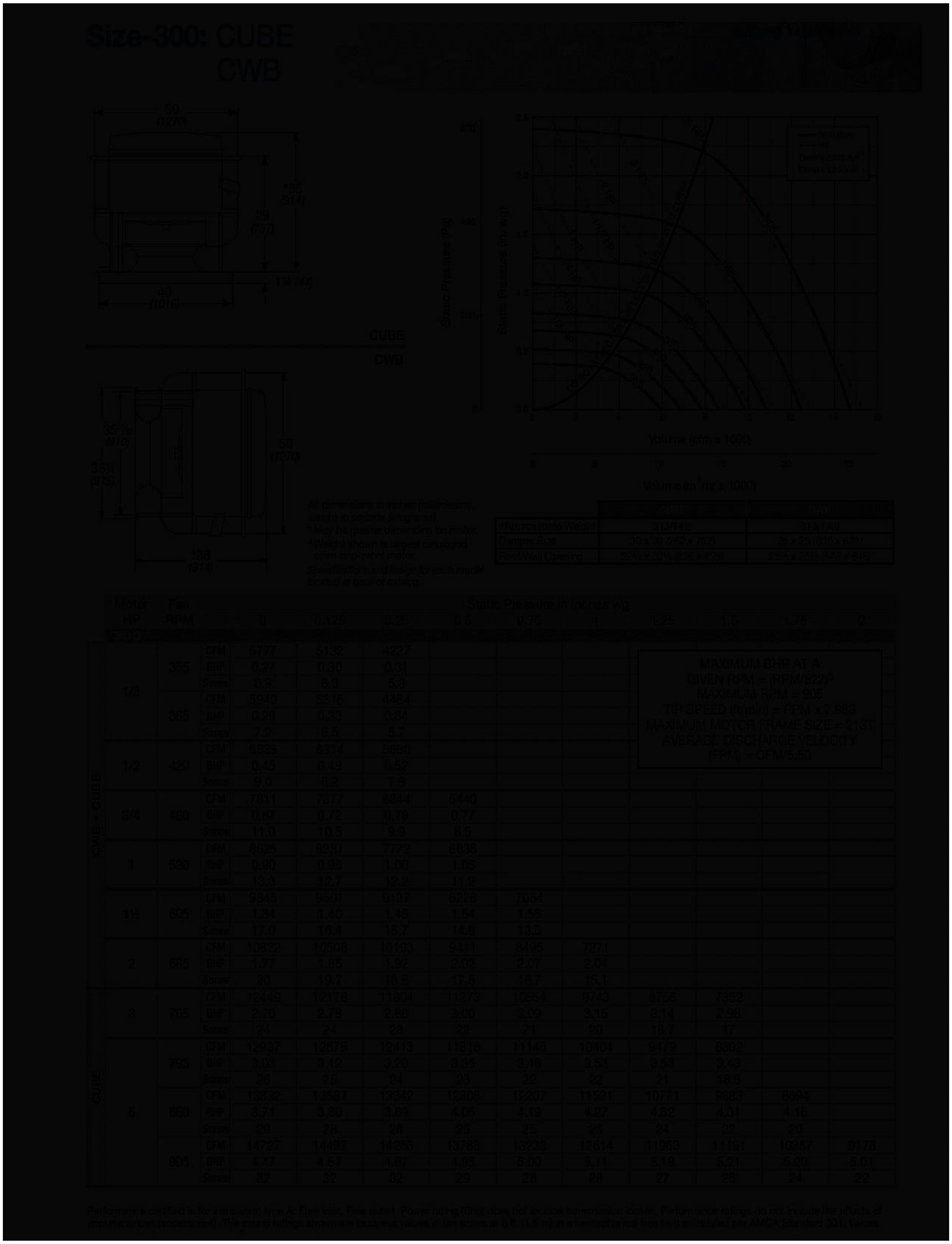
APPENDIX E.1: CWB EXHAUST FAN


Size-240: CUBE CWB

Motor HP	Fan RPM		0	0.125	0.25	0.375	0.5	0.625	0.75	1	1.25	1.5
1/4	410	CFM	3717	3170	2471							
		BHP	0.16	0.18	0.18							
		Sones	6.4	5.8	5.3							
	495	CFM	4216	3769	3188	2182						
		BHP	0.23	0.25	0.26	0.23						
		Sones	7.5	7.0	6.6	5.9						
1/3	510	CFM	4623	4249	3717	3134						
		BHP	0.31	0.33	0.34	0.34						
		Sones	8.9	8.1	7.3	6.9						
1/2	535	CFM	5303	4961	4540	4093	3585					
		BHP	0.46	0.49	0.51	0.52	0.51					
		Sones	11.5	10.5	9.5	8.8	8.4					
3/4	628	CFM	5693	5369	5010	4590	4141	3600				
		BHP	0.57	0.61	0.63	0.64	0.65	0.63				
		Sones	12.9	11.9	11.1	10.4	9.8	9.4				
	670	CFM	6074	5763	5461	5062	4659	4202	3524			
		BHP	0.69	0.74	0.76	0.78	0.79	0.78	0.73			
		Sones	14.3	13.4	12.8	12.2	11.5	11.0	10.6			
1	735	CFM	6663	6370	6133	5764	5409	5037	4618			
		BHP	0.92	0.97	0.99	1.01	1.03	1.04	1.03			
		Sones	16.6	15.9	15.5	15.1	14.6	13.9	13.4			
1½	790	CFM	7162	6883	6661	6361	6011	5693	5392	4453		
		BHP	1.14	1.20	1.22	1.26	1.27	1.28	1.29	1.24		
		Sones	18.2	17.5	17.2	16.8	16.3	15.7	15.0	14.3		
	845	CFM	7660	7400	7164	6947	6615	6334	6002	5262		
		BHP	1.39	1.46	1.49	1.51	1.54	1.56	1.57	1.56		
		Sones	19.3	19.0	18.6	18.2	17.6	17.0	16.4	15.4		
2	888	CFM	8050	7802	7560	7394	7053	6772	6489	5954	5098	
		BHP	1.62	1.69	1.72	1.75	1.78	1.81	1.82	1.83	1.77	
		Sones	21	21	21	20	19.5	18.7	18.0	17.0	16.4	
	930	CFM	8431	8194	7985	7798	7536	7230	6953	6375	5706	4324
		BHP	1.88	1.93	1.98	2.00	2.03	2.06	2.08	2.10	2.07	1.83
		Sones	24	23	23	22	22	21	19.9	18.7	17.8	17.9

MAXIMUM BHP AT A GIVEN RPM = $(RPM/725)^3$
MAXIMUM RPM = 930
TIP SPEED (ft/min) = RPM x 6.416
MAXIMUM MOTOR FRAME SIZE = 184T
AVERAGE DISCHARGE VELOCITY (FPM) = CFM/3.78

Figure 5: Size-240 CWB Exhaust Fan



Size-300: CUBE CWB

All dimensions in inches (millimeters), weight in pounds (kilograms).
*May be greater depending on motor.
†Weight shown is largest cataloged open drip-proof motor.
Specifications and weight for each model located at back of catalog.

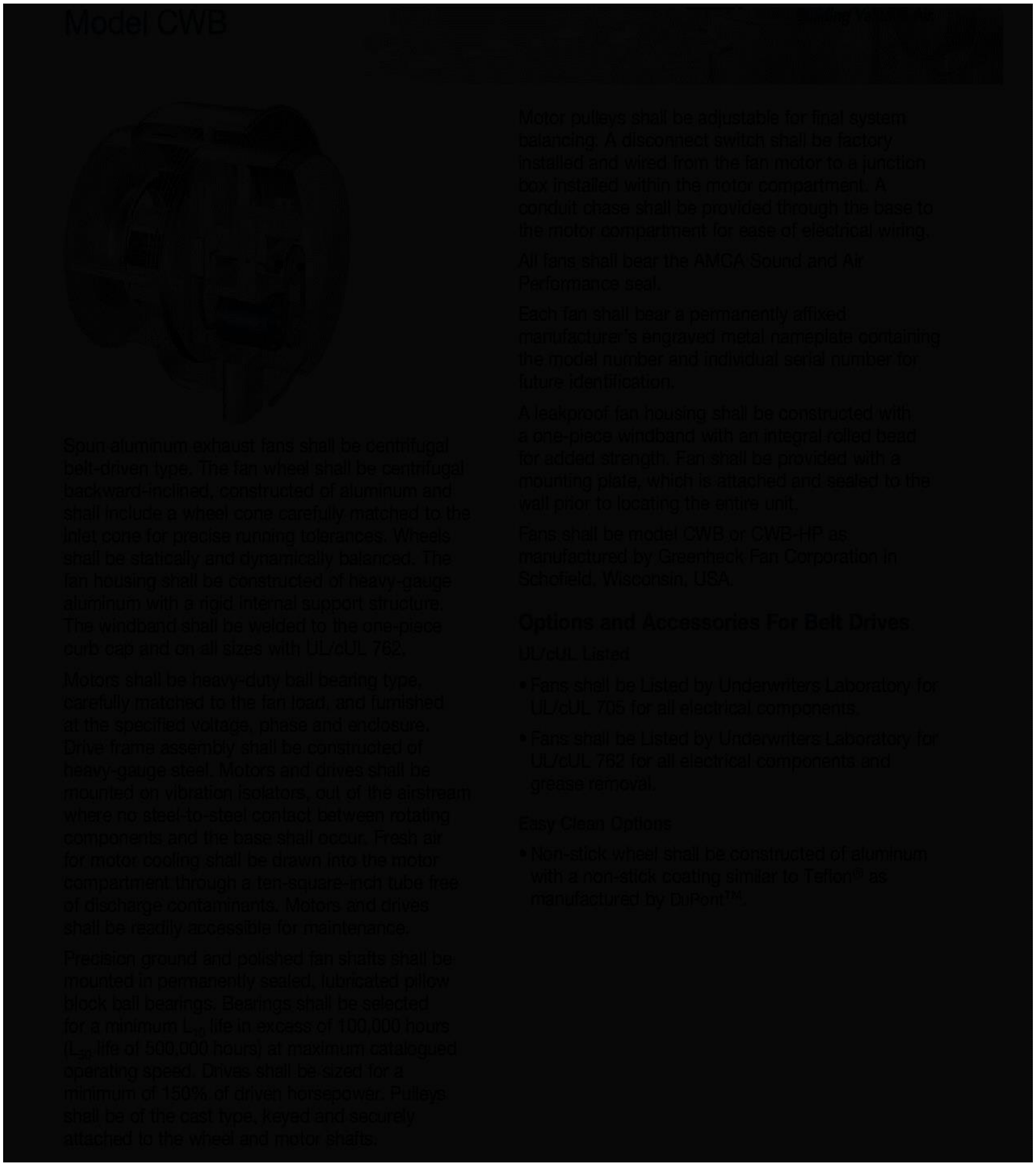
†Approximate Weight	313(142)	313(142)
Damper Size	30 x 30 (762 x 762)	25 x 25 (635 x 635)
Roof/Wall Opening	32½ x 32½ (826 x 826)	25½ x 25½ (648 x 648)

Motor HP	Fan RPM		Static Pressure in Inches wg 0	0.125	0.25	0.5	0.75	1	1.25	1.5	1.75	2
1/3	355	CFM	5777	5132	4227							
		BHP	0.27	0.30	0.31							
		Sones	6.8	6.3	5.3							
	365	CFM	5940	5316	4464							
		BHP	0.29	0.33	0.34							
		Sones	7.2	6.5	5.7							
1/2	420	CFM	6835	6314	5660							
		BHP	0.45	0.49	0.52							
		Sones	9.0	8.2	7.5							
3/4	490	CFM	7811	7377	6844	6440						
		BHP	0.67	0.72	0.76	0.77						
		Sones	11.0	10.5	9.9	8.5						
1	535	CFM	8625	8231	7772	6836						
		BHP	0.90	0.95	1.00	1.05						
		Sones	13.3	12.7	12.2	11.2						
1½	605	CFM	9845	9501	9127	8226	7084					
		BHP	1.34	1.40	1.46	1.54	1.55					
		Sones	17.0	16.4	15.7	14.8	13.5					
2	665	CFM	10822	10508	10193	9411	8495	7271				
		BHP	1.77	1.85	1.92	2.02	2.07	2.04				
		Sones	20	19.7	18.8	17.5	16.7	15.1				
3	765	CFM	12449	12118	11804	11273	10564	9743	8756	7352		
		BHP	2.70	2.78	2.86	3.00	3.09	3.15	3.14	2.98		
		Sones	24	24	23	22	21	20	18.7	17		
5	795	CFM	12937	12675	12413	11818	11145	10404	9479	8302		
		BHP	3.03	3.12	3.20	3.35	3.46	3.53	3.53	3.43		
		Sones	26	25	24	23	22	22	21	18.5		
	850	CFM	13832	13587	13342	12808	12207	11521	10771	9883	8694	
		BHP	3.71	3.80	3.89	4.05	4.19	4.27	4.32	4.31	4.16	
		Sones	28	28	28	26	25	25	24	22	20	
	905	CFM	14727	14497	14266	13788	13223	12614	11963	11191	10357	9178
		BHP	4.47	4.57	4.67	4.85	5.00	5.11	5.19	5.21	5.20	5.01
		Sones	32	32	32	29	28	28	27	26	24	22

MAXIMUM BHP AT A GIVEN RPM = $(RPM/522)^3$
MAXIMUM RPM = 905
TIP SPEED (ft/min) = RPM x 7.983
MAXIMUM MOTOR FRAME SIZE = 213T
AVERAGE DISCHARGE VELOCITY (FPM) = CFM/5.50

Performance certified is for installation type A: Free inlet, Free outlet. Power rating (Bhp) does not include transmission losses. Performance ratings do not include the effects of appurtenances (accessories). The sound ratings shown are loudness values in fan sones at 5 ft. (1.5 m) in a hemispherical free field calculated per AMCA Standard 301. Values

Figure 6: Size-300 CWB Exhaust Fan



Model CWB

Spun aluminum exhaust fans shall be centrifugal belt-driven type. The fan wheel shall be centrifugal backward-inclined, constructed of aluminum and shall include a wheel cone carefully matched to the inlet cone for precise running tolerances. Wheels shall be statically and dynamically balanced. The fan housing shall be constructed of heavy-gauge aluminum with a rigid internal support structure. The windband shall be welded to the one-piece curb cap and on all sizes with UL/cUL 762.

Motors shall be heavy-duty ball bearing type, carefully matched to the fan load, and furnished at the specified voltage, phase and enclosure. Drive frame assembly shall be constructed of heavy-gauge steel. Motors and drives shall be mounted on vibration isolators, out of the airstream where no steel-to-steel contact between rotating components and the base shall occur. Fresh air for motor cooling shall be drawn into the motor compartment through a ten-square-inch tube free of discharge contaminants. Motors and drives shall be readily accessible for maintenance.

Precision ground and polished fan shafts shall be mounted in permanently sealed, lubricated pillow block ball bearings. Bearings shall be selected for a minimum L_{10} life in excess of 100,000 hours (L_{50} life of 500,000 hours) at maximum catalogued operating speed. Drives shall be sized for a minimum of 150% of driven horsepower. Pulleys shall be of the cast type, keyed and securely attached to the wheel and motor shafts.

Motor pulleys shall be adjustable for final system balancing. A disconnect switch shall be factory installed and wired from the fan motor to a junction box installed within the motor compartment. A conduit chase shall be provided through the base to the motor compartment for ease of electrical wiring.

All fans shall bear the AMCA Sound and Air Performance seal.

Each fan shall bear a permanently affixed manufacturer's engraved metal nameplate containing the model number and individual serial number for future identification.

A leakproof fan housing shall be constructed with a one-piece windband with an integral rolled bead for added strength. Fan shall be provided with a mounting plate, which is attached and sealed to the wall prior to locating the entire unit.

Fans shall be model CWB or CWB-HP as manufactured by Greenheck Fan Corporation in Schofield, Wisconsin, USA.

Options and Accessories For Belt Drives

UL/cUL Listed

- Fans shall be Listed by Underwriters Laboratory for UL/cUL 705 for all electrical components.
- Fans shall be Listed by Underwriters Laboratory for UL/cUL 762 for all electrical components and grease removal.

Easy Clean Options

- Non-stick wheel shall be constructed of aluminum with a non-stick coating similar to Teflon® as manufactured by DuPont™.

Figure 7: EWB Exhaust Fan Description

APPENDIX E.2: CUBE EXHAUST FAN

Figure 8: Size-300 CWB Exhaust Fan

Model CUBE

Building Value in Air

Each fan shall bear a permanently affixed manufacturer's engraved metal nameplate containing the model number and individual serial number for future identification.

A leakproof fan housing shall be constructed with a one-piece windband with an integral rolled bead for added strength and shall be joined to the curb cap with a continuously welded seam.

Fans shall be model CUBE, CUBE-HP or CUBE-XP as manufactured by Greenheck Fan Corporation in Schofield, Wisconsin, USA.

Spun aluminum exhaust fans shall be centrifugal belt-driven type. The fan wheel shall be centrifugal backward-inclined, constructed of aluminum and shall include a wheel cone carefully matched to the inlet cone for precise running tolerances. Wheels shall be statically and dynamically balanced. The fan housing shall be constructed of heavy-gauge aluminum with a rigid internal support structure. The windband shall be one-piece and 100% continuously welded to the one-piece aluminum curb cap, including all sizes with UL/cUL 762.

Motors shall be heavy-duty ball bearing type, carefully matched to the fan load, and furnished at the specified voltage, phase and enclosure. Drive frame assembly shall be constructed of heavy-gauge steel.

Motors and drives shall be mounted on vibration isolators, out of the airstream where no steel-to-steel contact between rotating components and the base shall occur. Fresh air for motor cooling shall be drawn into the motor compartment through a ten-square-inch tube free of discharge contaminants. Motors and drives shall be readily accessible for maintenance.

Precision ground and polished fan shafts shall be mounted in permanently sealed, lubricated pillow block ball bearings. Bearings shall be selected for a minimum L_{10} life in excess of 100,000 hours (L_{50} life of 500,000 hours) at maximum cataloged operating speed. Drives shall be sized for a minimum of 150% of driven horsepower. Pulleys shall be of the cast type, keyed and securely attached to the wheel and motor shafts.

Motor pulleys shall be adjustable for final system balancing. A disconnect switch shall be factory-installed and wired from the fan motor to a junction box installed within the motor compartment. A conduit chase shall be provided through the base to the motor compartment for ease of electrical wiring.

All fans shall bear the AMCA Sound and Air Performance seal.

Options and Accessories For Belt Drives

UL/cUL Listed

- Fans shall be Listed by Underwriters Laboratory for UL/cUL 705 for all electrical components.
- Fans shall be Listed by Underwriters Laboratory for UL/cUL 762 for all electrical components and grease removal.

Curb Extensions

- Shall be mounted between roof curb and roof mounted fans to meet NFPA requirements of 40 inches *(1016 mm)* minimum discharge above the roof when mounted on a minimum 8-inch *(203 mm)* high roof curb.

Grease Containers

- Drain connection shall be constructed of aluminum and allow for single-point drainage of grease, water or other residues.
- Grease trap shall include the drain connection and shall be constructed from polypropylene. The unit shall collect grease and water from the fan and extract the grease from the water for ease of grease disposal.

Easy Clean Options

- Hinge kit shall be constructed of heavy-gauge aluminum hinges and shall include hold-open cables for field installation.
- Non-stick wheel shall be constructed of aluminum with a non-stick coating similar to Teflon® as manufactured by DuPont™.
- Clean-Out Port shall have a hole on the outside of the windband and a grease repellent compression rubber fit, allowing access to entire wheel for cleaning.

Windband Extension

- Shall be constructed from heavy-gauge aluminum tube that raises the discharge an additional 36 inches *(914 mm)*.

Figure 9: EWB Exhaust Fan Description

APPENDIX F : MAKE UP AIR UNITS

ENGINEERED AIR SPECIFICATIONS
FOR AIR HANDLING PRODUCTS

12/05/16
Page 1

AIR HANDLING UNIT SCHEDULE				
FAN NO.				
SERVICE		MUA-1	MUA-2	
MANUFACTURER		Engineered Air	Engineered Air	Engineered Air
MODEL		HE401/O	HE171/O	
SUPPLY	CFM:	39,623	14,170	
	ESP ("WC):	0.5	0.5	
	MOTOR (HP):	40	15	
	BLOWER:	36/30 DIDW – FC	20/18 DIDW - FC	
Electrical	VOLTAGE:	208/3/60	208/3/60	
HEATING	INPUT (BTU/H):	6,442,234	1,839,266	
	TEMP. RISE (F):	110	110	
	REMARKS:	Budgets MUA-1 - 40,000 MUA-2 – 20,000		

Figure 10: Make Up Air Units used for the Paint Facility Directly Provided by Mike Turek (Part 1/3)

EngA **ENGINEERED AIR** ELECTRICAL CALCULATION

Project Name: MECH4860 Date: 05-DEC-2016

Prepared for: Mike

Unit Model: HE401/O Qty: 1 Tag: MUA-1

Power Supply	Minimum Circuit Ampacity	Terminal Block to Accept	Maximum Fuse (Dual Element)	Maximum Breaker
208 / 3 / 60	137.5 AMPS	0 Awg	225 AMPS	225 AMPS

Components	Model	Quantity	Ampacity FLA
Supply Fan Motor	Super 'E' ODP (1750) 40 HP	1	109
Main Control Xfmr	250 VA	1	1.2

NOTES: The above calculation and components information are for discussion purpose only. Please refer to project submittals for actual ampacity, breaker, fuse and wire sizes.

COMMENTS

Prepared by: Mike Turek Office: WINNIPEG

Figure 11: Make Up Air Units used for the Paint Facility Directly Provided by Mike Turek (Part 2/3)

EngA® ENGINEERED AIR®

ELECTRICAL CALCULATION

Project Name: MECH4860 Date: 05-DEC-2016

Prepared for: Mike

Unit Model: HE401/O Qty: 1 Tag: MUA-1

Power Supply	Minimum Circuit Ampacity	Terminal Block to Accept	Maximum Fuse (Dual Element)	Maximum Breaker
208 / 3 / 60	52.1 AMPS	6 Awg	90 AMPS	90 AMPS

Components	Model	Quantity	Ampacity FLA
Supply Fan Motor	Super 'E' ODP (1750) 15 HP	1	40.7
Main Control Xfmr	250 VA	1	1.2

NOTES: The above calculation and components information are for discussion purpose only. Please refer to project submittals for actual ampacity, breaker, fuse and wire sizes.

COMMENTS

Prepared by: Mike Turek Office: WINNIPEG

Figure 12: Make Up Air Units used for the Paint Facility Directly Provided by Mike Turek (Part 3/3)

APPENDIX G : EXHAUST GRILLE AND LOUVER SELECTION

Application Guidelines

Introduction

Overview

It is the intent of this section to give some basic application guidelines for the use of supply and return grilles and registers in a simple non-technical manner. The information presented here is based on Price's laboratory results, as well as commonly accepted industry practices supported by ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers). These application guidelines are designed to enhance your ability to use the performance data in this catalog to select an air outlet that will create an air pattern in the occupied space conducive to the comfort of the occupant.

Single Deflection Supply

A grille or register consisting of a single set of adjustable blades that controls the air pattern in only one direction, depending on blade orientation. Horizontal blades control rise and drop of the air stream. This orientation would be used, for example, to prevent unwanted drop in a free space (no ceiling) application or to blow warm air down in a high sidewall application. Vertically oriented blades control the spread of the air pattern and would be used where throw, not drop, is a prime concern. These would be the most economical type of outlet. See **Figure 1**. Example — Model 510 or 21.

Double Deflection Supply

A grille or register consisting of two sets of adjustable blades oriented perpendicular to each other to allow control of the air pattern in both horizontal and vertical planes. While both sets of blades have an affect on the air pattern, the front or outward most set has the most influence. The front blades should be horizontal if control of rise and drop is primary (i.e. free space or high sidewall) and vertical if spread and throw are the largest concerns. Double deflection outlets are the most flexible type of grille or register. See **Figure 2**. Example — Model 520 or 22.

Eggcrate Return

A grille or register with a cubical grid core to be used for return or exhaust where maximum free area is desired and see-through is not a concern. Typically used in ceiling applications where see-through sight lines are minimized to directly below the grille. See **Figure 3**. Example — Model 80 Series.

Figure 1: Model 510 Single Deflection Supply

Figure 2: Model 520 Double Deflection Supply

Figure 3: 80 Series Aluminum Eggcrate Return

Figure 4: 10 Series Perforated Return

Figure 5: Model 530 Louvered Return

Perforated Return

This grille utilizes a symmetrically perforated sheet metal core for free areas of approximately 50%. It is typically used in ceiling applications where see-through and blending with the mounting surface are of prime concerns. See **Figure 4**. Example — Model 10 Series.

Louvered Returns

These grilles and registers utilize a core of parallel fixed blades set at a deflection, usually 45 degrees from horizontal, to provide a return or exhaust unit with minimum see-through. The most common application is sidewall with blade deflection upward in high applications and downward in lower applications. This type of outlet usually has a slightly higher sound and pressure drop than either the eggcrate or perforated. See **Figure 5**. Example — Model 530 or 630.

Figure 13: 80 Series Exhaust Grille

Suggested Specification

Eggcrate Face / Perforated Face / Filter Grilles

Eggcrate Face
80 — Return Grille

Furnish and install Price model 80 return grilles of the sizes and mounting types indicated on the plans and outlet schedule. Grilles shall be of aluminum construction, consisting of aluminum ½ in. x ½ in. x ½ in. [13 x 13 x 13] grid (eggcrate core) and an extruded aluminum border. The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

80D — Exhaust Register

Furnish and install Price model 80D exhaust registers of the sizes and mounting types indicated on the plans and outlet schedule. Registers shall be of aluminum construction, consisting of aluminum ½ in. x ½ in. x ½ in. [13 x 13 x 13] grid (eggcrate core) and an extruded aluminum border. The integral volume control damper shall be of the opposed blade type and shall be constructed of heavy gauge cold rolled steel (optional aluminum construction 80DAL). The damper shall be operable from the register face. The damper shall be coated steel (mill finish aluminum 80DAL). The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

81 — Return Grille

Furnish and install Price model 81 return grilles of the sizes and mounting types indicated on the plans and outlet schedule. Grilles shall be of aluminum construction, consisting of two aluminum ½ in. x ½ in. x ½ in. [13 x 13 x 13] grids (eggcrate core), stacked to make a ½ in. x ½ in. x 1 in. [13 x 13 x 25] core and an extruded aluminum border. The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

Options

- Optional core – one-piece ½ in. x ½ in. x 1 in. [13 x 13 x 25] aluminum grid (eggcrate).

81D — Exhaust Register

Furnish and install Price model 81D exhaust registers of the sizes and mounting types indicated on the plans and outlet schedule. Registers shall be of aluminum construction, consisting of two aluminum ½ in. x ½ in. x ½ in. [13 x 13 x 13] grids (eggcrate core), stacked to make a ½ in. x ½ in. x 1 in. [13 x 13 x 25] core and an extruded aluminum border. The integral volume control damper shall be of the opposed blade type and shall be constructed of cold rolled steel (optional aluminum construction 81DAL). The damper shall be operable from the register face. The damper shall be coated steel (mill finish aluminum 81DAL). The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

82 — Return Grille

Furnish and install Price model 82 return grilles of the sizes and mounting types indicated on the plans and outlet schedule. Grilles shall be of aluminum construction, consisting of aluminum 1 in. x 1 in. x 1 in. [25 x 25 x 25] grid (eggcrate core) and an extruded aluminum border. The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

82D — Exhaust Register

Furnish and install Price model 82 exhaust registers of the sizes and mounting types indicated on the plans and outlet schedule. Registers shall be of aluminum construction, consisting of aluminum 1 in. x 1 in. x 1 in. [25 x 25 x 25] grid (eggcrate core) and an extruded aluminum border. The integral volume control damper shall be of the opposed blade type and shall be constructed of cold rolled steel (optional aluminum construction 82DAL). The damper shall be operable from the register face. The damper shall be coated steel (mill finish aluminum 82DAL). The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

Perforated Face
10 — Return Grille

Furnish and install Price model (10 steel/ 10A aluminum) return grilles of the sizes and mounting types indicated on the plans and outlet schedule. Grilles shall consist of a perforated core with $^3/_{16}$ in. [5] holes on ¼ in. [6] centers staggered 60 degrees and an extruded aluminum border. The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

Filter Grilles - Louvered
530FF / 630FF / 730FF — Filter Return Grille

Furnish and install Price model (530FF steel / 630FF aluminum) filter return grilles of the sizes and mounting types indicated on the plans and outlet schedule. Grilles shall be 45 degree deflection fixed louver type with blades spaced ¾ in. [19] on center. The blades shall run parallel to the (long / short) dimension of the grille. The border shall be mounted to the filter frame with ¼ turn quick-release fasteners (and a hinge-tab mechanism on type 530FF). The mounting frame shall accept a standard 1 in. [25] filter media. The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

535FF / 635FF / 735FF — Filter Return Grille

Furnish and install Price model (535FF steel / 635FF aluminum / 735FF stainless steel) filter return grilles of the sizes and mounting types indicated on the plans and outlet schedule. Grilles shall be 45 degree deflection fixed louver type with blades spaced ½ in. [13] on center. The blades shall run parallel to the (long / short) dimension of the grille. The border shall be mounted to the filter frame with ¼ turn quick-release fasteners (and a hinge-tab mechanism on type 530FF). The mounting frame shall accept a standard 1 in. [25] filter media. The grille shall be finished in (B12 White Powder Coat / B15 Aluminum Powder Coat). Paint finish shall pass 500 hours of salt spray exposure with no measurable creep in accordance with ASTM D1654 and 1000 hours with no rusting or blistering as per ASTM D610 and ASTM D714.

Figure 14: Specifications for 80D Series Exhaust Grille (middle left)

HCD Series

Performance Data

Size	Duct Velocity, fpm / Velocity Pressure, in.wg.	300 / 0.006	400 / 0.010	500 / 0.016	600 / 0.022	700 / 0.031	800 / 0.040	900 / 0.050	1000 / 0.062	1200 / 0.090
15/18	Total Pressure, in.wg.	0.027	0.045	0.071	0.098	0.138	0.179	0.225	0.277	0.402
	Flow Rate, cfm	563	750	938	1125	1313	1500	1688	1875	2250
	NC	--	--	23	29	34	39	43	47	53
	Throw 150, 100, 50	27-41-64	37-53-74	46-59-83	53-64-91	57-70-98	61-74-105	64-79-112	68-83-118	74-91-129
15/24	Total Pressure, in.wg.	0.024	0.041	0.065	0.089	0.126	0.162	0.203	0.251	0.365
	Flow Rate, cfm	750	1000	1250	1500	1750	2000	2250	2500	3000
	NC	--	16	23	30	35	40	44	48	54
	Throw 150, 100, 50	31-46-74	41-61-86	51-68-96	61-74-105	66-80-114	70-86-121	74-91-129	78-96-136	86-105-149
15/30	Total Pressure, in.wg.	0.023	0.038	0.060	0.083	0.117	0.150	0.188	0.233	0.338
	Flow Rate, cfm	938	1250	1563	1875	2188	2500	2813	3125	3750
	NC	--	16	24	30	36	41	45	48	55
	Throw 150, 100, 50	34-50-83	45-67-96	56-76-107	67-83-118	73-90-127	78-96-136	83-102-144	88-107-152	96-118-166
15/36	Total Pressure, in.wg.	0.021	0.035	0.057	0.078	0.110	0.141	0.177	0.219	0.318
	Flow Rate, cfm	1125	1500	1875	2250	2625	3000	3375	3750	4500
	NC	--	17	25	31	36	41	45	49	55
	Throw 150, 100, 50	36-54-91	48-72-105	60-83-118	72-91-129	80-98-139	86-105-149	91-112-158	96-118-166	105-129-182
15/42	Total Pressure, in.wg.	0.020	0.034	0.054	0.074	0.104	0.134	0.168	0.208	0.302
	Flow Rate, cfm	1313	1750	2188	2625	3063	3500	3938	4375	5250
	NC	--	17	25	32	37	42	46	49	56
	Throw 150, 100, 50	38-57-98	51-76-114	64-90-127	76-98-139	87-106-150	93-114-161	98-120-170	104-127-180	114-139-197
15/48	Total Pressure, in.wg.	0.019	0.032	0.051	0.071	0.099	0.128	0.160	0.199	0.288
	Flow Rate, cfm	1500	2000	2500	3000	3500	4000	4500	5000	6000
	NC	--	18	26	32	37	42	46	50	56
	Throw 150, 100, 50	40-60-105	54-81-121	67-96-136	81-105-149	93-114-161	99-121-172	105-129-182	111-136-192	121-149-210
15/54	Total Pressure, in.wg.	0.018	0.031	0.049	0.068	0.096	0.123	0.154	0.191	0.277
	Flow Rate, cfm	1688	2250	2813	3375	3938	4500	5063	5625	6750
	NC	--	18	26	32	38	42	47	50	57
	Throw 150, 100, 50	42-63-112	56-84-129	70-102-144	84-112-158	98-120-170	105-129-182	112-137-193	118-144-204	129-158-223
15/60	Total Pressure, in.wg.	0.018	0.030	0.048	0.065	0.092	0.118	0.149	0.184	0.268
	Flow Rate, cfm	1875	2500	3125	3750	4375	5000	5625	6250	7500
	NC	--	18	28	33	38	43	47	51	57
	Throw 150, 100, 50	44-66-118	59-88-135	73-107-152	88-118-169	102-127-180	111-136-192	118-144-204	124-152-215	136-166-236
15/66	Total Pressure, in.wg.	0.017	0.029	0.046	0.063	0.089	0.116	0.144	0.179	0.260
	Flow Rate, cfm	2063	2750	3438	4125	4813	5500	6188	6875	8250
	NC	--	18	28	33	38	43	47	51	57
	Throw 150, 100, 50	46-69-123	61-91-142	76-111-159	91-122-174	106-133-189	116-142-201	123-151-214	130-159-226	142-174-247
15/72	Total Pressure, in.wg.	0.017	0.028	0.045	0.062	0.087	0.113	0.140	0.173	0.252
	Flow Rate, cfm	2250	3000	3750	4500	5250	6000	6750	7500	9000
	NC	--	18	27	31	36	43	47	51	56
	Throw 150, 100, 50	47-71-125	63-94-149	79-116-165	94-124-182	110-139-197	121-148-210	128-158-223	136-166-235	148-182-255

Performance Notes:

1. Tested in accordance with ASHRAE Standard 70-2006 "Method of Testing for Rating the Performance of Air Outlets and Inlets."
2. Air flow is in cfm.
3. All pressures are in in. w.g.
4. The NC values are based on a room absorption of 10 dB re 10^{-12} watts and one diffuser.
5. Blanks (--) indicate an NC level below 15.
6. Throw data is based on supply air and room air being at isothermal conditions.
7. Throw values are measured in feet for terminal velocities of 150 fpm (isothermal), 100 fpm (isothermal) and 50 fpm (isothermal).

Correction Factors

Model Deflection	HCD1 0°	HCD1 15°	HCD1 30°	HCD2 0°	HCD2 15°	HCD2 30°
NC	—	+4	+8	—	+4	+8
Throw	—	x .80	x .71	—	x .85	x .78
Total Press.	—	x 1.6	x 1.9	x 1.2	x 1.7	x 2.2

Based on HCD1 at 0° deflection, correction factors for other conditions are listed in table opposite.

Example: 12 x 36 HCD2
Flow Rate = 1800 cfm
Deflection = 15°
NC = 30 + 4 = 34
Throw (50 fpm) = 115 x .85 = 98 ft.
Total Pressure = .086 x 1.7 = 0.146 in. w.g.

Figure 15: HCD Series Louver Diffuser for Supply Ducts

APPENDIX H : ELECTRIC FORCE FLOW HEATER

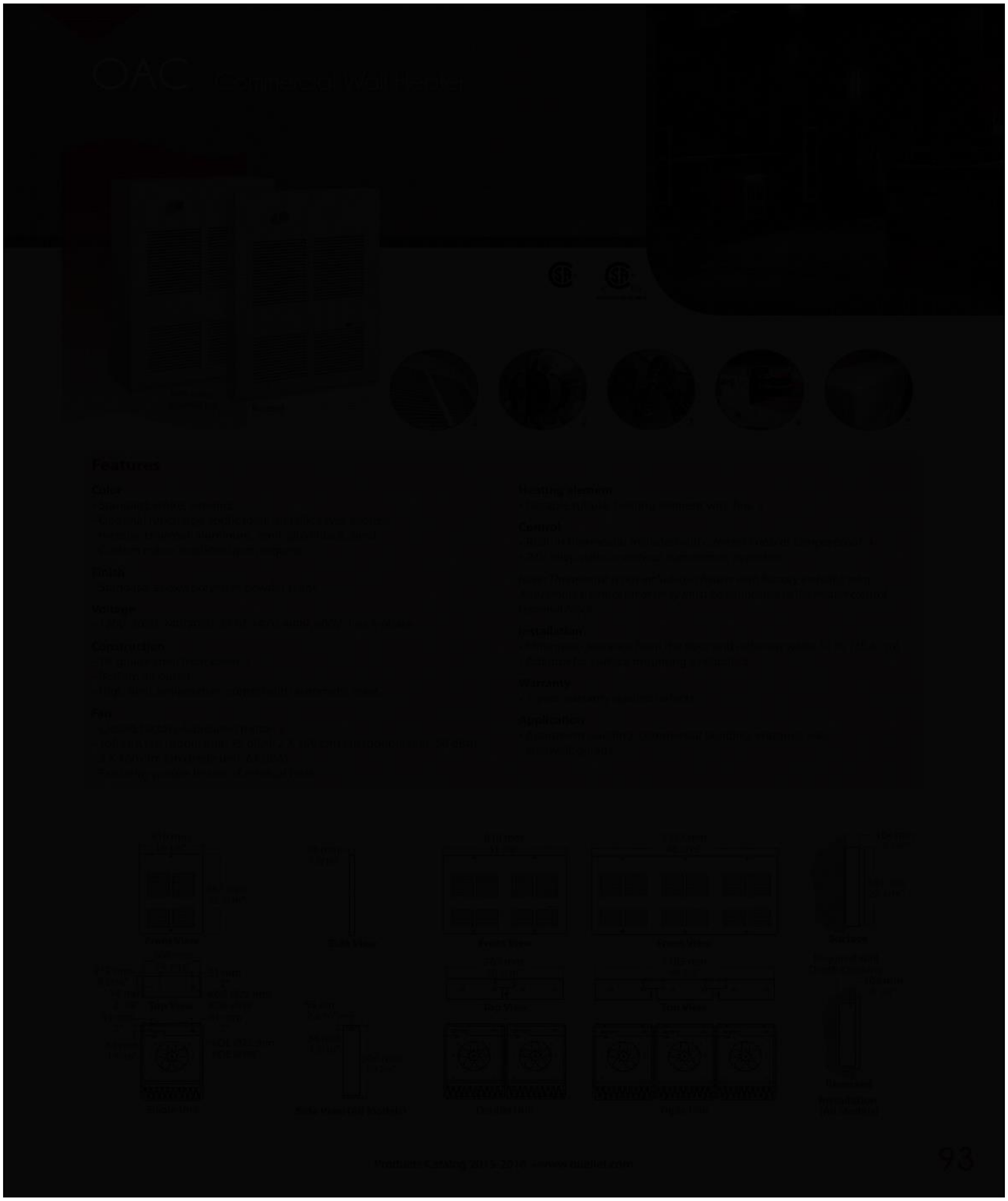


Figure 16: Forced Flow Heater for the Entry and Exit of the Paint Facility (Part 1/2)

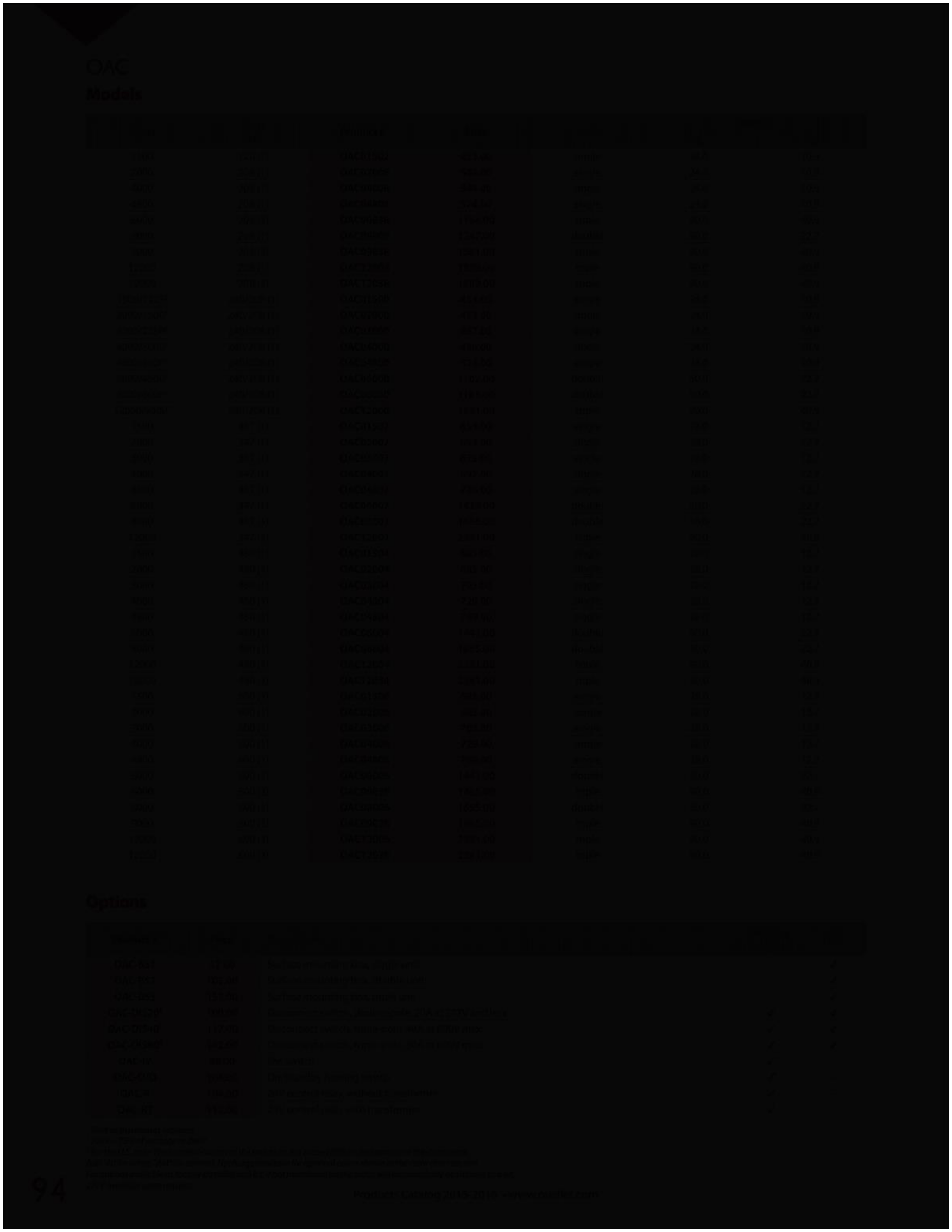


Figure 17: Forced Flow Heater for the Entry and Exit of the Paint Facility (Part 2/2)