MECH 4860

ENGINEERING DESIGN

Design of an Environmental Control System for Composites Innovation Centre's FibreCITY Lab

Final Design Report

Team #3

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Submitted to: Dr. Paul E. Labossiere, University of Manitoba

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Advisor: Dr. Juan Abello

Submitted: December 7, 2015

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Dr. Paul Labossiere
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Dear Dr. Labossiere,

We are pleased to present herewith the final design report (FDR), prepared by Team 3 for Composites Innovation Center, regarding the design of the humidity control system for their FibreCITY lab. The FDR presents the problem background and scope, discusses the client needs and specifications, analytically evaluates a series of conceptual designs, and discusses the details of the final design. The final design is then evaluated based on cost and risk in order to provide a baseline in determining the feasibility of implementation.

The report opens with an introduction, contextualizing the report by providing the problem background and scope, customer needs and specifications, as well as the project constraints and limitations. The following section discusses the current room envelope and environmental conditions of the laboratory that served as the foundation to move forward with our conceptual design process, and thereafter the final design.

The conceptual design methodology section presents our team's process of developing and analyzing each of our conceptual designs, where the advantages and disadvantages of each concept were considered from the perspective of critical client needs and criteria. Furthermore, an evaluation process was formalized by implementing a weighted criteria, screening and scoring process, which is reflected in the structure of the report. After subjecting each conceptual design to the concept evaluation process, our team selected a single conceptual design which is further developed in the final design phase of our project.

The final section of the FDR presents the final design specification, which discusses the, final design product selection, the expected method of implementation, cost analysis and risk assessment. Additionally, to conclude our final design report, a brief summary of the final design and results are provided. By providing CIC with the specific details of the final design, as well as a thorough and accurate cost and risk analysis, our team will provide all the necessary information for CIC to make an informed decision on whether or not to implement the humidity control system in the FibreCITY lab.

Finally, Team 3 would like to thank Dr. Juan Abello and Dr. Robert Derksen for their advice and guiding support through the conceptual and final design process, as well as Conviron and Composites Innovation Center for providing insightful industry knowledge to assist us in the development of our conceptual designs. If there are any comments or concerns regarding this report, we welcome you to contact Andrew Laban at . On behalf of Team 3, thank you.

Team #3

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EXECUTIVE SUMMARY

The final design report presents the humidity control system that team 3 has developed for Composites Innovation Centre (CIC) to regulate the humidity within their FibreCITY laboratory. Humidity control within the lab will enable FibreCITY to conduct standardized tensile testing on a variety of biofibre materials that are affected by ambient environmental conditions. CIC requires that the biofibres be conditioned and tested at 21 ± 1°C, and at either 50 or 65 ± 5% relative humidity (RH), depending on the material being tested. Moreover, CIC has already outfitted the laboratory with a forced air HVAC system to regulate the lab temperature; however, the system is currently unable to regulate the humidity. Our team was therefore tasked to develop a humidity control system that would be able to regulate the humidity within the FibreCITY lab.

The final design report (FDR) is the third and final written submission for the design of the humidity control system for the FibreCITY lab at CIC. This report outlines the project background, project needs and specifications, conceptual selection process, and concludes with the details of the final design. As a supplement to the final design, the report also includes an engineering drawing, a failure mode and effect analysis (FMEA), and a detailed cost analysis and economic evaluation which assesses the economic feasibility of implementing the final design.

The final design features a Nortec NH-EL in-duct steam humidifier, along with a ConnectSense CS-TH wireless temperature and humidity sensor, and three humidifier controllers. Additionally, the humidification device is coupled with an upgraded airtight GridLock ceiling system and improvements to existing door seals. Furthermore, the existing HVAC system will be modified to draw air from the CIC office space rather than simply recirculating the air within the FibreCITY lab, as is the current practice. In order to balance the fresh air intake, a new Greenheck AC-200 exhaust fan will be added to vent the lab air outside the CIC building. Incorporating the aforementioned components will allow CIC to regulate the humidity within the lab to 50 or 65% RH with a +/- 5% RH tolerance, resolve the current issue of inadequate air recirculation, and provide alerts when the humidity and temperature fall out of the desired set points.

The estimated cost for the initial capital expenditures and anticipated first year operating costs for the design was determined to be $21 050. Furthermore, the economic evaluation revealed the net present value (NPV) and annual cost of ownership (ACO) to be $49 310 and $2 490, respectively.

Our team is confident that the client needs will be met through the implementation of the final environmental control system design. By providing accurate humidity control for the FibreCITY lab, CIC will be able to further support economic growth through innovative research and development of composite materials and technologies locally and around the world.

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1.0 INTRODUCTION AND BACKGROUND

Composites Innovation Center (CIC) is a not-for-profit organization in Winnipeg, Manitoba that develops composite materials and technologies for the manufacturing industry. As a part of their mission, extensive research into the mechanical properties of the natural fibres used in constructing composite materials is conducted within their FibreCITY lab. However, the mechanical properties of the fibres tested at CIC have a direct correlation to their ambient conditions. Therefore, CIC has tasked team 3 to design an environmental control system that will be able to solve the issue of fluctuating, unregulated humidity levels within the FibreCITY lab. By regulating and controlling the humidity levels within the lab, CIC will be able to precisely understand how the humidity levels are affecting their experimental fibres; therefore resulting in more accurate and reliable results from their experimental analysis.

The final design report presents team 3's design of a humidity control system for the FibreCITY lab. Throughout the report, the customer design needs and our design methodology are outlined, along with details of our final design. As a supplement to the final design, a detailed risk assessment and cost analysis is provided. The risk and cost analyses present the failure modes and effect analysis (FMEA), the net present value (NPV), and the estimated annual cost of ownership (ACO) for the final humidity control system.

1.1 Problem Background

CIC has requested the design of a humidity control system for its FibreCITY lab. At CIC, commercially grown bales of biomass, such as flax and hemp straw, are separated into fibres and shive. The fibres are then mixed with a plastic-based material, such as a petroleum-based resin or a bioresin, to create biocomposites. When cured, the biocomposites are strong, lightweight and can compete with traditional composites such as those reinforced with fiberglass and carbon fibre. The FibreCITY lab seeks to develop renewable, natural fibre composite products for commercial applications. FibreCITY conducts research and testing on the material properties of biofibres, and explores the feasibility of implementing these fibres in composite materials [1].

A critical apparatus used in the FibreCITY lab is a fibre tensile testing device (Figure 1). This device rapidly measures the cross sectional area of small fibres that have been pre-loaded into the system before conducting a tensile test.

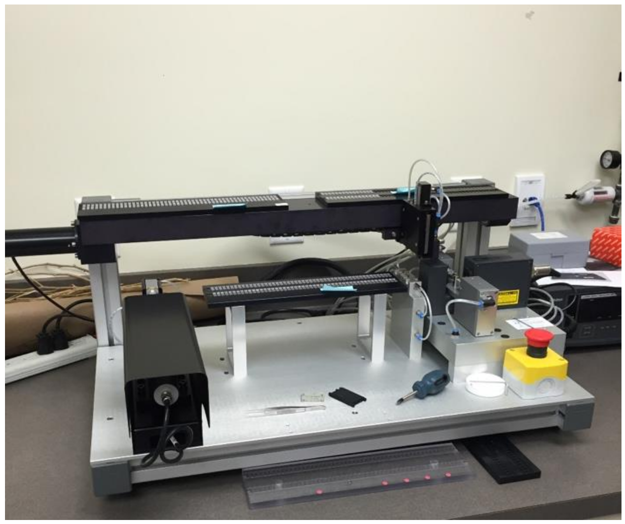


Figure 1 - Fibre tensile testing equipment used in FibreCITY lab [2]

Controlling the humidity in the FibreCITY lab is essential for this device to ensure that material properties of the fibre samples are controlled consistently. Density, tensile strength, and cross sectional areas of the fibre samples are all properties that can be influenced by changes in humidity [3]. According to CIC, testing standards require that moisture content be controlled through conditioning samples prior to, and during testing [4]. Textile conditioning standard ASTM D1776 [5] specifies textile materials should be conditioned and tested at 21 ± 1°C and a relative humidity (RH) of 65 ± 5%, while specialized testing requires a tolerance of ± 2% RH. Additionally, the conditioning of plastics (ASTM D618) [6], or nonwoven textiles, require that the materials be conditioned at 23 ± 1°C and a RH of 50 ± 5% prior to and during testing. In general, it is required that samples be conditioned and tested at constant and reliable set of environmental conditions, in order to perform reliable testing. Due to existing environmental laboratory conditions, CIC has specified the designed humidity control system should achieve a tolerance level of ± 5% RH for both 50 and 65% RH.

The FibreCITY lab was recently outfitted with a system that regulates temperature to 21 ± 1°C, therefore providing reliable temperature control within the laboratory. However, the system is unable to control humidity, and thus a new system must to be designed that will be capable of accurately controlling the humidity levels within the FibreCITY lab. By outfitting the laboratory with steady and reliable temperature and humidity control, CIC will be able test, prepare, and store fibre samples under steady environmental conditions, and meet the designated testing standards.

1.2 Project Objectives and Customer Needs

The goal of the design project was to design a humidity control system for the FibreCITY lab that would be capable of controlling and maintaining the humidity conditions at a desired set point, with a ± 5% RH tolerance. In order to communicate CIC's needs and requirements, the statement of needs and product specifications were created and are shown in Tables I and III. For each need identified, the customer priority is ranked from 1 to 5; where 1 represents a requirement of the final design, and 5 is a need of nominal importance.

TABLE I: STATEMENT OF NEEDS

No.	Need	Importance
1	Integrates with the existing HVAC system	4
2	Fits within the existing mechanical storage space	2
3	Can accurately regulate the humidity in the lab	1
4	Can be easily serviced and maintained by local technicians	1
5	Preventative maintenance required less than 3 times a year	2
6	Is not effected by airborne particulates	2
7	Automatically drains excess water from the system	1
8	Has more than one controller interface	5
9	Provides prompt notification when RH limits are exceeded	1
10	Displays relevant info on a clear user interface, within the lab	1
11	Can be programed to adjust humidity on a pre-set schedule	5
12	Restricts frequency of oscillations between the max. and min. RH limits	1
13	Highly reliable	2
14	Long life span	2
15	Energy efficient	4
16	Competitive start-up cost	2
17	Low operating costs	2
18	Minimally intrusive during installation	2
19	Operates quietly	1
20	Safe to operate and maintain	2
21	Isolates the laboratory environment from ambient conditions	1
22	Maintains a positive pressure within the laboratory	2

Upon completion of the statement of needs, the team interpreted each need into a quantifiable measure, and for each measure, assigned a corresponding metric. The compilation of the list of measures and metrics resulted in the statement of target product specifications shown in Table III. The statement of product specifications represents the marginal and ideal characteristics of a finalized design for the humidity control system for CIC. Similar to Table I, the specifications in Table III are ranked in order of priority by the customer, and show the interdependencies between each specification and need.

Metrics listed in the Statement of Product Specifications have been established using a variety of sources. Each source is denoted by a symbols, following the legend presented in Table II.

TABLE II: NEEDS AND METRIC LEGEND

*	Indicates a value assigned by the design team. This value could be physically measured or assigned based on logical reasoning.
**	Indicates a value assigned by CIC
[#]	Indicates a value assigned based on sourced and cited information. This value could be cited from government/industrial standard, or assigned based competitive benchmarking.

TABLE III: STATEMENT OF TARGET SPECIFICATIONS

Metric No.	Need No.	Metric	Imp.	Units	Marginal Value	Ideal Value
1	2	Humidification/dehumidification unit footprint*	2	m^2	< 2	< 1.5
2	2	Humidification/dehumidification unit volume*	2	m^3	< 1.5	< 1
3	1	Does the unit integrate with the existing HVAC system?**	4	Y/N		
4	3, 13	Level of humidity is within relative humidity error range**	1	RH	± 5%	± 4%
5	4	Unit height off the ground*	3	m	< 2	< 1
6	4, 5, 13, 14	Number of months between required maintenance [7]	1	month	4	12
7	6	Dust spot efficiency [8]	3	%	50-55	60-65
8	7	Drains water automatically	1	Y/N		
9	8	Number of controllers*	5	List	1	2
10	10	Controller is inside lab	1	Y/N		
11	9, 10	Controller display clearly indicates system operational modes	2	Subj.		
12	9	Time required for user to receive notification**	2	Minutes	< 10	< 5
13	12	High loads to the system stabilize within reasonable time frame	1	Minutes	10	5
14	11	Number of programmable modes*	5	List	2	4
15	12	Time of oscillation between min. and max. allowable humidity at equilibrium*	1	minutes	20	10
16	13, 14	System provides reliable humidity control	1	Subj.		
17	13, 14	Number of years until expected replacement*	1	Years	20	30
18	13	Number of hours system operates without main power**	3	Hours	24	48
19	13	Number of failures per year*	1	List	1	0

Metric No.	Need No.	Metric	Imp.	Units	Marginal Value	Ideal Value
20	15	Minimum Coefficient of Performance [9]	3	COP	3	> 3
21	16, 17	Initial capital investment*	3	CAD $	30 000	15 000
22	16, 17	Monthly operation and maintenance costs**	3	CAD $	< 400	< 200
23	18	Inconvenience of installation	2	Subj.		
24	18	Productive operational hours lost during installation**	2	Hours	< 40	< 24
25	19	Noise level outside FibreCITY mechanical room [10]	1	dBA	< 85	< 80
26	4	Easily accessed for maintenance	2	Subj.		
27	20	Meets the Manitoba Workplace and Safety Standards [10]	1	Y/N		
28	21, 22	Magnitude of air leakage rate per min per square meter of air barrier surface at a pressure difference of 75 Pa [11]	1	$(L*m^2)/min$	< 0.658	< 0.6

Consideration of the product specifications in Table III shows that there are many factors which influence the overall success of our design. Identifying each of the project dependent factors, and understanding how they are interdependent, was essential to laying the foundation of the design.

1.3 Constraints and Limitations

Compiling the needs and specifications for the humidity control system revealed numerous constraints and limitations that could restrict our final design. Identifying the constraints and limitations ensured transparency for project stakeholders and contributed to a fully defined project definition. Furthermore, in analyzing the project specific constraints and limitations, our team was sure to evaluate each restriction from a project management perspective, considering the affect each restriction would have on the three segments of the Iron Triangle: scope, cost, and time.

1.3.1 Cost

The client specified that the cost of the environmental control system be in line with the cost of comparable systems used in industry today. Therefore, the cost constraint restricted the project design to systems of comparable complexity and scope. Additionally, as per course requirements, our team was further constrained to an internal expense budget of $400. The internal budget therefore limited our access to professional software for HVAC modeling; outside of student versions and software provided by the University of Manitoba. Without access to this type of software, the scope of our design analysis was limited.

1.3.2 Scope

CIC has identified that the humidity control system be capable of maintaining a set point of 50 or 65% RH with a tolerance of ± 5% RH. This was the most defining characteristic of the design, and therefore acted as a project constraint that defined process requirements, and guided the conceptual design and product selection.

Additionally, the existing HVAC system and laboratory setup present unique constraints when defining the scope of the project. CIC has requested that the humidity control system be integrated within the existing HVAC ducts. CIC has provided drawings of the laboratory layout, and has provided technical specifications on the existing temperature control systems. However, our team was required to identify the processes, specifications, and flow requirements of the existing HVAC equipment, and include this data into the design of the humidity control system. Furthermore, the physical size of the CIC office, FibreCITY laboratory, and mechanical room also constrain the footprint and volume of the humidity control system. Lastly, the system design was constrained by building and environmental codes and standards including: The National Energy Code of Canada for Buildings 2011 [9], Manitoba Workplace Safety and Health Regulation [10], and the Moisture Control Guidance for Building Design, Construction and Maintenance [11]. Ensuring that the design conformed to these legal standards ensured quality of the final design.

1.3.3 Time

The design project was also heavily constrained by the completion due date of 2:30 pm on December 7, 2015. Considering this constraint, time available for our team to meet, discuss, review project stages with the client, and to meet with technical and faculty advisors was limited. Additionally, the time commitment of individual team members was limited by competing classes. The time constraints further limited the scope and quality of our project was further limited, as outlined through the concept of the iron triangle.

Through understanding the extent of the constraints and limitations associated with this particular design project, and by understanding the interdependencies between cost, scope, and time, our team was able to work with CIC to clearly lay the foundation for our future design. Conversely, with the initial project needs, specification, and constraints all defined, the design process was able to commence; which began with an analysis of the current laboratory configuration.

2.0 CURRENT CONFIGURATION AND DESIGN CONSIDERATIONS

Understanding the current laboratory design and operation was crucial to the development of the final design. In this section, the existing room envelope and ventilation system are discussed, along with the ventilation requirements for the laboratory as per HVAC codes and measured laboratory data. Lastly, the current lab humidity and temperature conditions are presented in order to determine the humidity load and set points that are needed to satisfy the client needs.

2.1 Ventilation

Ventilation for the FibreCITY laboratory is currently driven by continuous operation of the fume hood. Air exhausted from the laboratory through the fume hood is replaced by air infiltrating into the room from through the T-bar ceiling and other holes in the room envelope. No fresh air is intentionally mixed into the HVAC supply air, and therefore there is no dedicated method of ventilation in the lab when the fume hood is turned off. Not only does the current ventilation configuration present a safety concern, but the lack of controlled ventilation rates also proves problematic when attempting to control relative humidity to a tolerance of ±5%. In order to address both of these issues, it is necessary to introduce a dedicated method of ventilation and to seal the envelope of the room.

An inspection of the laboratory revealed that several improvements would be necessary in order to correctly isolate the laboratory from the surrounding environment. With this in mind, the current laboratory configuration does contain rudimentary methods of preventing moisture and air infiltration, including door sweeps (Figure 2) and industrial rubber baseboards sealing the seam between floor and walls.

Figure 2 - Depicts the current door sweeps [12]

Having considered these two beneficial aspects, it is important to note that the existing suspended T-bar ceiling is the source of a significant air infiltration into the room. The T-bar ceiling serves as a permanent ceiling envelope for a large portion of the laboratory, while a small area of the ceiling is constructed using a traditional drywall surface. The portion of ceiling in the laboratory space that is drywall is outlined in red in Figure 3.

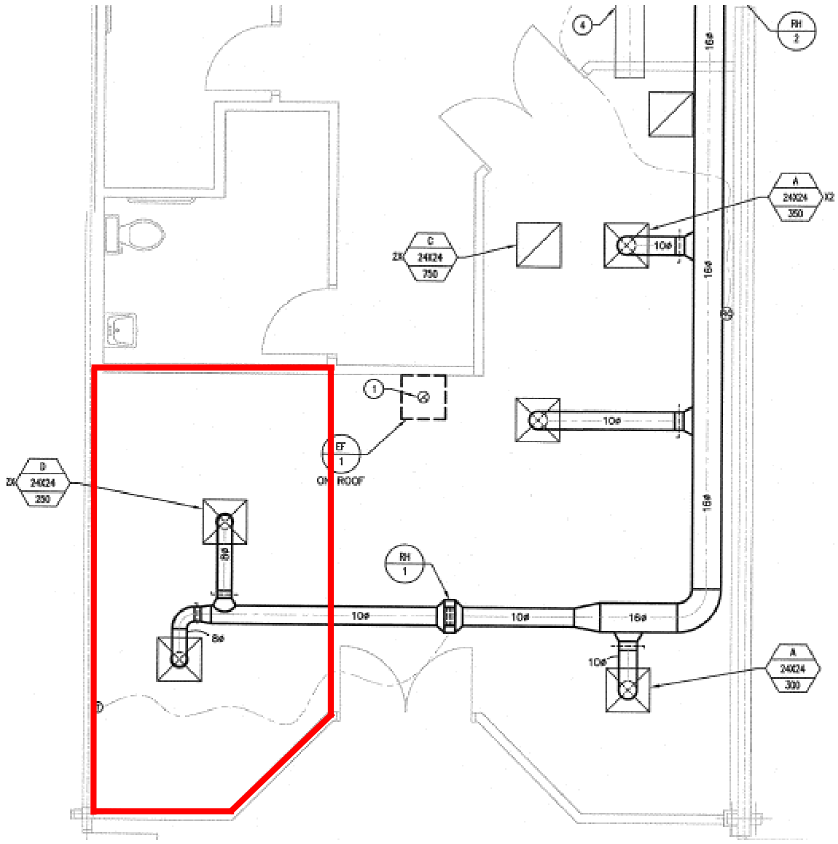


Figure 3 – Drawing of FibreCITY lab, area with drywall ceilings outlined in red [13]

While the outlined portion of the ceiling is drywall, the remaining ceiling surface is comprised of suspended gypsum ceiling tiles wrapped in vinyl that are hung using the T-bar grid system. Unfortunately, these tiles do not possess mechanisms to adequately prevent infiltration of moisture or air through the ceiling surface. Not only are the ceiling tiles inadequate, but there are also several installation issues that increase the permeability of the ceiling. For example, a ceiling tile was crudely cut when installing a pressurized airline, as shown in Figure 6, resulting in a large opening to the external environment.

Figure 4 – Installation issues with existing T-bar ceiling [14]

Inspection of the laboratory therefore revealed that changes are needed to the ceiling and doors to reduce the air and moisture infiltration with the controlled environment.

Having discussed the inadequacies of the current laboratory configuration, it was necessary to determine the appropriate ventilation rates for this space. ANSI/ASHRAE Standard 62-2001: Ventilation for Acceptable Indoor Air Quality specifies the required ventilation, or air changes per hour (ACH) for a variety of different room uses and occupancies, including laboratories [15]. The ANSI/ASHRAE Standard 62-2001 standard can therefore be used to calculate the required air changes for the FibreCITY laboratory as follows:

Space Conditions:
laboratory footprint: $A_1 = 756$ ft^2 (measured)
laboratory volume: $S_1 = 6804$ ft^3 (measured)
number of people in lab, on average: N = 3 (provided by client)

ASHRAE Standard 62-2001 Guidelines (Science Laboratory):
personal air rate: $V_1 = 10$ cfm/person
space air rate: $V_2 = 0.18$ cfm/ft^2

Total Required Air Ventilation:

$$V_T = V_1 * N + V_2 * A_1 \qquad \text{(Eqn.1)}$$
$$= 10[\text{ft}^3/(\text{min*person})]*3[\text{people}] + 0.18[\text{ft/min}]*756[\text{ft}^2]$$
$$= 166 \text{ cfm (cubic feet per minute)}$$

$$\begin{aligned} ACH &= (V_t * 60[min/hr]) / S_1 \\ &= (166[ft^3/min]*60[min/hr]) / 6804[ft^3] \\ &= 1.5 \text{ air changes per hour} \end{aligned} \quad \text{(Eqn.2)}$$

The calculated value of 1.5 air changes per hour for the FibreCITY laboratory is an appropriate value based on the ASHRAE guidelines. Due to the relatively low levels of human occupancy and activity in the laboratory, the calculated ACH for this space aligns more closely with residential requirements (1-2 ACH) than institutional laboratories (6-12 ACH) [16].

As previously mentioned, the laboratory currently relies on exhaust airflow provided by the fume hood, and infiltration through the room envelope for ventilation. While the final design features a dedicated ventilation system, the humidifier must also be able to operate effectively when the fume hood is temporarily turned on. For this reason, it is important to calculate the airflow through the fume hood.

Fume Hood Face Area: $A_2 = 3.75\ ft^2$ (measured)

Fume Hood Face Velocity: $v_1 = 50$ ft/min (assumed)

The face velocity of the fume hood is assumed to be 50 fpm because this is the recommended set point on the Labconco 335 Airflow Monitor [17][18].

Fume hood volumetric air flow:

$$\begin{aligned} V &= A_2 * v_1 \\ &= 3.75[ft^2] * 50[ft/min] = 187.5 \text{ cfm} \end{aligned} \quad \text{(Eqn.3)}$$

This calculation shows that the fume hood exhausts an estimated airflow of 187.5 cfm, therefore providing the necessary ventilation of 166 cfm as prescribed by ASHRAE. In the final design, a balanced damper is installed in the existing HVAC ducting to ensure a fresh airflow of 190 cfm from the CIC office space into the laboratory. A dedicated exhaust fan is interlocked with the fume hood so that one, and only one, of the two exhaust systems is in operation at any given time.

2.2 Humidity

In addition to assessing the laboratory ventilation, our team collected humidity data in order to further define the existing conditions within the laboratory. A relative humidity and temperature data logger, the RHT20 [19], was purchased and positioned within the laboratory and data was collected for three days. Two days' worth of data was collected in the FibreCITY laboratory, and one day of data was collected in the CIC office space. The readings from the data logger can be seen in Figure 5. Data from within the laboratory in shown from data points 500 to 5700, while data from the ambient office space is shown in data points 5700 to 6500.

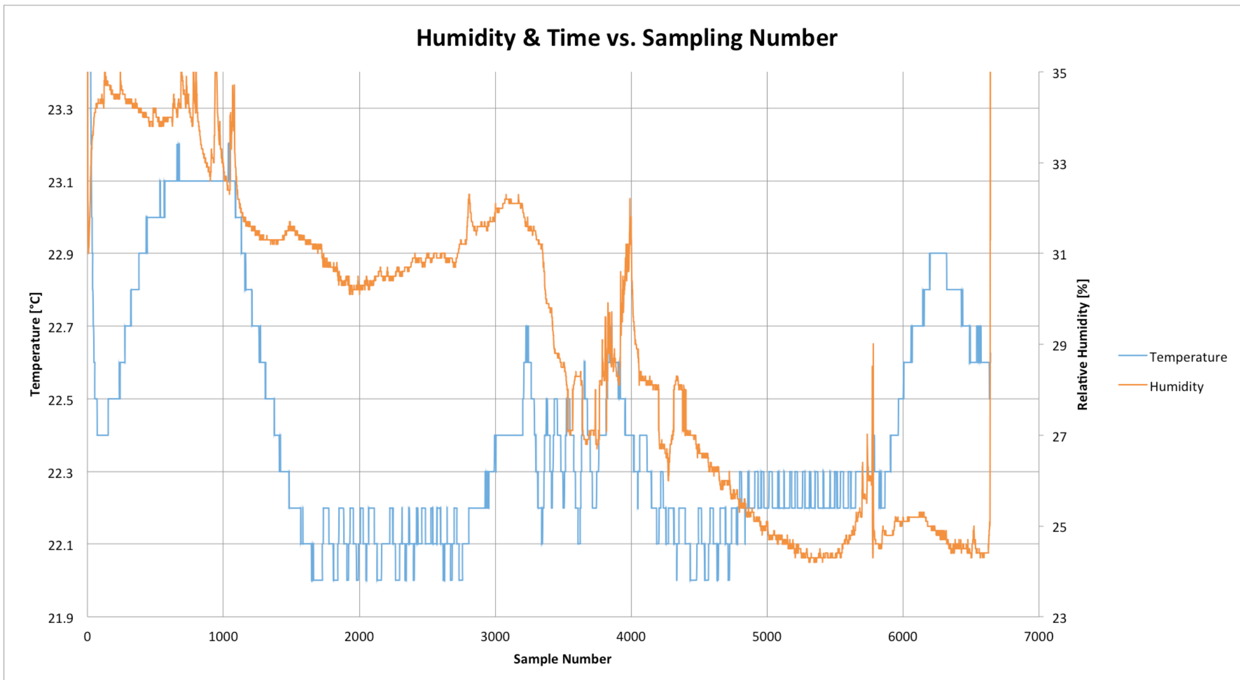


Figure 5 - Humidity and temperature data over a three day period

The data obtained using the logger shows that that the humidity in the laboratory ranges from 25 to 35% RH, while the temperature in the lab was within the expected tolerance of +/- 1°C. The data shows that there are no discernable trends between temperature and humidity, while the humidity of the ambient office space was between 25 and 30% RH and the temperature was slightly warmer at 22°C. While it would be ideal to continue gathering data for a longer period of time and for each season of the year, time restrictions dictate that we must extrapolate this data.

Having established the current humidity conditions in the laboratory and the CIC office space, the humidity load for the final design was determined. Humidity load refers to the rate at which water is introduced into air in order to achieve and maintain a desired humidity set point. In is important to note that final design specifies that air from the CIC office space will be drawn into the laboratory for ventilation purposes. In order to determine the humidity load, several key aspects were considered: ventilation, infiltration, opening doors, and people. The required ventilation rates for the laboratory were established in Section 2.1, where it was determined that 166 cfm of fresh air or 1.5 ACH is required. However, when the fume hood is engaged approximately 188 cfm of air is exhausted from the room. In order to design for worst case scenario, it was assumed that 188 cfm is required for the humidity load analysis. The 188 cfm of air will be drawn from the CIC office space, into the FibreCITY laboratory.

While the measured relative humidity of the ambient office air was approximately 30% RH, the humidity in the office space is unregulated and therefore there is no guarantee that the humidity won't fall below this point during the winter season. Therefore, in order to design for worst case humidity loading scenario, we assumed that the ventilation air will be replaced with completely dry air (0% RH). Under this assumption, the humidity load (w_v) due to ventilation was calculated as:

$$W_v = \frac{V_i\left[\frac{ft^3}{min}\right] * 0.0283168\left[\frac{m^3}{ft^3}\right] * \rho_{air}\left[\frac{kg}{m^3}\right](w1-w2)\left[\frac{\mathrm{g}}{\mathrm{kg}}\right] * 60\left[\frac{min}{hr}\right]}{1000\left[\frac{\mathrm{L}}{g}\right]} \qquad \text{(Eqn.4 [20])}$$

$$W_v = \frac{188\left[\frac{ft^3}{min}\right] * 0.0283168\left[\frac{m^3}{ft^3}\right] * 1.201\left[\frac{kg}{m^3}\right](10-0)\left[\frac{\mathrm{g}}{\mathrm{kg}}\right] * 60\left[\frac{min}{hr}\right]}{1000\left[\frac{\mathrm{L}}{g}\right]}$$

$$W_v = 3.84\ \mathrm{L}/h$$

where;

V_i = 188 cfm = volumetric flow of air

w_1 = 0 = ambient humidity ratio (g/Kg)

w_2 = 10 = desired in-lab humidity ratio (g/Kg) – for 65% RH @ 21°C as per Figure 6, Psychrometric Chart

ρ_{air} = density of air @ 21°C = (1.201 kg/m$_3$) [21]

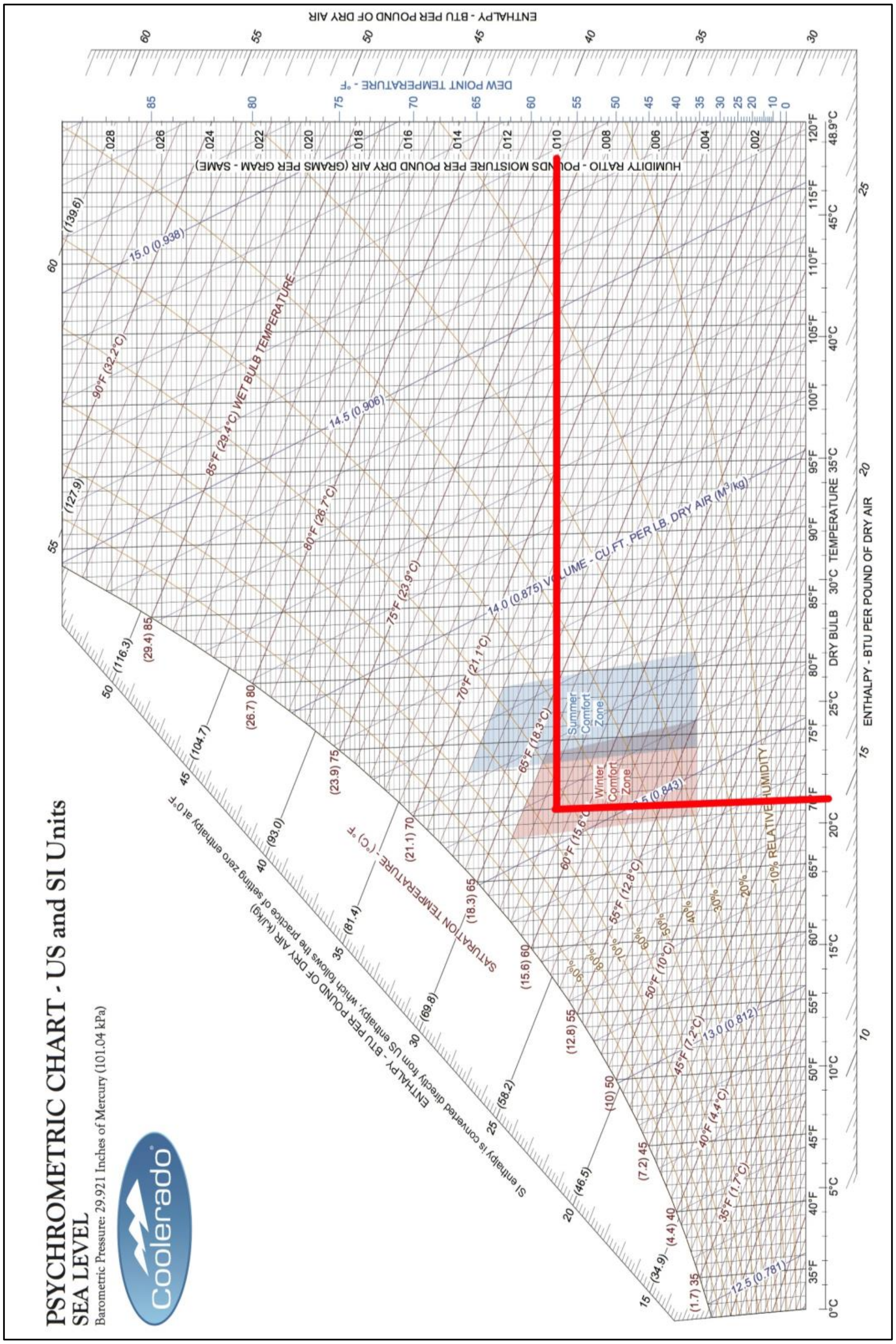


Figure 6 - Desired in lab humidity ratio at 65%RH and 21°C, shown on adapted psychrometric chart [22]

This calculation shows that 3.84 L/h of water is required to satisfy the ventilation humidity load based on the amount of fresh air that will be introduced into the laboratory for ventilation.

While 3.84 L/h represents that worst case scenario for the ventilation humidity load, it is also important to consider what the most likely loading circumstance will be. As previously noted, the measured humidity in the ambient CIC office was between 25 and 35% RH in early October. Industry experts have also advised our team that humidity in homes and offices is typically around 20% during the winter in Winnipeg, MB. Considering that these values are much higher than the 0% RH used in our worst case humidity loading calculations, the estimated humidity load was calculated for intake air at 10, 20, 30 and 40% RH when regulating the humidity of the laboratory to 50 and 65% RH. Using Equation 4, and a psychrometric chart, the humidity load for each of these scenarios was calculated and is presented in Table IV.

TABLE IV: ESTIMATED HUMIDITY LOAD FOR VENTILATION (L/h), VARYING SCENARIOS AT 21°C

	Relative Humidity of Intake Air				
Desired Relative Humidity	**0%**	**10%**	**20%**	**30%**	**40%**
50%	3.07	2.49	1.92	1.15	0.77
65%	3.84	3.26	2.69	1.92	1.53

Table IV shows that while 3.84 L/h may be required for the worst case scenario, it is more likely that the humidity load will be 1.92 L/h for a desired 50% RH, or 2.69 L/h for a desired 65% RH.

The next factor considered for humidity load was people, or the human occupancy within the laboratory space. This factor was actually already accounted for as part of the airflow requirements, as seen in Section 2.1. Aside from human occupancy, it was also assumed that there will be no processing occurring in the laboratory that involves large containers of water or liquid. This is a valid assumption based on our understanding of the testing activities that take place in the FibreCITY laboratory.

The final consideration for humidity load was opening doors, which can be a notable source of airflow into and exiting the laboratory. The door load per hour, W_d, was calculated as:

$$W_v = \frac{n*A*v*d*t*(M_1-M_2)}{120} \qquad \text{(Eqn.5 [20])}$$

$$W_v = \frac{6*1.85*0.5*0.0012*5*(10-4)}{120}$$

$$W_v = 0.0017 \text{ L/h}$$

where;

n = 6 = door openings (per hour)
A = 1.85 m^2 = open door area
v = 0.5 m/s = (assumed ¼ of typical office air duct velocity) ambient air velocity
d = 0.0012 kg/l = air density
t = 5 s = open time
M_1 = 4 g/kg (measured) = ambient humidity ratio
M_2 = 10 g/kg = lab humidity ratio

The effect of opening doors is very insignificant compared to the humidity load of ventilation (0.04%) and can therefore be ignored. In summary, the maximum required humidity load for the FibreCITY laboratory can be approximated exclusively using Table IV.

While prior calculations accounted for humidity load under steady state lab conditions, it is important to also consider how the system will react to changing environmental changes. For example, when studying the operation of the current FibreCITY HVAC system, it is evident that the temperature oscillates between the high and low values within the tolerance band of 21 ± 1°C, with a total cycle time of 40 minutes. How these temperature oscillations affect the relative humidity were considered in order to properly understand how humidity can be controlled in the laboratory. Referring to Figure 7, it is evident that air with a humidity ratio 10 g/kg has a RH of approximately 65% RH at 20°C (low end of tolerance band). When this air is heated to 22°C (high end of tolerance band) the air has a new RH of approximately 57% RH.

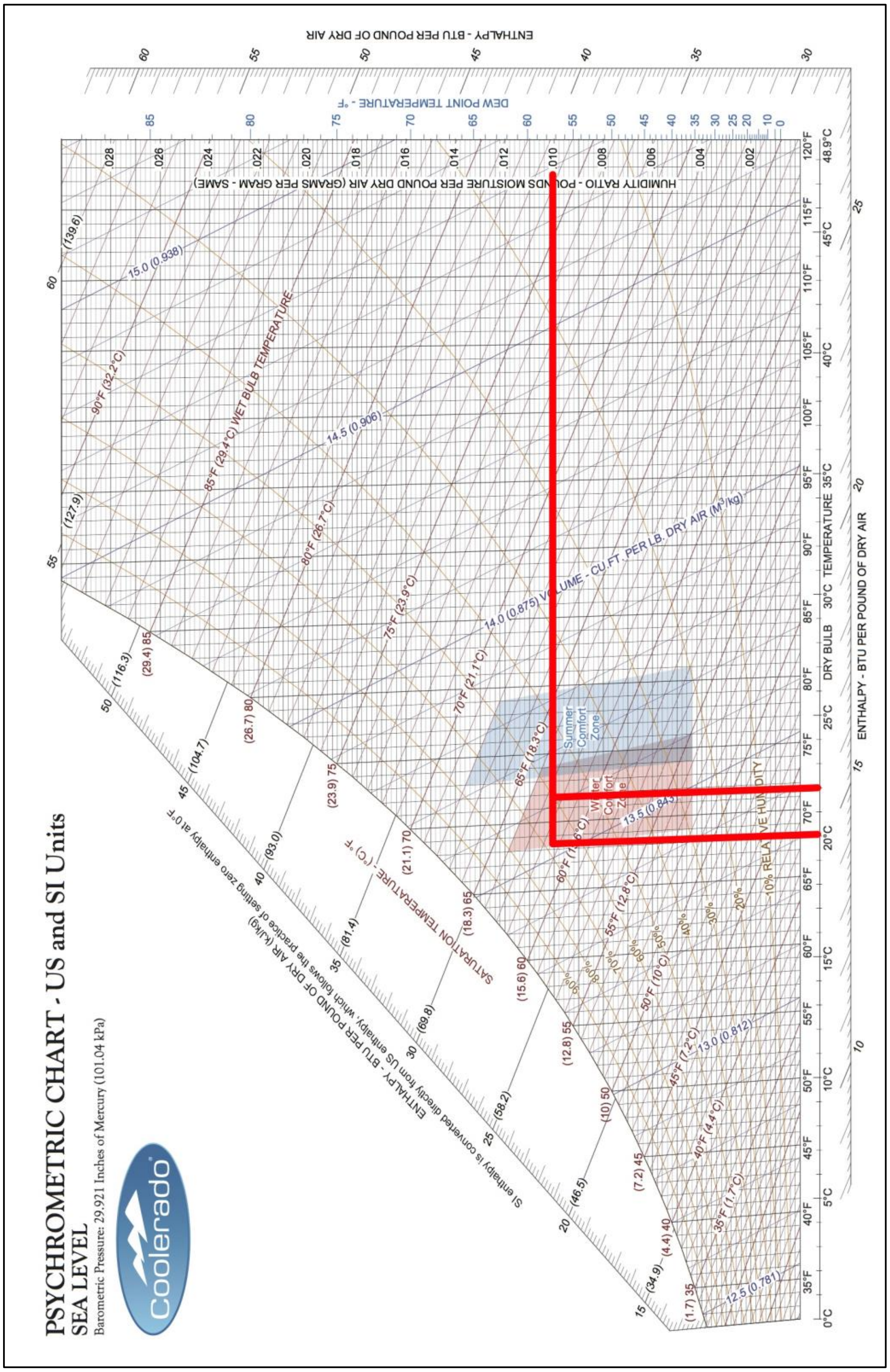


Figure 7 - Change in relative humidity due to temperature oscillations between 20°C and 22°C [22]

This shows that under no external influences, the relative humidity within the FibreCITY laboratory will fluctuate 8% RH or ±4% RH solely due to variation in temperature. Due to the fact that the final design specifies that the existing heating and cooling system will be used, this limits the tolerance of our humidity control to ±4% RH under the most ideal conditions.

2.2.1 Dehumidification

Furthermore, the topic of dehumidification was also addressed. According to the configuration of the final design fresh air will be pulled into the laboratory from the CIC office space. The air in the CIC office space is pre-conditioned to room temperature by a forced air system powered by rooftop heating/cooling equipment. However, relative humidity is not regulated in the CIC building. In the winter, cold dry air is drawn from outdoor ambient conditions and is heated to maintain the building at room temperature. Due to the fact that cold air inherently has an inability to hold water, the humidity in the office space was safely assumed to be below 30% during the cold months [23]. It was subsequently assumed that no dehumidification is required during the winter season. Throughout the summer months, hot and often humid air is drawn from outdoors and is cooled using the rooftop air conditioning unit before entering the CIC office space. As air is processed by the air conditioning unit, the air is naturally dehumidified by the condenser. The air conditioning process used during warm weather therefore provides adequate dehumidification, which allowed our team to assume that the relative humidity in the office space is below 50% RH during this season; as was validated during a short 3-day period of data collection, where the CIC office humidity was consistently under 35% RH. In summary, it was assumed that dehumidification equipment will not be required for the FibreCITY laboratory when ventilation air for the laboratory is drawn from the CIC office space.

2.2.2 Transient Response

Without a designated dehumidification unit, CIC will be required to rely on a natural transience to drop the humidity set point of the lab from 65% to 50%. While dehumidification will not be necessary for this process, it is important to consider the length of time it will take for this adjustment to take place. In the worst case scenario, fresh air drawn from the CIC office space has a relative humidity of 40%. Considering that 180 cfm of air is continually being exhausted from the laboratory space, we can approximate how long it will take for the humidity to drop from 65% to 50% RH. Calculating the time for the humidity to drop due to natural transience was requested by the customer in order to quantify the disadvantage of not installing a dehumidification unit.

Mass of Water to Be Extracted (M_1)

$$M_1 = V_{room} \times \rho_{air} \times (humidity\ ratio\ @\ 65\%\ RH - humidity\ ratio\ @\ 50\%\ RH) \quad \text{(Eqn.6)}$$

$$M_1 = 6804\ ft^3\ 0.0283168\ m^3/ft^3 \times 1.225\ kg/m^3 \times (10\ g/kg - 8\ g/kg)$$

$$M_1 = 944g$$

In the worst case scenario, the fresh air will have 40% RH and therefore a humidity ratio of 6 g/kg. Assuming that the air being exhausted from the room declines linearly from 10 g/kg (65% RH) to 8 g/kg (50% RH), we may approximate the humidity of exhaust air to be constant at 9 g/kg. This means that the room will lose 3 g/kg of moisture through air ventilation. The time it takes to extract 944g of water though this process can be calculated as follows:

Water Exhaust Rate = $\dot{M}$

$$\dot{M} = V_{air} \times \rho_{air} \times (3\ kg/g) \quad \text{(Eqn.7)}$$

$$\dot{M} = 166\ ft^3/min \times 0.0283168\ m^3/ft^3 \times 1.225\ kg/m^3 \times 3\ kg/g$$

$$\dot{M} = 17\ g/min$$

Time Required = 944g / 17 g/min = 56 min

Therefore, in the worst case scenario it would take approximately 1 hour to reduce the relative humidity in the laboratory from 65% to 50%.

2.3 Temperature

Our team chose to measure the temperature in the laboratory while we were measuring humidity because it was both convenient and useful to compare the humidity and temperature at any given instant. However, Composites Innovation Centre had conducted temperature scans within the laboratory after installing the existing HVAV temperature control system. The temperature scans conducted by CIC utilized 8 different temperature sensors evenly distributed throughout the room. The investigation was completed over a span of eight days in 2014, from October 20-27th. Throughout the duration of the test, adjustments were made to the HVAC control system and laboratory to ensure temperature uniformity throughout the room. After the adjustments were made, a final scan was conducted, showing the current temperature fluctuations occurring in the FibreCITY laboratory (Figure 8).

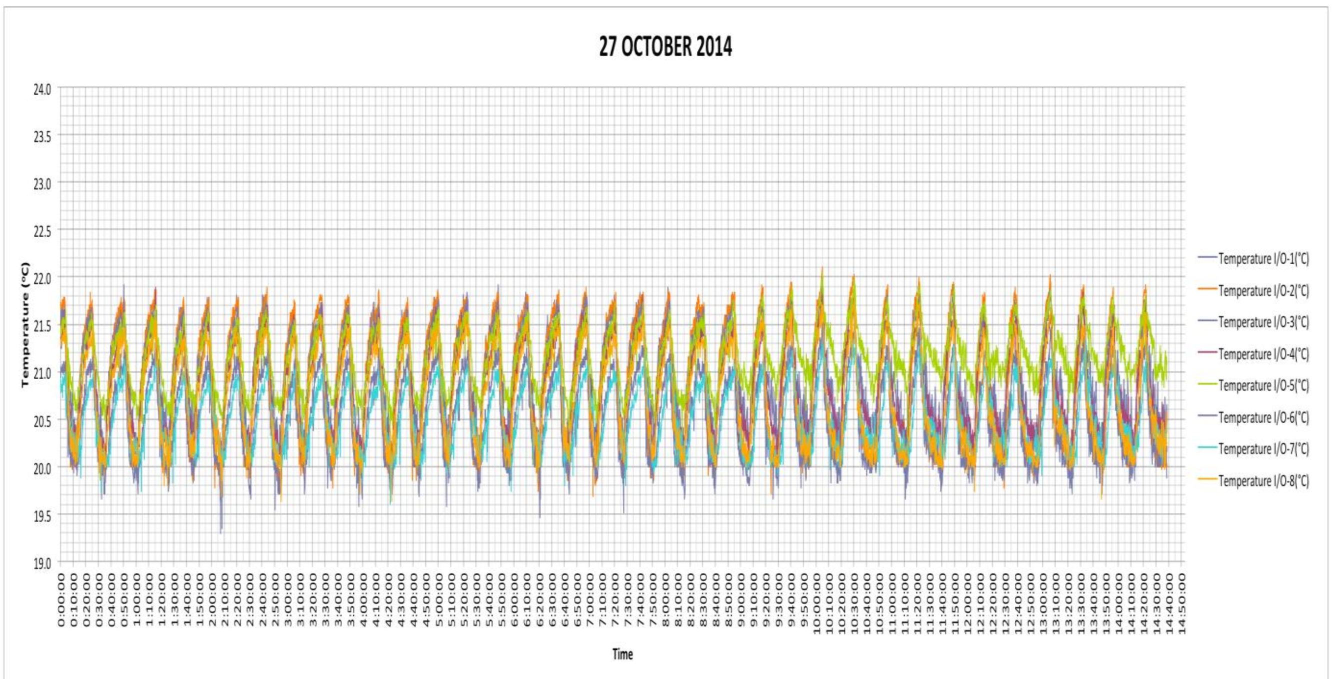


Figure 8 - Displays the eight temperature sensors and their fluctuations on October 27, 2014 [24]

The fluctuations in temperature displayed in Figure 8 are marginally within the temperature tolerance levels at the CIC FibreCITY laboratory (+/-1 °C). However, in some isolated instances, the sensors fall outside of the 21°C +/- 1°C. It is also evident that the temperature cycles between the maximum and minimum temperatures in the tolerance band in a 40-minute cycle time. This temperature data was used as a benchmark for temperature conditions within the laboratory space.

2.4 Required Humidity Set Points

As discussed in Sections 2.1 and 2.2, use of the existing HVAC system limits our ability to regulate the humidity in the laboratory due to the inherent temperature oscillations within the 21 ± 1°C control band. Figure 9 shows how the temperature oscillates in the room with a cycle time of 40 minutes.

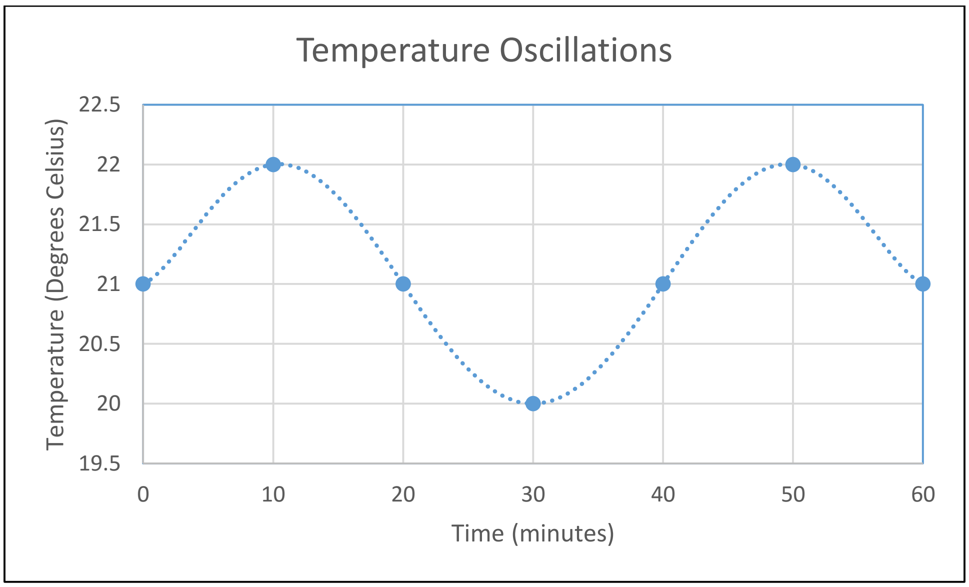


Figure 9 – Example of temperature oscillations, 40 minute cycle time

Due to the fact that relative humidity is temperature dependent, the relative humidity will also naturally oscillate. Figure 10 shows how that if the laboratory begins at 21°C and 65% RH, the relative humidity will oscillate between 69% RH and 61% RH as the temperature inherently oscillates between 20°C and 22°C.

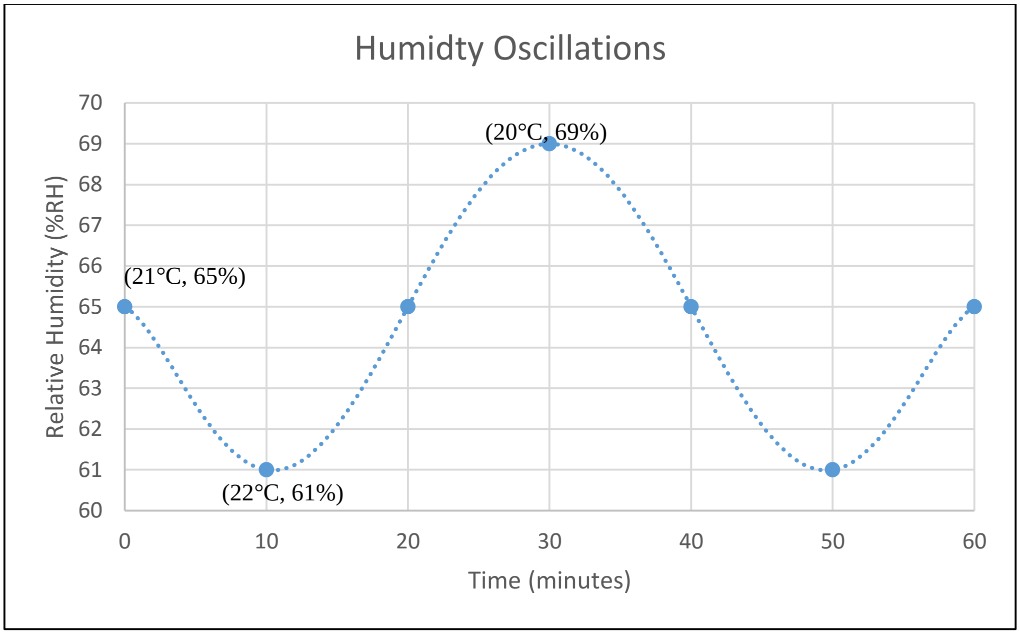


Figure 10 - Inherent humidity oscillations due to temperature oscillations

Inspection of Figure 10 shows how small oscillations in temperature cause the humidity to drastically oscillate. It is also important to note that relative humidity is inversely affected by changes in air temperature; as the temperature rises, the relative humidity falls. This occurs because warm air has a higher capacity to hold water than cold air. Consider two identical sized rooms filled with air, one warm and one cold. If the air in both rooms contains the same mass of water per kilogram of air, the relative humidity in the cold room is greater because it holds a higher percentage of its total water capacity.

Moreover, Figure 10 also illustrates the importance of ensuring that the mean amplitude of the humidity oscillations is aligned with the desired relativity set point. It is not sufficient to design a system that will turn on and humidify until the laboratory reaches the set point of 65% RH. In this scenario, the system will strive to maintain at 65% RH at all times while the temperature oscillations, and therefore humidity oscillations, will continue to occur. Figure 11 shows that if the humidity set point is 65%, the minimum relative humidity of the oscillations will be 65%.

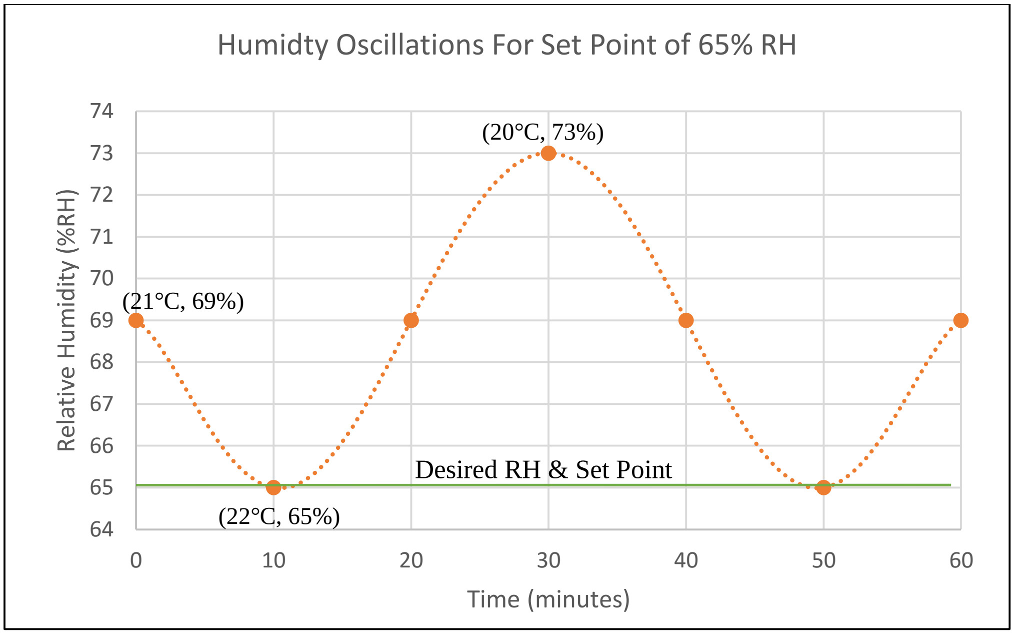


Figure 11 - Humidity oscillations for humidifier set point of 65% RH

The humidity clearly exceeds the 65% +/-5 tolerance band in this scenario. As discussed, warm air has the greatest capacity to hold water. Therefore, when the air temperature hits 22°C, the humidifier will introduce water until the air reaches 65% RH. When the temperature drops, the relative humidity in the room will rise and humidification will not be needed again until the temperature again rises to 22°C. This is why the humidity set point corresponds to the minimum humidity during oscillation patterns.

In order to attain a desired relative humidity of 65 ± 5% RH, the set point must therefore be 61% RH. In this scenario, the relative humidity oscillations would appear as in Figure 12.

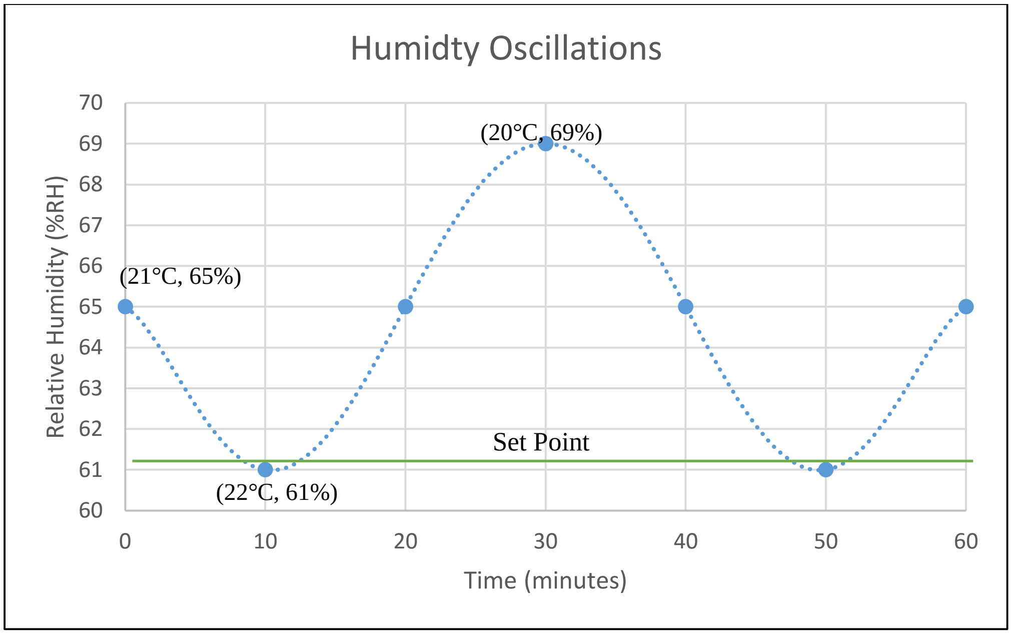


Figure 12 - Humidity oscillations, set point 61%RH for desired 65%RH

With the set point at 61%, the relative humidity oscillates between 61% and 69%, therefore satisfying the requirement of 65 ± 5%. It is also important to note that there remains a 1% RH safety band between the oscillation peaks and the humidity limits. This means that the accuracy of the humidifier must be 1% or better.

We can also find the set point for 50% RH desired humidity using the same logic that was used to determine the set point for 65% RH. Figure 13 shows that for 50% RH desired humidity a 46% set point is required.

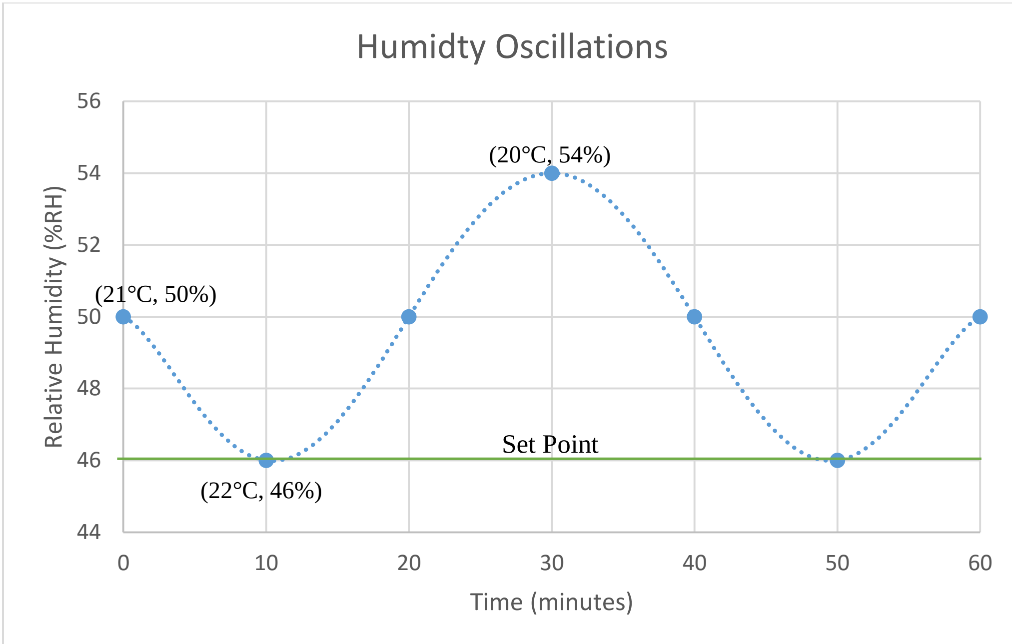


Figure 13 - Oscillating humidity for set point of 46% RH for desired 50% RH

It is evident that a set point of 46% is necessary in order to achieve the desired relative humidity of 50%.

3.0 DESIGN METHODOLOGY

Having completed the design project research, the next step was to generate concepts that would have the potential to achieve the desired humidity level in the laboratory. The process of concept generation was to combine various design aspects discussed in Section 2.0 to produce holistic concepts that could be realistically implemented at CIC. Each concept generated through this process was subsequently evaluated using a screening and scoring methodology, enabling our team to compare and rank concepts according to the prioritized client needs. Ultimately, this evaluation guided our team toward selecting a single concept that can be further developed into our detailed final design.

3.1 Concept Generation

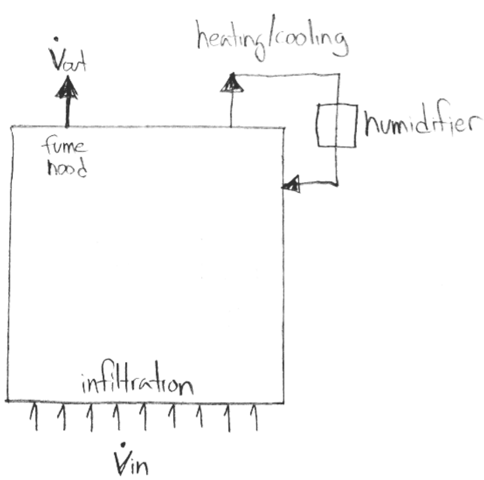
A collaborative team review of the concept research and client needs initiated the concept generation phase. Individual design features and product types that were determined to be viable for use in this project were combined in a number of different configurations to form five holistic design concepts. For the development of each concept the following terminology is used:

TABLE V: CONCEPTUAL DESIGN TERMINOLOGY

Humidifier	V_{OUT}	V_{IN}	Infiltration	Roof
Describes the type of humidifier used: in-line with duct work, or mounted on the wall.	Indicates the mass flow rate of air out of the lab; indicative of ‘ventilation out’	Indicates the mass flow rate of air into the lab; indicative of ‘ventilation in’	Indicates the presence of infiltration through walls, ceilings, and doors	Indicates a duct running from the FibreCITY lab to the roof of the CIC building

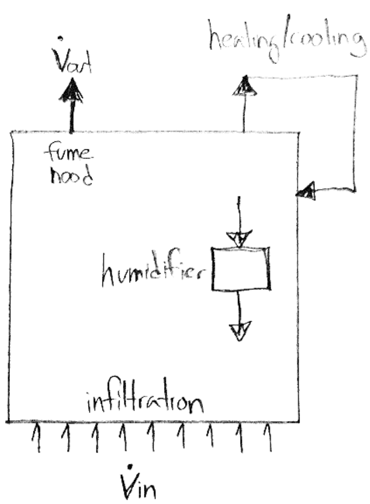
Throughout our conceptual design process, five concepts were generated, where each of the consecutive conceptual designs were built, or modified off of the previous. From concept #1 to concept #5, the complexity of the system increases, and thus so does the estimated cost, and the ability for the concept to meet the tight tolerance requirement of 2% RH. For each concept, a design schematic is provided, along with a brief description, and an estimated cost within +/-30% accuracy. Table VI summarizes the five generated concepts.

TABLE VI: SUMMARY OF CONCEPTS

<table>
<tr><th colspan="4">Conceptual Design Summary</th></tr>
<tr><th>Name</th><th>Humidification Unit</th><th>V_{OUT}</th><th>V_{IN}</th></tr>
<tr><td>Concept #1</td><td>Light commercial steam in-line duct unit</td><td>Fume hood</td><td>Uncontrolled infiltration from surrounding CIC office space</td></tr>
<tr><td>
</td><td colspan="3">

- Developed to allow regulation of humidity without the need to make changes to existing room envelope.
- No changes made other than installation of humidification unit into **duct network**.
- No dehumidification required (see Section 2.2)
- Unable to achieve +/-2% RH @ 50% or 65% RH due to unregulated infiltration; however, able to achieve +/-5%
- **Reliance on fume hood for ventilation is not recommended as sole source of ventilation (Section 2.1).**
- Air recirculates in the lab.

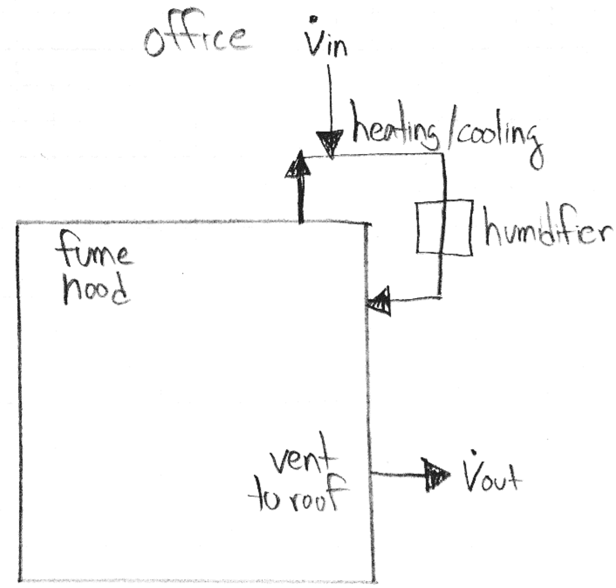
Concept 1 Estimated Cost:
In-Duct Humidifier – $2 000
Labour (100% of Subtotal) – 2 000
Total - $4 000
</td></tr>
</table>

<table>
<tr><th>Name</th><th>Humidification Unit</th><th>V_{OUT}</th><th>V_{IN}</th></tr>
<tr><td>Concept #2</td><td>Standalone humidifier mounted to inside wall</td><td>Fume hood</td><td>Uncontrolled infiltration from surrounding CIC office space</td></tr>
<tr><td>
</td><td colspan="3">

- Developed to allow regulation of humidity without the need to make changes to existing HVAC system or room envelope.
- No changes made other than installation of humidification unit on an **internal lab wall**.
- No dehumidification required (see Section 2.2)
- Unable to achieve +/-2% RH @ 50% or 65% RH due to unregulated infiltration; however, able to achieve +/-5%
- **Reliance on fume hood for ventilation is not recommended as sole source of ventilation (Section 2.1).**
- Air recirculates in the lab.
- Cheapest option.

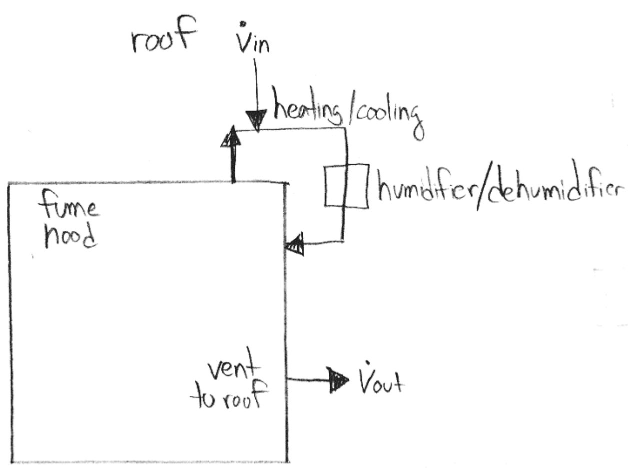
Concept 2 Estimated Cost:
All-In-One Wall Mounted Humidifier – $1 000
Labour (100% of Subtotal) – 1 000
Total - $2 000
</td></tr>
</table>

Name	Humidification Unit	V_{OUT}	V_{IN}
Concept #3	Light commercial steam in-line duct unit	Vent to roof	Controlled intake from surrounding CIC office space



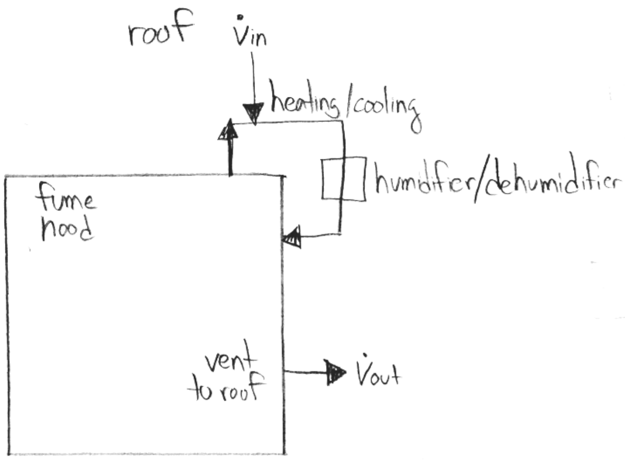
- Builds on Concept #1
- Incorporates installation of humidifier and **improvements to laboratory insulation.**
- Upgraded air tight ceiling, and additional seals added to lab doors.
- Additional insulation limits infiltration through walls and ceiling, and allows proper control of air changes.
- Eliminates reliance on fume hood for proper ventilation.
- **Provides proper air ventilation and air cycling through installed roof vent and fresh air intake from CIC lab space**.
- Does not require dehumidification (see Section 2.2)
- Unable to achieve +/-2% RH @ 50% or 65% RH due to current temperature oscillations (Section 2.3); however, able to achieve +/-5.

Concept 3 Estimated Cost:
In-Duct Humidifier – $2 000
Ceiling Replacement – 3 000
Door Sealing – 250
Roof Exhaust Venting – 1 000
<u>Labour (100% of Subtotal) – 6 250</u>
Total - $12 500

<table>
<tr><th>Name</th><th>Humidification Unit</th><th>V_{OUT}</th><th>V_{IN}</th></tr>
<tr><td>Concept #4</td><td>Light commercial steam in-line duct unit</td><td>Vent to roof</td><td>Controlled intake from building roof (outside air).</td></tr>
<tr><td>
</td><td colspan="3">

Builds on Concept #3
Incorporates installation of humidifier and improvements to laboratory insulation.
Upgraded air tight ceiling, and additional seals added to lab doors.
Additional insulation limits infiltration through walls and ceiling, and allows proper control of air changes.
Eliminates reliance on fume hood for proper ventilation.
Provides proper air ventilation and air cycling through installed roof vent and fresh air intake from outside ambient air.
Installation of additional mechanical equipment to precondition outside air.
Unable to achieve +/-2% RH @ 50% or 65% RH due to current temperature oscillations (Section 2.3); however, able to achieve +/-5.
Requires creation of vent ducting to CIC building roof.

Concept 4 Estimated Cost:
In-Duct Humidifier – $2 000
Dehumidification Device – 1 000
Ceiling Replacement – 3 000
Door Sealing – 250
Roof Exhaust Venting – 1 000
Roof Intake Venting – 1 000
<u>Labour (100% of Subtotal) – 8 250</u>
Total - $16 500
</td></tr>
</table>

<table>
<tr><th>Name</th><th>Humidification Unit</th><th>V_{OUT}</th><th>V_{IN}</th></tr>
<tr><td>Concept #5</td><td>Light commercial steam in-line duct unit</td><td>Vent to roof</td><td>Controlled intake from building roof (outside air).</td></tr>
<tr><td>
</td><td colspan="3">

- Total overhaul of existing environmental control system.
- Completely replaces the existing HVAC system (including heating and air conditioning) and replaces it with an integrated humidity and temperature control system.
- Greatly improved laboratory insulation.
- Dual system with dedicated heating and cooling ducts/humidification and dehumidification ducts.
- Eliminates reliance on fume hood for proper ventilation.
- Provides proper air ventilation and air cycling through installed roof vent and fresh air intake from outside ambient air.
- **Able** to achieve +/-2% RH @ 50% or 65% RH since infiltration has been regulated and temperature oscillations have been controlled.

Concept 5 Estimated Cost:
Heating/Cooling/Humidification/Dehumidification Equipment – 15 000
Ceiling Replacement – 3 000
Roof Exhaust Venting – 1 000
Roof Intake Venting – 1 000
<u>Labour (100% of Subtotal) – 20 250</u>
Total - $40 500
</td></tr>
</table>

3.2 Concept Selection

Each of the concepts presented in Section 3.1 were subjected to a design selection process that consisted of concept screening, and concept scoring methods to assist the team in developing the optimal solution for the humidity control system, according to a set of criteria selected through collaboration between the design team and the customer [25-26].

3.2.1 Criteria Description

In creating the concept screening and scoring processes, the crucial customer requirements, based on the highest ranked customer needs listed in Table II, were utilized to make up the selection criteria. The parameters for which each concept was rated are as follows:

1. Ability to achieve humidity set points and desired tolerance
2. Capital cost
3. Ability to regulate air changes
4. Ease of maintenance
5. Intrusiveness of system
6. Ease of implementation

In order to elucidate the aforementioned selection criteria, and to discuss each parameter in greater detail, a short description of each factor, and why it was chosen as a selection criterion is given below:

1.) Ability to achieve humidity set points and desired tolerance

As mentioned previously, the problem at hand is that the HVAC system in FibreCITY cannot control humidity to 50% or 65% +/-5%. Therefore, it is of utmost importance that the optimal design resolves this issue. The ability of a system to control humidity levels within an acceptable tolerance is governed by the mechanism of humidification it uses, the type of controls and their sensitivity, as well as its compatibility with the existing temperature control system.

2.) Capital cost

Cost is essentially always a consideration in an engineering design problem, as a project budget limits the features and quality of a design. As there was no specific budget dictated by CIC which the team could design to, it was decided to establish this parameter as a criterion and rank possible designs on their potential costs, but not be so limited by their costs in our decision making. The cost of equipment, controls and installation were included under this category, but cost of maintenance was not included as it was established as its own criterion

3.) Ability to regulate air changes

The selected design must be able to compensate for the lab air that is exhausted through the fume hood as well as exchange a minimum of 1.5 air changes per hour as per ASHRAE requirements described in Section 2.1 [15]. The concepts were evaluated based on their ability to supply the required air changes as well regulate the changes.

4.) Ease of maintenance

Maintenance was the next factor to be considered as equipment requiring frequent maintenance are less ideal than those that can be left a long time without being checked. Moreover, a system that can be maintained by the lab users themselves is more attractive than one that requires hiring expert personnel. The easiness of looking after an HVAC system also depends on its location and accessibility to the lab users. Therefore, ease of maintenance includes checkup, repair, level of expertise required to perform the maintenance, as well as location of the equipment and its accessibility.

5.) Intrusiveness of system

Intrusiveness of the humidity control system refers to the physical space that the system takes up that might interfere with workers' day-to-day operations. One of the CIC's major constraints is that the system must be installed either in the mechanical room, integrated into the HVAC duct work or be placed outside the lab. Therefore, a major criterion to base our decision on was whether our design would adhere to these constraints, or require the workers to compromise some physical space in the lab.

6.) Ease of implementation

This criterion refers to the ease of equipment integration with the exciting lab room set up well as well as ease of installation. Additionally, the possibility of a lab shutdown to install the humidity control and the duration of this shutdown play an important factor in defining ease of implementation.

3.2.2 Criteria Weighing

The second step in the concept selection process was to weigh each of the selection criterion according to the level of importance to the potential success of each individual concept. Rather than arbitrarily weighting each criterion, an effective numerical method to evaluate each criterion against one another was used. This numerical method involved the use of a weighing matrix as seen in Table VII, where each criterion is weighted against the others. For example, in row ‘A’, the “ability to achieve humidity set points and desired tolerance” is compared against column ‘B’, capital cost. Since the “ability to achieve humidity set points and desired tolerance” is of greater importance than “capital cost”, the space receives a “hit”, represented by the prioritized criteria’s assigned letter, the letter ‘A’. The number of “hits” each criteria receives is divided by the total number of available spaces in the table, and therefore derives the appropriate weighting for each criterion. As a result of this process, the most important criteria are weighted higher, and as a result, hold a greater impact on the results of the selection process.

TABLE VII: CRITERIA WEIGHING MATRIX

CRITERIA WEIGHING							
		A	**B**	**C**	**D**	**E**	**F**
A	Ability to achieve humidity set points and desired Tolerance		A	A	A	A	A
B	Capital cost			C	D	E	F
C	Ability to regulate air changes				C	C	C
D	Ease of maintenance					D	D
E	Intrusiveness of system						E
F	Ease of implementation						
	Total Hits	5	0	4	3	2	1
	Weighting	0.33	0.00	0.27	0.20	0.13	0.07

According the weighting process, the ability to achieve desired humidity set points and tolerances emerged as the most heavily weight criterion, followed closely by the ability of regulate air changes, which scored second in weight. This result aligns with the customer needs, and complies with ASHRAE HVAC design standards, and thus, validates the reliability of this criteria weighing process. Ease of maintenance came in third and intrusiveness of system came in fourth; illustrating that although frequency of maintenance and the convenience of location are important, they are not as essential as the fundamental principle of keeping the test samples within the desired humidity levels and tolerances. Additionally, the ease of implementation of the humidity control system was weighted fifth in overall priority. The result of this score reflects the readiness of CIC to implement a more difficult to install system over achieving a low maintenance system in the long run. Lastly, capital cost scored received the lowest weight because CIC has given us the flexibility to design and specify products without being constrained heavily by the cost.

3.2.3 Concept Screening

Upon successful completion of the criteria weighting, a concept screening analysis was performed to determine which of the conceptual designs would be investigated further. The concept screening consists of rating each concept against a reference according to the criteria discussed in Section 3.2.2, and using a +/-/0 system. In this system, a design received a "+" if it was better than, a "-"if it is worse than, or a "0" if it performs the same as the reference design. Table VIII shows how each of the concepts were rated according to this system.

TABLE VIII: CONCEPT SCREENING OF INITIAL HUMIDITY CONTROL SYSTEM DESIGNS

CONCEPT SCREENING					
	Concepts				
Selection Criteria	1 (REF)	2	3	4	5
Ability to achieve humidity set points and Desired Tolerance	0	-	+	+	+
Capital cost	0	+	-	-	-
Ability to regulate air changes	0	0	+	+	+
Ease of maintenance	0	+	-	-	-
Intrusiveness of system	0	-	0	0	-
Ease of implementation	0	+	-	-	-
Sum +'s	0	3	2	2	2
Sum -'s	0	2	3	3	4
Sum 0's	6	1	1	1	0
Net Score	**0**	**1**	**-1**	**-1**	**-2**
Rank	2	1	3	3	5
Continue?	Yes	Yes	Yes	Yes	No

Based on the results from the concept screening process, a standalone humidifier with a dedicated fan (concept 2) ranked first, followed by an in-duct humidifier with no insulation changes to the room (concept 1). Third rank was given to both concepts 3 and 4 since both designs involve tightly sealing the room, installing an in-duct humidifier and supplying fresh air from outside the lab to balance an air exhaust vent to the roof. Lastly, concept 5 ranked last due to the complexity of the design. Concept 5 requires a complete overhaul of the entire HVAC system, which would cause lab operations to be suspended for an extended period of time and would cost the most of the all the alternative concepts.

Due to the fact that the criteria used in the concept screening process is heavily weighted, and not to be based on a one-to-one basis, the team chose to move forward with the top four concepts. For each of the four remaining concepts, a scoring process was conducted for each as described in the following section.

3.2.4 Concept Scoring

As a final step in the concept selection process, each concept was rated on a scale of 1 to 4 according to each individual selection criterion. The rating was then scaled according to the weight of each criterion determined through the criteria weighing in Section 3.2.2. The scaled ratings were then summed together to determine the ideal conceptual design to proceed with for a detailed analysis. The concept scoring process can be seen in Table IX.

TABLE IX: CONCEPT SCORING TABLE

CONCEPT SCORING									
		Concepts							
		1		**2**		**3**		**4**	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ability to achieve humidity set points and desired Tolerance	0.33	1	0.33	1	0.33	4	1.33	4	1.33
Capital cost	0.00	3	1.00	4	1.33	2	0.67	1	0.33
Ability to regulate air changes	0.27	1	0.33	1	0.33	4	1.33	4	1.33
Ease of maintenance	0.20	3	1.00	3	1.00	3	1.00	3	1.00
Intrusiveness of system	0.13	4	1.33	1	0.33	4	1.33	3	1.00
Ease of implementation	0.07	3	1.00	4	1.33	2	0.67	1	0.33
Total Score		**5**		**4.6**		**6.3**		**5.3**	
Rank		**3**		**4**		**1**		**2**	
Continue?		**No**		**No**		**Yes**		**No**	

Through the combined results of the concept weighting, screening, and scoring, Concept 3 was selected as the optimal design which was used to move forward through the next phase of the design process. In the following section, a detailed summary of concept 3 is provided, and the benefits of implementing this concept within the FibreCITY lab are discussed.

3.1 Summary of the Conceptual Design

As a result of the conceptual design analysis, Concept 3 was selected because it effectively allows the FibreCITY lab to comply with minimum ASHRAE ventilation requirements as well as provide and maintain the required 50% or 65% humidity for test samples in the lab. Concept 3 is able to achieve the required humidity levels and meet ASHRAE requirements due to three factors. Firstly, the lab envelope will be sealed more tightly by replacing the T-bar ceiling tiles with a sealed grid commercial ceiling product, as well as installing weather stripping and door sweeps on existing doorways. These upgrades reduce air infiltration entering and escaping the lab. Secondly, fresh air from the CIC office space is mixed into the supply air of the lab, at a controlled rate, to balance an air exhaust vent to the roof of the CIC building. Thirdly, a light commercial steam humidifier is integrated in to the supply air duct to inject steam into the supply air and thus humidify the air, at a desired rate, before entering the lab.

Concept 3 proves to be more efficient in implementation and operation than the other suggested concepts. When compared to concept 1, concept 3 ensures that the necessary ventilation of 166 cfm (Section 2.1) is always provided in to the lab, as prescribed by ASHRAE, by mixing a controlled rate of fresh air into the supply air as opposed to just relying on the fume hood and natural infiltration air to supply the ventilation. When compared to concept 2, we find that integrating the humidifier in to the supply air duct, as opposed to a standalone humidifier, eliminates the need to a dedicated electrical and water supply in the lab to power and feed the humidifier. When compared to concept 4, drawing fresh air from the pre-conditioned CIC office air is more economical and faster than drawing from the outdoor air which would require a pre-conditioning unit installed on the roof of CIC before entering the lab. And lastly, concept 3 is more efficient than concept 5 because it eliminates the need to completely over-haul the existing HVAC system and thus significantly saves on the cost of the humidity control project.

In conclusion, concept 3 is unable to achieve a humidity tolerance of ± 2% RH. However, concept 3 is estimated to be able to achieve a humidity tolerance of ± 5% RH. The client had originally targeted ± 2% RH, but upon presenting our findings and consulting with CIC, concept 3 was still selected as the concept to move forward with for further development.

4.0 FINAL DESIGN

Completion of the technical analysis allowed our team to begin product selection for conceptual design 3, which was selected in the conceptual design phase of the project. The key products that were selected for this design configuration include a Nortec Electrode Steam (NH-EL) Humidifier, complete with a pair of modulating controllers, a high limit humidity controller, and an air proving controller. This humidification system was selected to accommodate the calculated humidity load, to fit within the mechanical space, and to provide safe, accurate and reliable humidity regulation. A Greenheck CSP-A200 in-line exhaust fan was selected in combination with a balancing damper to provide appropriate ventilation for the laboratory space. Due to the fact that the envelope of the room was identified as a problematic source of air infiltration, our team selected a GridLock suspended ceiling system to replace the existing T-bar ceiling. Additionally, door sweeps and weatherstripping are to be implemented to reduce infiltration around laboratory doors. Finally, a ConnectSense CS-TH wireless temperature and humidity sensor was selected to provide CIC employees with notification in the event that the relative humidity exceeds the allowable set point tolerances.

The total cost of the design is estimated to be $21,050.72, which encompasses material, labour, and contingency costs. Furthermore, the project will cost CIC an estimated $2,490.00 per year over the course of 30 years. The following sections discuss the methodology that our team used to select the humidity control system product, along with a potential failure modes analysis, proper implementation procedures and an engineering economic study of the system.

4.1 Product Selection

The client needs and specifications will be considered along with the results from the technical analysis in order to select the products for the final design. Equipment that needs to be specified includes a humidifier with controls and sensors, exhaust/ventilation equipment, and insulation materials.

4.1.1 Humidification

The selection of humidification equipment within the FibreCITY laboratory is a critical aspect of our final design. In order to begin the selection process, the client needs and specifications, as outlined within Section 1.3, must first be considered. Key client needs that will influence the selection of a humidifier include: the humidification rate (L/h), the physical size and required location of the humidifier, and the type of humidifier. In addition to the client requirements, our team must also consider the functional requirements for ventilation, humidity load, and the humidity set points as discussed in Section 4.1 of this report. Furthermore, the selected design configuration of Concept 3 will also guide our product selection process by specifying the type and location of humidification equipment. After reviewing all of the requirements, it is evident that there are several key criteria which will guide the selection of humidification equipment. Table X provides a summary of the top 3 selection criteria, and the corresponding requirements for each.

TABLE X: KEY DESIGN CRITERION FOR THE HUMIDIFICATION OF THE CIC LABORATORY

Criteria	Requirements
Humidification rate, L/h of water consumption	3.84 L/h
Type of Humidification System	In-duct
Physical size limitations and required location of equipment	Constrained within the CIC building, or within the mechanical room (multiple dimensional options)

The criteria listed in Table X were used to select the Nortec Electrode Steam Humidifier (NH-EL 010) as the system component to provide humidity to the FibreCITY lab. The NH-EL 010 is an isothermal humidification system, meaning that heat is added to the water that will eventually be used for humidification. The humidifier features a heated vapor generator that produces and supplies non-pressurized vapor into the supply air ducts of an HVAC system. The NH-EL 010 humidifier is able to heat and vaporize water by inducing electrical resistance between multiple electrodes immersed in the water [27]. The interior of the NH-EL 010 humidifier is depicted within Figure 14.

[redacted]

Figure 14 - Interior view of the NH-EL humidification system [27] (REMOVED DUE TO COPYRIGHT)

An electrode steam humidifier is suitable for our application due to the unit's humidification capacity, method of humidification injection, physical size of the equipment, system controls, and system cost.

The first factor to be considered in the selection of humidification equipment is humidity capacity. The ASHRAE Humidity Control Design Guide outlines that one of the major issues associated with implementing a humidity control system is oversizing [20]. If a humidification system is oversized for either humidity load or air flow, the desired system control will be unachievable, and it will be impossible to reach the desired humidity tolerances. Oversizing may also inhibit the system from reaching the target humidity level, either due to overshooting or air oversaturation, which can cause condensation within the ducting. Due to the fact that oversizing is the most common cause of humidification issues, appropriate sizing of the humidifier unit for the FibreCITY laboratory was considered to be the most important criterion.

With the importance of equipment sizing in mind, we may now consider the estimated humidity load for the FibreCITY lab, as presented in Table IV of Section 2.2. Table IV provides an estimate of humidification rates (liters/hour) for a variety of possible operational and environmental scenarios. The highest estimated humidification rate, or worst case scenario, was calculated to be 3.84 L/h, while the lowest rate was calculated to be 0.77 L/h. In order to satisfy the humidity load requirement, the selected Nortec NH-EL 010 humidifier is able to provide variable humidification, with a capacity ranging from 0.9-4.5 L/h. It should be noted that while the humidifier can produce a capacity of 0.72 L/h (an extra 16%) more than required, this is not considered to be oversized. An extra capacity of 0.72 L/h will not cause issues in system control or cause overshooting, as verified by Midwest Engineering (a Nortec distributor). In fact, an extra 16% humidity capacity is necessary to account for unanticipated humidity loads and any decreases in equipment performance due to installation. It should also be mentioned that although the Nortec humidifier is only rated for 0.9 L/h minimum humidity capacity, it is able to accommodate the lowest humidity at a rate of 0.77 L/h (on average) by simply reducing its run time. Due to the fact that the humidification capacity of the NH-EL 010 fully encompasses the required range of values as specified in Table IX and is not oversized, this unit is appropriately sized for the FibreCITY laboratory.

Furthermore, an additional aspect that was considered when selecting the humidifier was the method of humidification injection. The NH-EL 010 system provides humidification into the laboratory air by injecting steam directly into the supply air duct using a single tube vapour disperser nozzle; Nortec refers to this as an atmospheric steam distributor. The Winnipeg supplier, Midwest Engineering, has suggested two distributors be used in the 16” round supply duct in order to ensure appropriate absorption of the steam into the airflow, this can be found in Appendix B.1.1. The atmospheric steam distributor is depicted in Figure 15.

[redacted]

Figure 15 - Nortec's atmospheric in duct steam distributor also referred to as a single tube vapor disperser nozzle [27] (REMOVED DUE TO COPYRIGHT)

The method of humidity injection is important because improper steam distribution can cause condensation, which can cause fungi, mould growth, and corrosion within the ducts. Wetted mat and drum methods of humidification are prone to these issues and were therefore avoided during product selection. The single tube vapour disperser nozzle mitigates the risk of fungi, mold, and corrosion by not allowing the water to pool or become stagnant within the ducting.

Lastly, the client has specified that the humidification unit be optimally located within the mechanical room outside of the laboratory. Space within the mechanical room is limited, however, a small area on the wall is currently unoccupied. The footprint of this available space is approximately 4.2 x 5’, which encompasses the relatively small footprint of the NH-EL 010 humidifier. The humidifier unit measure 26.4” in height 16.5” in width and 14.4” in depth, as shown in Appendix B.1.1. The footprint and volume of the NH-EL010 humidifier will therefore fit within the confines of the CIC mechanical room, ensuring no intrusion to the laboratory.

In addition to meeting the basic client requirements and technical benchmarks, the NH-EL 010 humidifier also offers several benefits to the client. Value added features of this humidifier include: no preconditioning required for inlet water, quiet operation, automatic system drain, safety features prevent misuse, integrates within existing ducting, and unit parts are easily acquirable. Additionally, the unit can be sourced (and maintained) through a local company, Midwest Engineering Ltd., and the humidity data can be remotely monitored through Nortec's online software. While each of these features may not be project needs, they are value added features that ensure easy installation and reliable long term operation.

In summary, the NH-EL 101 fulfills the project needs and requirements for humidification. The humidification capacity of the NH-EL 010 fully encompasses the anticipated range of humidity loads for the FibreCITY laboratory. Lastly, the humidification injection method of the implemented atmospheric steam distributor mitigates the risk of mold and fungi growth, and the humidification unit fits within the constrained space. For these reasons, the NH-EL 010 humidifier is a perfect fit for CIC's FibreCITY laboratory.

4.1.2 Humidification Controls

With the humidifier chosen, selection of the humidification controls can now be considered. The controllers for the humidifier are essential for the successful implementation and operation of the humidification system. The NH-EL 010 humidifier is able to operate through the user interface on the front of the system, or through the use of independent controllers. Due to the fact that the client has specified that the humidifier must be controllable from within the confines of the laboratory, independent controllers will be implemented. The NH-EL 010 humidifier typically operates with inputs signals from three different types of controllers. The manufacturing company, Nortec, advises that all three of these controllers be implemented for optimal operation. Nortec offers their own version of each of these three controllers, which are the simplest to implement with the Nortec humidifier. Due to the fact that Nortec's controllers meet the client requirements and offer the easiest method of implementation, these controllers will be used. Each of the three controller types will be outlined and described in this section. After the descriptions of each controller type have been presented, the way that each sensor meets the client criteria will be discussed.

The first type of controller is an on/off air proving controller. Nortec provides this controller as part number 1329203. The on/off air proving controller is an in-duct sensor that monitors the airflow through the ducts and operates as a fail-safe mechanism. The airflow within the duct must be adequate in order for steam absorption to occur. If sufficient airflow is not present within the duct, pooling and condensation are able to occur. Pooling and condensation result in the growth of fungi and mold within the ducts. Therefore, if the airflow within the duct is not adequate the on/off air proving controller will not allow the humidification system to turn on or continue to operate.

The second type of controller is an on/off high limit humidistat. Nortec's part number for this controller is 2548732. The high limit humidistat operates as an additional fail-safe mechanism. This humidistat is designed to be installed in the ducting at a prescribed distance downwind from the last steam nozzle. The separation distance between the nozzle and high limit humidistat corresponds to the absorption distance, which will be described in greater detail in Section 4.3. The high limit humidistat is set to an 'alert RH value' which is well beyond what is required within the control environment. If this humidistat ever reads this alert relative humidity, the system is immediately turned off and the humidifier will display a notification. The purpose of this controller is to ensure that in the event the in-room wall humidistat fails, the system will not continue to introduce humidity into the space.

The last type of controller is a modulating room humidistat, which corresponds to the Nortec part number 1510142. This controller is located within the control environment and is mounted on the wall. The modulating room humidistat provides in-room variable control of the relative humidity via a digit user interface. The modulating room humidistat can be adjusted by employees working in the laboratory and displays the current relative humidity in the room. The user interface of the modulating room humidistat is depicted by Figure 16.

[redacted]

Figure 16 – Modulating room humidistat user interface [27] (REMOVED DUE TO COPYRIGHT)

The user set point for relative humidity dictates the signals sent to the humidifier, which may turn the humidifier on/off depending on the conditions in the room. The output signal produced by the sensor also regulates or varies the output humidity capacity (L/h) of the humidifier. This feature enables the humidifier's output to be throttled to a percentage of maximum output, depending on the humidity adjustments required in the laboratory space. More than one modulating room humidistat may be implemented, depending on room size and configuration.

The three types of humidification controls will work together in order to provide humidification control to the FibreCITY laboratory and additionally, providing fail-safe mechanisms for the system. A control logic flowchart was created in order to showcase how the controllers would work together in a continuous loop checking the humidity within the room. As mentioned, the control flow chart also demonstrates the fail-safe mechanisms and the logic they implement in order to monitor the system. The control logic flowchart is depicted within Figure 17.

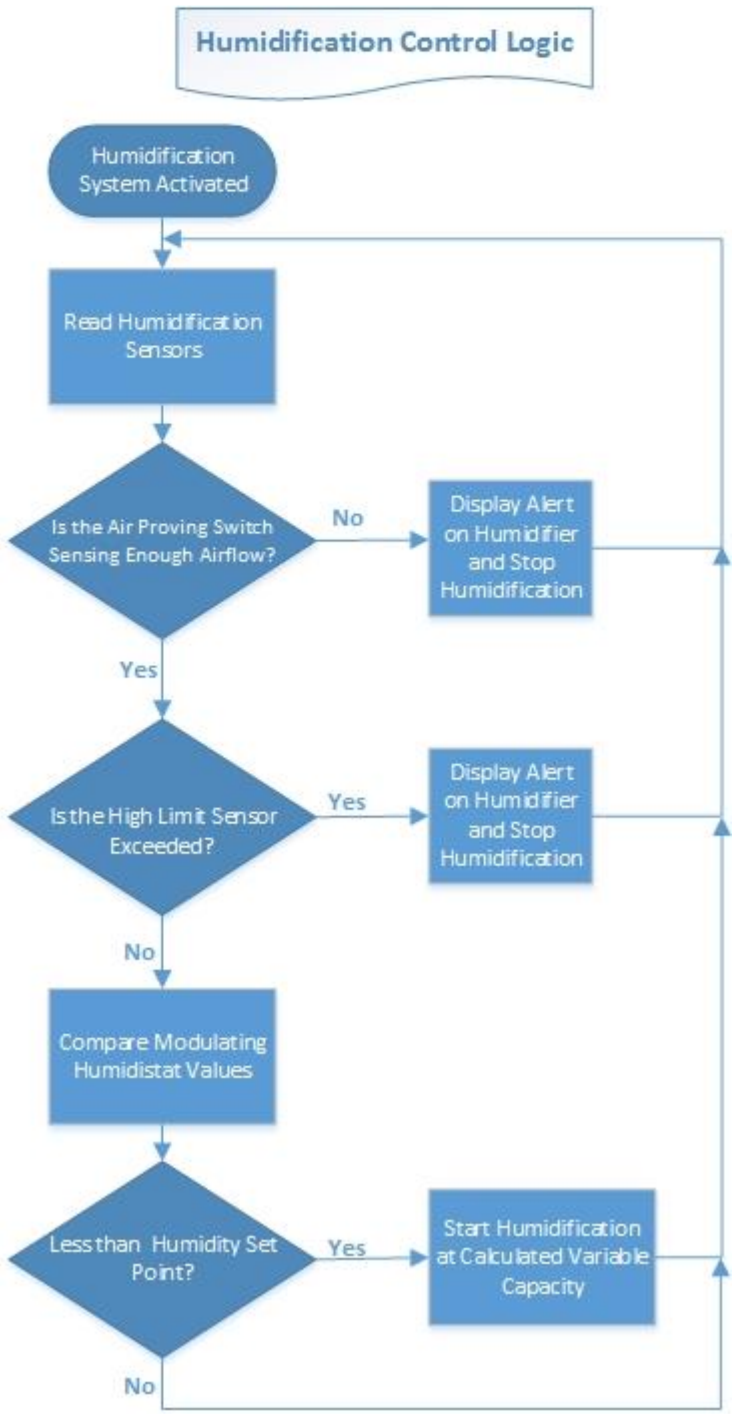


Figure 17 - Displays the humidification control logic upon implementation of all controllers within the humidification system

In summary, three unique control sensors must be implemented along with the NH-EL 010 humidifier. The on/off air proving sensor is necessary to ensure that there is adequate air flow past the steam nozzle, while the high limit sensor is needed to prevent over-humidification in the event of a system failure. Finally, the modulating room humidistat is needed in order to allow users to adjust the humidity set point within the laboratory, and to regulate the operation of the humidifier.

With the controllers for the NH-EL 010 humidifier selected, we will now consider how this combination of Nortec components is able to fulfill the client and project requirements. As previously noted, there are several important criteria that must be meet. These criteria include: accuracy of humidification control, ease of use of controllers, location of modulating controller, and safety. The key performance requirements for the humidification controls have been summarized in Table XI.

TABLE XI: KEY DESIGN CRITERIA FOR THE HUMIDIFICATION CONTROLS

Criteria	Requirements
Accuracy of the humidification control system	+/- 1% RH
Controller User Interface	Digital interface present and easy to use
Controller Location and Quantity	The user interface must be within the FibreCITY laboratory. Two modulating humidistats should be available for use.
Includes Fail-Safe Mechanisms	Restricts operation when system is not stable or safe

The first criterion to be considered is the accuracy of the humidification control system. The humidification controls must be accurate to ±1% RH in order to ensure that ±5% RH is achievable in the laboratory. Section 2.4 discusses this accuracy requirement in detail. It is also important to note that the modulating in-room humidistat is the only controller that will influence the system accuracy. This is because the other two controllers simply act as fail-safe mechanisms and are not directly linked to humidity regulation. The Nortec 1510142 modulating room humidistat meets the requirement of ±1% RH [28]. Therefore, the overall humidification system will fulfill the client requirement of ±5% RH control.

The second criterion to be considered is the controller interface. The client has identified that the controller interface must be easy to program and read and must also display and adjust settings in a digital interface. Again, because both of the on/off controllers are fail-safe mechanisms installed within the HVAC ducting, the in-room modulating humidistat is the only controller that is relevant to these criteria. The controller interface of Nortec's modulating room humidistat is displayed in Figure 16. As the figure suggests, the controller is easily programmable through the use of four physical buttons on the controller surface. The controller also displays and adjusts the relative humidity in digital units and is easy to read and interpret. Considering these features, it is evident that Nortec's modulating room humidistat satisfies the controller interface criterion.

The location and quantity of modulating in-room controller is also an important criterion to consider. The first requirement is that the user interface must be located within the CIC laboratory. As previously noted, the only controller with a user interface is the modulating in-room humidistat. As the name suggests, this sensor will be located within the laboratory, satisfying this aspect of the criteria. The second requirement is that two modulating user interface controllers should be operable together within the laboratory. On page 52 of the NH-EL 010 engineering manual it states that the humidifier can be controlled through the use of up to two modulating humidistats per cylinder [27]. Due to the fact that the humidifier has one cylinder, we can conclude that two modulating in-room humidistats can be used in combination within the CIC laboratory, satisfying the second aspect of this criterion. Finally, these two controllers will be placed in the room next two each of the two thermostats. This is beneficial because the temperature and humidity are interdependent, and should therefore be monitored in adjacent locations. Additionally, locating the humidistat's next to the thermostats ensure that the controllers are also easily accessible. The controller location and quantity is therefore satisfied through the use of two Nortec 1510142 modulating in-room humidistats.

The last criterion specified by the client was system safety. The inclusion of fail-safe mechanisms within the humidification control system satisfies this safety requirement. Nortec's controller portfolio offers two fail-safe mechanisms that are applicable to the humidifier that has been selected for our application and will prevent misuse and damage to the system. Implementation of the on/off air proving controller will ensure that there is adequate air flow prior to engaging the humidifier. The second safety feature is offered by the on/off high level humidistat. This humidistat features a high level alert that will shut down the humidifier if the relative humidity exceeds a pre-set threshold. The implementation of this sensor ensures that over-humidification does not occur in the event that the modulating in-room sensor fails. This is a critical safety feature because over-humidification will not only exceed the environmental design constraints but may also cause water condensation within the ducting and laboratory space. Therefore, Nortec's on/off air proving controller and on/off high level humidistat successfully provide fail-safe mechanisms that protect the system from hazardous operation.

In summary, the controllers that will be used in the design include one on/off air proving controller and one on/off high level humidistat, both located within the HVAC ducting. In addition to these two controllers, two modulating in-room humidistats will be installed within the FibreCITY laboratory. The specifications for each of these control sensors ensure that the humidification system will be accurate, easy to operate, and safe. Details pertaining to how each of these sensors will be installed will be discussed in Sections 4.3.2.1 and 4.3.2.2.

4.1.3 Secondary Exhaust System

Another key aspect of concept 3 was the implementation of a secondary exhaust system for the lab, which was to be interlocked with the existing fume hood exhaust. The reason for another exhaust system was that it was deemed unacceptable (from industry standards perspective as well as the client's) to rely solely on the fume hood to provide the required ventilation rate, as is currently the case in the FibreCITY lab. If the fume hood shuts down for whatever reason, there needs to be a backup exhaust system to displace airborne chemicals out of the lab space. As was determined in Section 2.1, 188 cubic feet per minute (CFM) was the ventilation rate required to ensure the safety of the lab occupants. After investigating the lab's mechanical HVAC drawings, the team noted that the HVAC system designers had indeed requested a secondary exhaust system and specified a roof deck exhaust fan to be installed; specifically the Greenheck Vector-H roof deck exhaust fan as shown in a drawing screen shot in Figure 18:

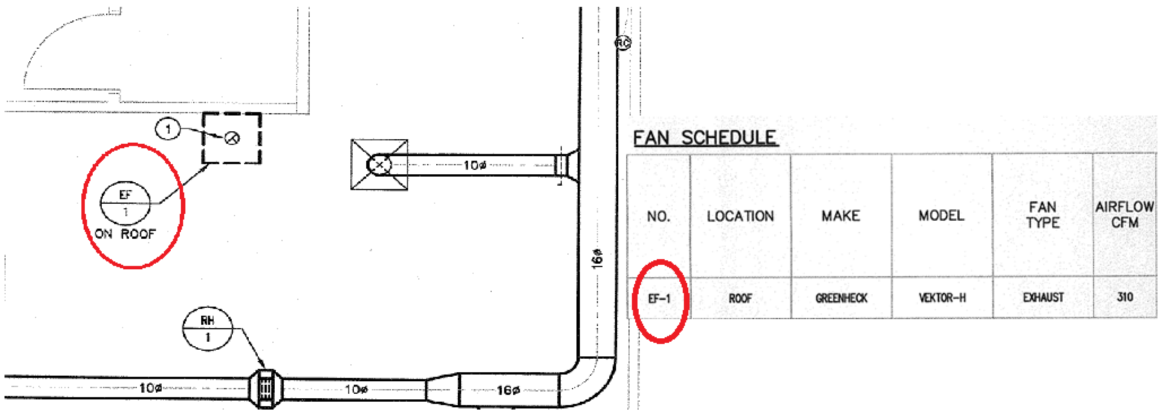


Figure 18 - Screenshot of the original Fibre CITY HVAC system drawings showing the intended installation of a roof deck exhaust fan that interlocks with the fume hood exhaust system [29]

However, to our surprise and the client’s, this fan was not installed and CIC did not have the parts in stock either. Our team had to make the judgment call; whether to re-order this fan to be installed or look into a more economical exhaust system. After researching and consulting with local suppliers, such as E.H Price Sales [30], the team decided that a roof deck exhaust fan was not an optimal solution to exhaust 188 CFM out of the lab, financially or functionally [31]. Instead, an in-duct cabinet fan would meet the ventilation requirements and cost approximately 50% less than the originally specified roof deck fan. The cabinet fan would be connected to the lab through a grille and the exhaust air would be directed through a series of ducts to the outdoor environment. The team has selected the Greenheck CSP-A200 premium inline fan that is specifically designed for inline exhaust applications. The fan is a direct drive model that has forward curved wheels for low sound (0.4 sones), high efficiency (48.2 Watts motor input) and can be calibrated at 190 CFM @ 0.2 in. Wg (inches of water, gauge). Figure 19 shows a depiction of the fan installed in-duct, between the lab ceiling and the CIC roof.

[redacted]

Figure 19 Remote mounted CSP-A200 in line fan with vibration isolators and insulated ductwork [32]
(REMOVED DUE TO COPYRIGHT)

The fan’s features include an aluminum backdraft damper to reduce backdrafts, a square outlet for quick and easy connections, a removable battery pack for ease of maintenance, embossed galvanized steel for rigidity, adjustable mounting brackets and a field rotatable discharge.

For discharge to the outside wall of the CIC building, the team selected the Greenheck model WC- Hooded side wall vent that has a steel construction and a built-in bird screen and damper as Figure 20 shows.

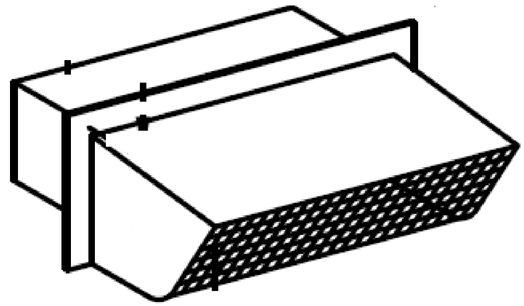


Figure 20 Greenheck Model WC – Hooded side wall vent with built-in birdscreen and damper [32]

The second accessory that pertains to the installation of the in line fan is the hanging kit shown in Figure 21. The kit is designed for vibration isolation, and includes four isolators and all hardware necessary for mounting one unit except for the 0.25 in. x 20 in. threaded rod to be supplied by the contractor. Furthermore, fan mounting brackets include pre-punched mounting holes for ease of installation.

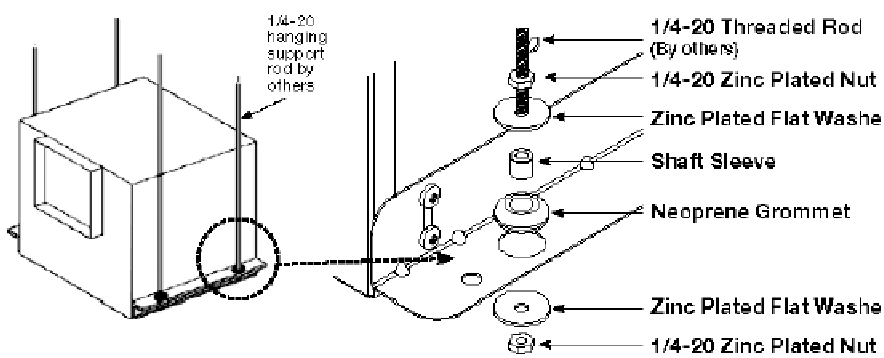


Figure 21 Isolation hanging kit of the CSP-A200 fan, supplied by Greenheck [Appendix B.1.2]

The budget price for the inline fan with the sidewall vent is $350.00 [30], while detailed manufacturers' specification sheets of the fan and the vent are attached in Appendix B.1.2.

Supplementary to the fan, an 8” x 8” 80 Egg Crate grille will be required as well as 7’’ round pipe and two rectangular-to-round fittings at a budget price of $400 and $390 of labor cost [33].

4.1.4 Office Air Intake

Another modification to the FibreCITY lab HVAC system is installing a balancing damper at the inlet section of the indoor unit (IU-1) fan. The balancing damper will be used to transport 188 CFM of CIC office fresh air to the lab, which will replace the exhausted air discussed previously in Section 4.2.3. Figure 22 shows the location where the damper should be installed in the HVAC system schematic, as well as a picture of the desired location taken by our team.

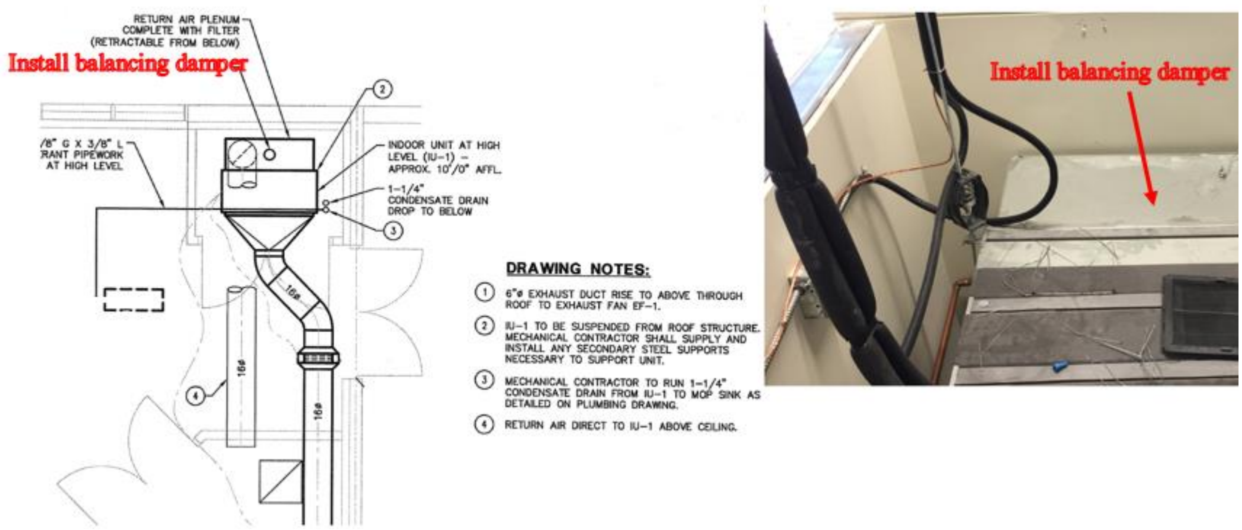


Figure 22 - Screenshot of the original FibreCITY HVAC system drawings as in Appendix A.1.1 (left) and a picture take by the team(right) showing the appropriate location of a balancing damper [29]

The balancing damper, as shown in Figure 23, is a control damper that regulates the flow of office intake air but is not intended to be used in applications as a positive shut-off or for automatic control. The team has selected a balancing damper, as opposed to a modulating damper run by actuators, because the exhaust system will be operating at all times and is always set at 190 CFM. Therefore, the intake air has to always be set to 190 CFM and the damper blade angle needs not vary.

Figure 23 A basic balancing damper that is installed by the sheet metal contractor and adjusted by the balancing contractor to achieve the desired 190 CFM [34] (REMOVED DUE TO COPYRIGHT)

A sheet metal contractor is responsible for installing the balancing damper and a balancing contractor is responsible for adjusting the damper blade to achieve the desired 190 CFM intake. The damper will cost approximately $25 and another $25 to install [30].

4.1.5 Insulation

Selecting appropriate methods of insulation to implement in the FibreCITY lab is an essential aspect of the humidity control system design. The benefits from insulation present themselves in two forms: maintaining the absolute humidity levels within the lab and dampening the high frequency of oscillations present in the current temperature control system. By sealing the major sources of air infiltration, the water vapor provided by the humidifier will remain in the lab without seeping into the surrounding CIC building. The second benefit stems from reducing the +/- 1°C temperature oscillations within the lab. Even with perfectly constant levels of absolute humidity in the lab, the temperature fluctuations alone will result in a +/- 4 % RH oscillation corresponding the oscillation in temperature. Therefore, in order to maintain the tightest tolerances possible, it is required to provide the FibreCITY lab with adequate methods of insulation. Throughout this section, insulation methods for sealing off the current T-bar ceiling tiles, the laboratory doors, and the other miscellaneous infiltration sources will be discussed, with product specifications for each presented.

4.2.5.1 Ceiling Tiles

Through our previous investigation into available literature, and research into competitive laboratory insulation techniques, our team has selected to incorporate an air tight GridLock® Fiberglass Ceiling Suspension System available through Life Science Products [35]. The GridLock® Ceiling Suspension system is an aggregate of Polymer Core 2 ceiling tiles that form a rigid suspension grid system. The Polymer Core 2 is a composite panel with an impervious high density polymer/aluminum core with a smooth, dense composite as the room-side surface. The Polymer Core panels are designed for research facilities, and are finished with a stain resistant, highly chemical resistant and moisture resistant surface [35]. The cross sectional profile of the Polymer Core 2 panel is shown representatively in Table XII.

TABLE XII - CROSS SECTIONAL VIEW OF THE POLYMER CORE 2 CEILING TILE [36] (REMOVED DUE TO COPYRIGHT)

[redacted]

The GridLock® ceiling system is composed of main runners and cross members, similar to the existing T-bar ceiling. However, unlike the current ceiling, the GridLock® ceiling is fitted with gaskets to allow for appropriate air tight sealing. The Selected Access (SA) design provides gaskets at all grid openings, where 90% of the panels are installed with lock down clips from above, while the remaining 10% of the tiles are installed with accessible clips from below. Due to the 10% of accessible tiles with bottom surface locking clips, the SA design allows for easy access to the interstitial space above [35]. Furthermore, the accessible Grid-lock clips require no tools for access from below, where each clip is constructed from Grade 1, Type 2 virgin PVC, and complies with UL 94 V-0 and USDA acceptance criteria [37].

The Polymer Core 2 GridLock® Fiberglass Ceiling Suspension System provides the FibreCITY lab with a range of properties and characteristics, which are illustrated in Table XIII below:

Table XIII - POLYMER CORE 2 GRIDLOCK® FIBERGLASS CEILING SUSPENSION SYSTEM SPECIFICATIONS [35-36]

Property	Rating
Fire Rating	Class 1 ASTM E 84 for flame spread of 25 or less and smoke developed of 65
Beam Strength	3-point bend test; failure @ 110 pounds in middle of 4′ span.
Grid Dimensions	2′ x 2′ or 2′ x 4′ – can be customized
Panel Light Reflectance	LR-1, 0.75 or greater
Panel Minimum Weight	2.0 lbs. per square foot
Panel Finish	Polyester gel coat
Panel Standard Sizes	2′x 2′ or 2′x 4′ (hard lid: 4′ x 8′ or 4′ x 10′)
Panel Thickness	7.5 mm
Core	Moisture insensitive
Thermal Conductivity (W/mK)	0.16 @ 20°C
Thermal Transmittance (W/m^2K)	5.7 @ 20°C
Operating Temperature	-40°C - +50°C

Based on the properties inherent to the Polymer Core 2 GridLock® Fiberglass Ceiling Suspension System, our team expects that the installation of this product will provide exceptional insulation to the ceiling of the FiberCITY lab. Incorporating the GridLock® ceiling will help to limit temperature fluctuations of the current temperature control system, and therefore provide tighter tolerances with regards to the RH within the lab. Additionally, due to the air tight design, the GridLock® system will be able to ensure that the humidity entering the lab stays in the lab, and doesn't escape due to infiltration through the ceiling. Furthermore, it is estimated that for the 756 ft^2 lab space, the cost for Polymer Core 2 tiles, GridLock® ceiling system,labor, job materials and supplies, as well as a job allowance to account for any unforeseen costs will be approximately $3,330 [38].

4.2.5.2 Laboratory Doors

Another key aspect in tightly sealing the FibreCITY lab is to properly seal the gaps and spaces of the laboratory doors. However, in doing so, it is important to realize that the doors are opening and closing throughout the day. Therefore, to install brand new air tight doors may not be cost effective for the purposes of controlling the humidity. For the implementation of our final humidity control system, our design will look to install upgraded door sweep and weather stripping to the existing laboratory doors.

For door sweeps, the Batallion 36" rubber mill door sweep, as shown in Figure 24, was selected due to its ability to properly seal industrial doors and threshold gaps up to ¾ of an inch. The Batallion door sweep sells for $22.25, and is constructed of a 1-3/16" aluminum flange an EPDM rubber insert to seal the bottom gap of the laboratory door [39].

Figure 24 - Batallion 36 inch rubber mill door sweep [38] (REMOVED DUE TO COPYRIGHT)

In addition to the door sweeps installed on each door of the lab, each door will also be upgraded with Batallion Weatherstripping as shown in Figure 25. The Batallion weatherstripping product is constructed of an aluminum flange and silicon insert, which when installed properly significantly reduces air infiltration through the sides and top of the door frame. The weatherstripping unit comes with one top and two side strips, enough for one door, and costs $91.94 per unit [40].

Figure 25 - Batallion weatherstripping [39] (REMOVED DUE TO COPYRIGHT)

There are two sets of double doors that open to the FibreCITY lab. Therefore, four door sweeps, and four weatherstripping sets would be required to properly seal each door, totaling $456.75. Through implementing proper insulation of the laboratory doors, the level of infiltration into the FibreCITY lab from the surrounding CIC office space will be further reduced.

4.1.6 Humidity Alert System

While regulating humidity in the FibreCity laboratory is the primary concern of this design project, the client has also specified that a notification system be implemented as part of our team's design. The notification system must immediately alert CIC employees when the humidity in the FibreCITY laboratory falls outside of the ± 5% RH tolerance band at set points of 50% or 65% RH. Although CIC currently has a temperature alert system, new equipment is required in order to provide alerts for humidity.

The ConnectSense CS-TH Wireless Temperature and Humidity Sensor has been selected to monitor the humidity. This device accurately senses temperature to ± 0.5 °C and humidity to ± 2% RH in the operating range of 0-80 °C and 0-100% RH. The CS-TH features built-in WiFi connectivity, which can be used to provide text messages, phone calls, and email notifications with no monthly service fee. A USB interface is used to power the device though an included adapter, which can be plugged into any standard wall outlet. Four AA batteries provide backup power in the event of a power outage. Alert notifications for temperature and humidity can be easily set and modified though an online user interface, accessed via a web browser or mobile application. Temperature and humidity history can also be viewed using the online interface.

The CS-TH is to be installed in the Southeast corner of the laboratory, near the existing alert system. Industrial Velcro included in the product packaging will be used to affix the device on the wall, directly above the electrical outlet. This method of installation will allow the sensor to be easily removed in the case that a connection to a computer is required for re-configuration or updates. Figure 26, shows this device attached to a wall.

Figure 26 - CS-TH Wireless Temperature and Humidity Sensor, external dimensions 4.2 x 2.8 x 1.6 inches [41] (REMOVED DUE TO COPYRIGHT)

4.1.7 Summary of Product Selection

All products selected for CIC's humidity control system are listed in Table XIV, complete with an estimated material cost for each.

TABLE XIV: SUMMARY OF PRODUCTS SELECTED

	Product Description	Product ID	Quantity	Estimated Cost (each)
Humidification	Nortec Electrode Steam Humidifier	NH-EL 010	1	$ 3 785
	Steam Injection Nozzle	-	2	
	Modulating In-Room Humidistat	1510142	2	
	On/Off High Limit Humidistat	2548732	1	
	On/Off Air Proving Sensor	1329203	1	
Ventilation	Greenheck Inline Exhaust Fan	CSP-A200	1	$ 350
	Greenheck Hooded Sidewall Vent	WC	1	
	Exhaust Ceiling Grille	Model-80	1	$400
	Exhaust Ducting	7" Round	1	
	Ducting Fittings	Rectangular to Round	1	
	Intake Air Damper	-	1	$ 25
Insulation	GridLock Fibreglass Ceiling Suspension System	-	756 sq. ft.	$ 3 330
	Batallion Rubber Mill Door Sweep Sets	36"	2	$ 23
	Weather Stripping	-	1	$ 92
Accessories	Humidity Alert Device	CS-TH	1	$ 150

While this table provides a useful summary of the key products required to implement this design, the installation and operational costs associated with the design will be considered in detail in Section 4.4 of this report.

4.2 Product Failure Modes and Effects Analysis

The identification of potential failure modes for each of the products selected for the humidity control system (Section 4.1) is critical to ensure that proactive and reactive measures are carried out in an efficient and timely manner; beginning with the installation stage and carried throughout the lifetime of the products. This section addresses a number of risks associated with the humidity control system, along with their causes and potential effects on the system functionality. The mitigation solutions that our team recommends for the top risks are discussed in detail in Section 4.3.

To identify possible failures in the system and the subsequent consequences of those failures, we have chosen a step-by-step approach known as Failure Modes and Effects Analysis (FMEA). This approach is a highly effective tool that provides the HVAC contractors and CIC with a visual to analyze the failure modes of the system, estimate the effects of failure, as well as devise ways of controlling the product so that failure can be averted.

Each failure mode is evaluated in terms of three factors: severity, probability and detectability. For example, a high risk failure mode of a product is one that causes severe effects to the functionality of the humidity control system, is highly probable, and very unlikely to be detected in a timely manner. Conversely, a low risk failure mode does not severely disrupt the system, is less likely to occur and can be easily dedicated in a timely manner. In order to quantify the various risks associated with the design, each potential failure mode is ranked from 1-10 for each of the three FMEA factors. The potential failure modes are then assigned a risk priority number (RPN), which is the product of the associated severity, probability and detectability rankings. The higher the RPN, the higher the risk involved with the failure, and the more immediate an intervention to remedy to failure mode is required. Tables XV, XVI, and XVII summarize the ranking criteria for the failure’s severity, probability and detectability, respectively.

TABLE XV: RANKING CRITERIA FOR FAILURE'S SEVERITY [42]

Effect	SEVERITY of Effect	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe system operation without warning	**10**
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe system operation with warning	**9**
Very High	System inoperable with destructive failure without compromising safety	**8**
High	System inoperable with equipment damage	**7**
Moderate	System inoperable with minor damage	**6**
Low	System inoperable without damage	**5**
Very Low	System operable with significant degradation of performance	**4**
Minor	System operable with some degradation of performance	**3**
Very Minor	System operable with minimal interference	**2**
None	No effect	**1**

TABLE XVI: RANKING CRITERIA FOR THE PROBABILITY OF FAILURE [42]

PROBABILITY of Failure	Failure Prob.	Ranking
Very High: Failure is almost inevitable	>1 in 2	**10**
	1 in 3	**9**
High: Repeated failures	1 in 8	**8**
	1 in 20	**7**
Moderate: Occasional failures	1 in 80	**6**
	1 in 400	**5**
	1 in 2,000	**4**
Low: Relatively few failures	1 in 15,000	**3**
	1 in 150,000	**2**
Remote: Failure is unlikely	<1 in 1,500,000	**1**

TABLE XVII: RANKING CRITERIA FOR THE FAILURE'S LIKELIHOOD OF DETECTION [42]

Detection	Likelihood of DETECTION by Design Control	Ranking
Absolute Uncertainty	Design control cannot detect potential cause/mechanism and subsequent failure mode	**10**
Very Remote	**Very remote chance the design control will detect potential cause/mechanism and subsequent failure mode**	**9**
Remote	**Remote chance the design control will detect potential cause/mechanism and subsequent failure mode**	**8**
Very Low	**Very low chance the design control will detect potential cause/mechanism and subsequent failure mode**	**7**
Low	**Low chance the design control will detect potential cause/mechanism and subsequent failure mode**	**6**
Moderate	**Moderate chance the design control will detect potential cause/mechanism and subsequent failure mode**	**5**
Moderately High	**Moderately High chance the design control will detect potential cause/mechanism and subsequent failure mode**	**4**
High	**High chance the design control will detect potential cause/mechanism and subsequent failure mode**	**3**
Very High	**Very high chance the design control will detect potential cause/mechanism and subsequent failure mode**	**2**
Almost Certain	Design control will detect potential cause/mechanism and subsequent failure mode	**1**

Upon assigning a RPN to each failure mode, a recommendation is made for a pro-action or reaction, that would either alleviate the failure or isolate the system from the failed component. The higher the RPN, the closer the contractor or CIC needs to monitor that failure mode and ensure that recommended actions be carried out in a timely manner.

Table XVIII lists 15 different failure modes that our team has identified relating to all aspects of the FibreCITY humidity control system. More specifically, each potential failure mode is categorized into either humidification, controls, ventilation or lab insulation. Each failure is listed with its cause, potential effects, severity, probability, likelihood of detectability, control procedures currently in place, and recommended actions. The recommended actions that required for the top are performed by CIC personnel, however some require the intervention of a HVAC contractor.

TABLE XVIII: FIBRECITY COMPLETED FMEA

Item number	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)
	Humidification									
1	Humidifier Cylinder	Cylinder Spent Warning	Increasing loss of humidification capacity as usage continues	3	Continued Usage	10	Humidifier Warning	4	**120**	Replace Cylinder within 72 hours
		Cylinder Spent System shut off	No humidification capacity	7	Continued Usage	10	Humidifier Alert	2	**140**	Replace Cylinder Immediately
2	Drain Valve	Partial blockage	Liquid water build up, optimal function of the system lost	3	Built up scale within the valve	10	Human Inspection	5	**150**	Inspect Routinely, Clean Out Scale
		Complete blockage	Liquid water build up, system fails	7	Built up scale within the valve	10	Human Inspection	3	**210**	Inspect Routinely, Clean Out Scale
3	NH-EL 010	Mechanical or Electrical Failure	Total humidification control lost	7	Continued Usage	3	A1 Humidification Alert Device	2	**42**	A1 Humidification Alert Device
4	Atmospheric Steam Distributor	Not level within ducting	Inadequate vapor distribution, results in water pooling	4	Installation Error	3	Installation Guide	7	**84**	Ensure Correct Installation, Visual Inspection of Ducting Routinely
		Blockage within the distributor nozzles	Inadequate vapor distribution, results in water pooling	4	Continued Usage	3	Human Inspection	7	**84**	Visual Inspection of Ducting Routinely
	Controls									
5	C3 Modulating Controller	Power loss	No signal to humidifier, loss of function	5	Electrical shortage or power outage	4	Human Inspection	1	**20**	Preventative Maintenance
		Loss of calibration	Unable to achieve %RH tolerance	4	Installation error or manufacturing defect	5	Humidity Alert Notification	3	**60**	None
6	C2 High Limit Fail-Safe Controller	Power loss	No signal to humidifier, loss of fail safe	5	Electrical shortage or power outage	4	Humidifier Warning	1	**20**	Preventative Maintenance
		Loss of calibration	Unreliable RH high limit fail safe	2	Installation error or manufacturing defect	3	Humidity Alert Notification	3	**18**	None
7	C1 Airflow Fail-Safe Controller	Power loss	No signal to humidifier, loss of fail safe	5	Electrical shortage or power outage	4	Humidifier Warning	1	**20**	None
		Loss of calibration	Unreliable airflow failsafe	2	Installation error or manufacturing defect	3	Human Inspection	6	**36**	None
	Accessories									
8	A1 Humidification Alert Device	Outlet power loss	Device is required to rely on battery power	1	Power outage or surge	4	Alert Notification	3	**12**	None
		Loss of WiFi Connectivity	No notification provided regarding loss of humidity regulation	2	IT network failure, maintenance, or power outage	6	Alert Notification	3	**36**	None
	Ventilation									
9	CSP-A200 In-Line Exhaust Fan	Mechanical/electrical fatigue	Loss of ventilation	7	Continued usage	3	Human Inspection	5	**105**	Inspect routinely
10	Exhaust Fan/Fume Hood Interlock	Electrical failure	Loss of ventilation	8	Interlock circuitry failure	5	None	3	**120**	Check interlock relay connection
			Excessive ventilation (x2 required ACH)	2	Interlock circuitry failure	5	None	3	**30**	Check interlock relay connection
11	7" round ducting	Excessive use of elbows, bends, offsets	Static pressure losses	2	Obstructions in the ductwork routing from lab to sidewall vent	4	None	6	**48**	Ensure straight ducting as much as possible
		Scratching of protective coating	Corrosion of bare metal and leakage of exhausted air leakage	7	Corrosive chemicals in the lab	4	Adequate coating layer during installation	6	**168**	Inspect routinely
12	Intake Damper	Unbalanced airflow	Failure to achieve required CFM in the lab	3	Perimeter gasket wear or poor installation	3	Damper blade positioning	6	**54**	Inspect blade position every 4-6 months
	Insulation									
13	Door Sweep	Rubber seal wears over time	Loss of humidity within the lab	3	Continued use	4	Human inspection	1	**12**	Inspect monthly
		Screws attaching sweep to door loosen	Loss of humidity within the lab	3	Continued use	4	Human inspection	1	**12**	Inspect monthly
14	Weatherstripping	Rubber seal wears over time	Loss of humidity within the lab	3	Continued use	4	Human inspection	1	**12**	Inspect monthly
15	Ceiling Tile Gaskets	Gasket becomes ridged	Loss of humidity within the lab	2	Temperature below 40°F	2	Human inspection	4	**16**	Inspect accessible panels monthly

As shown in Table XVIII, the highest risks can be attributed to the humidifier cylinder performance (item #1), blockage of the humidifier drain valve (item #2), operation of the CSP-A200 in-Line Exhaust Fan (item #9), the interlock between the fume hood and the secondary exhaust system (item #10), and lastly, the protective coating that is applied to the 7” round ducting of the secondary exhaust system (item #11).

The humidifier cylinder is a core component of the humidifier assembly, as it holds the water and steam that is eventually injected into the duct. A malfunctioning cylinder will result in failure to inject the proper amount of steam into the ducts, therefore resulting in a failure to reach the desired humidity level. Furthermore, the drain valve is responsible for draining any accumulated water inside the humidifier cylinder. A partial or complete blockage of the drain valve will result in water build up in the cylinder, and eventually impede the generation of steam. Drain valve blockage was assigned an RPN of 210 because of its direct influence on the humidity level in the room. A detailed discussion of proper installation and risk mitigation for the humidifier cylinder and drain valve are presented in Section 4.3.2.2.

In addition to humidification failure modes, some risk is also associated with the ventilation mechanism in the FibreCITY lab. More specifically, the risk associated with the inline exhaust fan of the secondary exhaust system, and the interlock relay between the exhaust system and the fume hood. The risks associated with the fan and interlock relay failure are high (RPNs of 105 and 120, respectively) since they both disrupt the interlock system, leading to either a loss of ventilation or excessive ventilation in the lab. A loss of ventilation would result in failure to remove the airborne toxins of the chemicals used in the lab, while excessive ventilation would result in strong currents and human discomfort. Ultimately, both restricted and excessive ventilation would result in loss of humidity control within the lab.

The last major risk in the FMEA table is the mechanical damage or scratching of the protective coating applied to the 7” round duct of the secondary exhaust system, with an RPN of 168. Because of the thin coatings generally used, pinhole defects in the coating are relatively common, which leads to corrosion of the duct bare metal and leakage of exhausted air. In order to elucidate the proper installation and risk mitigation techniques for duct protective coatings, a detailed discussion is presented in Section 4.3.2.4.

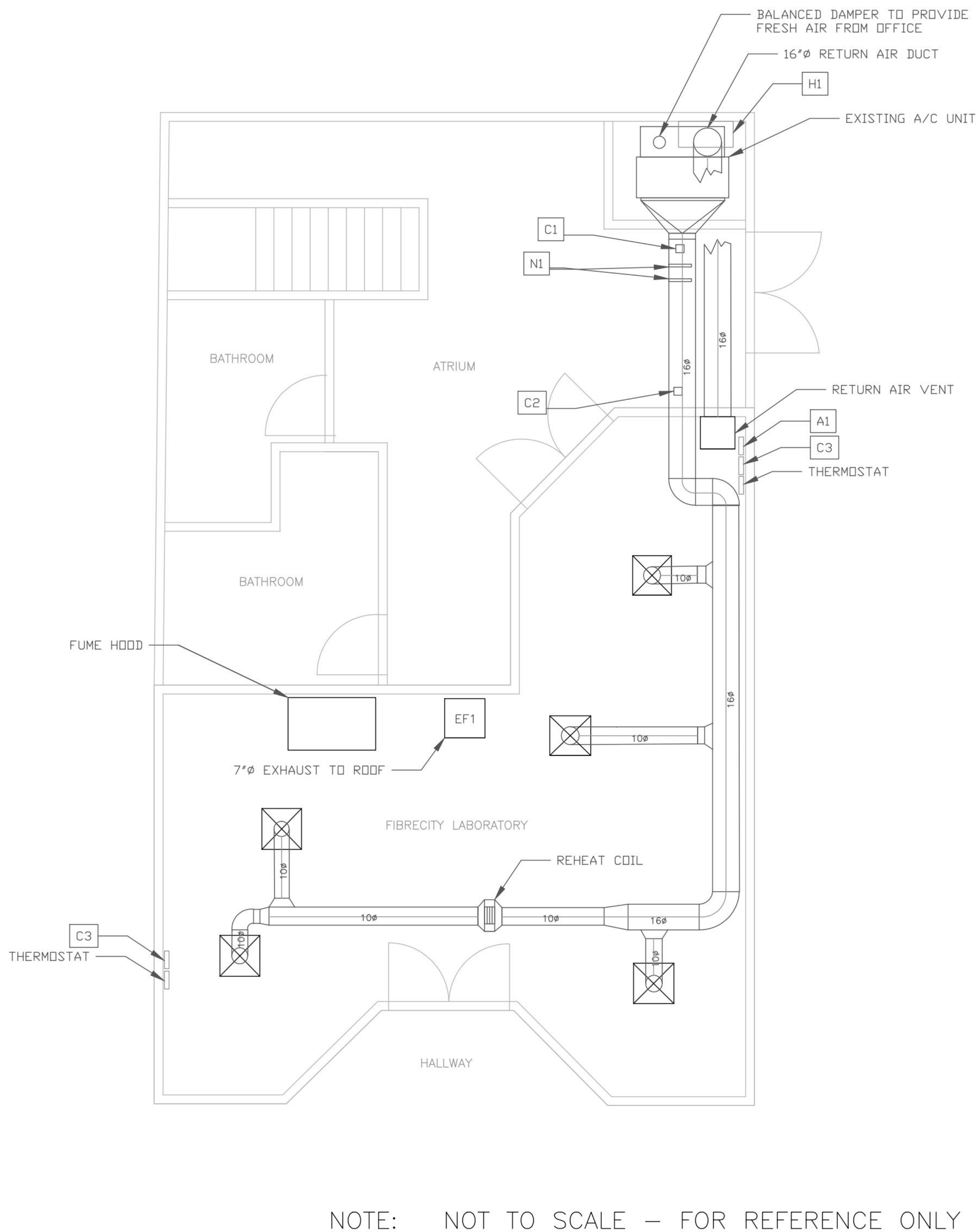
4.3 Methods of Implementation

With products selected and an FMEA performed on the detailed final design, it is important to consider the key aspects regarding the installation and implementation of the humidity control system. In this section, an engineering drawing is presented to communicate the physical configuration of the final design and the installation procedure for each of the key products is discussed.

4.3.1 Engineering Drawing

An engineering drawing was produced to show the relative positioning of the selected components in the FibreCITY laboratory (Figure 27).

REVISIONS				
ZONE	REV	DESCRIPTION	DATE	APPROVED



MECHANICAL COMPONENTS			
ID	DESCRIPTION	QUANTITY	NOTES
H1	NORTEC NH–EL 010 ELECTRODE STEAM HUMIDIFIER	1	INSTALLED ON WALL IN MECHANICAL ROOM UNDER MITSUBISHI A/C UNIT, INTERLOCK WITH A/C UNIT FAN
C1	NORTEC 1329203 ON/OFF PROVING CONTROLLER	1	INSTALLED IN DUCT >0.82FT FROM START OF 16"ø SUPPLY DUCT
C2	NORTEC 2548732 ON/OFF HIGH LIMIT HUMIDISTAT	1	INSTALLED IN DUCT 10FT AFTER SECOND N1
C3	NORTEC 1510142 MODULATING ROOM HUMIDISTAT	2	INSTALLED ADJACENT TO EXISTING THERMOSTATS
N1	NORTEC ATMOSPHERIC STEAM DISTRIBUTOR NOZZLE	2	INSTALLED SEQUENTIALLY IN DUCTING, >0.82FT FROM CI AND >0.82FT SEPARATION
EF1	GREENHECK CSP–A200 INLINE FAN	1	INSTALLED INLINE IN DUCT, VENT TO ROOF, INTERLOCK WITH FUME HOOD
A1	CONNECT SENSE CS–TH WIRELESS HUMIDITY ALERT	1	INSTALLED IN REPLACEMENT OF EXISTING TEMPERATURE ALERT DEVICE

FILE NAME	FIBRECITY MECHANICAL		
DRAWN MH			
CHECK JB, AL, TW	SIZE ANSI C	DWG NO 1234	REV
APPR.			
ISSUED NOV 30, 2015	SCALE NTS		SHEET 1 OF 1

Figure 27 - Engineering drawing shows the relative location of new and existing components in the FibreCITY laboratory made by Team 3.

4.3.2 Installation Procedure and Implications

The following section provides details regarding the installation of each product specified in Section 4.1. Our team has considered the installation of the equipment and materials in order to provide CIC with a general idea of the time, implications, and risks associated with the installation of each product.

4.3.2.1 Humidification

Proper installation of the humidifier is crucial to the smooth operation and successful control of humidity within the FibreCITY laboratory. The basic installation requirements for the NH-EL humidifier will be outlined in this section, including: system wall mounting, in-duct nozzle installation, power source connection, and plumbing connections. Implications that may arise due in the installation process will also be discussed in order to provide transparency for the client. Lastly, basic servicing and maintenance of the humidifier will be considered in this section.

The NH-EL 010 humidifier is to be installed within CIC's laboratory mechanical room. The humidifier will be mounted on the back wall, under the existing return air duct that feeds the Mitsubishi air conditioning unit, as per the drawings provided in Section 4.3.1. Figure 28 shows the location on the wall where the humidifier will be installed within the mechanical room.

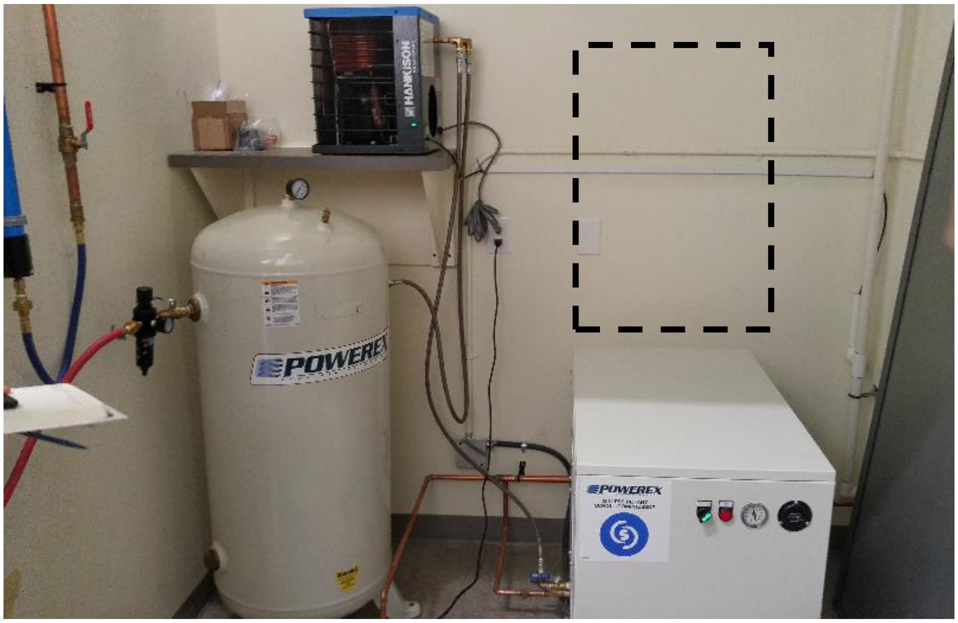


Figure 28 - CIC's current mechanical room layout [43]

The NH-EL 010 humidifier humidification unit will be mounted in the location on the wall denoted by a dashed line in Figure 28 above the POWEREX air compressor. Inspection of Figure 28 shows that there are two existing electrical lines will have to be moved down the wall in order to accommodate mounting the humidifier in this location. As per the installation manual, the humidifier must be installed with enough room on each side to allow the humidifier cabinet door to open for servicing. As well, the unit must also be installed with adequate space above and below the cabinet to allow for connections to the power, water supply, and steam injection line. The recommended spatial dimensions for installation of the humidifier unit are shown in Figure 29.

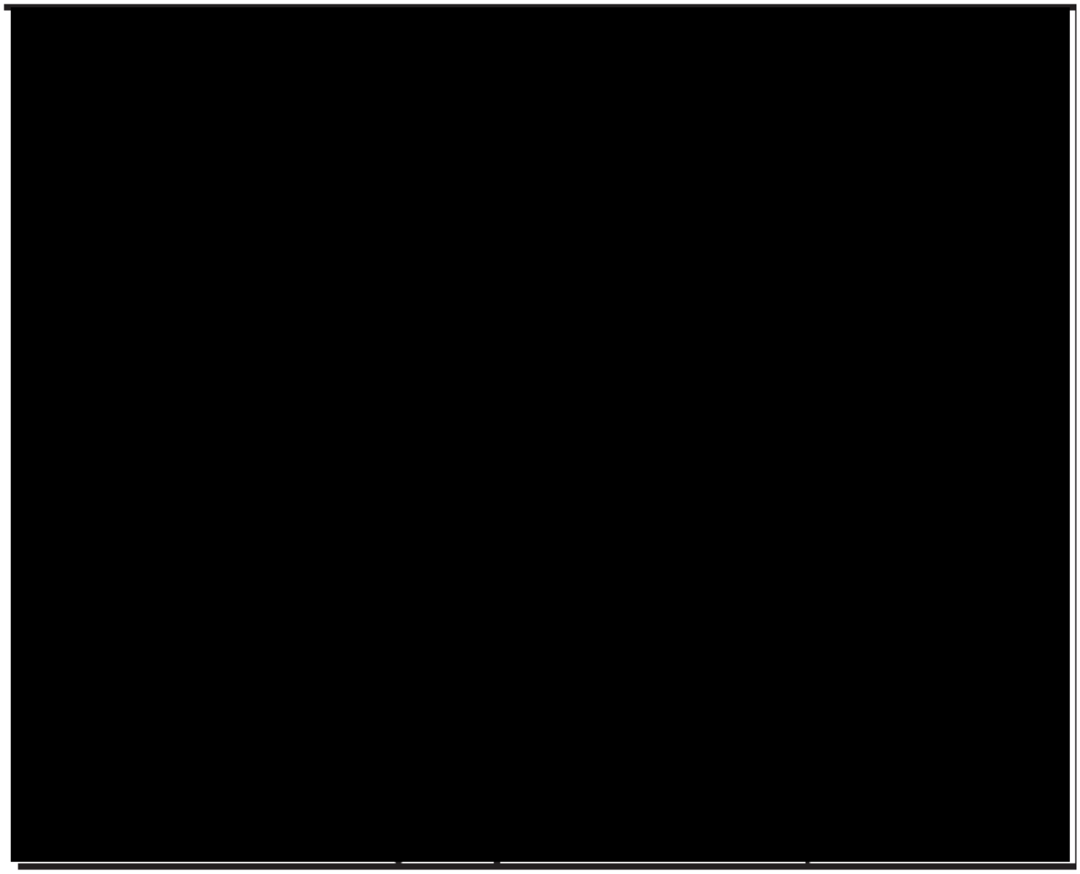


Figure 29 - Recommended spatial dimensions surrounding the NH-EL 010 humidification unit [27] (REMOVED DUE TO COPYRIGHT).

While adhering to the recommended spatial dimensions shown in Figure 29, the NH-EL 010 can be mounted to the wall according to the mounting procedures outlined on page 40 of the engineering manual for the NH-EL 010 [27].

In addition to mounting the humidifier unit, two atmospheric steam distributors (nozzles) must be installed into the 16" diameter supply ducting as noted on the engineering drawing in Section 4.3.1. The steam distributors must be installed according to absorption distance, which is the distance required for vapor to adhere to the air particles passing through the supply air duct. This distance is calculated using the airflow (cfm) flowing through the duct, the humidification rate (L/h), the RH of the air prior to injection, the method of injection, the method of humidification, and the size of the duct. This analysis is completed by the supplier of humidification equipment due to the fact that the variables affecting the absorption distance are specific to each humidifier and steam injector. The absorption distance required for our application was calculated by Midwest Engineering to be 0.82 feet as shown in Appendix B.1.1. Considering this absorption distance, the two atmospheric steam distributors for the humidifier should be mounted 0.82 feet apart from each other and 0.82 feet from the nearest downstream duct fitting or obstruction. The recommended location for the installation of these two nozzles is specified in the engineering drawing provided in Section 4.3.1. The specific process for installing the atmospheric steam distributors should follow the process outlined on pages 45-49 of the NH-EL 010 engineering manual [27]. It is important to note that FibreCITY HVAC system will have to be temporarily switched off for the duration of the installation of the atmospheric steam distributors.

While the humidifier may be mounted and nozzles installed in the ducting, several utility connections are required before the humidifier becomes operational. The connections required for the NH-EL 010 humidifier include those for the power source and plumbing. The voltage required for the humidifier is within the range of 208-600 Volts, while the max input power is 3.8 kW. The power source connection is depicted in Figure 30.

[redacted]

Figure 30 - Wiring for the NH-EL 010 to a single phase power source [44] (REMOVED DUE TO COPYRIGHT).

The power connection and wiring should be installed in accordance with page 24 of the installation manual, as well as per trade best practices [44]. The required plumbing connections for both the supply water and drain are shown in Figure 31.

Figure 31 – Depicts the plumbing and connections for supply water and drain [44] (REMOVED DUE TO COPYRIGHT).

The plumbing connections should be installed to the humidifier as outlined in Figure 31, as well as per trade best practices. Detailed instructions can be found within the installation manual on page 14 [44]. During the installation of the water and power connections, temporary outages to zones within the CIC building may be necessary.

Once installed and operational, the NH-EL 010 humidifier system will require basic service and routine preventative maintenance. The installation guide for the humidifier prescribes maintenance and service procedures for the system and will be discussed in more detail in Section 4.3.2.6. There are only two types of preventative maintenance required for the NH-EL 010 humidifier: component replacement and cleaning. The electrode cylinder and O-ring part each require replacement when the cylinder is “spent”. Notification as to when the cylinder is spent will be indicated on the humidifier interface, located on the front panel of the humidifier. A step-by-step guide to cylinder replacement can be found in the installation manual, pages 63-69 [44]. Drain valve cleaning is also required at the same time a new cylinder is installed. A step-by-step guide to drain valve cleaning is also described within the installation manual, pages 63-69 [44].

Proper installation and execution of maintenance procedures will ensure that the NH-EL 010 humidifier and nozzles function optimally, furthermore providing adequate humidity control to the CIC FibreCITY laboratory. Key aspects that should be considered when installing the humidification system including the mounting location of the humidifier, in-duct nozzle location, and power and water utility connections. While this section has discussed the basic elements that should be considered when implementing this humidification system, contractors should always refer to the installation and engineering manuals provided by the equipment manufacturer.

4.3.2.2 Humidification Controls

While a set of Nortec control sensors have been selected to both work with the Nortec humidifier and satisfy client needs, it is also important to consider how these components will be installed. The discussion for the controllers will primarily focus on the installation location for the on/off air proving switch, the on/off in duct high limit humidistat and the two modulating in-room humidistats. Proper controller placement is a requirement for the successful operation of the overall humidification system.

The first controller to consider is the on/off air proving switch. As outlined in Section 4.2.2, this controller ensures the air flow through the duct is sufficient for vapor absorption to occur and operates as a fail-safe mechanism. The on/off air proving switch is to be installed directly downstream from the Mitsubishi air condition unit, within the 16” diameter supply air duct, and prior to the atmospheric steam distributor. This location is also specified on the engineering drawing, as presented in Section 4.3.1

The installation location for the on/off in-duct high limit humidistat is also specified on the engineering drawing. As discussed in Section 4.2.2, this controller is a fail-safe mechanism to ensure the humidity levels within the ducting stays below critical levels. The on/off in-duct high level humidistat is to be installed in the 16” diameter supply air duct at least 0.82 feet downstream from the second atmospheric steam distributor. This distance corresponds to the absorption distance, which is unique to the application and as specified by Midwest Engineering. With the absorption distance restriction considered, it is important to note that the product installation guide indicates that the controller should be installed well after the atmospheric steam distributor, as outlined on the engineering drawings in Section 4.3.1 and the installation manual pages 22-32 [44]. Due to the fact that the manual specified distance is greater than the absorption distance, the on/off high humidity limit controller should be installed at least 10 feet downstream from the second atmospheric steam distributor. The location of installation should also be appropriate for easy access and servicing.

The last controller to be considered is the modulating in-room humidistat. As outlined in Section 4.2.2, this controller produces a varying output signal corresponding to the humidity capacity that is required at any given instant from the humidifier. As previously discussed, two modulating in-room humidistats will be implemented in order to provide uniform humidity control throughout the FibreCITY laboratory. Each of the two modulating controllers is to be installed adjacent to the existing thermostats. Wires for these two controllers should be routed through the cavities of the laboratory’s exterior walls and through the ceiling to the mechanical room, as per trade best practices [44].

If all four controller devices are installed in the locations as recommended above, the system is expected to function optimally, providing accurate humidity control within the FibreCITY laboratory. It should be noted that the installation of controllers within the ducts will result in temporary loss of use of the HVAC system, as the ducting must be cut to mount both types of on/off controllers. While this section has addressed the critical aspects associated with installing each type of controller, contractors should refer to Nortec’s installation guide, pages 22-32, and should adhere to trade best practices [44].

4.3.2.3 Secondary Exhaust System

This section outlines the proper methods and procedures required to install the secondary exhaust system. As described in Section 4.2.3, the system consists of the CSP-A200 inline fan, Model-80 Egg Crate grille, 7” round pipe, two rectangular-to-round fitters and the Greenheck WC hooded sidewall vent.

The flow diagram in Figure 32 shows the progression of the duct work required starting from the grille in the lab to the sidewall exhaust vent.

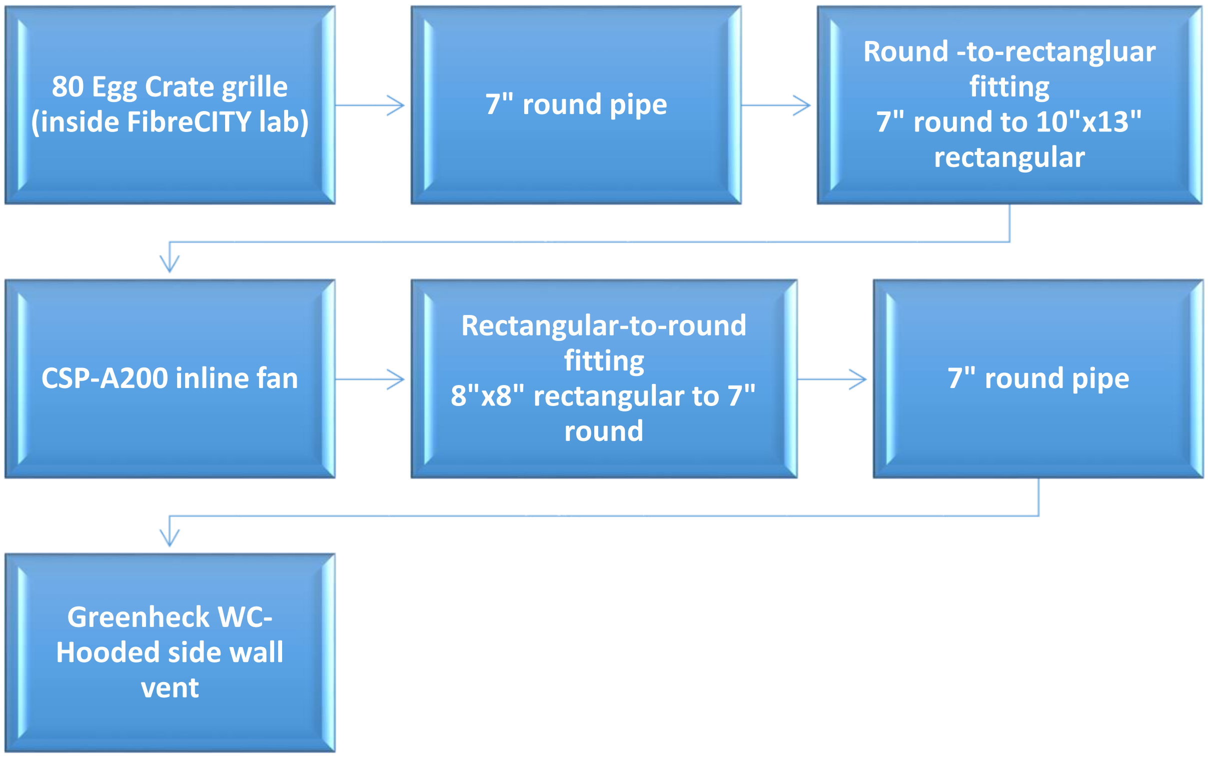


Figure 32 Flowchart of duct work required for installation of secondary exhaust system in the FibreCITY lab

The HVAC contractor should start by planning and measuring the duct routing from the lab ceiling to the side wall vent to ensure the right amount of ducting is used. Systems and ductwork shall be constructed to maintain negative pressure within all portions of the exhaust ductwork when the fan is in operation [45]. According to the Scientific Equipment Furniture Association, Standard SEFA 1.2-2002, smooth duct interior surfaces are recommended for minimal friction losses within the duct. Elbows, bends and offsets within the duct system should be kept to a minimum and should be long sweep in design configuration in order to minimize static pressure losses.

Exhaust duct material shall be in accordance with Chapter 34 on Duct Design of the ASHRAE 2015 Handbook Fundamentals and ANSI/AIHA Z9.5-2012 [45]. The material of the ducts should be resistant to corrosion by the agents to which they are exposed, and non-combustible if oxidizing agents that pose a fire or explosive hazard is used. According to ANSI/AIHA Z9.5-2012 Section 5.3.1.2, solid metal ductwork has good fire characteristics but has inferior corrosion resistance for some chemicals. Solid plastic ductwork, on the other hand, has good corrosion resistance but may not have acceptable fire resistance. An economical material that can be used when appropriate and if proper care is used in installation and maintenance is a metal duct with a protective coating. However, because of the thin coatings generally used, pinhole defects in the coating may be relatively common, which would eventually lead to a very small amount of leakage. Any mechanical damage or scratching of the coating in installation or maintenance would have to be immediately and properly repaired or the bare metal revealed in the scratch will be corroded. CIC must spend more time and money during installation to make sure the contractor coats all exposed metal during initial installation and similar care must be exercised whenever the coated exhaust duct is modified during renovations.

Regarding operation, ANSI/AIHA Z9.5-2012 Section 5.3.2.11 states that exhaust systems shall operate continuously to provide adequate ventilation at all times and to prevent backflow of air into the lab. Moreover, emergency backup power shall be provided to the secondary exhaust fan as well the fume hood fan in order to maintain operation even under power outage situations.

Lastly, it is the HVAC contractor's responsibility to inspect the side wall material and determine the best method to drill a slot for the side wall vent. As a rule of thumb, the vent should be nailed into place, spacing the nails every 4 inches around the perimeter of the vent flange [46]. The nails should be 1 inch in from the vent flange.

4.3.2.4 Office Air Intake

Installation and balancing procedure of the balancing damper, described in Section 4.1.4, for office air intake varies from one sheet metal contractor to the other, however there are common good practices that should be followed. First, the contractor should accurately measure and mark the size of the duct cut out required to install the damper. After the damper is mounted in place, the contractor is to measure the current air flow rate (CFM) in the duct using an anemometer, preferably a microprocessor-based anemometer to achieve higher accuracy in measurements. According to the measured CFM, the contractor is to adjust the damper blades angles so they provide the right amount of air in the FibreCITY lab to compensate for the exhausted air (190 CFM in this case). Upon adjustment of the damper, it is to be secured in the desired position with sheet metal screws around its perimeter, as well as sealed with a good quality aluminum duct tape. CFM monitoring every 4-6 months would ensure that the required CFM rate is being achieved in the lab and whether damper re-adjustment is necessary.

4.3.2.5 Insulation

In order to successfully install the GridLock Ceiling, all drawings and related general provisions of contract are required. The distributor will deliver the materials packaged so that all materials are clearly marked and identifiable showing the product name, manufacturer's name, and component designation [47]. Upon delivery, all materials are required to be stored on site at the final installation temperature for at least 24 hours prior to, during, and after installation. Furthermore, Life Science Products requires that:

1. Interior finish work, such as plastering, concrete, and resinous wall coating shall be completed and dry prior to installation of ceiling components.
2. Mechanical, electrical, HVAC and other work above the ceiling line which results in through-ceiling penetrations shall be completed, stubbed and approved prior to the start of ceiling installation.
3. Mechanical installations below the ceiling line such as space heaters, piping and other work shall not be completed until the ceiling installation is complete.

In order to install the new ceiling system, the current ceiling will need to be removed. However, the GridLock ceiling may be able to utilize the original hangers used in the current ceiling configuration; consultation with the contractor will be required to confirm this. Once the current ceiling is removed, and hangers installed and spaced, the main runners will be attached to the hangers to form the ceiling grid. It is important to keep main runner and carriers clear of abutting walls, and to install wall angle components by fastening them to the wall at a minimal 16 inch spacing, and not more than 3 inches from the ends [35]. Furthermore, all intersection with the wall and all through-ceiling penetrations, such as lighting and ducts, will be caulked to ensure proper sealing.

Once the grid is installed, the runners will receive self-adhesive EDPM profile gaskets made of 100% cellular rubber prior to the installation of panels [35]. As the panels are installed, the perimeter of each panel must rest evenly on the gasket so the gasket can serve as the seal. A total of 90% of the panels will be locked and held in place by Grid-Lock clips from above, while the remaining 10% of panels will be locked by similar clips from below.

The installation time for the GridLock ceiling system is estimated to be approximately 36 hours, which includes 24 hours to allow all materials to acclimate to the humidity and temperature in the FibreCITY lab and CIC building. Depending on the specifics of the installation process, the installation may be able to avoid significantly interrupting the day-to-day workings of the FibreCITY lab if completed over a weekend when there is minimal lab activity.

Furthermore, the Batallion door sweeps and weatherstripping are expected to be installed by CIC employees, as they simply require to be screwed onto the existing doors. As such, the installation of the door sweeps and weather-stripping is minimal, with no disruption to the day-to-day activities in the lab.

4.3.2.6 Maintenance Schedule

The implementation of the humidification system will require additional maintenance of the FibreCITY laboratory. A FMEA was conducted in Section 4.2, which resulted in a number of operational risks being identified. In order to mitigate these risks and ensure reliable operation, a maintenance schedule was developed. It should be noted that the maintenance schedule in Table XIX is not a replacement for existing maintenance practices and should complement existing preventative maintenance programs.

TABLE XIX: MAINTENANCE SCHEDULE FOR THE FIBRECITY LABORATORY

Frequency	Equipment	Task	Corrective Action	FMEA ID. Number
6 months	Humidifier	Inspect status of humidifier cylinder	Replace if necessary	1
		Inspect the drain valve for scale or blockage	Clean out scale or blockage if necessary	2
	Insulation	Inspect weatherstripping and door jams	Replace if damaged	13, 14
		Inspect room for other sources of air leakage	Mitigate air leakage if necessary	13, 14
	Ducting	Inspect ducting for debris, dust and blockages	Clean ducting if necessary	11
12 months	Humidifier	Inspect humidifier for damage or leaks	Consult engineering manual or contact HVAC service company for repair procedures	3
		Inspect steam line and steam injector for damage or leaks	Consult engineering manual or contact HVAC service company for repair procedures	4
	Humidification Controls	Test the C1 On/Off air proving controller	Replace or fix controller if necessary	7
		Test the C2 On/Off high limit controller	Replace or fix controller if necessary	6
		Test the C3 modulating controller	Replace or fix controller if necessary	5
	Accessories	Test the A1 humidification alert device	Replace or fix accessory if necessary	8
	Insulation	Inspect ceiling gaskets ensuring they are tight and in place	Seal gaskets if necessary	15
	Ducting	Inspect ducting for condensation (interior and exterior)	Consult engineering manual or contact HVAC service company for repair procedures	11
	Ventilation	Turn off fume hood and verify exhaust fan turns on	Repair interlock if necessary	10
		Inspect damper for blockages and debris	Clear damper intake from dirt and debris, call consultant if damper needs adjusting if necessary	12

Reflecting on the maintenance schedule, it is evident that most tasks are visual inspection based. The more frequent these inspections are performed the more likely the client will catch an issue in the event of a malfunction. However, based on our knowledge of the products we recommend inspections and maintenance be performed at six and twelve month intervals.

4.4 Cost Analysis

In order to provide CIC with a useful economic evaluation and comprehensive budget for the installation of the humidity control system, a cost analysis was performed. The cost analysis incorporates all costs associated with the humidity control system, such as specific material costs, estimated installation costs, estimated maintenance/operations costs, and contingency costs. In conducting the cost analysis, two economic criteria have been proposed for evaluating the economic impact of the humidity control system. For the needs of the current study, we used the following criteria:

1. NPV (net present value)
2. ACO (annual cost of ownership)

The ACO and NPV are both useful economic evaluators in assessing the benefits of an investment. The ACO is simply the extrapolated annual cost of the annual cash flows and initial capital expenditures of the design, whereas the NPV determines the present day value of the investment if CIC were to pay for the lifetime of the device in one payment. Financial analytical methods were used in determining the above criteria, and were based on the calculation of the cash flows (C_F) generated by the purchase and implementation of the selected humidity control design. The cash flows generated through the cost analysis are as follows:

1. Annual cost of maintenance and operation (estimated).
2. Initial capital expenditure (calculated).
3. Salvage value (estimated).

For the purpose the present cost analysis, the maintenance and operational costs include cleaning, servicing and operating the humidification device, and the initial capital expenditures include material, installation, and contingency costs. The following sections will describe in detail the specific costs and any associated assumptions involved in constructing the cash flows for each of the aforementioned cost categories.

4.4.1 Material Costs

The fixed material costs are associated with the specific products that are required for the humidity control system design. For each required product, the material costs have been either determined precisely through a product catalogue, or have been estimated through a quote provided by the supplier. In general, the material costs are broken into three categories: humidification, ducting, and insulation.

Relating to humidification, the Nortec Electrode Steam (NH-EL 010) Humidifier was selected. The NH-EL 010 humidifier is available locally through Midwest Engineering, and costs $3,785.00. Additionally, to ensure proper operation, the NH-EL humidifier requires periodic replacement cylinders, which cost $225.00 per cylinder, as well as an initial start-up inspection by the local distributor of $350.00.

In addition, the ducting system consists the secondary exhaust system and the intake balancing damper. The secondary exhaust system is composed of the Greenheck CSP-A200 inline exhaust fan, Model-80 Egg Crate grille, 7" round pipe, two rectangular-to-round fitters and the Greenheck WC hooded sidewall vent. The estimated material cost for the fan and the ductwork, based on EH price Sales and East Side ventilation quotes, is $775.00. Regarding the office air intake, the damper will cost approximately $25.00.

Insulation was the final design aspect that required the purchase of material items. The GridLock® Fiberglass Ceiling Suspension System available through Life Science Products, was unable to be assigned a precise cost without an inspection of the FibreCITY lab. Since an inspection of the lab would not be possible in the available time, a cost estimate was made per square foot for the GridLock® ceiling to be $4.47/ft^2. The current laboratory space is 756 sq.ft,, therefore, a total material cost for the GridLock® ceiling equates to $3,331.74. Furthermore, the design calls for upgrades to the current laboratory doors to prevent infiltration through gaps around the door frame. To meet this need, four Batallion 36" rubber mill door sweeps, and four sets of Batallion Weather stripping are required for purchase. The door sweep is available for $22.25 per unit, while the weather stripping has a material unit cost of $91.94. Therefore, in order to meet all insulation design criteria, a total of $3,788.50 must be spent on insulation material costs.

4.4.2 Installation Costs

For each product, the cost of installation was assumed to be approximately 100% of the total material costs. The assumption that installation and labor would approximately be 100% of material costs was made since obtaining the exact quotes for labor and installation would have required a commitment to purchase the product. Our team is satisfied with this assumption, as it is a conservative estimate, and will continue to be protected by the 10% contingency reserve for total capital expenditures.

4.4.3 Maintenance and Operational Costs

Maintenance costs were categorized into two distinct subgroups: cleaning and preventative failure. HVAC cleaning costs were estimated to be $850-$1050 for a small (>1200 ft^2) space, conducted by a licensed/bonded contractor, and with typical system complexity and access [47]. Therefore, our team took the mean of these values, $950, to be the cleaning cost associated with humidification maintenance costs. However, cleaning was assumed to be required once every 2 years, and thus the annual cleaning cost was taken to be $475. Furthermore, due to the fact that consistent cleaning will contribute to reducing system failure, the preventative failure maintenance was assumed to include only direct service and repairs to the HVAC system. It is difficulty to accurately estimate the cost of service and repair, as the degree of service is dependent on a variety of external factors that are difficult to predict. However, our team has estimated the annual cost of servicing the system to be approximately 1% of the total capital investment of the humidifier and exhaust fan [48]. Equation 8 uses the 1% estimate to calculate the annual serving and repair cost of the humidifier and exhaust fan.

$$Annual\ Maintenance\ Costs = \frac{1}{100} \cdot (C_{NH-EL} + C_{CSP-A200}) \quad \text{(Eqn. 8)}$$

$$Annual\ Maintenance\ Costs = (0.01) \cdot (3785 + 350) = \$41.35$$

Where C_{NH-EL} *and* $C_{CSP-A200}$ are the total material costs of the NH-EL humidifier, and CSP-A200 exhaust fan respectively.To calculate the annual operational costs, the kW ratings from the 3.8 kW NH-El humidifier and 48.2W Greenheck Vector H exhaust fan were combined with the local cost of electricity, and estimated operational hours per year. Based on a worst-case model, the humidifier would be required to run at full capacity 100% of the time, however, to make a more realistic estimate, our team assumed 90% operational time. The assumption of continued operation 90% of the day was made since the humidification unit is variable, and will not operate at full load every day, all day. Additionally, it is important to note that the annual operating hours (AOH) is going to be an approximated value, which is heavily dependent on assumed operating time percentage. Our team does recognize that the annual average operating hours (AOH) will fluctuate year to year. However, the approximated value will provide a reasonable estimate of expected operating costs. Therefore, based on the above information, the annual operational costs will be estimated as follows:

$$Annual\ Operating\ Hours\ (AOH) = 365 \left(\frac{days}{year}\right) \cdot 24 \left(\frac{hours}{day}\right) \cdot (0.90) = 7884\ hours \quad \text{(Eqn. 9)}$$

$$Annual\ Operating\ Cost\ (AOC) = 0.03552 \left(\frac{\$}{kWh}\right) \cdot 3.8482(kW) \cdot 7884 = \$1077.65 \quad \text{(Eqn. 10)}$$

where the current local per kWh cost of electricity in Winnipeg, Manitoba was taken to be \$0.03552/kWh based off information provided through Manitoba Hydro [49]. Therefore, combining the estimated annual operating cost of \$1,077.65 and maintenance cost of \$516.35, our team can generate the first and only annuity which will be used in the determination of the investment NPV.

In determining the specific and estimated cash flows, each value will be rounded to the nearest dollar, while we predicted the level of accuracy of the estimates to be within +/- 15% for all cost categories. Additionally, a contingency reserve, equal to 10% of the initial capital expenditures, was added to the sum of project costs to produce the total cost baseline. The addition of the contingency reserve will provide a buffer to account for error in estimates and unforeseen costs. The completed project budget is shown in Table XX, where details and assumptions pertaining to the individual entries are provided within the budget table, along with the estimated quantity and cost per unit.

TABLE XX: FINALIZED BUDGET FOR THE HUMIDIFICATION OF THE FIBRECITY LABORATORY

Category	Quantity	Cost per Unit	Subtotal	Notes
Humidification				
Nortec Electrode Steam (NH-EL) Humidifier	1	$3,785.00	$3,785.00	Start-up costs are for Midwest to inspect instillation. 4 replacement cylinders are quoted as back ups
202 Replacement Cylinders	4	$225.00	$900.00	
Start-up & Calibration	1	$350.00	$350.00	
Humidification Costs Total			**$5,035.00**	
Ducting				
Greenheck CSP-A200 Exhaust Fan	1	$350.00	$350.00	Fan ducting includes the grille, two fittings and the 7" pipe.
Fan ducting	1	$400.00	$400.00	
Balancing Damper	1	$25.00	$25.00	
Ducting Costs Total			**$775.00**	
Insulation				
GridLock Suspended Ceiling	1	$3,331.74	$3,331.74	Ceiling system includes panels, hangers and runners. 4 units are required for door sweeps and weatherstripping.
Batallion Door Sweep	4	$22.25	$89.00	
Batallion Weatherstipping	4	$91.94	$367.76	
Insulation Costs Total			**$3,788.50**	
Installation				
Installation of Humidification	1	$3,785.00	$3,785.00	All installation costs are assumed to be 100% of the material costs.
Installation of Ducting/Fan	1	$775.00	$775.00	
Installation of Insulation	1	$3,331.74	$3,331.74	
Installation Costs Total			**$7,891.74**	
Accessories				Humidtiy alert system plugs into an outlet and will send an e-mail or text when humidity and/or temperature exceed preset limit.
Humidity Alert System	1	$197.37	$197.37	
Accessory Cost Total			**$197.37**	
Operation				Operational costs are estimated on an annual basis, at a 90% useage rate, 3.8482 kW, and $0.03552/kWh cost of electricity
Annual Energy Costs	1	$1,078.00	$1,078.00	
Operation Costs Total			**$1,078.00**	
Maintenance				Maintenance costs are estimated on an annula basis, where service and repair costs are approximated as 1% of ducting and humidification captial expenses.
Annual Cleaning	1	$475.00	$475.00	
Annual Service/Repair	1	$41.35	$41.35	
Maintenance Costs Total			**$516.35**	
Contingency Reserves				Provides a reserve of funds for unforseen expenses taken at 10% of all capital expenditures
Contingency Costs	1	$1,768.76	$1,768.76	
Contingency Reserves Total			**$1,768.76**	
ESTIMATED GRAND TOTAL			**$21,050.72**	

4.5 Economic Evaluation

Using the information provided through the cost budget presented in Table XIX, we can now construct a series of cash flows which can be used to calculate the net present value (NPV), and average cost of ownership (ACO) of the investment. However, in order to determine the ACO, the NPV must first be calculated using Equation 11:

$$NPV = Y \cdot \left(\frac{P}{A}, i^*, N\right) + C_{initial} - C_{salvage}\left(\frac{P}{F}, i^*, N\right) \qquad \text{(Eqn. 11) [50]}$$

Where Y is the annual net costs:

$$Y = C_{Operation} + C_{Maintenance} \qquad \text{(Eqn. 12)}$$
$$Y = \$1078 + \$516.35 = \$1{,}594.35 \cong \$1{,}595.00$$

and $C_{initial}$ is the initial capital investment:

$$C_{initial} = C_{humid.} + C_{Duct/Fan} + C_{Insul.} + C_{Install} + C_{Accessory} \qquad \text{(Eqn. 13)}$$
$$C_{initial} = \$5{,}035 + \$775 + \$3788.50 + \$7891.74 + \$197.37 = \$17{,}687.61$$
$$C_{initial} \cong \$17{,}690.00$$

Additionally, $C_{salvage}$, is the salvage cost, and $\left(\frac{P}{A}, i^*, N\right)$ and $\left(\frac{P}{F}, i^*, N\right)$ are the present worth factor of a geometric series at i^* percent for N years for an annuity and future values respectively. Furthermore, N is the life span of the investment, and i* represents the interest rate of geometric series due to the energy inflation rate, and. The term $i*$ in the NPV equation is used for gradient series cash flows, and relates the energy inflation and market discount rate together such that:

$$i^* = \frac{1+i}{1+g} - 1 \qquad \text{(Eqn. 14)}$$

In the above equation, *g* is the energy inflation over time (%) and i is the market discount rate (%). Moreover, in order to successfully complete our economic analysis for the humidification system design, certain assumptions were made, such as:

1. Lifetime (L) = 20 years.
2. The energy inflation rate and market discount rate are taken to be 3% and 6% respectively.
3. Assume a cost of capital of 6%.
4. Salvage value at the end of life is equal to the cost of removal.

With a salvage cost equal to the cost of equipment removal, the NPV expression simplifies to:

$$NPV = Y \cdot \left(\frac{P}{A}, i^*, N\right) + C_{initial} \quad \text{(Eqn. 15)}$$

Therefore, for an energy inflation rate of 3% (g = 0.03), and interest rate of 6% (i = 0.06), the adjusted gradient series interest rate was calculated as:

$$i^* = \frac{1+(0.06)}{1+(0.03)} - 1 = 0.029 = 2.9\% \quad \text{(Eqn. 16)}$$

Knowing the value of i*, and an assumed life span (L) of 30 years, the present worth factor is given as [50]:

$$\left(\frac{P}{A}, i^*, N\right) = \frac{(1+i^*)^n - 1}{i(1+i^*)^n} = 19.82369 \quad \text{(Eqn. 17)}$$

Using the present worth factor, the net annual costs, and the initial capital expenditure, the NPV of the investment over a 30 year life span is calculated as:

$$NPV = Y \cdot \left(\frac{P}{A}, i^*, N\right) + C_{initial} \quad \text{(Eqn. 18)}$$

$$NPV = (1595) \cdot (19.82369) + (17690) = \$49{,}308.79 \cong \$49{,}310.00$$

The NPV indicates the present day value of the 30 year investment into the humidification design. However, the NPV can be a deceivingly large amount, as it accounts for annual costs that would be paid up to 30 years from now. In order to provide CIC with a more accurate estimation of what to expect annually, the NPV was broken into a constant annuity over 30 years, thus calculating the ACO.

To calculate the ACO, the NPV was broken into 30 equal annual payments, which still account for inflation in energy rates and interest rates, and is calculated as follows:

$$ACO = NPV \left(\frac{A}{P}, i^*, N\right) \quad \text{(Eqn. 19)}$$

where $\left(\frac{A}{P}, i^*, N\right)$ is the annuity factor for a present amount at i* % for N years, given by [50]:

$$\left(\frac{A}{P}, i^*, N\right) = \frac{i(1+i^*)^n}{(1+i^*)^n - 1} = \frac{i(1+0.029)^{30}}{(1+0.029)^{30} - 1} \quad \text{(Eqn. 20)}$$

$$\left(\frac{A}{P}, i^*, N\right) = 0.0504447$$

and NPV is the previously calculated value for the net present value. Based on the previously calculated values, the ACO can be determined as:

$$ACO = NPV \left(\frac{A}{P}, i^*, N\right) = (49310) \cdot (0.0504447) \quad \text{(Eqn. 21)}$$

$$ACO = \$2{,}487.54 \cong \$2{,}490.00$$

Therefore, CIC can expect the total cost of material purchase, installation, maintenance, and operation to approximate \$2,490.00 per year; where \$2,490.00 per year takes into account both energy inflation rates (3% per annum) and a cost of capital of 6%.

4.6 Final Design Summary

All in all, our team has developed a holistic solution that is capable of providing accurate and reliable humidity control for Composite Innovation Centre's FibreCITY laboratory. The final design phase of this project consisted of an in-depth technical analysis, product selection, FMEA, considerations for installation/implementation, and a detailed cost and economic analyses. This phase of the design project enabled our team to establish a detailed design, complete with specific products, as well as evaluate the design from the perspectives of risk, implementation, and cost. Ultimately, this phase of the design culminates the work conducted for both project definition and conceptual design in order to produce a completed design that satisfies the client needs.

Although a preliminary technical analysis was performed as part of the conceptual design phase, it was necessary to revisit the analysis in order to re-check calculations and to expand on several key aspects. The in-depth technical analysis revisited the topics of ventilation and humidity load while also addressing humidity set points. Through this analysis, our team reconfirmed that 166 cfm of airflow is required in order to satisfy ASHRAE ventilation standards, and that the humidity load in the FibreCITY laboratory is expected to range from 0.77 to 3.84 L/h. Furthermore, it was determined that set points of 61% RH and 46% RH will be necessary in order to regulate the humidity to 65 or 50 ± 5% RH respectively (for the current controller configuration).

Completion of the technical analysis allowed our team to begin product selection for conceptual design 3, which was selected in the conceptual design phase of the project. The key products that were selected for this design configuration include a Nortec Electrode Steam (NH-EL) Humidifier, complete with a pair of modulating controllers, a high limit humidity controller, and an air proving controller. This humidification system was selected to accommodate the calculated humidity load, to fit within the mechanical space, and to provide safe, accurate and reliable humidity regulation. A Greenheck CSP-A200 in-line exhaust fan was selected in combination with a balancing damper to provide appropriate ventilation for the laboratory space. Due to the fact that the envelope of the room was identified as a problematic source of air infiltration, our team selected a GridLock suspended ceiling system that will replace the existing T-bar ceiling. Additionally, door sweeps and weatherstripping will be implemented to reduce infiltration around laboratory doors. Finally, a ConnectSense CS-TH wireless temperature and humidity sensor was selected to provide CIC employees with notification in the event that the relative humidity exceeds the allowable set point tolerances. With the products selected, engineering-style drawings were produced and a failure mode and effects analysis was performed.

After developing drawings and performing an FMEA, our team addressed the installation procedures and implications for each of the products, as well as the overall system. The most critical failure modes, as identified by the FMEA (Table XVIII) were addressed through either the installation method or suggested preventative maintenance.

Finally, the detailed design calculated the total cost of the design, estimated to be $21,050.72, which encompasses material, labor, and contingency costs. Furthermore, results from the cost analysis were used to conduct an economic evaluation, which revealed that the total cost of the project will cost CIC an estimated $2,490.00 per year over the course of 30 years.

5.0 CONCLUSION

In review, CIC has requested the design of a system to regulate and maintain the humidity levels within the FibreCITY lab. CIC has specified that in order to conduct standardized tensile testing the laboratory environment must be controlled to 21 ± 1°C, and be maintained at either 50 or 65% ± 5% relative humidity (RH) (depending on the material being tested). While CIC has already been able to outfit the laboratory with a forced air HVAC system to regulate the lab temperature, the current laboratory configuration does not allow for the capability to accurately regulate the relative humidity. Our team has been tasked to develop a humidity control system design that is capable of not only regulating the humidity in the FibreCITY laboratory, but is also capable of providing appropriate ventilation to the room.

The key products that were selected for the final design are as follows:

1. Nortec Electrode Steam (NH-EL) Humidifier and associated controllers
2. Greenheck CSP-A200 exhaust fan
3. GridLock suspended ceiling system
4. Batallion door sweeps and weatherstripping
5. ConnectSense CS-TH wireless temperature and humidity sensor

Together, these key products form a holistic system that can regulate the humidity within the FibreCity lab to the desired user set point. Additionally, these products provide a reliable and safe method of ventilation to the room, while simultaneously reducing the effects of infiltration through the room envelope.

Moreover, when designing the final system configuration, our team paid special attention to ensure that each of the highly ranked customer needs were met (Section 1.3, Table II). Table XXI illustrates how the final design is able to meet each of the highly ranked customer needs that were presented in Section 1.3.

Table XXI - DESCRIPTION OF HIGHLY RANKED NEEDS

No.	Need	How Final Design Satisfies Need
3	Can accurately regulate humidity in the lab	The NH-EL humidifier, GridLock ceiling system, ventilation fans, door sweeps, and weatherstripping will maintain the +/-5% RH levels (Section 4.1.1 and 4.1.5) The humidifier has a 3.84 L/hr humidification capacity, which meets the specified humidity load analysis requirements (Section 4.1.1).
4	Can be easily serviced and maintained by local technicians	Nortec NH-EL humidifier is easily accessible to technicians and CIC employees and can be serviced by local Midwest Engineering (Section 4.1.1 and 4.3.2.2).
7	Automatically drains water from the system	The NH-EL humidifier has waste water collector system that drains automatically (Section 4.1.1).
9	Provides prompt notification when RH limits are exceeded	The ConnectSense CS-TH Wireless Temperature and Humidity Sensor will provide notification to CIC employees (Section 4.1.6).
10	Displays relevant info on a clear user interface, within the lab	The NH-EL humidifier is equipped with two controllers positioned in the laboratory and a control panel unit itself (Section 4.1.2).
12	Restricts frequency of oscillations between the max. and min. RH limits	NH-EL humidifier is sized appropriately and features variable output, allowing it to maintain low frequency of oscillations (Section 4.1.1).
16	Competitive start-up cost	Section 4.5 illustrates the affordable cost of implementing and operating the humidification system.
18	Minimally intrusive during installation	Installation procedures addressed and implications mitigated in Section 4.3.2.
19	Operates quietly	NH-EL humidifier and Greenheck exhaust fan are isolated from the FibreCITY lab (Section 4.1.1, 4.1.3 and 4.1.4).
21	Isolates the laboratory environment from ambient conditions	Upgraded FibreCITY lab insulation keeps the humidity added to the lab within the lab (Section 4.2.5). GridLock ceiling system and door insulation upgrades will provide decreased uncontrolled air infiltration from the ambient CIC office space (Section 4.2.5).

As illustrated in Table XXI, our final design products are able to meet each of the highly ranked client needs.

Furthermore, in order to provide CIC with comprehensive details for the implementation of our selected design, a Failure Modes and Effect Analysis (Section 4.2) was performed, as well as a cost analysis and economic evaluation (Section 4.4 and 4.5). The FMEA was able to identify some of the major potential causes of failure (Section 4.2) and identify a recommended maintenance schedule (Section 4.3.2.6), whereas the cost analysis and economic evaluation provides CIC with a cost baseline and economic background for investing in the humidity control system. More specifically, the cost analysis provided a cost budget for the initial capital expenditures and estimated first year costs of $21 050. By building on the data provided in the cost analysis, the economic evaluation extended the analysis to include the entire estimated 30-year life span of the system. Through the results of the economic evaluation, CIC can expect the investment to have a net present value (NPV) of $49 310, and an annual cost of ownership (ACO) of $2 490; assuming 3% annual energy rate inflation, a cost of capital of 6%, and a life time of 30 years.

Through constructing the client needs and specification, generating conceptual designs, and implementing a numerical approach to select an appropriate design concept, our team was able to develop a final design that is economical, and meets the desired client requirements. Furthermore, by implementing the final humidity control system design for the FibreCITY lab, CIC will be able to advance their composite material research, thereby continuing the development and economic growth of composite materials and technologies in Western Canada.

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7.0 REFERENCES

[1] B. Hearsum, "Compositesinnovation.ca," Composite Innovation Centre, 1 May 2015. [Online]. Available: http://www.compositesinnovation.ca/composites-innovation-centreopens-new-location-to-house-fibre-processing-and-prototypingcentre/?doing_wp_cron=1443059635.4914569854736328125000. [Accessed 23 September 2015].

[2] Team 3. "Tensile Testing Equipment Located in the FibreCITY Lab." Winnipeg: Engineering Design, University of Manitoba, Winnipeg, MB, October 30, 2015.

[3] C. I. Centre, Interviewee, The U of M IDEA Program. [Interview]. 23 September 2015.

[4] M. Alcock (private communication), Sept. 17, 2015.

[5] ASTM International. (2013). ASTM D1776 / D1776M – 15 *Standard Practice for Conditioning and Testing Textiles*. [Online]. Available: http://www.astm.org/Standards/D618.htm. [October 22, 2015].

[6] ASTM International. (2013). ASTM D618-13 *Standard Practice for Conditioning Plastics for Testing*. [Online]. Available: http://www.astm.org/Standards/D618.htm. [October 22, 2015].

[7] Autodesk. (2013, Aug.) Autodesk Sustainability Workshop: HVAC Operations and Maintenance. [Online]. Available: http://sustainabilityworkshop.autodesk.com/buildings/hvac-operations-and-maintenance.

[8] Mechanical Reps Inc. (2013 Oct.) MERV Rating Chart. [Online]. Available: http://www.mechreps.com/PDF/Merv_Rating_Chart.pdf.

[9] N. R. C. o. Canada, "Equipment Efficiency," in *National Energy Code of Canada for Buildings 2011*, Winnipeg, Natural Resources Canada, 2011, pp. Division B Article 5.2.12 Pages 5-13:5-18.

[10] Manitoba Workplace and Safety. (2015, Jul.) Manitoba Workplace Safety and Health Regulation. [Online]. Available: http://www.manitoba.ca/labour/safety/pdf/2015_wsh_mr217.06.pdf.

[11] United States Environmental Protection Agency. (2013, Dec.) Moisture Control Guidance for Building Design, Construction and Maintenance. [Online]. Available: www.epa.gov/iaq/moisture.

[12] Team 3. "Door Sweeps." Winnipeg: Engineering Design, Univ. Manitoba, Winnipeg, MB, October 18, 2015.

[13] Team 3. "Drywall Ceiling Sections." Winnipeg: Engineering Design, Univ. Manitoba, Winnipeg, MB, October 18, 2015.

[14] Team 3. "T-bar Ceiling Insufficient Seal." Winnipeg: Engineering Design, Univ. Manitoba, Winnipeg, MB, October 18, 2015.

[15] ASHRAE. (2003). *Ventilation for Acceptable Indoor Air Quality – ashrae.* [Online]. Available: https://www.ashrae.org/file%20library/doclib/.../200418145036_347.pdf. [October 22, 2015].

[16] The Engineering Toolbox. (2003). *Air Change Requirements for Typical Rooms and Buildings.* [Online]. Available: http://www.engineeringtoolbox.com/air-change-rate-room-d_867.html. [October 22, 2015].

[17] LABCONCO. (2015). *Guardian Digital Airflow Monitor – Labconco*. [Online]. Available: http://www.labconco.com/product/guardian-digital-airflow-monitor/2834. [October 22, 2015].

[18] ESCO. (2015). *A Guide to Laboratory Fume Hoods*. [Online]. Available: http://www.escoglobal.com/resources/pdf/guide-fumehoods.pdf. [October 22, 2015].

[19] Extech. (2009-2013). "Humidity/Temperature Datalogger RHT20" [Online]. Available: http://www.extech.com/instruments/resources/datasheets/RHT20data.pdf [October 10, 2015].

[20] L.Harriman, G. Brundrett, R. Kittler, "Dehumidification Loads," in Humidity Control Design Guide for Commercial and Institutional Buildings, Atlanta: ASHRAE, 2001, ch. 12, pp. 187–192.

[21] S. Gribble, 'Air density calculator (useful for estimating rho)', *Gribble.org*, 2015. [Online]. Available: http://www.gribble.org/cycling/air_density.html. [October 24, 2015].

[22] Coolerado Corporation. (2009, March 11). *Sea Level Psychrometric Chart Ledger Size Air Properties*. [Online]. Available: http://www.coolerado.com/pdfs/Psychrmtrcs/0000Psych11x17US_SI.pdf. [October 22, 2015].

[23] Dr. Robert Derksen (private communication), Sept. 28, 2015.

[24] Frank Wheeler (private communication), Oct 12, 2015.

[25] Mercedes Alcock (private communication), Oct. 1, 2015.

[26] Frank Wheeler (private communication), Oct 1, 2015.

[27] Nortec Humidification and Evaporative Cooling. (2015). *NH-EL Series Engineering Manual* [Online]. Available: http://www.humidity.com/m/0/2577597-a-nh-el-eng-manual.pdf [November 11, 2015].

[28] Nortec Humidification and Evaporative Cooling. (2015). *Nortec Controls For Every Humidifier Application* [Online]. Available: http://www.humidity.com/Nortec-Humidifiers-for-Humidity-Control/controls-for-commerical-humidification [November 11, 2015].

[29] Team 3. "Exhaust fan." Winnipeg: Engineering Design, Univ. Manitoba, Winnipeg, MB, November 11, 2015.

[30] Doug Castor, Engineering Sales, Air distribution division, E.H Price (private communication), Nov 9, 2015.

[31] Reg Quiring (private communication), Oct 15, 2015.

[32] Models SP and CSP: Ceiling and Cabinet Fans. (2015). *Centrifugal Ceiling Exhaust and Inline Cabinet Fans: Models SP and CSP* [Online]. Available: http://www.greenheck.com/media/pdf/catalogs/SPCSP_catalog.pdf [November 11, 2015].

[33] East Side Ventilation Ltd (private communication), Nov 11, 2015.

[34] Round and Rectangular Balancing Dampers. (2015). *McGill AirFlow LLC* [Online]. Available:http://www.mcgillairflow.com/textDocs/volDampers/volDamp_balancingDampers.htm [November 12, 2015].

[35] Life Science Products, Inc. (2015). *GridLock™ Suspended Ceiling Systems* [Online]. Available: http://lspinc.com/wpcontent/uploads/2015/10/st_ceilings_suspended_pds_Fiberglass.pdf [November 16, 2015].

[36] Life Science Products, Inc. (2015). *GridLock™ Polymer Core 2 Panels* [Online]. Available: http://lspinc.com/wp-content/uploads/2015/10/Gridlock-Polymer-Core-2-Ceiling-panel-10-15.pdf [November 16, 2015].

[37] Life Science Products, Inc. (2015). *GridLock™ Polymer Core 2 SA Ceiling System* [Online]. Available: http://lspinc.com/wp-content/uploads/2015/10/GridCeiling-System-_SA_-Specification-Poly2-panels.pdf [November 16, 2015].

[38] Homewyse. (2015). *Cost to Install Ceiling Tiles* [Online]. Available: http://www.homewyse.com/services/cost_to_install_ceiling_tiles.html [November 10, 2015].

[39] Acklands Grainger, Inc. (2015). *Battalion Door Sweep 36in Rubber Mill* [Online]. Available: https://www.acklandsgrainger.com/AGIPortalWeb/WebSource/ProductDisplay/globalProductDetailDisplay.do?item_code=GGH2RRG5&searchClick=true [November 16, 2015].

[40] Acklands Grainger, Inc. (2015). *Battalion Weatherstrip 1/4inX7/8in DR JM* [Online]. Available: https://www.acklandsgrainger.com/AGIPortalWeb/WebSource/ProductDisplay/globalProductDetailDisplay.do?item_code=GGH2RRN2&searchClick=true [November 16, 2015].

[41] Amazon. (2015). *Amazon.com: ConnectSense CS-TH Wireless Temperature and Humidity Sensor: Home Improvement* [Online]. Available: http://www.amazon.com/ConnectSense-CS-TH-Wireless-Temperature-Humidity/dp/B00ISKS8HG/ref=sr_1_2?ie=UTF8&qid=1447717140&sr=8-2&keywords=cs-th. [November 16, 2015].

[42] Potential Failure Mode and Effects Analysis Spreadsheet Template. (2015). *Lehigh University Resources* [Online]. Available: http://www.lehigh.edu/~intribos/resources.html [November 11, 2015].

[43] Team 3. "Mechanical Room." Winnipeg: Engineering Design, Univ. Manitoba, Winnipeg, MB, November 11, 2015.

[44] Nortec Humidification and Evaporative Cooling. (2015). *NH-EL Series Installation and Operation Manual* [Online]. Available: http://www.humidity.com/m/0/2570435-d-nh-el-install-manual.pdf [November 11, 2015].

[45] Laboratory Guidelines and Standards, Application note LC-125. (2015). *TSI* [Online]. Available:http://www.tsi.com/uploadedFiles/_Site_Root/Products/Literature/Application_Notes/LC-125-LabGuidelinesStandards.pdf [November 16, 2015].

[46] Ductwork 101 (Bath Fans). (2015). *GAF* [Online]. Available: http://www.gaf.com/Video_Library/0_ozuyrftp [November 16, 2015].

[47] Homewyse. (2015). *Cost to Clean HVAC System* [Online]. Available: http://www.homewyse.com/maintenance_costs/cost_to_clean_hvac_system.html [November 10, 2015].

[48] T. Mateus, "Solar cooling technologies in Greece. An economic viability analysis," Applied Energy, vol. 23, pp. 1427-1439, 2003.

[49] Manitoba Hydro. (2015). *Current Electricity Rates* [Online]. Available: https://www.hydro.mb.ca/regulatory_affairs/energy_rates/electricity/current_rates.shtml [November 8, 2015]

[50] Valparaiso University. (2015). *Engineering Economics – Cash Flow* [Online]. Available: http://www.valpo.edu/student/asme/FE%20Slides/EngEconSlides.pdf [November 9, 2015]

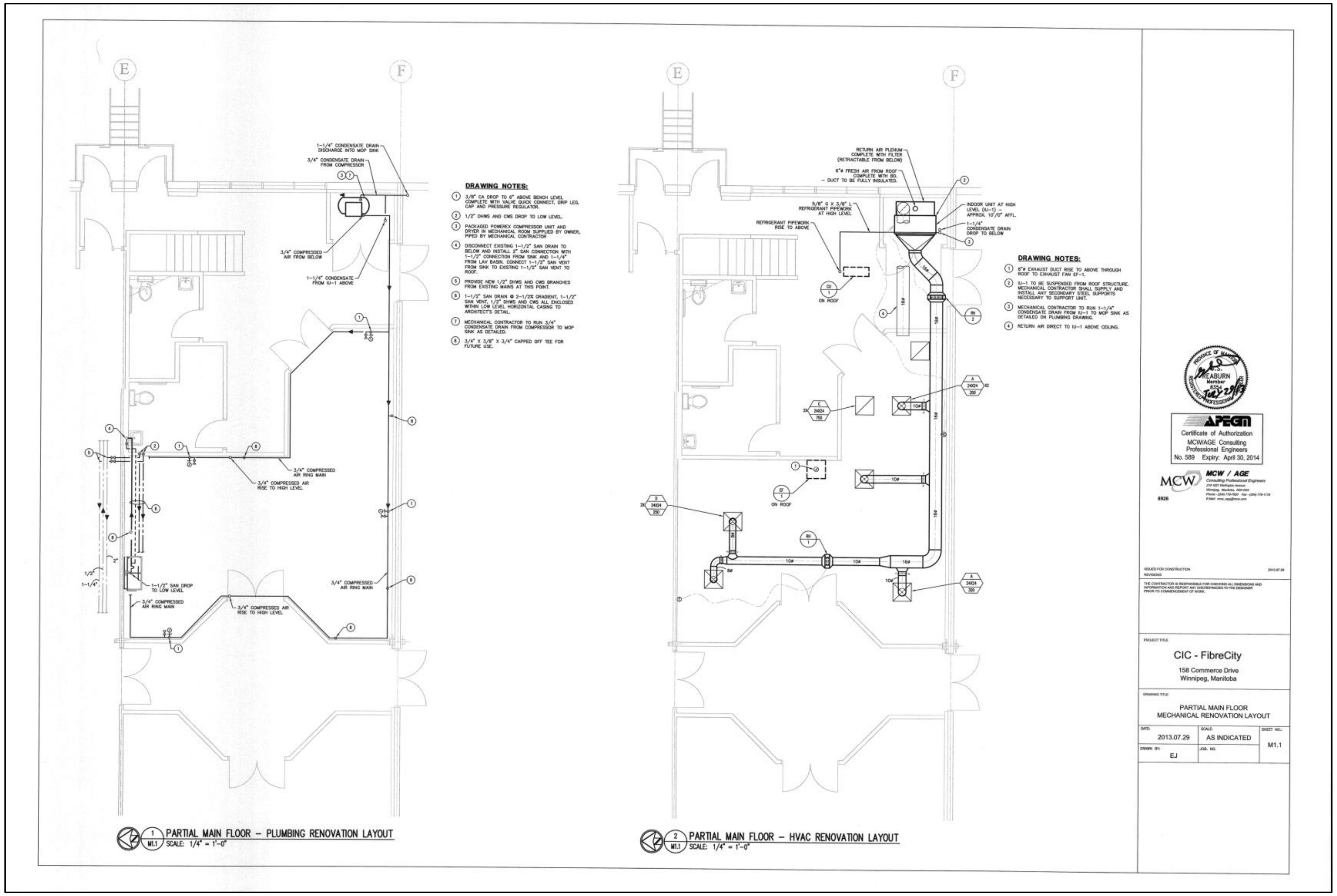
APPENDIX A – DOCUMENTS PROVIDED BY CLIENT

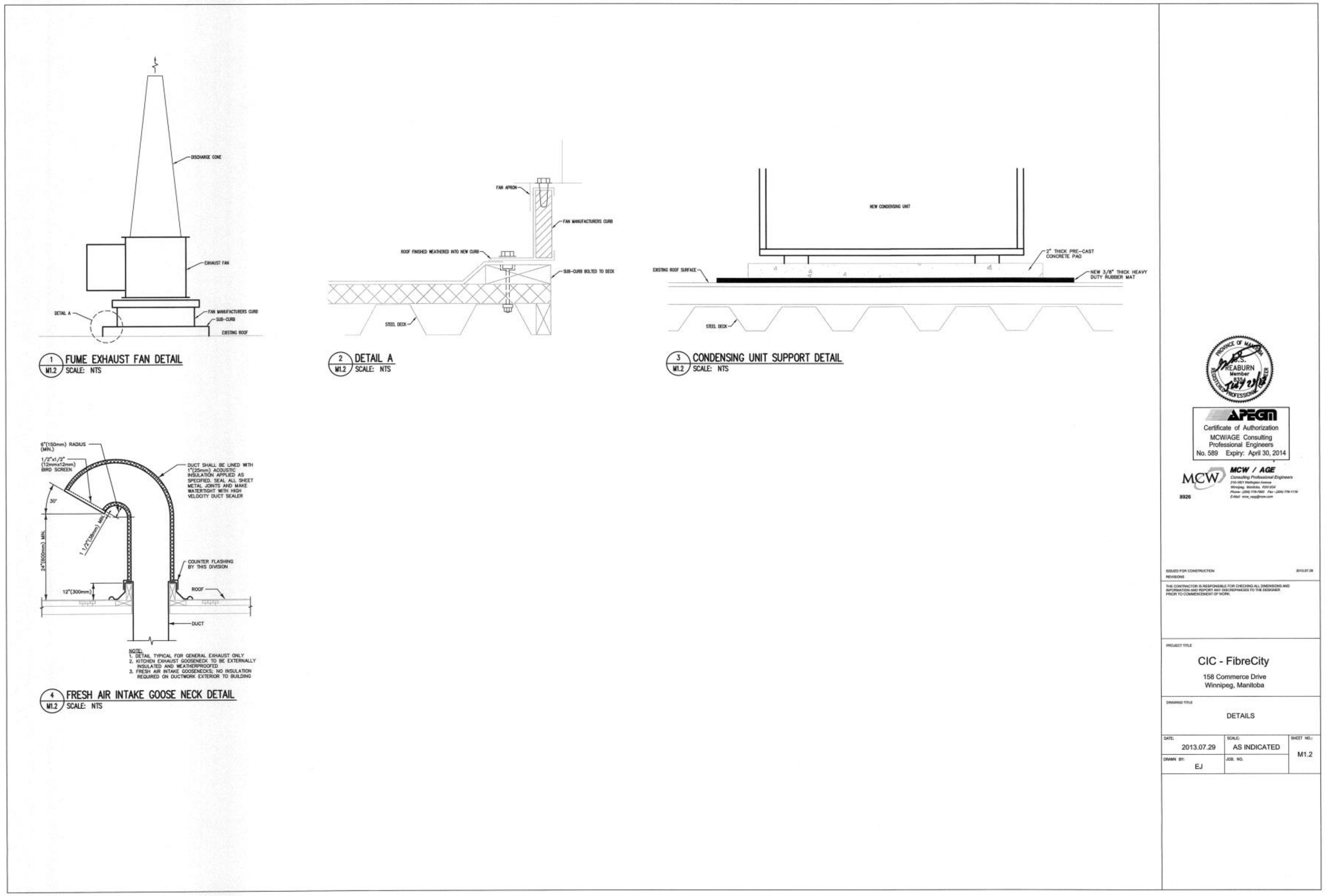
Table of Contents

A.1 Drawings from Client

Composites Innovation Centre provided our team with the mechanical engineering drawings for the FibreCITY laboratory. These are stamped drawings that were provided to CIC when the forced air HVAC system was installed to regulated the temperature within the laboratory [1].

A.1.1 Mechanical Drawings




DISCHARGE CONE
EXHAUST FAN
DETAIL A
FAN MANUFACTURERS CURB
SUB-CURB
EXISTING ROOF
1 FUME EXHAUST FAN DETAIL
M1.2 SCALE: NTS
FAN APRON
FAN MANUFACTURERS CURB
ROOF FINISHED WEATHERED INTO NEW CURB
SUB-CURB BOLTED TO DECK
STEEL DECK
2 DETAIL A
M1.2 SCALE: NTS
NEW CONDENSING UNIT
2" THICK PRE-CAST CONCRETE PAD
EXISTING ROOF SURFACE
NEW 3/8" THICK HEAVY DUTY RUBBER MAT
STEEL DECK
3 CONDENSING UNIT SUPPORT DETAIL
M1.2 SCALE: NTS
6"(150mm) RADIUS (MIN.)
1/2"x1/2" (12mmx12mm) BIRD SCREEN
30°
1 1/2"(38mm) MIN.
24"(600mm) MIN.
12"(300mm)
DUCT SHALL BE LINED WITH 1"(25mm) ACOUSTIC INSULATION APPLIED AS SPECIFIED. SEAL ALL SHEET METAL JOINTS AND MAKE WATERTIGHT WITH HIGH VELOCITY DUCT SEALER
COUNTER FLASHING BY THIS DIVISION
ROOF
DUCT
NOTE:
1. DETAIL TYPICAL FOR GENERAL EXHAUST ONLY
2. KITCHEN EXHAUST GOOSENECK TO BE EXTERNALLY INSULATED AND WEATHERPROOFED
3. FRESH AIR INTAKE GOOSENECKS; NO INSULATION REQUIRED ON DUCTWORK EXTERIOR TO BUILDING
4 FRESH AIR INTAKE GOOSE NECK DETAIL
M1.2 SCALE: NTS
APEGM
Certificate of Authorization
MCW/AGE Consulting Professional Engineers
No. 589 Expiry: April 30, 2014
MCW / AGE
Consulting Professional Engineers
8926
ISSUED FOR CONSTRUCTION 2013.07.29
REVISIONS
THE CONTRACTOR IS RESPONSIBLE FOR CHECKING ALL DIMENSIONS AND INFORMATION AND REPORT ANY DISCREPANCIES TO THE DESIGNER PRIOR TO COMMENCEMENT OF WORK.
PROJECT TITLE
CIC - FibreCity
158 Commerce Drive
Winnipeg, Manitoba
DRAWING TITLE
DETAILS
DATE: 2013.07.29
SCALE: AS INDICATED
SHEET NO.: M1.2
DRAWN BY: EJ
JOB. NO.

INDOOR UNIT SCHEDULE

NO.	LOCATION	MAKE	MODEL	AIRFLOW CFM	EXTERNAL STATIC PRESS. IN. H_2O	PACKAGE UNIT	# OF FANS	FILTER	COOLING COIL	SUPPLY FAN MOTOR	SUPPLY FAN		UNIT WEIGHT LBS	CONTROLS							HP	FLA	MCA	MOCP	POWER						REMARKS/ACCESSORIES
											AIRFLOW CFM	ESP IN. H_2O		INTERLOCK			F.A. SHUT DOWN	DATA CONN.	NOTES	PANEL					EM	V/ø	FEEDER	COND	BRKR	CCT	
														SUPPLY	INSTALL	WITH															
IU-1	MECH ROOM	MITSUBISHI	PEAD-A42AA4	1500	0.6 WC	YES	1	POLYPROPYLENE HONEYCOMB	R-410A DIRECT EXPANSION NOMINAL CAPACITY 42 MBH, INTEGRAL CONDENSATE PAN WITH 1-1/4" DRAIN.	244W, 208/1, 3.5A MCA, 2.8A FLA	1500	0.6"WC	95	MECHANICAL	MECHANICAL	CU-1 + RH-2	—	—	—		—	2.8	3.5			208V/1ø	2#12 RW90	1/2" (16MM)	15A/2P	FL-43,44	UNIT COMPLETE WITH WALL MOUNTED WIRED REMOTE CONTROLLER TYPE PAR-21MAA AND EXTERNAL HEATER ADAPTOR.

FAN SCHEDULE

NO.	LOCATION	MAKE	MODEL	FAN TYPE	AIRFLOW CFM	EXTERNAL STATIC PRESS. IN. H_2O	SPEED RPM	SIZE	NOZZLE	DIMENSIONS	UNIT WEIGHT LBS	CONTROLS							HP	FLA	MCA	MOCP	POWER						STARTER							REMARKS/ACCESSORIES
												INTERLOCK			F.A. SHUT DOWN	DATA CONN.	NOTES	PANEL					EM	V/ø	FEEDER	COND	BRKR	CCT	TYPE	SUPPLY	INSTALL	FUNC	PL	PB	HOA	
												SUPPLY	INSTALL	WITH																						
EF-1	ROOF	GREENHECK	VEKTOR-H	EXHAUST	310	0.75" WC	—	9	4"	22" X 22" X 122" HIGH	258			—	—	—	—		1/3	—	—	—	— (—)	120V/1ø	2#12 RW90	1/2" (16MM)	15A/1P	FC-37	MAGNETIC	ELECTRICAL	ELECTRICAL	FWR	•		•	UNIT COMPLETE WITH ROOF CURB, ISOLATION DAMPER WITH LOW VOLTAGE ACTUATOR, POSITIVE PRESSURE TRAP ON PLENUM DRAIN, VSD. UNIT INTERLOCKED WITH FUME CUPBOARD.

REHEAT COIL SCHEDULE

NO.	LOCATION	MAKE	TYPE	AIRFLOW CFM	MAXIMUM AIRFLOW PRESSURE DROP IN.	TEMP. RISE MIN. °F	CAPACITY kw	PREFERRED DUCT SIZE	CONTROLS							HP	FLA	MCA	MOCP	POWER						REMARKS/ACCESSORIES
									INTERLOCK			F.A. SHUT DOWN	DATA CONN.	NOTES	PANEL					EM	V/ø	FEEDER	COND	BRKR	CCT	
									SUPPLY	INSTALL	WITH															
RH-1	OVER LABORATORY	PRICE	F	500	0.025	9	1.5	10"ø	MECHANICAL	MECHANICAL	REMOTE SENSOR	—	—	—		—	—	—	—	— (—)	208V/1ø/60	2#12 RW90	1/2" (16MM)	15A/2P	◇1	HEATER COMPLETE WITH TYPE HEC CONTROLLER AND X100 ROOM THERMOSTAT. ◇1 FEED FROM PANEL OTHER THAN PANEL FC.
RH-2	OVER LOBBY	PRICE	F	1500	0.025	9	4.5	18"ø	MECHANICAL	MECHANICAL	IU-1	—	—	—		—	—	—	—	— (—)	208V/1ø/60	—		—	◇1	HEATER COMPLETE WITH TYPE HEC CONTROLLER. ◇1 FEED FROM PANEL OTHER THAN PANEL FC.

CONDENSING UNIT SCHEDULE

NO.	LOCATION	MAKE	MODEL	CAPACITY BTUH (NOMINAL)	REFRIGERANT TYPE	GROSS COOLING	REFRIGERANT PIPE SIZE	OUTDOOR AMBIENT TEMP. °F		MINIMUM SEER RATING	SIZE	UNIT WEIGHT LBS	CONTROLS						HP	FLA	FLC	MCA	MOCP	POWER					REMARKS/ACCESSORIES
								MIN	MAX				INTERLOCK			DATA CONN.	NOTES	PANEL						V/ø	FEEDER	COND	BRKR	CCT	
													SUPPLY	INSTALL	WITH														
CU-1	ROOF	MITSUBISHI	PUY-A42NHA4	42,000	R-410A	42 MBH @ 50F SUCTION TEMP	5/8" SUCTION 3/8" LIQUID	-40	+35	13	36" X 31" X 39" HIGH	237	MECHANICAL	MECHANICAL	IU-1	—	—		—	—	—	—	—	208/1	2#10 RW90	1/2" (16MM)	30A/2P	FC-41,42	UNIT COMPLETE WITH ULTRA LOW AMBIENT KIT TO ACCOMMODATE -40F OPERATION.

GRILLE, DIFFUSER & LOUVER SCHEDULE

TYPE	SERVICE	MAKE	MODEL	CORE	FRAME	FIXING	FINISH	REMARKS
A	SUPPLY AIR	PRICE	PCFD	N/A	N/A	T-BAR (LAY IN)	B12	REFER TO MECHANICAL DRAWINGS FOR SIZES AND LOCATIONS. COLORS AND FINISHES BY ARCHITECTURAL.
B	RETURN AIR	PRICE	82	N/A	N/A	T-BAR (LAY IN)	B12	REFER TO MECHANICAL DRAWINGS FOR SIZES AND LOCATIONS. COLORS AND FINISHES BY ARCHITECTURAL.
C	TRANSFER AIR	PRICE	80	FIXED	—	LAY-IN	B12	REFER TO MECHANICAL DRAWINGS FOR SIZES AND LOCATIONS. COLORS AND FINISHES BY ARCHITECTURAL.
D	SUPPLY AIR	PRICE	PDS	N/A	TYPE 1	SURFACE MOUNT	B12	REFER TO MECHANICAL DRAWINGS FOR SIZES AND LOCATIONS. COLORS AND FINISHES BY ARCHITECTURAL.

E.H. GARFINKEL Member

REABURN Member 8354

ELECTRICAL ITEMS ONLY

MECHANICAL ITEMS ONLY

APEGM

Certificate of Authorization
MCW/AGE Consulting
Professional Engineers
No. 589 Expiry: April 30, 2014

MCW / AGE
Consulting Professional Engineers

8926

ISSUED FOR CONSTRUCTION 2013.07.29
REVISIONS

THE CONTRACTOR IS RESPONSIBLE FOR CHECKING ALL DIMENSIONS AND INFORMATION AND REPORT ANY DISCREPANCIES TO THE DESIGNER PRIOR TO COMMENCEMENT OF WORK.

PROJECT TITLE

CIC - FibreCity

158 Commerce Drive
Winnipeg, Manitoba

DRAWING TITLE

SCHEDULES

DATE:	SCALE:	SHEET NO.:
2013.07.29	AS INDICATED	ME1.1
DRAWN BY: EJ/JE	JOB. NO.	

A.2 Appendix A References

[1] Frank Wheeler (private communication), Oct 1, 2015.

APPENDIX B – PRODUCT SPECIFICATION SHEETS

Table of Contents

B.1 Product Specification Sheets

Product specifications sheets, as provided by equipment manufacturers, have been included in his appendix to support product selection and implementation requirements. Specifications for the Nortec humidifier [1] and Greenheck in-line exhaust fan [2] are provided.

B.1.1 Humidification Specifications Sheets

Submittal Package

Project Name:	Composites Innovation Centre
Project Number:	123
Preparation Date:	2015/11/12
Locally Represented By:	Midwest Engineering 1369 Erin Street Winnipeg Manitoba R3E 2S7
Salesperson:	Norm McCreight

1.0 Zone List

Zone Tag	Location	Qoa	DBoa	RHoa	Qma	DBbh	RHbh	DBah	RHah	DBsd	RHsd	HTot	Wduct	Hduct	Absorption	Technology
Zone(1)	In Duct	25	-25	58	1500	55	48	55	64	72	35	9	16	16	0.82	ElectrodeSteam

Qoa = Outside Air (%)
DBoa = Outside Air Design Dry Bulb Temperature (°F)
RHoa = Outside Air Design Relative Humidity (%)
Qma = Mixed Air Volume (CFM)
DBbh = Before Humidification Dry Bulb Temperature (°F)
RHbh = Before Humidification Relative Humidity (%)
DBah = After Humidification Dry Bulb Temperature (°F)
RHah = After Humidification Relative Humidity (%)
DBsd = Space Design Dry Bulb Temperature (°F)
RHsd = Space Design Relative Humidity (%)
HTot = Total Humidification (lbs/hr)
Wduct = Duct Width (in.)
Hduct = Duct Height (in.)
Absorption = Absorption Distance (ft)

2.0 Bill of Materials

Zone Tag	Item	Part Number	Quantity
Zone(1)	NH-EL 010/208/1	2573380	1
Zone(1)	Cylinder 202, 005-010, 110-277/1	1519002	1
Zone(1)	Steam Distributor ASD 12in	2553718	2
Zone(1)	SP Switch Air Proving, Duct, mtd.	1329203	1
Zone(1)	Humidistat, On/Off, High Limit,Dig. Duct	2548732	1
Zone(1)	Humidistat, Control, 0-10V, Dig. Wall	1510142	1

nortec
humidity.com

3.0 Humidifiers

3.1 Electrode Steam: NH-EL

NH-EL

An electrode humidifier that produces sterile steam at atmospheric pressure from potable water. To generate steam an electrical current is passed through the dissolved minerals in potable water. The result; the water heats itself offering the highest energy efficiency of any steam humidifier. Utilizing the patented P+I Auto-Adaptive Control, the system automatically adjusts to incoming potable water conditions optimizing water usage. In turn, energy is conserved due to low hot water drain rates.

Minerals removed during steam generation process accumulate in a disposable cylinder. Replacing the cylinder is quick, easy and does not require any scraping or descaling chemicals. The intelligent control system maintains steam generation efficiency until the end of the cylinder life. Replacing the cylinder returns the humidifier to a like new condition.

Steam produced by the NH-EL can be introduced into a duct or air handler using a short absorption manifold (SAM-e) or single tube distributor (ASD, BSD, CSD). For direct space applications steam can be distributed by using a built-on blower pack (NH-EL Space model) or a remote mounted blower pack (BP-RM).

FEATURES

- Touchscreen controller with intuitive color user interface.
- Standard BMS communication protocols BACnet IP, BACnet MSTP and Modbus. Lonworks option available.
- Standard embedded web interface for easy configuration and remote monitoring from any computer with a web browser.
- USB interface for new software/feature upload and download of operational information.
- Modulating steam output of 20%-100% from any control signal type: Single or dual analog demand, single or dual analog relative humidity sensor input, or digital control from a BMS.
- Internal Drain Water tempering to 140°F (60°C) or less and 1 inch internal air gap for backflow prevention to meet plumbing codes.
- Auto-Adaptive Control for accurate steam output (±5% RH), efficient water use and peak energy efficiency until end of cylinder life.
- Packaged unit in durable corrosion resistant powder coated cabinet will all service connections conveniently located for easy installation.
- Zero right and left hand side clearance requirement for minimal installation footprint.

•Disposable cylinder for easy and economical maintenance.
•Two year limited warranty or 30 months from ship date. Extended warranty available.
•UL Listed.

humidity.com

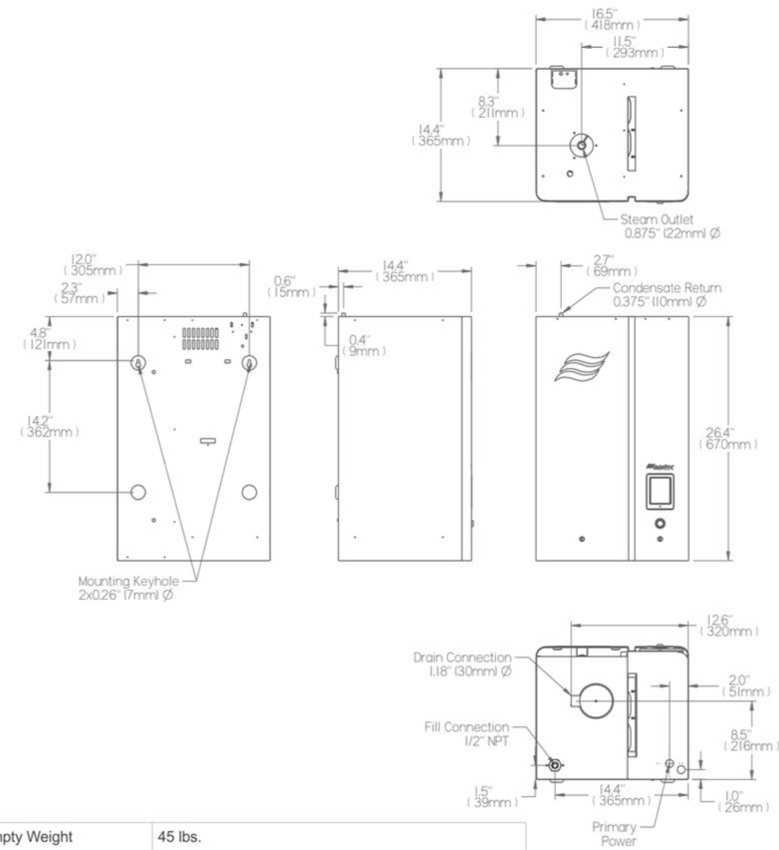
Data Sheet

Product Name: NH-EL 010/208/1

Product Number: 2573380

Performance		Dimensions	
Nominal Capacity	10.00 lbs/h	Height	26.40 in.
Output Range Minimum	2.00 lbs/h	Width	16.50 in.
Output Range Maximum	10.00 lbs/h	Depth	14.40 in.
Rated Power	3.80 kW	Net Weight	45.0 lbs
Power Circuit	208/1/60 V/(phase)/Hz	Full Weight	55.0 lbs
Rated Current	18.30 A	Front Clearance	36.00 in.
Maximum Current	25.00 A	Left Clearance	0.00 in.
Min. Water Pressure	30.00 psig	Right Clearance	0.00 in.
Max. Water Pressure	80.00 psig	Ceiling Clearance	12.00 in.
Controlled Circuits	1	Floor Clearance	24.00 in.
Cylinders	1	Supply Water O D	0.50 in.
Fill Rate	0.13 GPM	Qty Steam Outlets	1
Drain Rate	1.60 GPM	Condensate Return	0.38 in.

Schematics



Empty Weight	45 lbs.
Full Weight	55 lbs. for 005 and 010, 65 lbs. for 020, 80 lbs. for 030
Front Clearance	36 in.
Ceiling Clearance	12 in.
Left and Right Clearance	0 in.
Floor Clearance	24 in.
Water Inlet Pressure	30-80 psig

nortec humidity.com

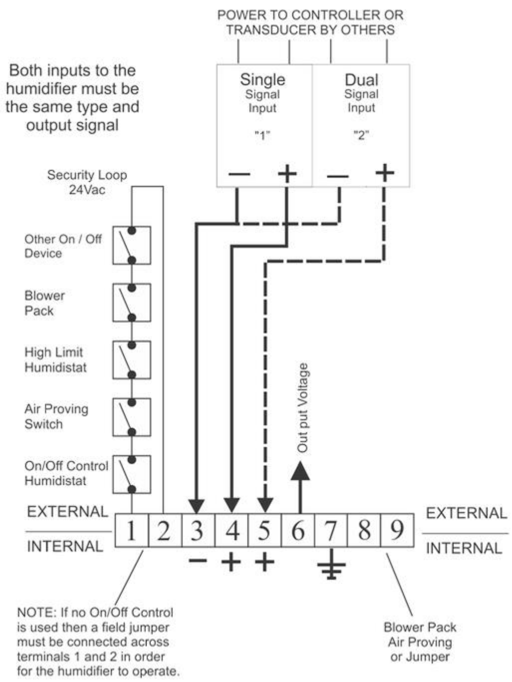
NH-EL 005-030
Physical Data & Dimensions
Revision A, July 16, 2013

Installation

NORTEC SERIES
EXTERNAL CONTROLS WIRING CONNECTIONS
LOW VOLTAGE TERMINAL STRIP

For all controller and transducer signals by others

WARNING: Failure to wire the controller in accordance with the wiring diagram supplied with the unit could permanently damage the electronics. Such errors will void the unit warranty.



Transducers:
To be complete with sensing element, power source and 2 wire varying output signal. RH set point adjustment is made at unit keypad. RH set point and % RH sensed are viewed on display

Output signal across 3 - 4 and 3 - 5 increase on RH rise

Controllers (Humidistat):
To be complete with RH set point adjustment, sensor circuit, sensing element, power source and 2 wire varying output signal. RH demand are viewed on display

Output signal across 3 - 4 and 3 - 5 decrease on RH rise

Output Voltage:
For NH-EL models select. either 10 VDC or 24 VDC using JP1 on driver board.

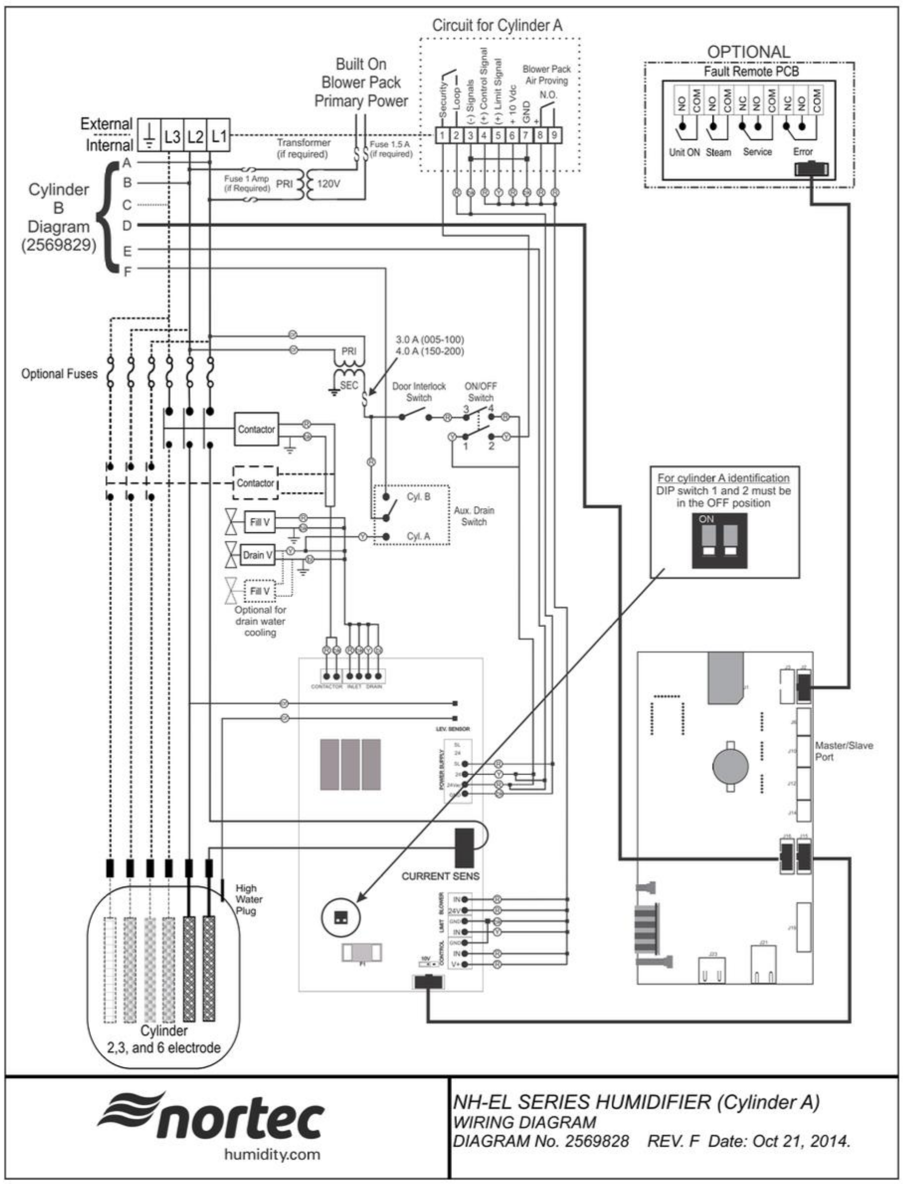
For NHTC models, select either 5 VDC or 24 VDC using JP3 on driver board.

nortec humidity.com

NORTEC HUMIDIFIERS
EXTERNAL CONTROLS WIRING CONNECTIONS
LOW VOLTAGE TERMINAL STRIP
Diagram No. 1509816 Rev.E July 15, 2013

- www.humidity.com -

Wiring


Circuit for Cylinder A
Built On
Blower Pack
Primary Power
OPTIONAL
Fault Remote PCB
Unit ON
Steam
Service
Error
External
Internal
L3
L2
L1
Transformer
(if required)
Fuse 1.5 A
(if required)
Security
Loop
(-) Signals
(+) Control Signal
(+) Limit Signal
+ 10 Vdc
GND
Blower Pack
Air Proving
N.O.
Fuse 1 Amp
(if Required)
PRI
120V
Cylinder
B
Diagram
(2569829)
3.0 A (005-100)
4.0 A (150-200)
SEC
Door Interlock
Switch
ON/OFF
Switch
Optional Fuses
Contactor
Cyl. B
Cyl. A
Aux. Drain
Switch
Fill V
Drain V
Optional for
drain water
cooling
For cylinder A identification
DIP switch 1 and 2 must be
in the OFF position
ON
Master/Slave
Port
CURRENT SENS
High
Water
Plug
Cylinder
2,3, and 6 electrode
NH-EL SERIES HUMIDIFIER (Cylinder A)
WIRING DIAGRAM
DIAGRAM No. 2569828 REV. F Date: Oct 21, 2014.
humidity.com

4.0 Humidifier Options

Item	Part Number	Description
Cylinder 202, 005-010, 110-277/1	1519002	**Disposable Cylinders**, are the standard NORTEC supply. Available in a variety of capacities up to 100 lbs/hr, with voltages ranging from 115 to 600V, 1 or 3 ph. Designed to accommodate a wide variety of water conditions.

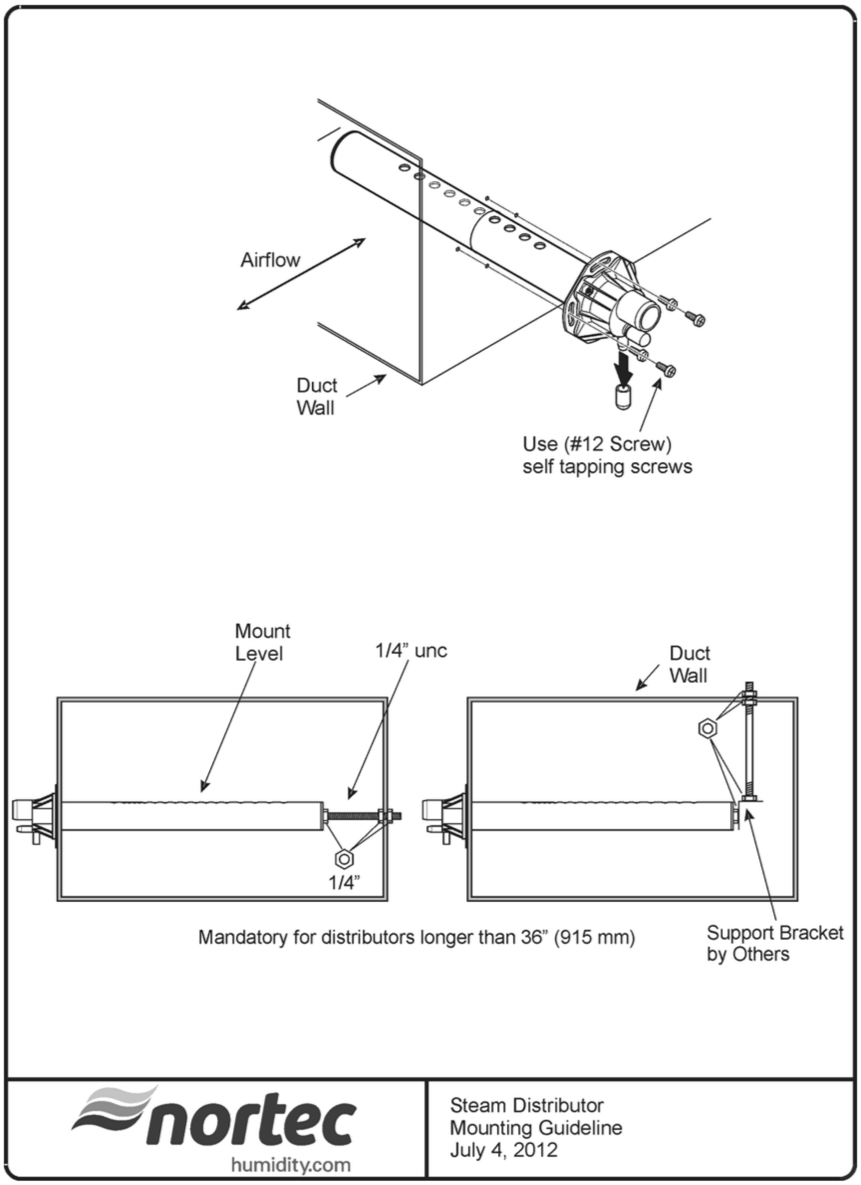
5.0 Distributors

5.1 Steam Distributors ASD

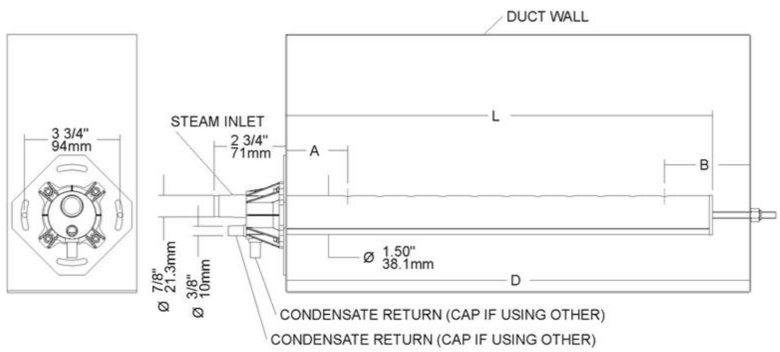
ASD Stainless Steel Steam Distributor, suitable for capacities up to 25 lbs/hr. Machined from high quality stainless steel. Steam is dispersed through evenly spaced outlet orifices along the top of the steam distributor's "Active Zone". The portions of the distributor closest to the duct walls are not considered "Active Zones" due to reduced air flow. The length selection of a steam distributor is defined by the duct width.

Zone Tag	Tube Quantity	Tube Length (in)	Absorption Distance (ft)
Zone(1)	2	12	0.82

Installation



Shop Drawing



Distributor Model	Max Capacity (lbs/hr)	Dimensions						Minimum Duct Dimensions	
		A		B		L		D	
		in	mm	in	mm	in	mm	in	mm
ASD 12	25	2	51	1.75	44	10	254	12	305
ASD 18	25					16	406	18	457
ASD 24	25	2.25	57			20	508	24	609
ASD 30	25					26	660	30	762
ASD 36	25					32	813	36	914
ASD 42	25	2.5	64	2	51	38	965	42	1066
ASD 48	25					44	1118	48	1219
ASD 54	25					50	1270	54	1371
ASD 60	25	3	76	2.5	64	56	1422	60	1524
ASD 66	25					62	1575	66	1676

Note:
- ASD distributor suitable for 25 lbs/hr (11.3 kg/hr).
- Steam distributor tube made of stainless steel.
- Steam inlet and end cap made of fire rated plastic.
- Distributor is adjustable for horizontal or downflow applications.
- Condensate return hose and steam hose provided for steam line connection.

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Steam Distributor,
ASD, 25 lbs/hr (11.3 kg/hr)

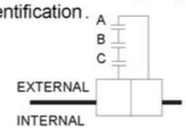
6.0 Controls

Item	Part Number	Description
SP Switch Air Proving, Duct, mtd.	1329203	**Air Proving Switch**, on/off, duct mounted, pressure differential switch, adjustable set point from 0.07 IWC to 12.0 IWC, good for positive, negative or differential pressure applications, stops humidifier if duct air pressure is not sensed. Turns humidifier off if air handler fails.
Humidistat, On/Off, High Limit,Dig. Duct	2548732	**On/Off Digital Duct Humidistat,** for use with all product lines. Duct mounted controller with digital display. This humidistat can be configured for either humidity control or as a high limit safety device. An internal humidity sensor provides accurate control of the RH in a zone or space. An optional remote sensor can be used for outdoor temperature setback in the fresh air duct. FEATURES • 24 Vac On/Off control. • Single speed fan support. • Password protected programmable user and control parameters. • Accuracy of ±5 %RH. • No loss of set parameters when returning from power failure.
Humidistat, Control, 0-10V, Dig. Wall	1510142	**Modulating Wall Mounted Humidistat c/w Digital Display,** for use with all product lines. The controller with internal sensor will provide accurate control of the RH in a zone or space. Can be used with a remote sensor for outdoor temperature setback in the fresh air duct.

Installation

Controls are available from the factory as options. If controls were not ordered with the humidifier, they may be purchased/supplied by others. The following information is relevant to all ON/OFF controls, factory supplied or otherwise.

Controls are to be wired in series (only one path for current) across the control terminals on the low voltage control terminal strip, or replaced with a jumper wire for constant operation. Consult each individual unit wiring diagram for terminal identification.



A. Control On/Off Humidistat - Wired to make on drop in humidity, break on rise. Set to desired %rh.

B. Duct High Limit On/Off Humidistat - Wired to make on drop in humidity, break on rise. Set to a higher set point (max. 85% rh) as a safety to prevent saturation.

C. Air Proving On/Off Switch - Wired to make when sensing air flow, break when no air flow. As a safety to prevent duct saturation when no air flows.

1. The factory offers various versions of controls to suit each application.
2. Field wiri ng from humidistat to humidifier and between devices should be 18 AWG or heavier.
3. The low voltage control terminal strip is provided in the electrical compartment.
4. Each unit is supplied with a wiring diagram. Consult each individual unit wiring diagram for exact terminal identification.
5. Mount any wall humidistat (control or high limit) over a standard electrical box at a height similar to a typical thermostat. Any wall humidistat should be in a location representative of the overall space being humidified and not in the path of a blower pack or an air supply grille.
6. Mount any duct control humidistat in a location representative of the overall air hum idity, usually the return duct. Do not mount it directly in front of the steam distributor or in a turbulent or mixing zone. Mount it where the air's humidity and temperature are uniform.
7. Mount any duct high limit humidistat downstream of steam distributors far, enough that under normal humidity and air flow conditions the steam will have been fully absorbed (typically more than 10 feet). It must be location to sense high humidity only when the uniform and representative air is over-humidified or approaching saturation.
8. Mount any air proving switch so that it is able to sense air flow or the lack of it. Wire it to make when air flow is sensed and break with no air flow.
9. Check operation of controls before starting unit.

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Controls-On/Off

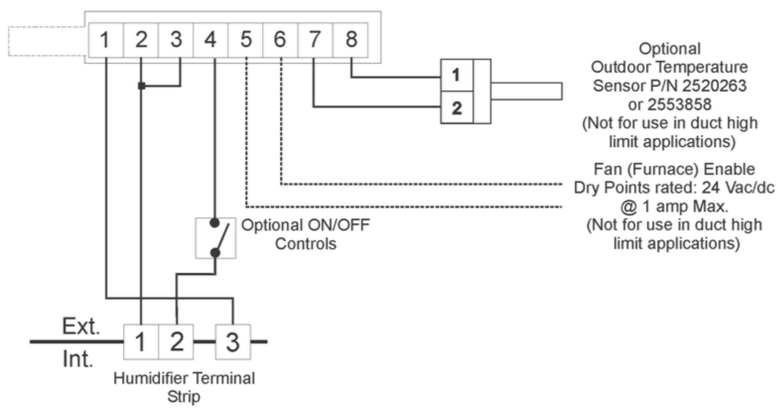
Installation

NORTEC Wall and Duct ON/OFF HUMIDISTAT WIRING DIAGRAM

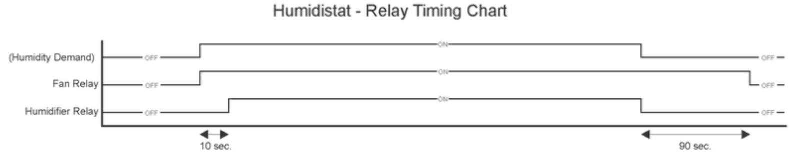
Use for NHTC/NHPC, RH Series, NHRS, GSTC/GSP, SETC/SEP, MHTC, AIRFOG, and HP with:

Part #	Description
2548731	Digital ON/OFF Wall Humidistat
2548732	Digital ON/OFF Duct Humidistat
2520263	Outdoor Temperature Sensor
2553858	Outdoor Mount Temperature Sensor

Warning: Failure to wire the humidity transducer in accordance with wiring diagram could permanently damage the electronics. Such errors will void the warranty. Cabling between transducers and unit should be shielded 18 AWG



Humidistat - Relay Timing Chart

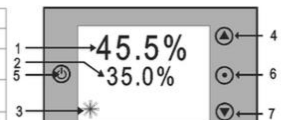


WID Nortec Digital ON/OFF Humidistat
INSTALLATION INSTRUCTION/WIRING DIAGRAM
DIAGRAM NUMBER 2548733 REV. C
DATE April 19, 2010

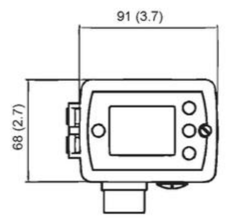
Shop Drawing

Technical Data

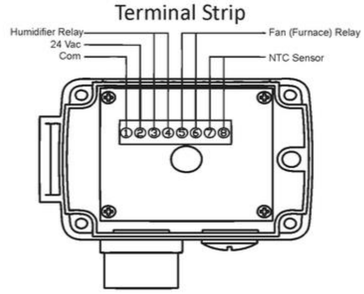
Power Supply	Operating Voltage	24V AC/DC ± 10%, 50...60Hz
	Power Consumption	Max. 1.5 VA
	Electrical Connection	Terminal Connectors, Wire: AWG 24...12
	Internal Rectification Signal ground = Power ground	Half wave rectified Isolation transformer required
Signal Inputs	Humidity Input: Range Accuracy Hysteresis	Element: Polymer-Based Capacity Sensor 0...100% r.H. 10%...90% r.H. ± 5.0% 0%...10% and 90%...100% ± 7.0% ± 1% r.H.
	Temperature Input Range	External NTC (P/N: 2520263) -40...70°C (-40...158°F)
	Accuracy	-40...0°C (-40...32°F): 0.5 C 0...50°C (32...122°F): 0.2 C 50...70°C (122...158°F): 0.5 C
Signal Outputs	Digital Switching Outputs Switching type AC Switching power	DO1...DO2 Relays 2 x 1.0 A, 24 Vac max.
Environment	Operation Climatic Conditions Temperature Humidity Transport & Storage Climatic Conditions Temperature Humidity Mechanical Conditions	To IEC 721-3-3 class 3 K5 0...50 °C (32...122 °F) <95 % r.H. non-condensing To IEC 721-3-2 and IEC 721-3-1 class 3 K3 and class 1 K3 -25...70 °C (-13...158 °F) <95 % r.H. non-condensing class 2M
Standards	Product standards Automatic electrical controls for household and similar use	EN 60 730 –1 EN 60 730 – 2 – 9
	Degree of Protection	IP30 to EN 60 529
	Safety Class	III (IEC 60536)
Housing	Cover, back part Mounting Plate	Polycarbonate PC (UL94 class V-0) PTFE coated 1im pores
General	Dimensions (H x W x D): Transmitter case: Probe length:	 91 x 68 x 47mm (3.7" x 2.7" x 1.9") 76 mm (3.0")
	Weight (including package)	220g

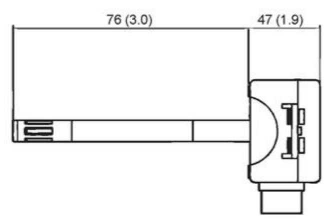


Legend:
1 Display of current humidity value.
2 Display of setpoint.
3 Snow flake displayed if outdoor temperature setback active.
4 Adjusts setpoint and calibration (Up).
5 Power On/Off.
6 Toggles between RH setpoint and temperature (if temperature sensor present).
7 Adjusts setpoint and calibration (Down).



Terminal Strip





nortec humidity.com

On/Off Digital Duct Humidistat
P/N 2548732
July 5, 2012

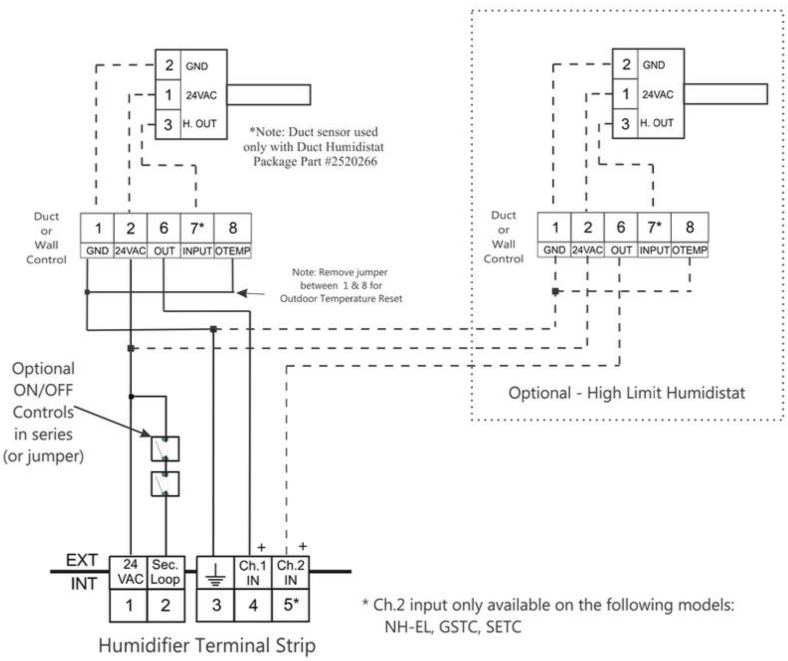
Installation

NORTEC 0-10V DIGITAL HUMIDISTAT
WIRING DIAGRAM

Use on: NH-EL, GSTC/GSP, SETC/SEP, MHTC, AIRFOG, HP and Rh series
with the following accessories:

Part #	Description
1510142	0-10V Digital Wall Humidistat
2520266	0-10V Digital Duct Humidistat Package

Warning: Failure to wire the humidistat in accordance with the wiring diagram could permanently damage the electronics. Such errors will void the warranty. Cabling between controls and unit should be shielded 18 AWG



NOTE: Nortec recommends using the Network Staged Modulation option when controlling multiple humidifiers with a single set of controls.

nortec humidity.com

Nortec 0-10V Digital Humidistat
Wiring Diagram/Installation Instruction
Part Number: 2520528 **Revision: G** **Date:** 03/10/14

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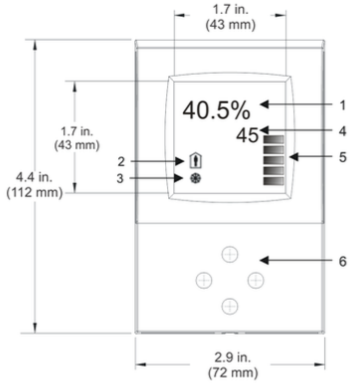
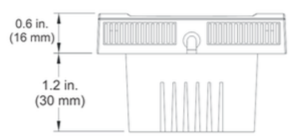
Shop Drawing



Functions

1. Display of current humidity value.
2. Operation modes: Comfort mode,
   Humidstat Off
3. Snowflake indicates that outdoor temperature setback is in effect.
4. Setpoint display.
5. Graphical display of output value with increments of 10%.
6. Buttons for operating the humidistat:
   - POWER button: Pressing the button for more than 2 seconds switches the humidistat off.
   - △ ▽ UP/DOWN buttons: Change setpoint value.
   - ▷ OPTION button: Used for accessing the sensor calibration routine. (See page 3)



Technical Data

Power Supply	Operating Voltage	24 VAC ±10%, 50/60 Hz
	Power Consumption	Max 3 VA
	Internal Rectification	Half Wave Rectified
Analog Inputs	Voltage Input	X1
	Input Signal	0 - 10 VDC
	Resolution	39 mV
	Impedance	98kΩ
	Temperature Input	External Thermistor
	Range	-40° to 140°C
	Resolution	0.1 K
	Accuracy	0.2 to 0.5K
Analogy Outputs	Analog Output	Y1
	Output Signal	0 to 10 VDC
	Resolution	39 mV
	Maximum Load	Voltage 1kΩ
	Accuracy	1%
Humidity Sensor	Type	Capacity Sensor
	Range	0 to 100%RH
	Accuracy	±3% (10-90% RH)
	Hysterisis	±1%
	Repeatability	± 0.1%
	Stability	<0.5% /year
Environment	Operating Temperature	0 to 50°C
	Operating Humidity	<95% RH
Housing Materials	Cover / Back	Fire Proof ABS Plastic
	Mounting Plate	Galvanized Steel

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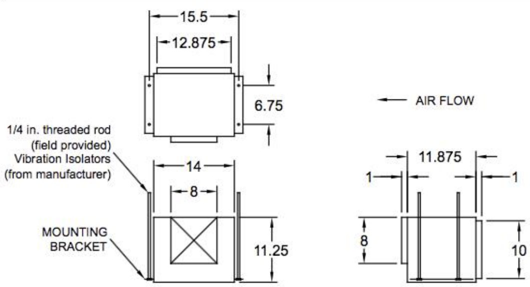
humidity.com

Controller, Wall Mtd. c/w Integral Sensor with Digital Display, Part 1510142
July 29, 2014

B.1.2 Exhaust Fan Specifications Sheets

GREENHECK
Building Value in Air.

Printed Date: 11/10/2015
Job: U of M Student Project
Mark: Mark 1



Model: CSP-A200

Inline Cabinet Fan

Standard Construction Features:

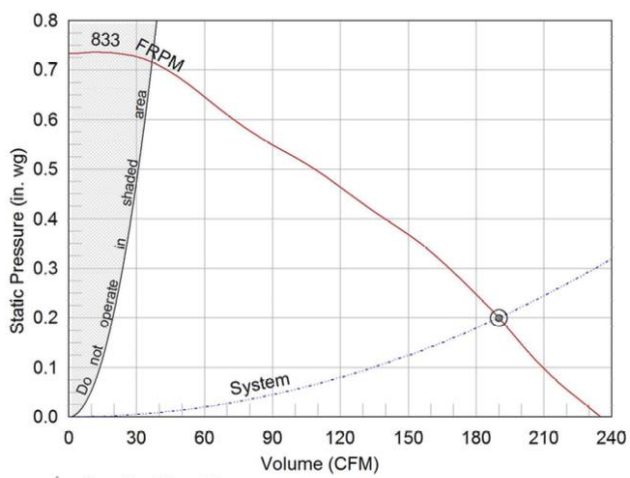
- Corrosion resistant galvanized steel scroll and housing - Sound absorbing insulation - Rectangular inlet and outlet duct collar - Outlet with integral spring loaded back draft damper - Double inlet forward curved wheel - Plug type disconnect - Adjustable mounting brackets - Field rotatable discharge

Selected Options & Accessories:

Motor with Thermal Overload
Motor with CSA Approval
Motor with 40 Degree C Ambient Temperature
UL/cUL 507 Listed - Electric Fan
Solid State Speed Control, 6 Amp, Shipped Loose
Rectangular Hooded Wall Cap, (PN: WC-10X3) Shipped Loose
Isolation Kit, (PN: VI KIT-SP/CSP), Shipped Loose
Polypropylene Wheel Material

Dimensional	
Quantity	1
Weight w/o Acc's (lb)	23
Weight w/ Acc's (lb)	28

Performance	
Requested Volume (CFM)	190
Actual Volume (CFM)	190
External SP (in. wg)	0.2
Total SP (in. wg)	0.2
Fan RPM	833
Amps (A)	0.43
Elevation (ft)	784
Airstream Temp.(F)	70
Air Density (lb/ft3)	0.073
Sones	0.4



△ Operating Bhp point
○ Operating point at Total SP
• Operating point at External SP
Fan curve
System curve
Brake horsepower curve

Motor	
Motor Mounted	Yes
Input Watts (W)	48.2
Voltage/Cycle/Phase	115/60/1
Enclosure	ODP

Notes:

All dimensions shown are in units of in.
*FLA is approximate and will vary slightly with the motor.
LwA - A weighted sound power level, based on ANSI S1.4
dBA - A weighted sound pressure level, based on 11.5 dB attenuation per Octave band at 5 ft
Sones - calculated using AMCA 301 at 5 ft
AMCA certified ratings seal applies to sone ratings only.
Wattage is shown at free air.
Wattage is approximate and may vary between motors.

CAPS 4.18.2016 F:\CAPS 4\Jobs\U of M Student Project.gfcj Page 1 of 11

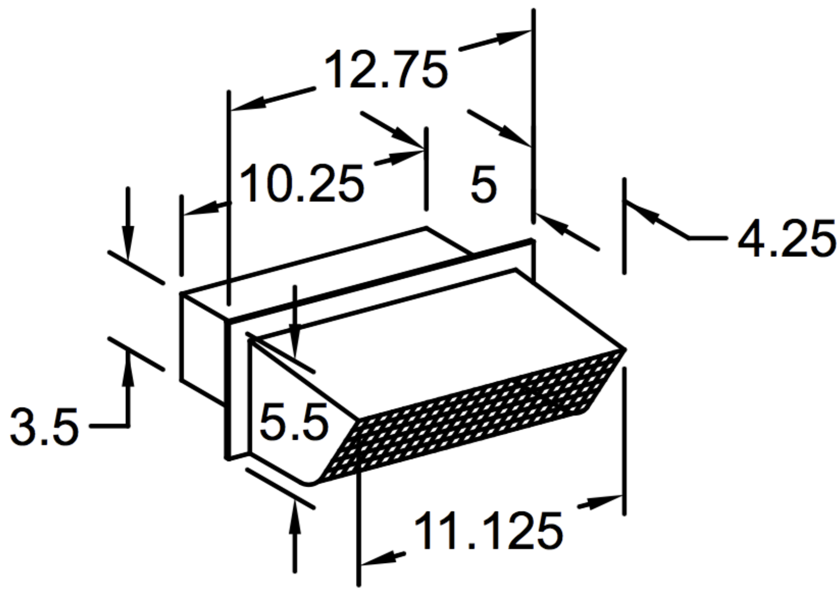
GREENHECK
Building Value in Air.

Printed Date: 11/10/2015
Job: U of M Student Project
Mark: Mark 1

Discharge Accessory

Type: Wall Cap - Rct

Standard Construction Features:
- Steel construction with black enamel finish - Designed for outside wall application - built in birdscreen and damper



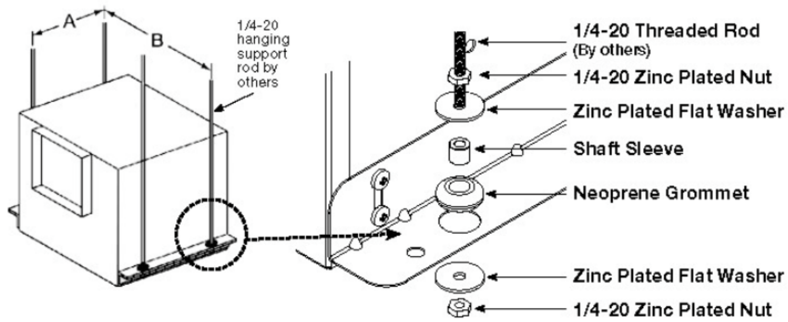
Notes: All dimensions shown are in units of in.

Isolation Kit

Type: Hanging

Standard Construction Features:

- Neoprene vibration isolation for hanging installation - Kit includes four isolators and all hardware necessary for mounting one unit except for the 0.25 in. x 20 in. threaded rod to be supplied by others - Fan mounting brackets include prepunched mounting holes for ease of installation



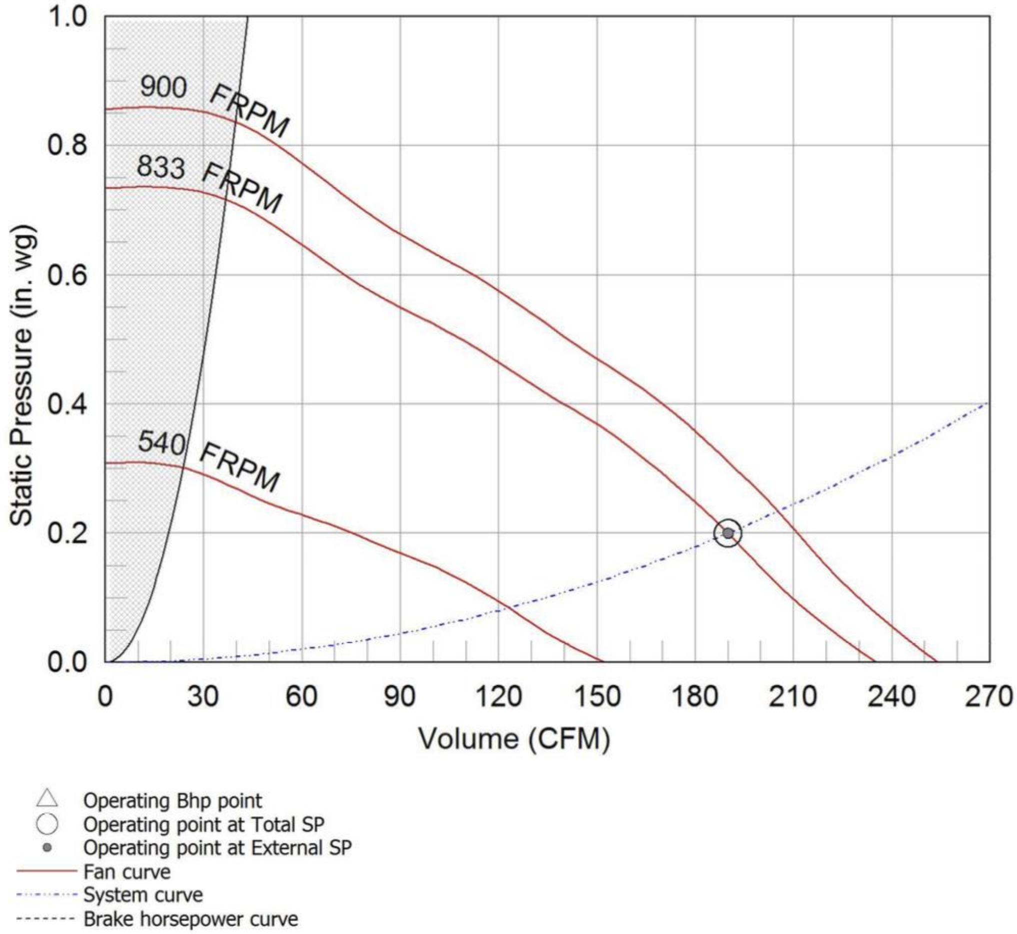
Unit Size	A	B
B50-B200	4 1/2 (*114*)	15 5/8 (*397*)
A50-A190	5 1/2 (*140*)	14 5/8 (*371*)
A200-A390	6 3/4 (*171*)	15 1/2 (*394*)
A410, A510, A710, A780	9 1/4 (*235*)	19 5/8 (*498*)
A700	5 1/2 (*140*)	25 1/8 (*638*)
A900 - A1050, A1410 - A1550	9 1/4 (*235*)	25 3/8 (*645*)
A1750, A2150	9 1/4 (*235*)	36 3/4 (*933*)
A3600	9 1/4 (*235*)	48 5/8 (*1235*)
All dimensions shown in inches (*millimeters*).		

Description	Qty
Neoprene Grommets	4
1 x 32 Zinc Plated Nuts	8
Zinc Plated Flat Washers	8
3/8 x 3/16 Shaft Sleeves	4

CSP-A200 Min/Max Fan Curve

Performance

Requested Volume (CFM)	Actual Volume (CFM)	External SP (in. wg)	Total SP (in. wg)	Fan RPM	Operating Power (hp)
190	190	0.2	0.2	833	0



B.2 Appendix B References

[1] Norm McCreight, Product Support Manager, Midwest Engineering Inc. (private communication), November 12, 2015.

[2] Doug Castor, Engineering Sales, Air distribution division, E.H Price (private communication), Nov 9, 2015.