Ventilation Improvement Feasibility Study

University of Manitoba, Bannatyne

Winnipeg, MB

Prepared For:

University of Manitoba
89 Freedman Crescent
Winnipeg, MB R7A 7H2

Prepared By:

Unit M – 675 Berry Street
Winnipeg, MB, R3H 1A7
(204) 318-2127

By: Andrew McCorrister, MIT

Johann Baetsen, P.Eng.

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Executive Summary

The feasibility report will provide information to assist the University of Manitoba with decisions related to the increase in the outdoor air change rate provided within high occupancy rooms and with measures to better control the spread of airborne pathogens, specifically for spaces called out as Priority in a previous air change rate study. The existing system effective outdoor air was measured to be below current recommended rates and did not meet baseline ASHRAE best practice standards. The study reviewed the option of increasing central air handler filter ratings, increasing outdoor air rates and coupling dedicated room side air cleaning devices to achieve the desired increased ventilation rate and control of airborne pathogens.

The impact of both an increase of airborne infectious diseases and an increase in the outdoor air pollution levels associated with frequency of forest fires, high occupancy spaces should have means for properly disinfecting air steams and have the means for monitoring air pollutants beyond CO_2. It is recommended that disinfection of the air stream can be achieved using UV-C, Bipolar ionization, or Photocatalytic means, and measurement of the pollution levels should have an outdoor reference and new indoor space monitors.

The proposed options reviewed the potential increases to energy demand, requirements to alter air handlers and existing supply air systems in the spaces, and the serviceability of any stand-alone support system. Based on this information, to achieve a higher effective outdoor air rate within the high occupancy spaces and employ air side infection control, for all of the Priority spaces, the recommended approach is to utilize a separate filtration unit with some additional changes to overall supply air rate, refer to Table 1 below. Outdoor monitoring and indoor monitoring of additional pollutants is recommended to ensure that indoor air quality is not compromised during high outdoor pollution instances.

Air side infection control strategies reviewed the available data from manufacturers and recommendations from standards authorities. While UV-C technologies have proven track records and the support of ASHRAE, the overall effectiveness on systems is dependant on exposure time and are more limited in small scale applications. Bipolar ionization and Photocatalytic disinfection systems are better infection control system, with Photocatalytic systems providing the best option for safe and effective means to disinfect airborne infectious diseases.

Table 1 Effective Outdoor Air Change Rates

Building	Room	Existing SA ACH	Existing Effective OA ACH	Option 1 OA ACH	Option 2 OA ACH	Option 3 OA ACH	Option 4 OA ACH	Option 5 OA ACH	Option 6 OA ACH
BMSB	153A	2.5	2.0	2.4	2.5	2.8	2.7	5.6	--
BMSB	253A	1.7	1.3	1.6	1.6	7.4	7.1	7.3	--
Med Rehab	R160	3.4	2.2	2.6	2.7	3.5	3.3	--	6.0

Building	Room	Existing SA ACH	Existing Effective OA ACH	Option 1 OA ACH	Option 2 OA ACH	Option 3 OA ACH	Option 4 OA ACH	Option 5 OA ACH	Option 6 OA ACH
Med Rehab	R170	3.0	1.9	2.3	2.4	4.9	4.8	--	6.0
Med Rehab	R224	3.3	2.1	2.6	2.7	5.0	4.8	--	6.1
Med Rehab	R230	4.2	2.7	3.2	3.4	5.0	4.9	--	6.4
Med Rehab	R236	2.7	1.7	2.1	2.2	4.9	4.8	--	6.0
Apotex	050	10.5	6.5	--	--	--	--	--	--
Apotex	071	6.3	6.1	--	6.1	--	--	--	--
Apotex	156	5.9	5.7	6.0	--	--	--	--	--
Apotex	164	8.1	7.9	--	6.0	--	--	--	
Apotex	264	3.5	3.4	--	--	6.1	--	--	
Dentistry	D220	6.0	4.6	--	6.2	--	6.0	--	
Pathology Building	P133	4.9	3.7	--	--	--	--	6.3	
William Norrie Centre	124	6.6	5.3	--	--	--	6.0	--	6.0

Option 1: Increase filtration rate of delivered air to space to MERV 15
Option 2: Increase filtration rate of delivered air to space to MERV 15 and UV
Option 3: Increase the overall supply air, increase to MERV 13 and add UV.
Option 4: Increase the overall supply and increase to MERV 15
Option 5: Increase the overall maximum supply air rate (varies per room), filtration rate at central air handler to be MERV 11, add separate HEPA unit parallel to existing system with UV.
Option 6: Increase the overall supply air rate (varies per room), change VAV units to Fan powered boxes with MERV 13, filtration rate at central air handler to be MERV 11, add separate HEPA unit parallel to existing system with UV.

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1. Introduction

The University of Manitoba has tasked MEER Engineering (MEER) to undertake a study to determine the feasibility of increasing the overall Indoor Environmental Quality of the high-density occupancy spaces at the Bannatyne Campus. Specific rooms outlined as Priority were determined by the University and a previous study of the existing conditions on the campus. MEER is tasked with providing a review of existing ventilation conditions, conduct a feasibility study, and develop suitable options to improve ventilation rates within the following buildings and spaces at the Bannatyne Campus:

Table 2 - Priority Spaces For Study

Building Name	Room Number	Air Handler	Space Type
Basic Medical Sciences Building	153	AHU-4	Lecture Theatre
Basic Medical Sciences Building	253	AHU-4	Lecture Theatre
Medical Rehabilitation Building	R160	AH-1	Classroom
Medical Rehabilitation Building	R170	AH-1	Classroom
Medical Rehabilitation Building	R224	AH-2	Classroom
Medical Rehabilitation Building	R230	AH-2	Classroom
Medical Rehabilitation Building	R236	AH-2	Classroom
Apotex	050	AHU-5	Classroom
Apotex	071	AHU-2	Lecture Theatre
Apotex	156	AHU-2	Teaching Lab
Apotex	164	AHU-2	Lecture Theatre
Apotex	264	AHU-2	Lecture Theatre
Dentistry	D220	AH-4	Teaching Lab
Pathology Building	P133	AHU-2	Classroom
William Norrie Centre	124	HP-4/MUA-1	Classroom

The review of the existing conditions of the systems by the University indicated that the ventilation rates currently provided to the spaces did not meet all of the best practice rates established by ANSI/ASHRAE Standard 62.1-2022, Ventilation and Acceptable Indoor Air Quality (ASHRAE). The minimum of three (3) effective ACH is the recommendation and would meet the current standards. The potential to target higher effective ACH would be on a case by case basis.

The ventilation rate provided to the spaces is only one part of achieving proper indoor air quality (IAQ), and IAQ within a space can be different depending on the end user. ASHRAE defines IAQ as the type and concentrations of airborne contaminants found in buildings and thermal comfort as “that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation”. Both Thermal Comfort and IAQ are important to this study and a better term that should be used going forward is Indoor Environmental Quality (IEQ). The study will provide an IEQ analysis based on the best practices for minimizing human exposure to airborne particulates, aerosols, gaseous contaminants, and maintaining the required thermal comfort in the spaces.

The application of an air side disinfection strategy is to be reviewed, in addition to IEQ analysis. The influenza endemic and the current COVID-19 pandemic are the concerns of the population when gathering in spaces and the removal and control of these airborne pathogens is reason for this study. Airborne pathogens are a small component of IEQ, the technologies that form this disinfection are not considered a major contributor to the IEQ of a space. The effectiveness of the disinfection of the air stream is dependant upon dwell time and intensity of these systems. UV-C systems, bipolar ionization and photocatalytic systems make up most of the available technologies with many different approaches by manufacturers of the systems.

In addition to these items, consideration of the current and predicted outdoor air conditions near to the buildings is required. Government agencies predict increases in wildfires events, with longer durations as the climate changes. Under these conditions, increased outdoor air rates can have negative impacts on indoor occupants and they should be minimized. Control and measurement of the pollutants in the outdoor air should also play a role in the proper control of the air system.

The government of Manitoba states the following with respect to air quality:

> *"Health Canada estimates there are 14,000 to 15,000 deaths in Canada per year due to air pollution from human activity. Air pollution contributes to the hospitalization of many more Canadians each year. Even at low levels, air pollution has been linked to an increased risk of heart and lung problems, as well as other health effects. These can include difficulty breathing, irritation of the eyes, nose and throat, and worsening of chronic conditions (e.g., heart disease, bronchitis, emphysema, asthma), and in some cases premature death. Individuals react differently to air pollutants. Children, the elderly, and people with heart or lung conditions or diabetes are more sensitive to the adverse effects of air pollution. People participating in sports or strenuous work outdoors may also be more susceptible to the negative impacts of air pollution because they are breathing air deeply and rapidly."*

2. Limitations

The report specifically excludes:

- Review of concealed elements,
- Engineering design or analysis.
- Engineering Construction Documents.
- Energy modelling.

3. References

The report references the following items:

- American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE)
    - 52.2-2017 – Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size
    - 62.1- 2022 - Ventilation for Acceptable Indoor Air Quality
    - Epidemic Task Force Filtration & Disinfection Guide
    - Handbook Fundamentals 2021
    - Handbook Applications 2019
- Harvard T.H. Chan School for Public Health
    - Healthy Buildings for Health
- Health Canada
    - Guidance for Cleaner Air Spaces during Wildfire Smoke Events
    - Maintain and Improve Indoor Air Quality
    - Ventilation and the indoor environment
- Manitoba Building Code (MBC)
- Manitoba Conservation and Climate
    - Canadian Ambient Air Quality Standards (CAAQS) for Fine Particulate Matter ($PM_{2.5}$) and Ozone.
- National Building Code of Canada (NBCC)
- The WELL Building Standard (WELL)
    - Air Quality
- Underwriter Laboratory (UL)
    - 2998 - Environmental Claim Validation Procedure (ECVP) for Zero Ozone Emissions from Air Cleaners

4. Code requirements and Best Engineering Practices

4.1. Code Required Ventilation Rates and Baselines

The ventilation code requirement under the Manitoba Building Code (MBC) follows the 2010 National Building Code of Canada (NBCC) requirements for Part 6, with only some small variation for smoke and carbon monoxide control. The NBCC part 6 requires outdoor air conditions provided to buildings meet the criteria stated in the National Ambient Air Quality Objectives of the Canadian Environmental Protection Act (limiting PM_{10}, Ozone, and Carbon Monoxide), as well spaces are to be ventilated to the ASHRAE 62-2001 requirements (15 CFM/person for classrooms, and 20 CFM/person for laboratories).

The NBCC and ASHRAE require the outdoor air being provided to the buildings meet a minimum quantity level, referring to the Canadian Ambient Air Quality Standards (CAAQS). The current requirements are as noted below:

Table 3 - Canadian Air Quality Standards

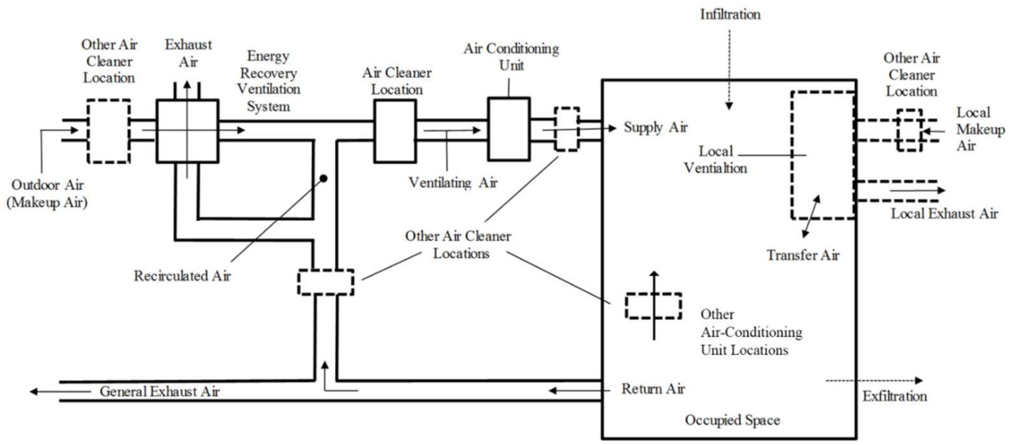
Pollutant	Averaging Time	Limit - 2020	Limit - 2025	Statistical Form
Fine Particulate Matter ($PM_{2.5}$)	24-hour	28 µg/m^3	27 µg/m^3	The 3-year average of the annual 98th percentile of the daily 24-hour average concentrations
	Annual	10.0 µg/m^3	8.8 µg/m^3	The 3-year average of the annual average of the daily 24-hour average concentrations
Ozone (O_3)	8-hour	62 ppb	60 ppb	The 3-year average of the annual 4th highest of the daily maximum 8-hour average ozone concentrations
Sulphur Dioxide (SO_2)	1-hour	70 ppb	65 ppb	The 3-year average of the annual 99th percentile of the SO2 daily maximum 1-hour average concentrations
	Annual	5.0 ppb	4.0 ppb	The average over a single calendar year of all 1-hour average SO2 concentrations
Nitrogen Dioxide (NO_2)	1-hour	60 ppb	42 ppb	The 3-year average of the annual 98th percentile of the daily maximum 1-hour average concentrations
	Annual	17.0 ppb	12.0 ppb	The average over a single calendar year of all 1-hour average concentrations

Ozone generation from air filtration or air stream disinfection is not permitted as per the NBCC and all devices need to be tested in accordance with UL 2998 for compliance.

4.2. Best Practices and Standards

Although code requires adherence to ASHRAE 62.1 2001, the most recent publication of this standard (2022) provides further insight into ventilation strategies that go beyond the requirements in 2001 and will be used as the baseline. This standard allows for air treatment at multiple locations in a system in order to provide good IEQ. In the figure below, the current standards permit the treatment of air in multiple locations to achieve the effective outdoor air change rate (eACH). This allows for a greater energy savings and to ensure that under poor outdoor air quality conditions, that the indoor population is protected.

Figure 1 - ASHRAE 62.1-2022 Ventilation System



The Harvard T.H. Chan School for Public Health has generated several studies and recommendations for various building spaces. For educational spaces they establish a minimum of three air changes per hour (ACH) of outdoor air, either with direct outdoor air or the effective outdoor air rate. Providing beyond a minimum of 3 ACH is a goal of the UofM and would be handled on a case by case to each space. These rates were chosen as they showed the greatest impact on occupant health while optimizing energy demands on the systems.

Health Canada and the Manitoba government provide additional information on recommended pollutant levels within the indoor spaces:

Table 4 - Government Recommended Limits on Pollutants

Pollutant	Rate	Description
O^3	20 ppb	Threshold Limit
CO	10 ppm	Threshold Limit
CO_2	1000 ppm	Proposed Health Canada Limit

WELL certification is a newer building certification system that is gaining in popularity and focuses on the well being of the building beyond what a normal LEED building would provide. It establishes some additional recommended values for minimum exposures to particulates and VOC's as follows:

Table 5 - WELL Certified Indoor Air Limits

Pollutant	Rate	Description
$PM_{2.5}$	15 μg/m^3	24-hour average
PM_{10}	50 μg/m^3	Threshold Limit
TVOC	500 μg/m^3	Threshold Limit
CO	10 ppm	Peak exposure recommended limit
O^3	51 ppb	3-year Average

Under a forest fire condition, Health Canada recommends the following indoor air quality limits (nitrogen oxides (NOx), polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs):

Table 6 - Health Canada IAQ Targets Under Forest Fire Conditions

Pollutant	Rate	Description
$PM_{2.5}$	Lower than OA	24-hour average
CO	10 ppm	Threshold Limit
CO_2	1000 ppm	Threshold Limit
Temperature	26°C	
Relative Humidity	35-50%	
NO_x, PAH, VOC	---	As low as possible

A growing consensus in the scientific community is the impact of the relative humidity (RH) within the indoor environment and the ability for airborne illnesses to spread. Both Influenza A and COVID-19 have been studied with respect to the transmissibility and relative humidity of a space and the data has shown that a RH range of 40-60% is the ideal range to help slow transmissions. Anything less than 20% or higher than 80% has been shown to have little effect on slowing the spread of the virus.

5. Filtration and Disinfection System Analysis

5.1. MERV Filters

The Minimum Efficiency Reporting Values (MERV) ratings report a filter's ability to capture larger particles between 0.3 and 10 microns (µm), the higher the number, the better the filter is at removing particulates. ASHRAE Standard 52.2 establishes the means for testing of these filters and the ratings are as follows:

Table 7 - MERV Rating Table

MERV Rating	Average Particle Size Efficiency in Microns
1-4	3.0 - 10.0 less than 20%
5	3.0-10.0 less than or equal to 20%
6	3.0-10.0 less than or equal to 20%
7	3.0-10.0 less than or equal to 50%
8	1.0-3.0 less than or equal to 20% 3.0-10.0 less than or equal to 70%
9	1.0-3.0 less than or equal to 35% 3.0-10.0 less than or equal to 75%
10	1.0-3.0 less than or equal to 50% 3.0-10.0 less than or equal to 80%
11	0.30-1.0 less than or equal to 20% 1.0-3.0 less than or equal to 65% 3.0-10.0 less than or equal to 85%
12	0.30-1.0 less than or equal to 35% 1.0-3.0 less than or equal to 80% 3.0-10.0 less than or equal to 90%
13	0.30-1.0 less than or equal to 50% 1.0-3.0 less than or equal to 85% 3.0-10.0 less than or equal to 90%
14	0.30-1.0 less than or equal to 75% 1.0-3.0 less than or equal to 90% 3.0-10.0 less than or equal to 95%
15	0.30-1.0 less than or equal to 85% 1.0-3.0 less than or equal to 90% 3.0-10.0 less than or equal to 95%
16	0.30-1.0 less than or equal to 95% 1.0-3.0 less than or equal to 95% 3.0-10.0 less than or equal to 95%

5.2. HEPA Filters

High Efficiency Particulate Air filters (HEPA) is a type of air filter that is designed to remove at least 99.97% of any airborne particles with a size of 0.3 microns (μm). Particles that are larger and smaller are trapped with even higher efficiency. HEPA filters are composed of a mat of randomly arranged fibers and are typically composed of polypropylene or fiberglass with diameters between 0.5 and 2.0 micrometers. These fibers create a narrow-convoluted pathway through which air passes. When the largest particles are passing through this pathway, the bundles of fibers behave like a kitchen sieve which physically blocks the particles from passing through. However, when smaller particles pass with the air, as the air twists and turns, the smaller particles cannot keep up with the motion of the air and thus they collide with the fibers. Key factors affecting the performance of the filter are functions are fiber diameter, filter thickness, and face velocity.

5.3. Ultraviolet Treatment

Ultraviolet light belongs in the electromagnetic spectrum with a wavelength in the range of 200 to 400 nm (nanometers), which is shorter than that of visible light, but longer than X-rays. The UV spectrum can be subdivided into the following bands:

- UV-A (long-wave; 400 - 315 nm): used for black lights, skin tanning, ink/resin curing.
- UV-B (medium-wave; 315 - 280 nm): used for psoriasis therapy, can cause sunburn, skin cancer.
- UV-C (short-wave; 280 - 200nm): most effective for germicidal disinfection.
- UV-V (vacuum UV, below 200 nm): can produce ozone in the air.

The UV-C light from the sun is blocked by the ozone layer, and consequently microorganisms on earth have not developed a natural defense against UV-C energy. When the DNA of a microorganism absorbs UV-C energy, molecular instability occurs, resulting in the disruption of the DNA sequence. This renders the cell unable to grow or reproduce. The application of UV-C energy to inactivate microorganisms is known as Germicidal Irradiation (UVGI). Most commercial UV-C lamps are low pressure mercury lamps that emit UV energy at 253.7 nm, which is an ideal wavelength for disrupting the DNA of microorganisms.

The amount of UV-C energy needed to inactivate a given microorganism is measured by dose, which is determined by a combination of irradiation energy and exposure time. A key difference between surface inactivation and airstream inactivation of micro-organisms is exposure time. Residence time in the UV field for microorganisms in the air stream is in the order of seconds and would require a much higher UV-C dose as compared to a surface application. Research has shown that organisms differ in their susceptibility to UV-C inactivation; in general, viruses are the most susceptible to UV-C followed by bacteria with molds and fungal spores being the least susceptible. UV-C irradiation obeys the inverse–square law of light, where the intensity at a given point is inversely proportional to the square of its distance from the light source. Prolonged exposure to UV can cause photo degradation of organic and synthetic materials (discolouring of materials)

Ultraviolet germicidal irradiation used for water, air and surface disinfection is biocidal to microorganisms but presents a health hazard to humans as well. Excessive exposure to UV can result in damage to the eyes in form of photo keratitis and conjunctivitis. Ultraviolet radiation exposure can also affect the skin and cause erythema (skin-reddening). Most of the UV-C gets reflected and absorbed by the outer dead layer of the human skin, thus minimizing the UV-C transmitted through the epidermis layer.

There are two types of UV disinfection marketed in the HVAC communities, coil and air stream. Coil disinfection relies on the placement of UV lamps upstream of the cooling coil and will break down built up biological material on the cooling coil. As the lamps are directed at the coil and have little exposure time to the air stream, they have little effect on airborne particles. As the ability to treat the air is based on intensity and duration, to maximize the ability to disinfect and limit the need for energy intensive lamps, slow moving airflow across a length of lamps is ideal. Duct mounted lamps, positioned in the along the side of the duct is the most common method for disinfection of air. In the smaller in-room air purifier systems, the lamps are positioned so that they are exposed to a slow-moving air stream (slower than in the duct arrangement) but are more energy intensive as they don't have the same exposure time as a duct section would have.

5.4. Bipolar Ionization Treatment

Needlepoint bipolar ionization, or simply bipolar ionization (BI), works by introducing positive and negative ions into the airstream through a proprietary electrical system. This ionization in turn causes hydroxyl (OH) radicals to form on the surface of airborne organic materials. The production of OH takes place by extracting hydrogen from the organic material cells, effectively damaging the cells. These free radicals remain in the air stream until consumed, with the by-product being trapped in the filtration media or falling out of the air within a space, but the pathogen remains active. Bipolar ionization has the potential to generate ozone and other potentially harmful by-products indoors, unless specific precautions are taken in the product design and maintenance. Manufacturers of BI products should bear the UL 2998 mark to ensure that the generation of O_3 from their product has been demonstrated to be zero. The risks of not maintaining these systems creates the potential of inducing O^3 into the air stream on systems that do not bear the proper UL mark.

5.5. Photocatalytic Oxidation

Photocatalytic Oxidation (PCO) and Advanced PCO is a technology that produce gaseous hydrogen peroxide (H_2O_2), hydroxyl radicals, and hydroxyl ions, via a UV light activating a non-depleting catalyst. These scrubbing molecules are distributed throughout the room where they pull apart bacteria, viruses, mold spores, and volatile organic compounds in the air, as well as reduce bacteria, viruses, and mold spores on surfaces. The largest advantage is that the advanced system does not produce O_3 while it eliminates the pathogen. PCO is available in small scale room side equipment and large components for air handling units. PCO has been shown to be very effective at providing air stream disinfection of airborne illnesses and with effective kill rates higher than 95%.

6. Existing Mechanical System Review

Outdoor Air requirements from the NBCC and ASHRAE 62.1, supplied to the space should be within the threshold limits noted in section 5. The Government of Manitoba provides real-time $PM_{2.5}$ and O^3 outdoor air conditions in Winnipeg (the closest being measured at 65 Ellen Street) and list the historical measurements and is showed to historically be within the limits, though there have been several occurrences in the last several years where these values are beyond the limits. During recorded forest fire incidents, the levels have been beyond the recommended limits, but there have been noted incidents where levels are beyond the limits (November 20, 2021, had a O^3 8-hour average of 500ppb). As of October 2022, the historical averages for downtown Winnipeg are as follows:

Table 8 - Winnipeg OA PM2.5 and O3 Averages

Pollutant	Rate	Description
$PM_{2.5}$	21 $\mu g/m^3$	24-hour average
$PM_{2.5}$	6.4 $\mu g/m^3$	Annual average
O^3	55 ppb	3-year average

The University does not measure these pollutants directly and they are not currently utilized as part of the outdoor air control strategy. The current strategy for outdoor air monitoring is with outdoor air sensors (providing information at or near to the buildings being controlled) measuring pressure, dry bulb temperatures, and wet bulb temperatures or relative humidity.

6.1. Basic Medical Sciences Building

There are two separate air handlers that provide ventilation to the spaces within the BMSB scope of work. AHU-1 serves the Lab 02 along with other similar spaces on the lower level. AHU-4 serves Theatre A and the surrounding corridor spaces and offices. Both systems are complete with independent cooling and heating systems and are able to control the discharge temperature to the system and react to changes in the end spaces to accommodate changes in the occupancy.

Table 9 - BMSBS Air Handler Existing Supply Conditions

Building	Room	Existing SA ACH	Existing Effective OA ACH	Supply Air Volume	Maximum Outdoor Air	Minimum Outdoor Air	Installed Filtration (MERV)
AHU-4	153A	2.5	2.0	3,704 CFM	3,704 CFM	1,296 CFM	11
	253A	1.7	1.3	436 CFM	436 CFM	153 CFM	11

6.1.1. – AHU-4 and Theatre A – 153 and 253

AHU-4 appears to be original to the building, with component repair and replacement occurring over the last 50 years of operation. The system is a constant volume system with the supply fan and return fan modulating to maintain duct and building pressure. There are only temperature and humidity monitors within the existing unit, and a single filtration section with local visual pressure measurement only.

The existing Theatre is scheduled for a refresh (scope not confirmed by the University at the time of the report writing) and is arranged with high level supply diffusers and wall mounted returns. The space is a tiered Theatre with a movable divider that separates the upper level and lower level (253 and 153 respectively). At the time of review the system was operating at a significant reduced capacity from the original design (only supplying 4,460 CFM of the original 8,600 CFM), and through some discovery efforts by the University the existing vortex damper was found to be partially closed. The damper has been subsequently opened to its original state and the system is reporting a 38% increase in supply air pressure, which should translate into an increase in supply flow of 17% from the AHU. The upper level and lower-level theatre are complete with re-heat coils and local thermostats to control the temperature in the space. With the reduced supply air volume to the space, the space air distribution system may not be fully mixing when fully occupied, and stratification of temperature and ventilation air is likely an issue.

6.2. Medical Rehabilitation Building

There are two separate air handlers that provide ventilation to the spaces within the MRB scope of work. AH-1 serves the lower levels (L000 and L100) and serves two spaces R160 and R170 from a small basement mechanical space. AH-2 serves the upper levels (L200 and L300) and serves three spaces R224, R230 and R236 from an upper-level penthouse. The other spaces connected to the systems are support and offices spaces. Both systems are complete with independent cooling and heating systems and are able to control the discharge temperature to the system and react to changes in the end spaces to accommodate changes in the occupancy

Table 10 - Medical Rehabilitation Building Air Handler Existing Supply Conditions

Building	Room	Existing SA ACH	Existing Effective OA ACH	Supply Air Volume	Maximum Outdoor Air	Minimum Outdoor Air	Installed Filtration (MERV)
AH-1	R160	3.8	2.2	826 CFM	330 CFM	0 CFM	11
	R170	3.0	1.9	1006 CFM	402 CFM	0 CFM	11
AH-2	R224	3.3	2.1	938 CFM	375 CFM	0 CFM	11
	R230	4.2	2.7	1,135 CFM	454 CFM	0 CFM	11
	R236	2.67	1.7	835 CFM	334 CFM	0 CFM	11

6.2.1. – AH-1 and R160/R170

AH-1 has been replaced within the last 30 years, with some minor changes to control and sensing devices over the life of the unit. The system is a variable volume system with the supply fan and return fan modulating to maintain duct and building pressure. There are only temperature and humidity monitors within the existing unit, and a single filtration section with local visual pressure measurement only.

Located in the L000 of MRB, this system serves the R160 and R170 with variable air volume units. The system has a temperature reset based on room loads, with the VAV controlled on cooling requirements and a perimeter wall fin to treat the envelope losses. The system is currently operating at a reduced supply air capacity from the original design but has the ability to can be increased via the speed drive.

6.2.2. – AH-2 and R224/R230/R236

AH-2 has been replaced within the last 15 years, with some minor changes to control and sensing added over the life of the unit. The system is a variable volume system with the supply fan and return fan modulating to maintain duct and building pressure. There are only temperature and humidity monitors within the existing unit, and a single filtration section with digital and local visual pressure measurement.

Located in the penthouse, it serves the R224, R230, and R236 with variable air volume units, along with the other upper-level spaces of the building. The system has a temperature reset based on room loads, with the VAV controlled on cooling requirements and a perimeter wall fin to treat the envelope losses. The system is currently operating at a reduced supply air capacity from the original design, but can be increased, it was reduced due to noise complaints while still maintaining temperature controls.

6.3. Apotex Centre

There are two air handling units and a make up air unit that provide ventilation to the spaces within the Apotex scope of work. AHU-5 serves the classroom 051, AHU-2 serves Theatre 071, 156 and 164 and various other non-laboratory spaces and offices on L000 and L100. MUA-2 classroom 264 and many other lab and support spaces within the building. Each of the systems are complete with independent cooling and heating systems and are able to control the discharge temperature to the system and react to changes in the end spaces to accommodate changes in the occupancy and are complete with variable speed drives for fans.

Table 11 - Apotex Air Handler Existing Supply Conditions

Building	Room	Existing SA ACH	Existing Effective OA ACH	Supply Air Volume	Maximum Outdoor Air	Minimum Outdoor Air	Installed Filtration (MERV)
AHU-5	050	10.7	6.5	3,416 CFM	1,708 CFM	170.8 CFM	8
AHU-2	071	6.3	6.1	1,945 CFM	1,945 CFM	973 CFM	15

Building	Room	Existing SA ACH	Existing Effective OA ACH	Supply Air Volume	Maximum Outdoor Air	Minimum Outdoor Air	Installed Filtration (MERV)
	156	5.9	5.7	1,517 CFM	1,517 CFM	789 CFM	15
	164	8.1	7.9	1,945 CFM	1,945 CFM	973 CFM	15
	264	3.5	3.5	826 CFM	826 CFM	413 CFM	15

6.3.1. – AHU-5 and 050

AHU-5 has been installed within the last 3 years and is as per the original plans. The system is a variable volume displacement ventilation system with the supply fan and return fan modulating to maintain duct pressure based on cooling demand. The ventilation is provided via a duct from MUA-1 and modulates based on CO2 levels. There are temperature and humidity monitors, filter bank pressure sensors, and variable fan speed indications within the existing unit.

The existing classroom has recently been renovated and consists of wall supply displacement ventilation grilles and high-level return. The existing supply rate is as per the original design and appears to be functioning as a displacement ventilation system.

6.3.2. – AHU-2 and 071, 156, 164, and 264

AHU-2 is original to the building and is approximately 14 years old. The system is a variable volume system with the supply fan and return fan modulating to maintain duct pressure based on cooling demand. There are temperature and humidity monitors, filter bank pressure sensors, and variable fan speed indications within the existing unit.

Each of the rooms is complete with a variable air volume (VAV) box, re-heat coil and dedicated thermostat. The spaces are served from overhead plaque diffusers and high-level returns. 156 control is located in an adjacent space used as a pharmacy prior to the pandemic and is isolated from the Teaching Lab via a roll up door.

6.4. Dentistry

D220 is served via a multi-zone air handler located in the basement of the Dentistry Building and it is original to the building, approximately 65 years old. The other spaces connected to the systems are classrooms, support and offices spaces. The system is complete with independent cooling and heating systems and is able to control the discharge temperature to the system and react to changes in the end spaces to accommodate changes in the occupancy.

Table 12 - Dentistry Building Air Handler Existing Supply Conditions

Building	Room	Existing SA ACH	Existing Effective OA ACH	Supply Air Volume	Maximum Outdoor Air	Minimum Outdoor Air	Installed Filtration (MERV)
AH-4	D220	6.0	4.6	1,416 CFM	1,416 CFM	425 CFM	11

6.4.1. – AH-4 and D220

AH-4 is a multi-zone unit, with a central heating coil and filtration and local cooling and heating coils for each zone. There are only temperature and humidity monitors within the existing unit, and a single filtration section with local visual pressure measurement only. Located in the L000 of Dentistry, this system serves the D220 as a constant air volume system. The system has a temperature reset based on room loads, and a perimeter wall fin to treat the envelope losses. The air handler is original to the building and is beyond the life expectancy of similar style units.

D220 is a constant volume space with overhead air distribution, with perforated diffusers and high-level returns. The space is a teaching space for dentistry students on moulds and other teaching aid for teeth care. Adjacent to the space is a shared space for the casting and generation of the training devices and has fume hoods and exhaust systems.

6.5. Pathology

P133 is served from AHU-2, located on the north side of the building roof and it is a newer unit (approximately 15 years). The systems are complete with independent cooling and heating systems and are able to control the discharge temperature to the system and react to changes in the end spaces to accommodate changes in the occupancy.

Table 13 - Medical Rehabilitation Building Air Handler Existing Supply Conditions

Air Handler	Room	Existing SA ACH	Existing Effective OA ACH	Supply Air Volume	Maximum Outdoor Air	Minimum Outdoor Air	Installed Filtration (MERV)
AHU-2	P133	4.9	3.7	940 CFM	940 CFM	282 CFM	11

6.5.1. – AHU-2 and P133

AHU-2 has been replaced within the last 15 years, with some minor changes to control and sensing devices over the life of the unit. The system is a variable volume system with the supply fan and return fan modulating to maintain duct and building pressure. There are only temperature and humidity monitors within the existing unit, and a single filtration section with local visual pressure measurement only.

AHU-2 servers many spaces within Pathology and P133 is complete with variable air volume unit. The system has a temperature reset based on room loads, with the VAV controlled on cooling requirements. There are overhead square cone diffusers and a return at high level in the space.

6.6. William Norrie Centre

The classrooms in the building are served with distributed heat pumps and a make-up air unit provides the ventilation to the space. The heat pumps are located in the corridors and the central MUA is located in a mechanical room at the east end of the building.

Table 14 - Medical Rehabilitation Building Air Handler Existing Supply Conditions

Building	Room	Existing SA ACH	Existing Effective OA ACH	Supply Air Volume	Maximum Outdoor Air	Minimum Outdoor Air	Installed Filtration (MERV)
HP-4	124	6.6	5.3	1,389 CFM	555 CFM	150 CFM	11

6.6.1. – HP-1, MAU-1 and 124

The heat pump and the make-up air units are original to the building with some modifications to the make-up air unit with a by-pass and humidifier added within the last 10 years. The space is currently operating as designed and provides the minimum ventilation when the make-up air unit is operating as intended but does operate at a reduced rate when by-passing.

7. Analysis

Each of the systems were looked at from the standpoint of increasing the overall effective outdoor air rate (the clean air delivered to the space) under different conditions and reviewing the increase in cost to operate, how serviceable the solution is, if the solution can meet all of the requirements of comfort in the space, and the overall speed at which the change could be implemented. Additionally, consideration was made to with respect to the reduction of outdoor air supply rates during periods when the pollution levels in the outdoor air are beyond the minimum limits, as such systems with increased outdoor air rate would pose a detriment to the health of indoor occupants.

Priority spaces, the effective outdoor ACH and the overall supply ACH of the spaces were below the best practice recommendations. These low levels lead too poor indoor IEQ and comfort, either drafty or stagnant depending on the occupant's location in the space. Without changing the existing supply fan or rebalancing the system and strictly increasing the MERV rating on filtration system utilized, the effect of this alteration is not great enough to bring the effective outdoor ACH rates up to the recommended level of 3 ACH. The addition of UV lights (with or without MERV ratings increased) did not see a large enough increase in the overall eACH to reach a target level.

Although an increase in the outdoor air rate as a percent of the supply air is sufficient to achieve the targeted eACH, the increase in the energy demand, cost to upgrade the cooling and heating systems, and the use of the system when outdoor air conditions are beyond the minimum requirements for occupant exposure to pollutants, this arrangement was not considered a viable solution. Combinations of increased outdoor air volumes, MERV filtration ratings, and UV lights were significant, but the increase to the operational costs, maintenance costs, and reliance of high levels of outdoor air, do not make these scenarios desirable.

The use of an in-room (IR) dedicated HEPA unit can provide the required boost to the overall eACH to reach the target level. There are expenses associated with these pieces of equipment, but this approach appears to be instrumental in achieving the target and when coupled with BI or CPO, provide a means for disinfection. These HEPA systems would need bi-annual maintenance filter replacement/checks to ensure proper operation of the systems. The systems should be provided with pre-filtration, minimum MERV 8, to protect the HEPA filter and ensure a long lifespan. MERV 8 pre-filters can be expected to be changed twice annually, but the HEPA filters can expect a replacement cycle between 1 and 2 years.

Installation of PCO and UV-C systems within the ductwork or air handler, have an advantage when trying to treat a large system, as they can deal with a larger amount of the spaces from a central location, but the carry and increased capital costs and a reliant on the operation of the central system during night set-back operation to disinfect the air volume. An IR HEPA system paired with BI, or a separate PCO smaller system allows for a capital cost decrease and an operational cost decrease, as they can be operated independent of the central HVAC system. Maintenance of the PCO and BI systems are typically on an annual basis, but the PCO maintenance is much simpler and has less risk associated with the replacement of components. The PCO systems require an annual replacement of the UV bulb in the system, where the BI product required the replacement of the needle point itself. A purchased BI replacement component could potentially lead to the production of O^3, if the parts are improperly sourced. If the maintenance is provided beyond the annual schedule, the PCO product will still provide some measure of disinfection provided the UV bulbs are functional. Some of the PCO system providers have maintenance programs and will provide the required inspections and replacement of parts as part of these programs.

As humidity also plays some role in the transmission of airborne pathogens, maintaining a minimum threshold of 30% is ideal, although in our climate it become impractical and expensive. The humidification coils installed within the air handling units serving the spaces attempt to maintain the RH at a reasonable level in the spaces, but buildings tend to operate below the desired RH levels. The challenge in our climate to maintain indoor RH's levels is that water vapour in the air wants to migrate to from a condition with high vapour pressure to low vapour pressure, regardless of air pressure differential. During our winters and early springs there are drastic differences in vapour pressure between the outdoor and indoor spaces, so the water vapour introduced by these air handlers supply air migrates to the exterior and is lost. It makes it very challenging, and expensive, to humidify spaces to a level above 20%. There are means to proving isolated localized humidification to these spaces with adiabatic humidifiers (high pressure systems) but would still be lost adjacent spaces. It is not practical in these spaces to attempt to maintain the 40-60% RH but should be an ideal goal for as much of the year as possible.

7.1. Basic Medical Sciences Building

7.1.1. – Theatre A, Rooms 153 & 253

The current arrangement in Theatre A does not provide adequate mixing and there are drafty conditions in some spaces, particularly at in the upper level (253). The original diffusers have been modified to provide a lower air flow rate (it is not clear as to when or how the air volumes were reduced to the space) and this affects the overall ability for the system to function as intended, a fully mixed constant air volume system with trim coils for temperature control.

Although this space would be suitable for a change from a fully mixed system to a displacement ventilation system, the construction and limitations on where diffusers could be placed limits the potential of changing this space system. It would also require all of the spaces supplied by this AHU to be changed to displacement ventilation, and due to these limitations, it does not appear to be feasible to change the delivery system in this Theatre.

The challenge for the increase in the overall mixing of this high volume space being that the existing ceiling and space above currently has ACM's and removal of the ACM's is very costly Replacement of the existing slot diffusers with some high throw, low sound nozzles towards the south of the space and relocating slot diffusers in the upper level as far north as possible, and only throwing south would help to create a fully mixed space. There is additional capacity located in the old projector room north of the 253, which only houses a small projector and is over supplied. Repurposing this supply air to high level above the last row of 253 would help to increase the overall supply air to the space without increasing the supply from the current ducted system, limiting sound increase.

Even with the changes to the diffusers, an increase of the supply air volume to the space should be considered to provide a properly mixed system and ensure the delivery of outdoor air to the occupants. To achieve a reasonable supply air ACH of 6, the overall supply volume should be increased from 2,021 CFM to 9,900 CFM. This would be more in line with the original design and properly mix the volume. Care would need to be taken to ensure that the overall volume is increased in a manner that any sound generated from diffusers and ductwork is minimized.

With the increase in the supply to the space, without changes to the existing AHU filtration arrangement, the space would still require an additional 1,600 CFM of HEPA cleaned air to reach a possible 6 eACH. There are many locations that these units could be located and provide a clean installation, be limited on the sound impact, and be serviceable. There are two landing locations on the L200 level that could either house the units or provide the supply and intake portions of the units. The units could be installed in the corridors north or south of these landings to ensure better access and sound mitigation. Alternatively, under the renovation plans developed to 99%, the partition and the closets that house the partitions are to be removed and the rooms converted to storage space. Units could be placed in this space, providing secure and easy access, though more work would be required to ensure that sound it mitigated.

7.2. Medical Rehabilitation Building

7.2.1. Room R160 & R170

The two spaces are connected to the same supply air duct fed from the air handing unit below and are conditioned in a similar manner. As noted in the 8.0 section, updating the air handing unit will not provide sufficient air cleaning to reach a possible eACH of 6.0. As there is capacity in the ductwork system after the VAV unit to handle additional air volume, an easier means to increase the local supply air change rate and increase MERV rating would be to implement a Fan Powered Terminal Unit (FPTU), series type, with inlet sound adapter and MERV 13 filter rack. Replacing the existing VAV unit with a FPTU would require only a small change in the controls to the space and would require the same service access, though it would need additional maintenance on the filter.

With the addition of the FPTU and MERV 13, there is still a need for an IR HEPA system to meet the target eACH. There are two spaces east of the rooms R160 and R170 that are large volume spaces for storage, that could be used for the installation of a unit capable of delivering 600 cubic feet per minute of clean air (one per space) and provide means to reach the target eACH, provide the disinfection to the air stream without the need to run the central AHU and allow for easier access and maintenance.

7.2.2. Rooms R224, R230 & R236

The three spaces are connected to the same supply air duct fed from the air handing unit on the roof level. It appears that in previous renovations that the maintenance of the existing duct system was a cost saving measure and the spaces use a very complicated and superfluous duct arrangement to condition the spaces. The supply air drop is adjacent to R230, and then splits to the north and south, with the south duct routing west at the south end of R236 and then routing north and supplementing R236, R230 and R224 with additional VAV's and supply air ductwork. To keep costs lower, maintaining the existing duct routing is viable and as there is capacity in the ductwork system after the VAV unit using a fan powered terminal unit FPTU, series type, with inlet sound adapter and MERV 13 filter rack would again be beneficial to achieving the target eACH. Like R160 and R170., replacing the existing VAV unit with a FPTU would require only a small change in the controls to the space and would require the same service access, though it would need additional maintenance on the filter.

With the addition of the FPTU and MERV 13, there is still a need for an IR HEPA system to meet the target eACH. There is a service space within the east portion of room R236 that could be used for the installation of two 600 CFM unit and provide means to reach the target eACH and provide the disinfection to the air stream without the need to run the central AHU and allow for easier access and maintenance. Two additional IR units would be required to be installed and could be placed in the corridor ceiling space east of the room R230 and ducted over to R224 and R230. A portion of the air volume from one unit in R236 would need to supplement R230.

7.3. Apotex

7.3.1. – Room 050

The current arrangement in 050 can provide the required effective air change rate and appears to well exceed the minimums required and could be modified to reduce the energy demand on the building. Currently the maximum outdoor air rate provides a 9.4 eACH when at maximum supply air and can easily achieve the required rates under lower occupancy. A reduction in the maximum allowable outdoor air and the addition of PM2.5 measurements in the space would help to ensure that the energy demand of the space is limited and maintain the appropriate ventilation conditions.

As the AHU-5 only serves this space, an in duct PCO device from Active Pure or UVDI would provide the disinfection of the space without the need to place serviceable items within the room and limit the amount of maintenance required for these units.

7.3.2. – Room 071 and 164

Both of these spaces currently exceed the 6 effective air change rate and have the required supply air change rate for good air distribution. The central unit that feeds these spaces use a MERV 15 and have a minimum outdoor air percentage of 50%. The central unit can be modified to use a reduced outdoor air fraction (40%) and meet the required outdoor air rates to the spaces it serves. The central MERV rating can be reduced on the central unit to 13 and still achieve the desired rate.

In space PCO devices should be implemented to provide an increase of disinfection to the space and permit the operation of the disinfection of these spaces without the reliance of the central unit to operate, i.e., a lower operational cost.

7.3.3. – Room 156

The current arrangement in Room 156 almost meets 6 effective air change rate and has nearly an ideal supply air change rate. As the space has been separated with a new door between the pharmacy sales space and the learning space, the pharmacy space is oversupplied, and the teaching space is undersupplied. In addition to this, the temperature control device is located in the unoccupied and closed off pharmacy space.

If the recommendation to replace the central filter rate from MERV 15 to MERV 13 and adjust the outdoor air rate down is completed (as discussed for the 071 and 164 spaces) the eACH drops to 5.4, which is still within the recommended rate, possible to reach a higher eACH. An in-room HEPA filter system could be provided for the space, installed in the ceiling of the pharmacy and ducted into the teaching space, and help to increase the eACH to 6.0.

In space PCO devices should be implemented to provide an increase of disinfection to the space and permit the operation of the disinfection of these spaces without the reliance of the central unit to operate, i.e., a lower operational cost.

7.3.4. – Room 264

The existing space does not have sufficient outdoor air and supply air rates to exceed the minimum eACH but does meet the minimum outdoor air rate code requirements. The overall supply air to this space appears to be lower than the original design conditions. Increasing the supply air will improve the overall indoor air quality in the space. Having a central air handling unit filter rate of MERV 13 and an outdoor rate of 40% of the supply air, the supply air flow is recommended to be revised from 826 CFM up to 1,550 CFM.

In space PCO devices should be implemented to provide an increase of disinfection to the space and permit the operation of the disinfection of these spaces without the reliance of the central unit to operate, i.e., a lower operational cost.

7.4. Dentistry

7.4.1. Room D220

The space supply air change rate meets the current design standards, with the outdoor air effective rate above the minimum eACH. The multi-zone system is beyond the service life of equipment of this nature and requires replacement. The current arrangement may require the replacement of the adjacent AHU (AH-5) as they are interconnected. There would be considerable cost to replace this unit, but a more energy efficient system could be provided.

If the replacement of the central systems is not within the current budget, the addition of an in-room HEPA unit capable of 350 CFM of clean air delivery would be needed to increase the effective air change rate to 6.0. This unit could be located within the shared space ceiling cavity and ducted through the wall to serve the teaching area.

In space PCO devices should be implemented to provide an increase of disinfection to the space and permit the operation of the disinfection of these spaces without the reliance of the central unit to operate, i.e., a lower operational cost.

7.5. Pathology Building

7.5.1. Room P133

The space supply air change rate and the outdoor air effective rate are meeting the minimum but could be corrected to increase the eACH. The current supply rate to the space appears to be lower than the original design rates and should be increased to 1,450 CFM in order to achieve proper air distribution. With the increase of supply air to the space, the effective air change rate will increase to 5.8.

To achieve the 6.0 eACH, the addition of an in-room HEPA unit capable of 100 CFM of clean air delivery would be all that is required to increase the effective air change rate to 6.0. This unit could be located within the empty server space located on the west side of the space.

In space PCO devices should be implemented to provide an increase of disinfection to the space and permit the operation of the disinfection of these spaces without the reliance of the central unit to operate, i.e., a lower operational cost.

7.6. William Norrie Centre

7.6.1. Room 124

The current arrangement just falls short of 6.0 eACH but can be achieved by either of the options indicted below. Upgrade the central make-up air unit and the heat pumps MERV filters from MERV 11 to MERV 13, increasing the eACH to 6.0. The added benefit is seen within the building and would provide better quality air throughout. The existing heat pumps may not have enough static pressure to overcome the increased MERV rating and all of the heat pumps in the building would need to be upgraded for the whole building to see the improvement of increasing the central MUA filter rate.

The other method to achieve the 6.0 eACH would be the installation of a in-room HEP unit capable of 250 CFM. This unit would need to be installed in the corridor with the heat pumps and ducted back into the room.

In space PCO devices should be implemented to provide an increase of disinfection to the space and permit the operation of the disinfection of these spaces without the reliance of the central unit to operate, i.e., a lower operational cost.

8. Recommendations

Each space and system require a slightly different approach to meet the a higher eACH than the minimum and they are highlighted below as the best solution for the best value. There are some measures that should be undertaken to establish updated control and measurement strategies throughout the Bannatyne campus to ensure that the best IEQ is achieved for all spaces going forward, and not just the P1 spaces discussed below.

A $PM_{2.5}$, O_3, and TVOC outdoor measurement station should be installed and actively monitored in the general area of the University buildings, ideally capturing the most intakes as possible. If any one of the air quality indices exceeds the maximums as defined above, the outdoor air quantity should be reduced where possible, limiting exposure of occupants in the spaces.

Additionally, in large Theatre spaces and the return ducts of other air distribution systems, $PM_{2.5}$, O_3, and TVOC should be monitored for indoor occupant health.

8.1. Basic Medical Sciences Building

8.1.1. Theatre A, Rooms 153 and 253

The first portion of work that should be undertaken to ensure the space is provided with clean air is the installation of IR HEPA filters and PCO equipment. These units would ideally be installed within the partition closet or within the empty projector room at the top of 253, and a total of 3 HEPA units, each delivering 600 CFM each of cleaned air, such as the Price OAP size 30 unit, can provide the required clean air rate. The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The project working on the refresh of the space should consider increasing the supply air to the space, revising the supply diffuser arrangement to promote the proper mixing of the air volume, and increasing the filtration at the new unit to include a PCO section.

If new thermostats are provided under the renovation scope of work, the new thermostats should be provided as the Delta UNO-7TB which can read $PM_{2.5}$, O_3 and TVOC in addition to RH and temperature. The $PM_{2.5}$, O_3 and TVOC should be actively controlled with O/A settings to ensure that when poor outdoor air conditions occur that the indoor remains in the recommended range. Additionally duct mounted measurement devices on the return from Theatre A should be provided as well within both return cavities in the room.

As discovered the existing AHU had its vortex inlet damper moderately closed and is now opened. The overall system should be measured for the increase in the air volume and the total volume to the Theater should be confirmed with the new volume. Based on the provided operational conditions after the damper was adjusted, the fan may be limited on the amp draw at the variable speed drive. The existing blower should be reviewed to determine if the limitation in place can be altered to permit higher speed from the blower. Existing drawings and name plates for the blower should confirm that the blower can provide higher speeds and that the fan curves will permit this operation without surging, prior to any changes at the blower. If the blower is capable of the increase in speed, the variable speed drive should have the artificial limits altered to permit the higher amp draw needed to increase the supply air to the Theatre.

Internal maintenance increase for these systems would be a bi-annual inspection of the IR equipment with a replacement of the pre-filters on these units. HEPA filters can be expected to be replaced annually (depending on the room use). Local contractors can provide the maintenance contracts on these units or could be provided by the University staff if possible. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.2. Medical Rehabilitation Building

8.2.1. Rooms R160 and R170

The existing VAV units should be replaced with FPTU, complete with MERV 13 filters and inlet attenuators to increase the overall supply air volume to the space and provide an additional filtration level. The remaining cleaning of the indoor air should be provided by an IR HEPA unit, Price OAP or similar, located in an adjacent space and ducted to a high-level supply grille in the existing ceiling. The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3 and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high.

Internal maintenance increase for these systems would be a bi-annual inspection of the IR equipment with a replacement of the pre-filters on these units. HEPA filters can be expected to be replaced annually (depending on the room use). Local contractors can provide the maintenance contracts on these units or could be provided by the University staff if possible. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.2.2. Rooms R224, R230, and R236

The existing VAV units should be replaces with FPTU, complete with MERV 13 filters and inlet attenuators to increase the overall supply air volume to the space and provide an additional filtration level. The remaining cleaning of the indoor air should be provided by an IR HEPA, Price OAP or similar, unit located in an adjacent space and ducted to a high-level supply grille in the existing ceiling. The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3 and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high.

Internal maintenance increase for these systems would be a bi-annual inspection of the IR equipment with a replacement of the pre-filters on these units. HEPA filters can be expected to be replaced annually (depending on the room use). Local contractors can provide the maintenance contracts on these units or could be provided by the University staff if possible. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.3. Apotex Centre

8.3.1. Room 050

The existing ventilation air system should be re-balanced to the reduced air volume rate to help reduce the energy demand the space requires. The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3 and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.3.2. Room 071 and Room 164

The existing ventilation air system should be re-balanced to the reduced air volume rate to help reduce the energy demand the spaces require. The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3 and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.3.3. Room 156

The existing ventilation air system should be re-balanced to the reduced air volume rate to help reduce the energy demand the spaces require. The remaining cleaning of the indoor air should be provided by an IR HEPA, Price OAP or similar, unit located in an adjacent space and ducted to a high-level supply grille in the existing ceiling The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3, and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high.

Internal maintenance increase for these systems would be a bi-annual inspection of the IR equipment with a replacement of the pre-filters on these units. HEPA filters can be expected to be replaced annually (depending on the room use). Local contractors can provide the maintenance contracts on these units or could be provided by the University staff if possible. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.3.4. Room 264

The existing ventilation air system should be re-balanced to the reduced air volume rate to help reduce the energy demand the spaces require. The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3, and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.4. Dentistry

8.4.1. Rooms D220

The cleaning of the indoor air should be provided by an IR HEPA, Price OAP or similar, unit located in an adjacent space and ducted to a high-level supply grille in the existing ceiling The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3, and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high.

Internal maintenance increase for these systems would be a bi-annual inspection of the IR equipment with a replacement of the pre-filters on these units. HEPA filters can be expected to be replaced annually (depending on the room use). Local contractors can provide the maintenance contracts on these units or could be provided by the University staff if possible. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.5. Pathology Building

8.5.1. Rooms P133

The cleaning of the indoor air should be provided by an IR HEPA, Price OAP or similar, unit located in an adjacent space and ducted to a high-level supply grille in the existing ceiling The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3, and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high.

Internal maintenance increase for these systems would be a bi-annual inspection of the IR equipment with a replacement of the pre-filters on these units. HEPA filters can be expected to be replaced annually (depending on the room use). Local contractors can provide the maintenance contracts on these units or could be provided by the University staff if possible. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.

8.6. William Norrie Centre

8.6.1. Rooms 124

The cleaning of the indoor air should be provided by an IR HEPA, Price OAP or similar, unit located in an adjacent space and ducted to a high-level supply grille in the existing ceiling The disinfection of the air within the space should be completed with an in-space PCO system, Active Pure Guardian Clouds or similar, which will permit the treatment of the air without need to operate the central AHU.

The $PM_{2.5}$, O_3, and TVOC should be actively controlled with O/A measurements and updated controls sequences should be provided to minimize the outdoor air when particulate counts in the outdoor air are too high.

Internal maintenance increase for these systems would be a bi-annual inspection of the IR equipment with a replacement of the pre-filters on these units. HEPA filters can be expected to be replaced annually (depending on the room use). Local contractors can provide the maintenance contracts on these units or could be provided by the University staff if possible. The PCO in room units require an annual replacement of the UV light and can be provided by the manufacturer as a service cost.